Estimations of the Potential and the Impact of Rail Freight in Urban Areas

Author(s):
Fumasoli, Tobias

Publication Date:
2018-03

Permanent Link:
https://doi.org/10.3929/ethz-b-000256137

DISS. ETH NO. 24609

ESTIMATIONS OF THE POTENTIAL AND THE IMPACT OF RAIL FREIGHT IN URBAN AREAS

A thesis submitted to attain the degree of

DOCTOR OF SCIENCES of ETH ZURICH

(Dr. sc. ETH Zurich)

presented by

TOBIAS MASSIMO FUMASOLI

MSc ETH SD&IS

born on 5 July 1983

citizen of
Zürich ZH, Lugano TI and Buchs ZH

accepted on the recommendation of

Prof. Dr. Ulrich Alois Weidmann, examiner
Prof. Dr. Wolfgang Stölzle, co-examiner
Prof. Dr. Bernd Scholl, co-examiner
Martin Ruesch, co-examiner

2018

Contents

List of Figures

List of Tables

Abstract

Increasing density – of population, infrastructures and activities – is one of the major current challenges of urban areas in Europe. Urban regions are not only subject to increasing passenger traffic but also to growing good flows. The need to include freight transport in urban transport planning is increasingly acknowledged by urban planners. In the urban context, the use of alternative modes for freight – unlike passenger transport – has so far enjoyed little resonance. Against the background of concentrated urban development and environmentally friendly transport this seems surprising.

The capability of rail freight in urban areas is not well understood. Opinions on the possibilities and boundaries of rail freight in urban areas differ widely. It is often not clear which are the limiting factors for rail freight. This gap leads to the following research question:

> Can rail freight systems be designed to allow for the integration into urban supply chains in modern economies and which conditions need to be met?

In order to estimate the potential and the implications of railways as an alternative freight transport system, a range of issues needs to be addressed.

Current freight transport strategies of public bodies – cities, metropolitan areas and regions – are mostly infrastructure-centred. The underlying assumptions on train operation come from transport concepts no longer existing in urban areas. It needs to be shown how an adaptation of train operations to the rather rigid structure of urban (mainline) rail systems affects rail freight productivity.

Areas for freight terminals are a prerequisite for rail freight, but suitable sites are often under pressure from urban development. It needs to be analysed how suitable terminal areas are safeguarded, and how the safeguarding processes relate to private terminal location planning.

In order to derive area requirements, the performance of freight terminals needs to be understood. A body of research and insights from practice exist for container terminals, for non-containerized cargo much less so.

Rail freight not only faces technical and planning hurdles in urban areas. A number of framework conditions shape the potential scope.

The market environment determines demand for rail freight services. Especially transport costs need to be examined in order to estimate the potential.

Environmental policies more and more focus on freight transport. The environmental impact of rail-based urban transport chains needs to be estimated.

Planning policies shape the availability of areas. Freight transport competes with a range of other desirable uses, for instance housing, commercial and industrial spaces or public facilities.

A wide range of methods and inputs are used to analyse all aspects of rail freight in urban areas.

Train movement is modelled in order to estimate the effects of freight trains adapted to operations in urban areas. Rail freight can close the operational gap to passenger trains by shortening trains, improving braking and traction and by reducing train weight. It can be shown that a combination of shorter trains and improved traction allows to maintain freight capacity, while better fitting into urban railway operations.

A process analysis of public and private planning is conducted, using literature research of planning guides and terminal location choice research. The analysis shows that the planning of freight terminals in urban areas faces several challenges. Insufficient data prevents actors from having a full overview of the planning problem. The objectives and standards of public and private actors diverge. It is also noticed that public and private planning are mutually dependent and planning deadlocks can occur.

The land use efficiency is determined in a design process for terminal units for a range of commodities. Performance calculations show that annual terminal throughput can reach approximately 160 000 to 250 000 t/ha a for heavy dry bulk, 65 000 to 98 000 t/ha a for light dry bulk and for (palletized) volume goods 38 000 to 48 000 t/ha a. A modal shift of 5 % would require 0.05 to 0.90 m^2 of terminal area per inhabitant, depending on commodity and terminal type (assuming a total freight generation of approximately 30 t/a per inhabitant). The results are however sensitive to a few important parameters such as operating times, number of transhipment devices and load factors.

Exemplary transport cost functions are calculated to illustrate the potential of rail-based urban transport from a commercial perspective. Multimodal urban freight transport in Switzerland can compete with direct road transport from a distance of approximately 80 to 100 km, depending on train size and commodity group. In case of road network congestion, critical distance might even be lower.

The environmental impact of rail-based urban transport is evaluated in terms of carbon and greenhouse gas emissions, and energy efficiency. Multimodal transport emits around 10 to 50 % of the well-to-wheel carbon emissions of road transport. The respective energy consumption is however only partially lower for multimodal transport. Over short distances, road haulage consumes less “well-to-wheel” energy than multimodal transport.

The urban planning environment is difficult for freight terminals. In Switzerland, the focus of local land use planning is strongly on housing and office space. Although ample internal area reserves exist, most projects for converting former railway areas focus on residential uses.

From the results it is concluded that railway has the potential to complement the urban freight system with an alternative transport system. The challenge for planners will be to provide the freight system with the best possible conditions to offer multimodal transport to and from cities.

Zusammenfassung

Die Zunahme der Bevölkerungsdichte, der Aktivitätendichte und der Infrastruktur ist eine der grössten Herausforderungen von städtischen Gebieten in Europa. Der urbane Raum muss nicht nur wachsende Pendlerströme bewältigen, sondern auch zunehmende Güterströme. Güterverkehr erfährt deshalb seit kurzer Zeit einen grösseren Stellenwert in der Raumplanung. In der städtischen Raumplanung führen Alternativen zum Güterverkehr auf der Strasse jedoch weitgehend ein Schattendasein – ganz im Gegensatz zum öffentlichen Verkehr; dies ist eine Überraschung angesichts zunehmender städtischer Verdichtung und der Förderung umweltfreundlichen Verkehrs.

Das Leistungsvermögen des Schienengüterverkehrs im urbanen Raum ist noch nicht erforscht. Die Meinungen zu den Möglichkeiten und Grenzen des Bahntransports gehen weit auseinander und die limitierenden Faktoren sind weitgehend unbekannt. Die folgende Forschungsfrage soll deshalb beantwortet werden:

> Kann Schienengüterverkehr auf eine Art und Weise gestaltet werden, die die Integration in zeitgemässe städtische Transportketten erlaubt und welche Bedingungen müssen dazu erfüllt sein?

Um das Potential und die Auswirkungen von Güterbahnen als Alternative im urbanen Güterverkehr abschätzen zu können, müssen verschiedene Aspekte geklärt werden.

Die aktuellen Verkehrsstrategien und -pläne der öffentlichen Hand – von Städten, Metropolitanräumen und Regionen – sind zumeist Infrastruktur-orientiert. Die zugrundeliegenden betrieblichen Annahmen zum Schienengüterverkehr basieren auf Transportprozessen, welche in dieser Form in Städten häufig nicht mehr vorkommen. Es ist aufzuzeigen, wie sich die Anpassung von Güterzügen auf dichten Mischverkehr in städtischen Vollbahnsystemen auf die Produktivität auswirkt.

Die Voraussetzung für Schienengüterverkehr im urbanen Raum sind Umschlagsanlagen. Die dafür in Frage kommenden Flächen sind allerdings unter Siedlungsdruck. Deshalb soll untersucht werden, wie geeignete Flächen gesichert werden, und wie sich die Flächensicherung in der Standortplanung der verladenden Wirtschaft spiegelt.

Um den Flächenbedarf von Umschlagsanlagen abzuschätzen, bedarf es belastbarer Leistungskennzahlen. Während für Containerterminals umfangreiches Datenmaterial vorhanden ist, fehlen die Grundlagen für den konventionellen Umschlag weitgehend.

Für die Planung von Schienengüterverkehr im urbanen Raum sind zudem verschiedene Rahmenbedingungen zu beachten.

Die Nachfrage nach Bahntransport wird massgeblich durch das Marktumfeld bestimmt. Transportkosten spielen dabei eine zentrale Rolle und sollen deshalb untersucht werden.

Der Fokus der Umweltpolitik richtet sich wieder vermehrt auch auf den Güterverkehr. Die ökologischen Auswirkungen der Verlagerung von Güterverkehr auf die Schiene sollen deshalb abgeschätzt werden.

Das Planungsumfeld prägt die Verfügbarkeit von Umschlagsflächen massgeblich. Der Güterverkehr steht dabei in Konkurrenz zu verschiedenen anderen Flächenbedürfnissen, zum Beispiel für Wohn- und Gewerbenutzungen, Industrie und öffentliche Einrichtungen.

Verschiedene Methoden und Grundlagen werden angewendet, um alle Aspekte des Schienengüterverkehrs im urbanen Raum zu beleuchten.

Eine vereinfachte Zuglaufrechnung wird verwendet, um die Produktivität von Güterzügen abzuschätzen, welche an Mischverkehr angepasst sind. Güterzüge können durch Verkürzung, bessere Traktion, verbessertes Bremsvermögen und Reduktion des Zuggewichts an den Betrieb in urbanen Netzen angepasst werden. Es wird gezeigt, dass mittels einer Kombination aus verbesserter Traktion mit kürzeren Zügen die Leistungsfähigkeit konventioneller Güterzügen erreicht werden kann.

Die Planungsprozesse privater und öffentlicher Akteure für Umschlagsanlagen werden anhand von Planungsliteratur analysiert. Die Analyse zeigt die Herausforderungen der Anlagenplanung auf. Aufgrund der mangelhaften Datenverfügbarkeit erhält keiner der Akteure eine vollständige Übersicht. Die Zielsetzungen und Ansprüche öffentlicher und privater Akteure divergieren. Zudem sind öffentliche und private Planungsprozesse gegenseitig voneinander abhängig, was zu Planungsproblemen führen kann.

Die Flächeneffizienz von Umschlagsanlagen wird mittels Dimensionierung von Terminalmodulen bestimmt. Die Leistungsberechnung ergibt Jahresdurchsätze von rund 160 000 bis 250 000 t/ha für schweres Schüttgut, 65 000 bis 98 000 t/ha für leichtes Schüttgut und 38 000 bis 48 000 t/ha für leichte (palettisierte) Güter. Für eine Verlagerung von 5 % des Güteraufkommens von der Strasse auf die Schiene würde – abhängig von Gutart und dem Anlagentyp – Terminalfläche im Umfang von rund 0.05 bis 0.90 m^2 pro Einwohner benötigt (bei einem Gesamtaufkommen von rund 30 t/a pro Einwohner). Die Resultate weisen jedoch hohe Sensitivitäten bezüglich wichtiger Parameter auf, zum Beispiel Betriebszeiten, Anzahl Umschlaggeräte und Fahrzeugauslastung.

Kostenfunktionen werden berechnet, um das kommerzielle Potential von urbanen Bahntransporten abzuschätzen. Die Transportkosten lassen darauf schliessen, dass die Schiene schon ab Distanzen von rund 80 bis 100 km, abhängig von Zugsgrössen und Warengruppe, konkurrenzfähig ist. In Gegenden mit hoher Staudichte kann die kritische Distanz auch kürzer ausfallen.

Die Umweltwirkungen von urbanem Schienengüterverkehr werden anhand des Energieverbrauchs und der Emissionen von Kohlenstoffdioxid und Treibhausgasen beurteilt. Multimodaler Güterverkehr erzeugt nur rund 10 bis 50 % der «well-to-wheel» Emissionen im Vergleich zu Strassentransport. Der Energieverbrauch ist hingegen nur teilweise geringer als im reinen Strassentransport: über kurze Distanzen verbraucht Strassentransport weniger Energie als multimodaler Verkehr.

Anlagen des Güterverkehrs befinden sich in einem schwierigen Planungsumfeld. In der Schweiz liegt der planerische und politische Fokus häufig sehr stark auf Wohn- und Gewerbenutzungen. Für den Güterverkehr geeignete Flächen kommen so unter Druck, obwohl häufig grosse innere Flächenreserven vorhanden sind.

Die Ergebnisse der Studie zeigen auf, dass Schienengüterverkehr eine valide Ergänzung des urbanen Güterverkehrs bietet. Die Herausforderung für Planer besteht darin, die Rahmenbedingungen dafür aktiv zu gestalten.

Acknowledgement

Many thanks go to
. . . family and friends, for moral support;
. . . Professor Ulrich Weidmann, for encouragement and patience;
. . . the co-examiners, Martin Ruesch, Professor Bernd Scholl and Professor Wolfgang Stölzle, as well as to Professor Dirk Bruckmann, for expertise;
. . . colleagues at the Institute of Transport Planning and Systems and to research project partners, for inspiring discussions.

Abbreviations

ACTS	roller container system (*Abrollcontainer-Transportsystem*)
AGV	automated guided vehicle
ATC	automatic train control
ATO	automatic train operation
ATP	automatic train protection
BFS	Swiss Federal Statistical Office (*Bundesamt für Statistik*)
BRT	bus rapid transit
CT	container terminal
DC	distribution centre
DEGURBA	degree of urbanisation
ETF	empty trip factor
FIBC	flexible intermediate bulk container
FUA	functional urban area
FTL	full truckload
GHG	greenhouse gas
GQGV	Swiss survey of foreign freight transport vehicles (*Grenzquerender Güterverkehr auf der Strasse*)
GTE	Swiss freight transport survey (*Gütertransporterhebung*)
GTS	Swiss freight transport statistics (*Gütertransportstatistik*)
LTL	less-than-truckload
HGV	heavy goods vehicle
ILU	intermodal loading unit
IM	railway infrastructure manager
ISO	International Organization for Standardization

ITU intermodal transport unit (the same as ILU)

LCV light commercial vehicle

LOS level of service

LSP logistics service provider

LSVA Swiss heavy vehicle charge

MPGM maximum permissible gross mass

NCFRP National Cooperative Freight Research Program

NIBA Swiss rail infrastructure appraisal method (*Nutzenindikatoren Bahn*)

NISTRA Swiss road infrastructure appraisal method (*Nutzenindikatoren Strasse*)

NRP Swiss National Research Programme

NST standard goods classification for transport statistics (*nomenclature uniforme des marchandises pour les statistiques de transport*)

NUTS nomenclature of territorial units for statistics (*nomenclature des unités territoriales statistiques*)

OD origin-destination

OECD Organisation for Economic Co-operation and Development

POE point-of-entry

POS point-of-sale

RMG rail mounted gantry crane

RTG rubber tyred gantry crane

RU railway undertaking

SBB Swiss Federal Railways (*Schweizerische Bundesbahnen*)

TSP travelling salesman problem

TTW tank-to-wheel

TEU twenty-foot equivalent unit

UCC urban consolidation centre

UIC International Union of Railways (*Union Internationale des Chemins de fer*)

VOS vehicle operating system

WTT well-to-tank

WTW well-to-wheel

Chapter 1

Introduction

1.1 Rationale

Increasing density – of population, infrastructures and economic activity – is one of the major current challenges of urban areas in Europe. Urban regions are not only subject to increasing passenger traffic but also to changing goods flows. Following the de-industrialisation of cities, freight transport activities have increasingly moved out of urban areas.

The convergence of three developments can be observed: (i) increasing population density leads to higher demand in commuter traffic; (ii) together with changing consumer behaviour it also leads to higher demand for goods in urban areas; (iii) logistics polarisation leads to longer trips for distributing goods. Additionally, good flows tend to overlap – in time and in space – with commuter movements.

This convergence leads to bottlenecks on urban transport infrastructure. Especially road infrastructure suffers from congestion, compromising the accessibility of cities. For goods traffic this leads to increasingly inefficient and costly transport chains. Additionally, it is a source of noise, accidents and air pollution. Not surprisingly, urban and regional governments identified the need for environmentally sustainable urban freight transport.

The need to include freight transport in urban transport planning is increasingly acknowledged by urban planners. It is obvious that alternative modes should be considered for freight transport. Modes other than road are however rarely considered for cities. For instance, the European Commission's White Paper on transport defines the goal to shift road freight to rail or waterways for longer distances only (EC, 2011). In the urban context, the use of alternative modes for freight – unlike passenger transport – has so far enjoyed little resonance.

1.2 Goal

The goal of this research project is to evaluate the potential and the implications of railways as an alternative freight transport system in urban areas. It should give answers to the question why the share of rail in urban freight transport remains marginal – despite growing problems in road freight.

Compared to long haul transport, rail freight is of comparably little significance in cities. Against the background of concentrated urban development and environmentally friendly transport, this seems surprising. Or, in the words of the White Paper: "Rail,

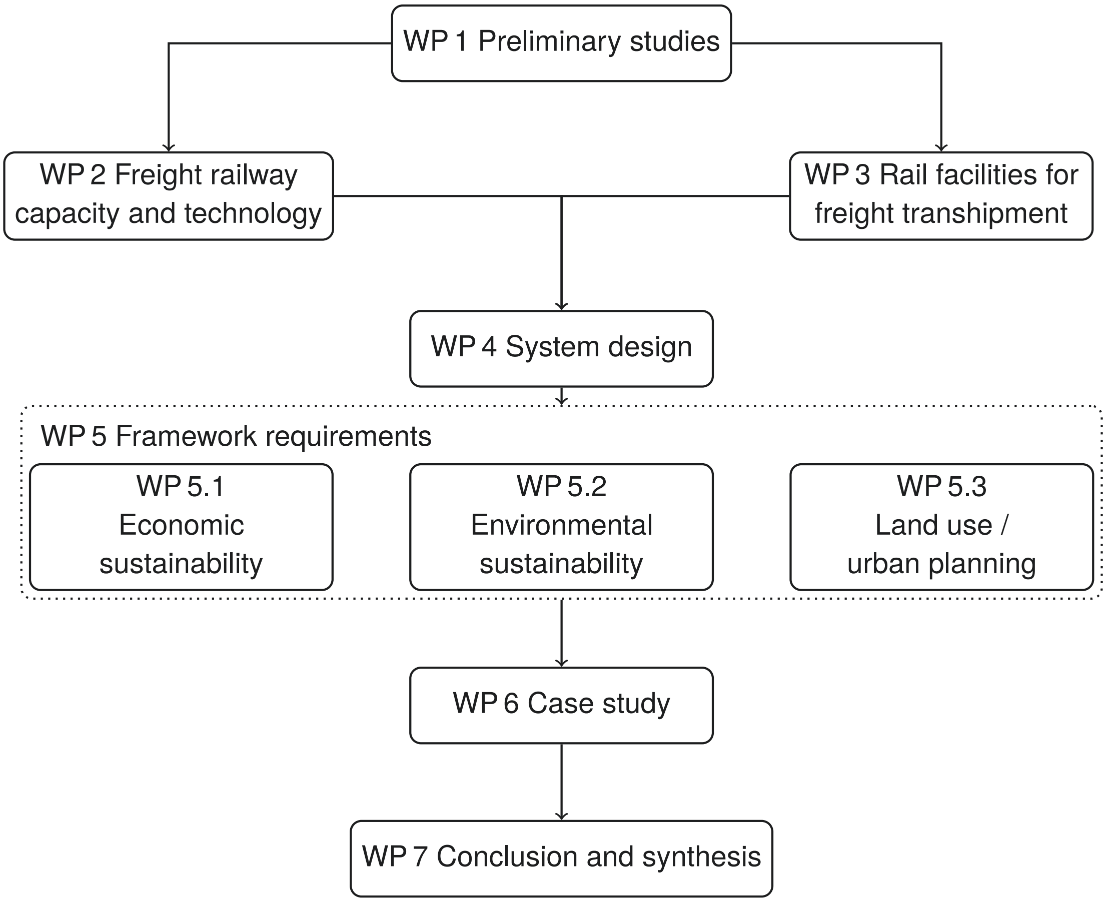


Figure 1.1: Structure of work packages

especially for freight, is sometimes seen as an unattractive mode." (EC, 2011).

The research question of this project therefore is:

> Can rail freight systems be designed to allow for the integration into urban supply chains in modern economies and which conditions need to be met?

To account for the interdisciplinary nature of the research question, the following subquestions are raised:

What are the effects of adapting freight train operation to densely used railway networks in urban areas? ______ WP 2
How can areas for the transhipment of goods from rail to road be secured? ______ WP 3
How much can rail freight contribute to urban freight transport? ______ WP 4
At what cost can rail freight be operated in urban areas? ______ WP 5.1
What are the environmental benefits of rail freight in urban areas? ______ WP 5.2
How can rail freight be considered in urban planning? ______ WP 5.3

1.3 Structure

The above-mentioned questions are covered by five work packages as shown in Fig. 1.1. The report is structured as follows.

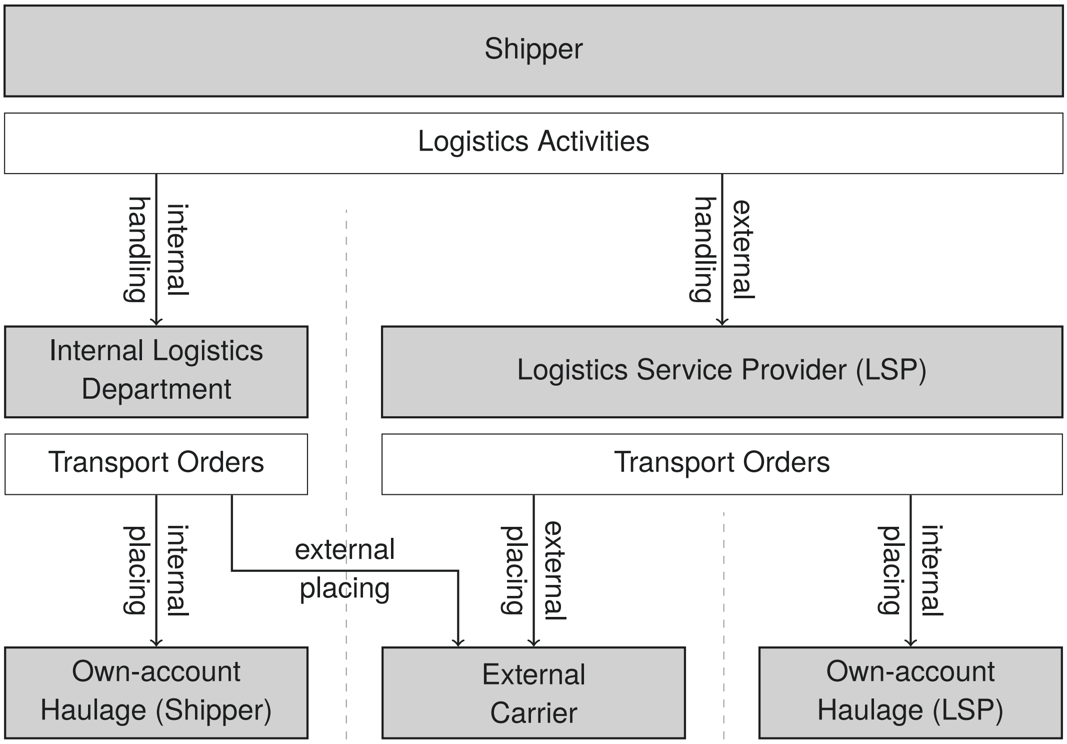


Figure 1.2: Actors in freight transport and transport chain organisation (adapted from Fries (2009))

Chapter 2 (WP 1) provides an introduction to urban freight transport and includes a preliminary study on the current practice of rail freight planning in European cities. The research hypotheses are covered by Chapter 3, followed by a brief overview of the applied methods in Chapter 4. The performance of rail freight transport is examined in Chapter 5 (WP 2). Chapter 6 (WP 3) deals with safeguarding sites for freight terminals in urban areas. Chapter 7 (WP 4) deals with the system performance in order to determine the area requirements.

Chapter 8 (WP 5) covers the framework conditions for urban rail freight, mainly the market and policy environment. The first part covers the economic conditions under which the proposed systems designs are viable (Section 8.3, WP 5.1). The second part covers the environmental effects of increased rail share and the third part the impacts of urban planning (Sections 8.4 and 8.5, WP 5.2 and 5.3).

1.4 Actors' perspectives

Freight transport generally involves various actors, which leads to a complex system of client-supplier-relationships. This is in contrast to passenger transport with its rather straightforward relation between carrier and passenger. In addition, passenger traffic deals with largely uniform transport subjects – persons and their luggage –, while freight displays a large variety of goods and their physical state and packaging.

Figure 1.2 shows the principal actors in the production of freight transport services. The organisation of the transport chain ranges from the shipper's own-account haulage, its simplest form, to multimodal transport chains, involving pre-, main- and post-haulage by different carriers. The transhipment of goods – not explicitly shown – adds to complexity and increases the need for organisation.

At the source of freight transport demand are the *shippers* of goods. The production, trade and consumption of goods leads to the need to transport goods between different locations. Shippers manufacture, or trade with, goods and have therefore commercial interests, i.e. customers to serve and suppliers to manage. Their view is the entire supply chain, and their focus is on the integration of internal and transport logistics. Their goal is to optimise production, storage and sales processes.

Transport logistics is the domain of the *carriers* (or *forwarders*) of goods. These include road hauliers, railway undertakings, and operators of ships and airplanes. Their main goal is to maximise the utilisation of vehicles and labour, whilst minimising costs. In many industries, companies operate their own fleet of transport vehicles – especially in road transport – and are therefore both shippers and carriers.

If transport logistics is outsourced to external carriers, *logistics service providers (LSPs)* act as intermediaries between shippers and carriers. Especially for complex, multimodal transport chains, LSP are essential for the organisation and management of transports and the coordination between different carriers and the shipper. Increasingly, LSP not only act as agents between shippers and carriers, but also provide additional services. In this function they reach further and further into the shippers' internal processes, e.g. storage/warehousing, data management and value-adding services such as picking and packing. Their goal is cost-efficient order fulfilment.

Although not directly involved in transport services, the *public sector* plays an important role. Its main influence is the planning and regulation of land use on different territorial scales. This includes national, regional and local administration and the respective planning authorities. The public sector also provides and manages most of the transport infrastructure – especially roads. It regulates infrastructure utilisation through traffic legislation. The public sector's task is to protect the interests of the population, balancing social, economic and environmental objectives. The diversity of public administration entails a multitude of priorities that cannot be fully aligned. From a public sector view, freight transport is just one of many stakeholders using transport infrastructure and land.

Chapter 2

Freight transport in urban areas

2.1 Introduction

Freight transport is gaining attention in urban areas, from both the public and the private sector. Growing urban density and the transforming transport sector put freight on the map of economic, environmental and social considerations.

This chapter provides an introduction to current freight transport in urban areas. Section 2.2 clarifies the understanding of *urban areas*, *railway in urban areas* and *urban freight*. A short introduction to the structure and processes of urban freight transport is provided in Section 2.3. Section 2.4 summarises how some European cities deal with rail freight in their transport strategies.

2.2 Definitions

2.2.1 Urban areas

The term *urban* is essentially used to distinguish urban and non-urban areas – both for statistical reasons and in a social context. Naturally, there are different perceptions of what is *urban*, and suburbanisation and the emergence of polycentric conurbations have complicated matters further. Today, a division into urban, suburban (or peri-urban) and rural areas is widely established and categories such as *urban agglomeration* or *metropolitan area* are applied. Opinions differ on which area should be termed *urban* – the core city, the urban agglomeration or the full metropolitan area. While sociology and urban design mostly attribute the label *urban* to the (core) city, most statistical definitions apply it to the agglomeration and the metropolitan region (OECD, 2012; UNDESA, 2016; BFS, 2017d; Eurostat, 2017b).

For the statistical definition of areas, objective criteria that are in line with perception of what is *urban* need to be found (Goebel and Kohler, 2014). There are two approaches to define urban areas, the morphological and the functional definition of urban areas.

The morphological approach uses measures of density and size. As Häussermann (2007) points out, the concurrence of structural and social density creates *urbanity*. However, measures of the density of activities and interactions are often not available for statistics. Common morphological definitions therefore use structural data such as population and employment density. Other parameters are sometimes included, e.g. education or tourism (Goebel and Kohler, 2014).

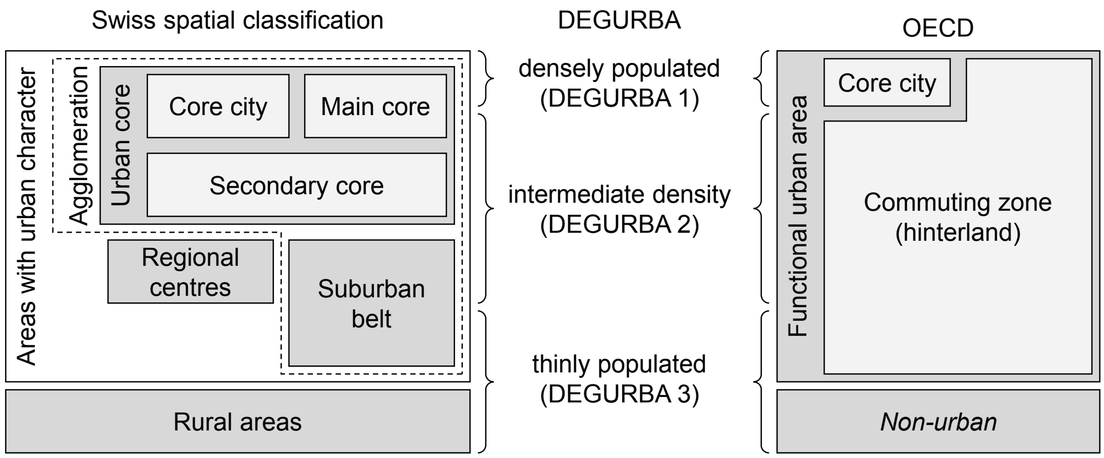


Figure 2.1: Comparison of morphological and functional definitions of urban areas (source: own)

Due to diverging perceptions, the density thresholds vary. Eurostat's degree of urbanisation (DEGURBA) for example, uses a population density of at least 1500 persons per square kilometre and a minimum population of 50 000 for "densely populated areas" (cities) (Dijkstra and Poelman, 2014). The United States Census Bureau also uses a minimum population of 50 000 for *urbanized areas*. However, the density threshold for the urban core is 1000 persons per square mile (approximately 390 persons per square kilometre) (US Census, 2011).

The functional definition of urban areas usually extends the density-based approach with measures of mobility. For example, OECD's definition of functional urban areas (FUAs) and the Swiss Federal Bureau of Statics' definition of "areas with urban character" both use commuting patterns to assign suburban municipalities to their respective urban core (OECD, 2012; Goebel and Kohler, 2014).

In the Swiss spatial classification, "areas with urban character" encompass urban cores (further divided into core city, main core and secondary core), the suburban belt and regional centres (not connected to an urban core). OECD's functional urban areas encompass a core city and the commuting zone (or urban hinterlands). However, the different classification systems do not categorise along the same delimitations. Figure 2.1 compares the DEGURBA classes (morphological) with Swiss and OECD spatial classifications (functional).

This research project uses the DEGURBA classification for spatial analyses. It provides a widely applied, standardised definition and facilitates comparisons. The focus is on the urban core, corresponding to *densely populated areas* (DEGURBA 1).

2.2.2 Urban freight

Urban freight refers to shipments to and from densely populated areas (DEGURBA 1, compare Section 2.2.1), excluding transports within the same urban core. Included are thus OD-pairs between densely populated and intermediate density regions, densely populated and thinly populated areas and between densely populated areas of different cores. Not included are transports with origins and destinations outside densely populated areas and within the same urban core.

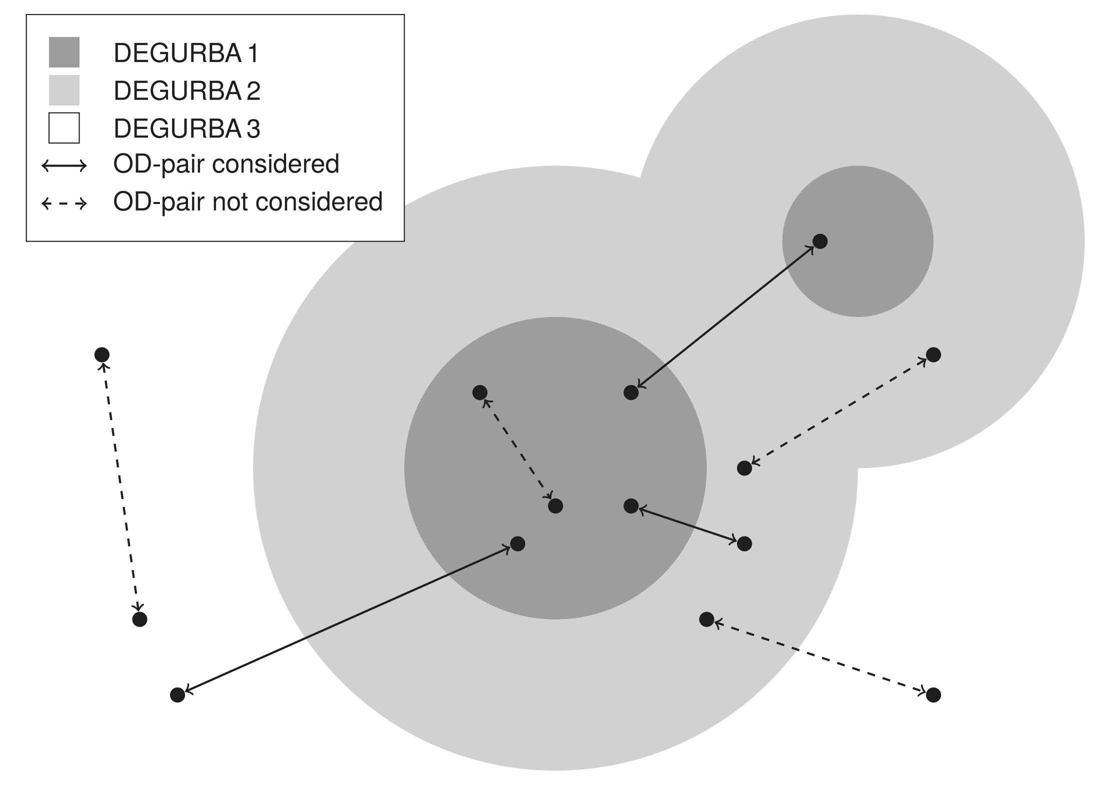


Figure 2.2: Definition of urban freight transport using DEGURBA codes (source: own)

Figure 2.2 shows the concept of the OD-pairs considered for urban freight transport. Breaks in the transport chain – at loading, unloading and transhipment points – are not included.

2.2.3 Freight railways in urban areas

In this research project the term *railway in urban areas* refers to main line railway, sometimes called *heavy* railway. It is characterised by national and international interoperability, mixed use of the network for both passenger and freight, mixed distance categories (long, medium and short distance services) and – in Europe – the use of standard gauge tracks. It is therefore in contrast to trams, light-rail and underground systems (rapid transit) – which are sometimes referred to as *urban railways* and usually not used for freight transport. Although this is sometimes suggested, this research project does not consider the use of non-standard railways for freight transport.

Rail freight is suitable for different transport chains. It is used, for instance, in the construction, postal and retail sectors. Figure 2.3 shows examples of rail freight terminals in urban areas. Figure 2.3(a) is an urban cross dock for fresh produce (vegetable, fruit) in the wholesale market of Paris-Rungis. Figure 2.3(b) is a bulk terminal for excavated material in London.

(a) Cross-docking terminal Paris-Rungis

(b) Bulk terminal Cricklewood (London)

Figure 2.3: Examples of road–rail terminals (pictures: (a) K. Barry, marché international de Rungis, (b) GB Railfreight, media centre)

2.3 Urban freight transport

2.3.1 Introduction

The characteristics of freight transport in urban areas differ from non-urban areas. The near-absence of the secondary economic sector, i.e. manufacturing, in the urban core leads to distinctive freight transport patterns. Transport is characterised by the supply of consumer goods, the removal of waste and recyclables, and the construction and maintenance of buildings and infrastructure.

The urban area thus shapes the structure of the sector – the number and market power of the actors involved in urban freight transport. It also shapes the composition of the commodities transported, the structure of freight flows (i.e. the origins, destinations and quantities) and how transport chains are organised. Additionally, it influences the significance of alternative transport modes.

Freight railways have long focused on cities as centres of manufacturing, not consumption. Due to protected markets, slow innovation and low margins, they have had few incentives and opportunities to adapt and modernise.

Changing forces behind freight flows however, present rail freight with new challenges. Freight railways need to blend in with the urban transport industry. Commodity structure in urban freight transport has implications in railway operations and sets the requirements for freight terminals. The predominant transport chains in urban areas shape potential multimodal freight systems.

2.3.2 Transport industry structure

The structure of freight transport follows that of other network industries. Knieps (2007) defines the layers of network industries as (1) network services, which are consumed by the customers; (2) infrastructure management, to organise the utilisation of the network; (3) network infrastructure, the physical infrastructure; (4) public resources, which are needed for the network. Examples in road and rail freight transport in the 4-layer-model are:

1. Network services
    - Road freight transport services (vehicles, routes)

    - Rail freight transport services (connections, timetable)
2. Infrastructure management
    - Road: Traffic management and control, road safety
    - Railway: Network access and capacity, scheduling, operations management, emergency response
3. Network infrastructure
    - Roads, bridges, tunnels, road signs, . . .
    - Railway tracks, electrification systems, stations and terminals, bridges, tunnels, signals, . . .
4. Public resources
    - Road: Land for roads and facilities, land use planning, environmental impacts
    - Railway: Land for railway lines and facilities, land use planning, environmental impacts

Freight transport is subject to competition in all network layers. In the layer of network services, there is competition between different modes of transport (*intermodal competition*). In the layers of network infrastructure and infrastructure management, there is competition for capacity and priority between the users of the same infrastructure (*intramodal competition*). Lastly, in the layer of public resources, there is competition for space.

2.3.3 Commodity structure of urban freight

The commodity structure of freight transport in urban areas differs from the general patterns. In densely populated areas, the service sector dominates freight demand. This shows in the type of goods transported, as well as in the form goods are transported (i.e. the type of cargo).

In order to distinguish urban from non-urban transports in Switzerland, an analysis of transports with heavy goods vehicles (HGVs) was conducted. The Swiss Federal Statistical Office (BFS) provides surveys of domestic HGV transport (GTE) and cross-border traffic of foreign HGV (GQGV). Both surveys (year 2013) were merged with spatial data (BFS, 2017c, 2016) and the freight trips' origin and destination analysed. The DEGURBA codes of municipalities (obtained through postal codes) were used for origins and destinations in Switzerland; for origins and destinations outside Switzerland, NUTS 3 regions were used.

In accordance with the definition in Section 2.2.2, *urban freight* refers to HGV transports to and from densely populated areas, excluding transports within the same urban core.

Good type The type of good is recorded by the 20 divisions of the European standard goods classification for transport statistics (NST). In Switzerland, an alternative classification with 10 commodity groups is in widespread use. The conversion between the two systems can be found in Table A.1.

Table 2.1 shows the shares of good types in urban freight transport by freight volume. The main commodities are mining and quarrying products, followed by food products, other mineral products (which include glass, cement and other building materials) and waste and recycling goods.

Table 2.1: Shares of HGV transport volume with origin or destination in densely populated areas (DEGURBA 1) by NST-divisions in Switzerland, 2013 (*BFS Gütertransportstatistik* (BFS GTS))

NST-division	Good type	Share
01	Agricultural and forestry products	4.9 %
02	Coal, crude petroleum and natural gas	0.1 %
03	Metal ores, mining and quarrying products	26.0 %
04	Food products	13.7 %
05	Textiles and leather products	0.4 %
06	Wood and paper products	2.5 %
07	Refined petroleum products	7.7 %
08	Chemical products	3.1 %
09	Other non metallic mineral products	12.5 %
10	Basic metals and metal products	3.9 %
11	Machinery and equipment	1.1 %
12	Transport equipment	0.5 %
13	Furniture and other manufactured goods	1.5 %
14	Secondary raw materials, wastes	10.0 %
15	Mail, parcels	1.6 %
16	Equipment utilized in the transport of goods	4.1 %
17	Goods being moved for repair	2.9 %
18	Grouped goods	2.7 %
19	Unidentifiable goods	0.7 %
20	Other goods	0.1 %

Cargo type The surveys analysed also record the type of cargo. It describes the general appearance of transported goods and indicates its handling characteristics. For this reason, the type of cargo is of major interest to multimodal transport, since additional handling is required.

Liquid and *dry bulk goods* do not require cargo units and are mostly transhipped by pumping and dumping respectively. This includes liquids and liquefied gases, molten and slurried solids, powders, granular solids and large solids.

Large freight containers cover marine (ISO) containers and swap bodies and are transhipped with gantry cranes or reach stackers. Roller containers (often used in waste transport) and some horizontal transhipment systems also fall under this category. Among the category *other freight containers* are skips (or dumpsters), mostly used in waste transport and construction and are picked up directly by the lorries.

Palletised goods make up a large share of retail and trade and require forklifts for loading and unloading. Besides pallets it includes slip-sheets and any assembled cargo suitable for forklifts.

Pre-slung goods are bundled using straps, slings or bulk bags (so-called flexible intermediate bulk containers (FIBCs)), including packaged timber.

Mobile units are vehicles of any type. Self-propelled units include motor vehicles, truck-trailer combinations and live animals. Non-self-propelled units, such as semi-trailers in unaccompanied combined transport, require craning, hoisting or tractors for transhipment.

Other cargo types cover a large range of goods otherwise not specified. This includes break bulk of varying shapes and sizes, such as coils, barrels, drums, boxes, bags etc. This category therefore includes transhipment with specialised equipment as well as manual handling of roll cages and trolleys.

The main type of cargo (by freight volume) in urban freight is dry bulk with 32.1 %, followed by palletised goods (23.8 %). Figure 2.4 shows the good types and cargo types of urban freight transport in Switzerland, the full table can be found in Appendix A, Table A.3.

As a range of good and cargo types are transported by the same means in the same logistics sector, commodities can be grouped. “Commodity groups” are defined based on assumptions on haulage and transhipment means and on Fig. 2.4.

Table 2.2 shows the chosen assignment of good and cargo types and the corresponding annual freight volumes in Switzerland. The main commodity groups in urban freight transport are construction, food and other retail, and waste and recycling. Additional clusters are hazardous liquids, general containerized goods and general trade. General containerized goods and general trade include all good types not covered elsewhere, which complicates an assignment to a certain logistics sector. From the cargo types, mobile units (self-propelled and others) are omitted.

Table 2.2: Commodity groups by good type and cargo type (source: own)

Group	Annual volume	Good types	Cargo types
Excavation and construction:	17 718 000 t	Mining and quarrying products, other mineral products	Dry bulk and containers
Food and other retail:	9 884 000 t	Food products, textiles and paper products	Dry bulk, containers, pallets, pre-slung and other cargo types
Waste and recycling:	5 049 000 t	Secondary raw materials, wastes	Dry bulk, containers and pallets
Hazardous liquids:	5 319 000 t	Refined petroleum and chemical products	Liquid bulk
General containerized goods:	2 449 000 t	All other good types ([1])	Containers
General trade:	8 970 000 t	All other good types ([1])	Pallets, pre-slung and other cargo types

([1]) NST divisions 01, 02, 10, 11, 12, 13, 15, 16, 17, 18, 19 and 20

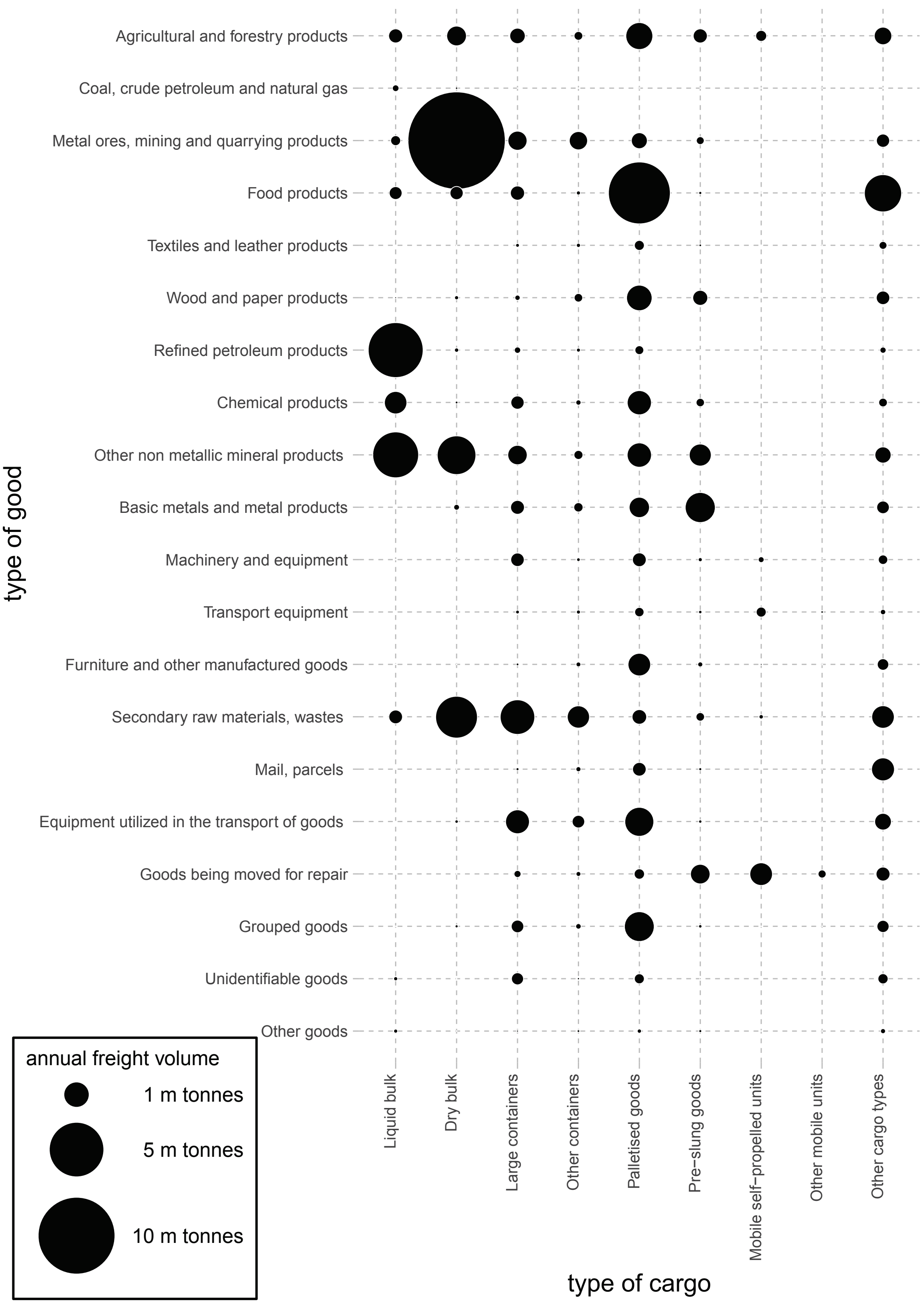


Figure 2.4: Composition of good type and cargo type in urban freight by volume (source: own, data: BFS GTS)

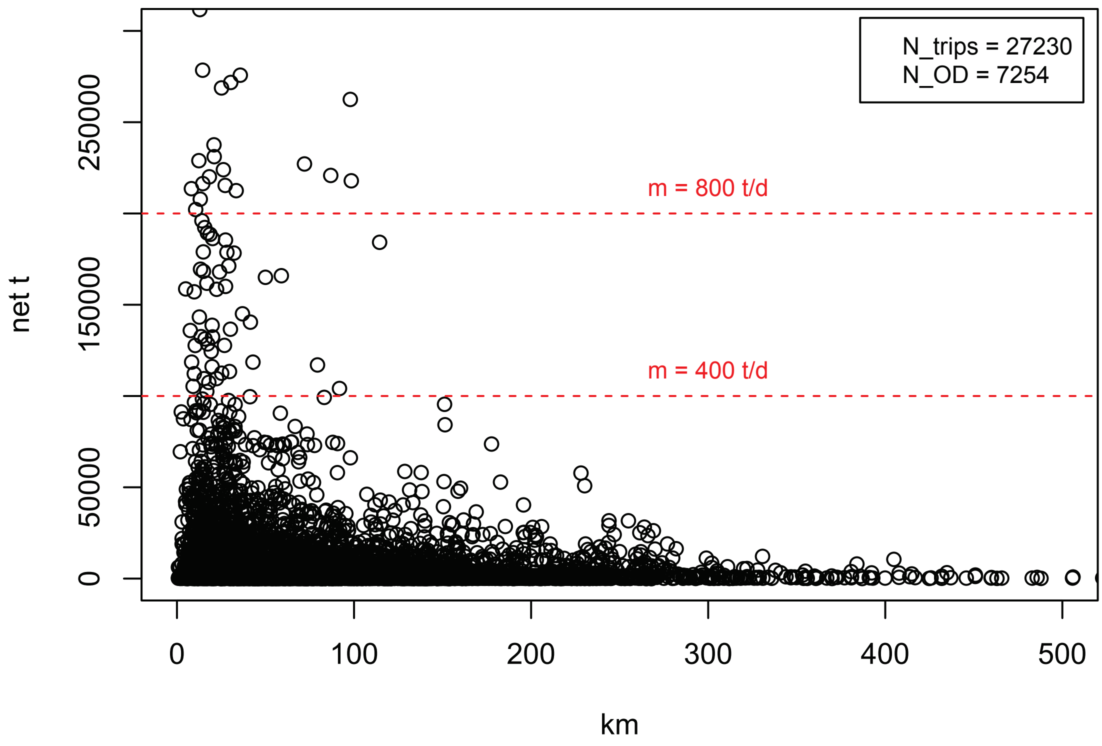


Figure 2.5: Freight flows in Switzerland by OD-pair (municipalities), for all regions and commodities, transported by HGV (source: own, data: BFS GTS)

2.3.4 Urban freight flows

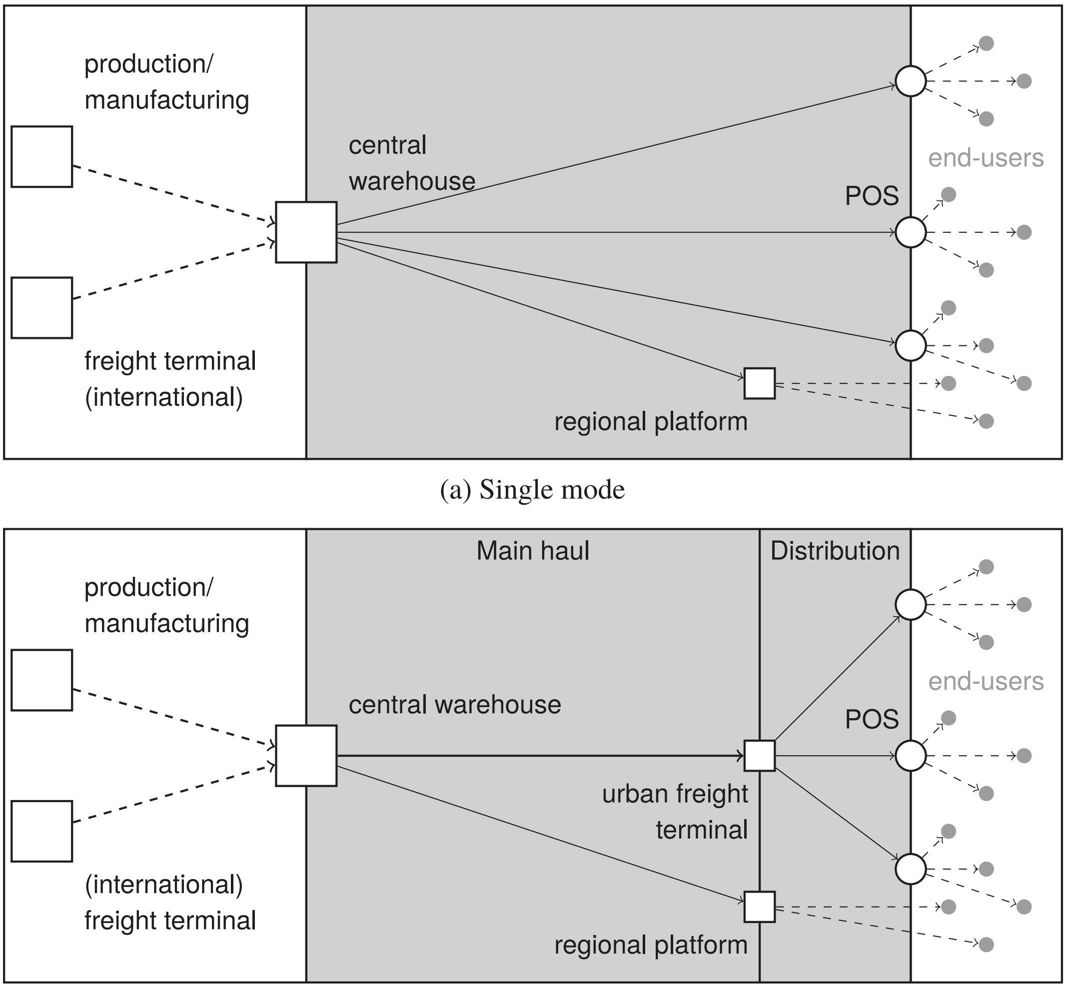
The spatial distribution of freight flows reveals some of the characteristics relevant to urban transport chains. For this purpose, the destinations, load and distance of freight trips in urban areas were evaluated by origin-destination-pairs (OD-pairs). This allows to estimate the potential of shifting freight to multimodal transport.

The analysis was made for both municipalities (7254 OD-pairs, in Switzerland only) and NUTS 3 regions (1819 OD-pairs including destinations and origins abroad) (Fig. 2.5). All freight trips from the sample are added up for each OD-pair. The annual freight volumes per OD-pair are obtained by grossing up the respective loads.

The analysis shows that the vast majority of flows involves only small freight volumes. The median annual freight volume is 1036 t per OD-pair (for municipalities). To illustrate the order of magnitude, the corresponding average daily freight volume (assuming operations on 250 days per year) is pictured in Fig. 2.5 (in red).

The total annual freight volume only partially relates to the freight volume per OD-pair. The largest freight volumes in Switzerland are in *excavation and construction* (with a median volume of 16 000 t per OD-pair), followed by *hazardous liquids* (6000 t) and *waste and recycling* (4000 t). Despite large annual freight volumes (compare Table 2.2), *food and other retail* and *general trade* display rather small freight flows with approximately 1000 t per OD-pair each.

The analysis also shows that the majority of transports are very short (despite eliminating transports within the city). This illustrates that urban freight transport is a difficult market for conventional rail transport concepts.



(a) Single mode

(b) Multimodal

Figure 2.6: Scope of the project, with single mode (a) and multimodal (b) freight transport

2.3.5 Urban transport chains

The study covers the main haul and the distribution legs of urban transport chains (Fig. 2.6). At the transport interfaces lie central warehouses, conventional and urban freight terminals and distribution centres. In general 3 types of transport chains can be distinguished (Savy and Burnham, 2013):

- Direct traffic (single OD-trips)
- Tours (single vehicle, multiple OD)
- Logistics systems (multiple vehicles, multiple OD, transhipment)

In terms of transport systems, two fields can be distinguished: (i) The *landside* of urban freight transport, i.e. the distribution of goods to points-of-sale (POS), end consumers (in the case of home delivery) and other destinations (or origins) of freight movements. Planning tasks mainly focus on the planning of delivery tours. This generally involves road transport, since other transport systems (rail, water, pipelines) do not have comparable network densities. (ii) The *railside* of urban freight transport, i.e. the transport from hubs (e.g. central warehouses, intermodal terminals) to distribution centres, sometimes referred to as de-feeder transports (Hesse and Clausen, 2012). The two fields of railside and landside of urban freight transport are connected by the transhipment process.

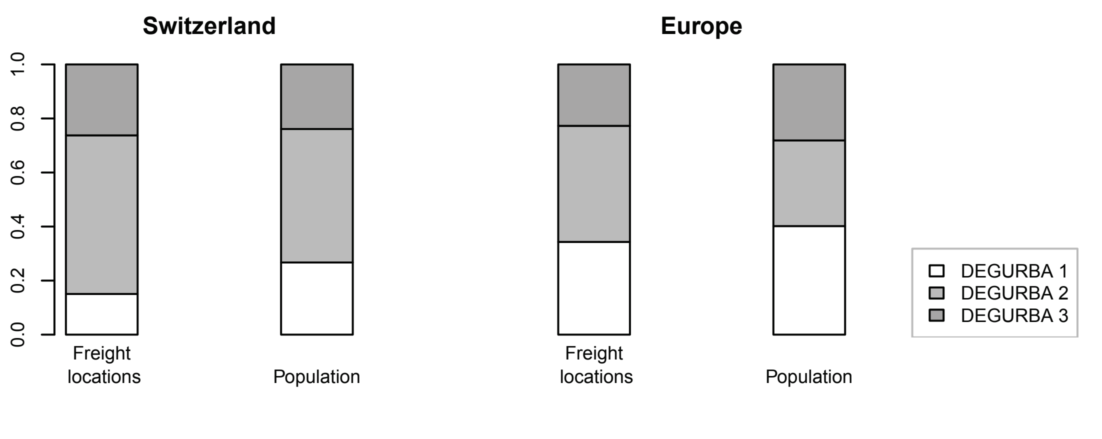


Figure 2.7: Rail freight locations and population in Switzerland and Europe by DEGURBA class (source: own, data: Hacon (2017); Eurostat (2017a))

The focus of road distribution is on the delivery to shops (POS). Not considered are the transport by end-users (i.e. shopping trips) and home delivery.

All main hauls are considered, where shifting to rail could be a possibility. Not considered are (international) main hauls from seaports and between centres of production and (non-urban) central warehouses.

2.3.6 Alternative modes in urban freight

The use of alternative modes for urban freight transport, such as railways or even inland waterways, is limited. Currently the share of rail freight in cities is 5 to 6 % in Greater London (TfL, 2007b; Allen et al., 2013), 3 to 5 % in Paris (Browne et al., 2007; Ripert and Browne, 2009) and approximately 7 % in Berlin (Jahn and Krey, 2014).

The locations of over 3500 rail freight access points throughout Europe were analysed with data from the research project behind *railfreightlocations.eu* (Galonske et al., 2016; Hacon, 2017) combined with geographical information from Eurostat (Eurostat, 2017a). Unfortunately, no data on the utilisation of the access points is available.

It is shown that 34 % of the access points in Europe are located in cities (DEGURBA 1) (Fig. 2.7). In Switzerland (over 250 rail freight access points in total), the share is 15 %. In both cases, the numbers roughly correlate to the distribution of the population (though the access density is much higher in Switzerland). It can therefore be assumed that sufficient access to railway exists in urban areas.

Reasons often identified are high costs for rail transport, land use pressure on rail areas and local opposition to rail freight (Giuliano et al., 2013). Railway networks have a comparably low density and only few goods recipients can be served directly via rail. Goods need to be transhipped and distributed by road, which increases the need for coordination and costs. The development of residential and business properties along railway corridors irreversibly bars areas from rail-freight-oriented use.

Against the background of growing and densifying cities, governments – local, regional and national – have an interest in shifting some freight to rail. For reasons of economic development, environmental impacts and public health and safety, it is desirable to maintain access to the rail freight system in urban areas.

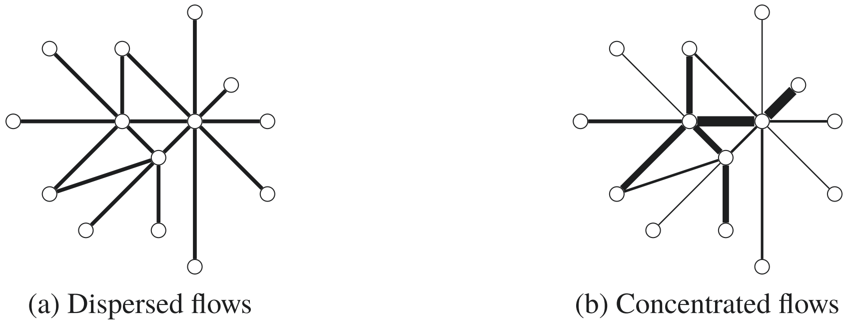


Figure 2.8: Distribution of freight volume among OD-pairs, with a low (a) and high (b) Gini coefficient (source: own)

2.3.7 Shifting freight to rail

It is clear that the rail system cannot cover all freight transports for various reasons. Similar to public passenger transport, the bundling of transport demand is essential. Also similar to public transport, some shippers are bound to road transport, some are forced to use rail transport. In between, shippers can take a decision to use one or another means of transport.

The distribution of freight volume among the relations – and hence the degree of potential consolidation – can be expressed by the Gini coefficient. It ranges between 0 (completely equally distributed) and 1 (completely unequally distributed). A low Gini coefficient therefore expresses freight volumes dispersed among all OD-pairs; a high Gini coefficient expresses freight volumes concentrated on a few strong relations (Fig. 2.8). It is assumed that higher concentration – and hence a higher Gini coefficient – better suits rail freight, where freight needs to be consolidated.

Table 2.3 shows the total freight volume, the median transport distance and the Gini coefficient of HGV transports in Switzerland for each commodity group. The OD-pairs based on the NUTS 3 regions display – not unexpectedly – a higher concentration of freight volume (higher Gini value). The larger size of the NUTS 3 regions are of larger significance for short freight trips.

Municipality-based OD-pairs display higher dispersion of freight volumes in con-

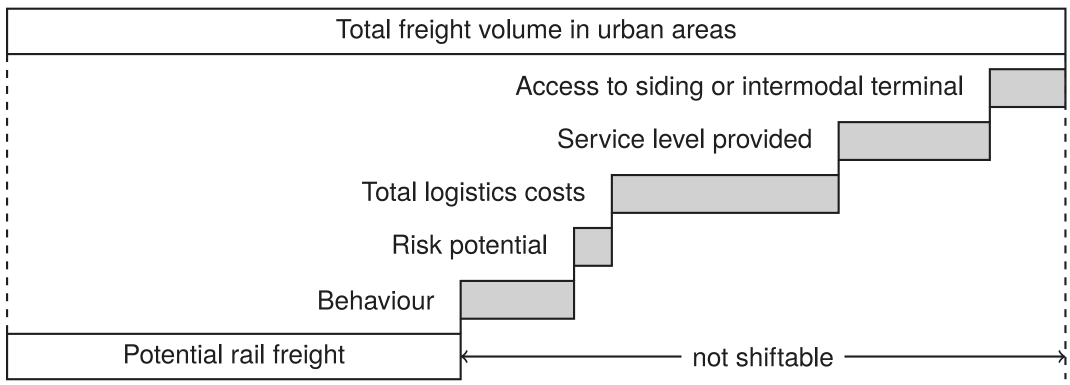


Figure 2.9: Non-shiftable freight and factors determining the suitability for rail freight (source: own)

Table 2.3: Total freight volume, median transport distance and Gini coefficient in Switzerland by commodity group (source: own, data: BFS GTS)

	OD by municipality			OD by NUTS 3		
	M_{total} t	d_{median} km	k_{Gini} –	M_{total} t	d_{median} km	k_{Gini} –
Construction	17 718 000	23	0.62	20 251 000	40	0.85
Food/retail	9 884 000	69	0.75	11 261 000	109	0.80
Waste/recycling	5 049 000	21	0.73	5 768 000	52	0.80
Liquid	5 319 000	46	0.62	5 847 000	50	0.80
Containers	2 449 000	24	0.67	2 916 000	76	0.78
General trade	8 970 000	69	0.74	11 573 000	116	0.81

struction material and hazardous liquids, and a higher concentration in food/retail and general trade.

A number of factors influence the shipper's choice of mode (Fig. 2.9):

Access to transport networks: Direct rail access is comparably sparse. Multimodal transport however mostly solves this restriction.

Service level: The customers' requirements in terms of transport time, punctuality, reliability and flexibility.

Logistics costs: They are usually composed of rates for transport and transhipment, capital costs and inventory costs.

Risk considerations: The likeliness of the good being damaged or lost due to environmental hazards or theft.

Behavioural factors: Personal preferences of logistics managers and the firm's policy or public image.

Estimations of the potential to shift freight from road to rail vary. Bryan et al. (2007) mentions potentials of 80 % for gravel, crushed stone and non-metallic minerals (i.e. cement), as well as waste and scrap, and 40 % for foodstuffs (Table A.2). Depending on the transport distance, BVU et al. (2016) estimates potential (total) shares of rail of approximately 45 % for distances below 200 km, up to 80 % for distances above 400 km.

For shorter distances (below 100 km), it must be assumed that the potential for shifting freight is lower. Considering the aforementioned current shares of rail freight in cities (Section 2.3.6), an (additional) shift of 5 % seems already generous.

2.4 Rail freight in urban transport strategies

Parts of this section have previously been published in:

- Fumasoli, T. and U. Weidmann (2016) The state of urban rail freight strategies in European cities, paper presented at the *95th Annual Meeting of the Transportation Research Board*, Washington, D.C., January 2016.

2.4.1 Introduction

For many cities, the focus of urban planning is currently shifting towards urban freight transport. In the debate on urban logistics the use of (heavy) railways is increasingly being advocated (Dinwoodie, 2006; Maes and Vanelslander, 2010; Alessandrini et al., 2012; Browne et al., 2014). The shift to rail-based supply chains is expected to reduce the dependency on road infrastructure, and to contribute to a range of current challenges in transportation, such as congestion, pollution and road safety. Additionally, freight transport plans are instruments for economic development.

However, planners often give little thought to the requirements for freight railways in urban areas. The need for additional infrastructure (e.g. transhipment facilities), improved rolling stock and organizational integration of transport services is mostly covered on a conceptual level only. Additionally, the disintegration of railway infrastructure managers, operators and regulators in Europe (EC, 2001) has led to a loss of planning competence in the public administration.

On the basis of urban (or metropolitan) transport strategies and freight plans, this section analyses the state of specific measures to improve rail freight transport in urban areas in Europe. It should identify if – on the local level of administration and planning – there is awareness of railways as an alternative mode for freight transport. Is there understanding of the requirements for rail freight in urban areas and of its (potential) contribution to urban freight transport? Are railway considerations based on land use alone, or do they include railway operations? Does a clear picture exist of what role railways can take in urban freight transport and is this expressed appropriately?

In order to answer these questions, a range of freight plans and transport strategies by urban and metropolitan administrations is analysed. A categorization is applied and specific rail freight planning measures are identified.

In transport strategies and freight plans, rail freight can be approached from different sides. In a *modal approach*, transportation is viewed through an infrastructural classification, i.e. road, rail, waterways, etc. In the *sectoral approach*, the purpose of the trip – passenger, goods and services – is essential. Occasionally, commercial, public and private transport are distinguished instead.

2.4.2 Selection of rail freight strategies

The state of strategic rail freight planning in urban areas was analysed by reviewing publicly available transport plans and strategies. The research was limited to cities belonging to the largest metropolitan areas in Europe; Table 2.4 shows the cities selected for this study and the respective strategies.

Only plans and strategies from bodies of the public administration were regarded, excluding corporate strategies of freight train operators and infrastructure managers. This approach was taken due to the strong regulatory role of municipalities and regional governments in urban transportation matters on one hand, and the administrations' increasing awareness of the need for improving freight transport policies on the other.

Since urban areas are often not congruent with administrative structures, a range of public entities was considered as sources of freight transport strategies in the urban context. Depending on territorial definitions and administrative structures, strategies and long term plans can be issued by (i) municipalities or greater cities, (ii) inter-administrational cooperation, if the urban area does not form a single administrative unit, (iii) regional, state or provincial governments, if the urban area is congruent to the mentioned, or

Table 2.4: Selected cities and strategies/plans (source: own)

City, country	Name of strategy/plan	Abbr.	Year
London, UK	London Freight Plan	FP	2007
London, UK	Rail Freight Strategy	RFS	2007
Paris, France	Plan de déplacements urbains d'Île-de-France	PDUIF	2014
Paris, France	Document d'orientations stratégiques pour le Fret en Île-de-France à l'horizon 2025	Fret-IdF	2012
Berlin, Germany	Integriertes Wirtschaftsverkehrskonzept Berlin	IWV	2005
Barcelona, Spain	Pla de Mobilitat Urbana de Barcelona	PMU	2012
Barcelona, Spain	Pla Director de Mobilitat de la Regiò Metropolitana de Barcelona	pdM	2015
Milano, Italy	Piano Urbano Della Mobilità Sostenibile Milano	PUMS	2015
Rome, Italy	Piano per la Mobilità delle Merci	PMM	2007
Hamburg, Germany	Mobilitätsprogramm 2013	MobP	2013
Warsaw, Poland	Strategii Transportowej Miasta Stołecznego Warszawy	STMSW	2013
Brussels, Belgium	Le Plan régional de mobilité Région de Bruxelles-Capitale	IRIS II	2011
Brussels, Belgium	Plan stratégique pour le transport de marchandises en Région de Bruxelles-Capitale	TranMar	2013

(iv) governmental bodies, if the central state takes responsibility for a certain urban area (e.g. in capital cities).

2.4.3 Classifications of rail freight strategies

Rail freight strategies were classified according to the type of the issuing body, the specificity of the document and special local circumstances. Table 2.5 shows the classification of the different rail freight strategies and their respective issuing body. Specificity describes the significance of the railways sector in the document. Is it (i) mentioned in a general strategy/plan, (ii) a self-contained chapter in a general strategy/plan, (iii) a follow-up/specification to a broader strategy, or (iv) a stand-alone strategy?

In some cities, special local circumstances – apart from freight distribution – have to be considered. This is the case when a cities' freight transport system is (i) dominated by transport-intensive industries (e.g. coal power plant) and/or (ii) holding a function exceeding the supply of the city (e.g. major sea ports with hinterland transport).

Table 2.5: Transport plans: issuing entities and classification (source: own)

City, plan abbr.	Issuing public entity	Entity type	Specificity	Local circumstances
London, FP	Transport for London TfL	municipal	mentioned	port traffic
London, RFS	Transport for London TfL	municipal	follow-up/ specification	port traffic
Paris, PDUIF	Syndicat des Transports d'Île-de-France STIF	inter-administrational cooperation	mentioned	
Paris, Fret-IdF	Direction Régionale et Interdépartementale de l'Équipement et de l'Aménagement d'Île-de-France DRIEA	governmental body	self-contained	
Berlin, IWV	Senatsverwaltung für Stadtentwicklung	municipal	self-contained	
Barcelona, PMU	Ajuntament de Barcelona	municipal	mentioned	port traffic
Barcelona, pdM	Autoritat del Transport Metropolità ATM	inter-administrational cooperation	mentioned	port traffic
Milano, PUMS	Comune di Milano	municipal	mentioned	
Rome, PMM	Città metropolitana di Roma Capitale	regional authority	mentioned	
Hamburg, MobP	Behörde für Wirtschaft, Verkehr und Innovation	municipal	mentioned	port traffic
Warsaw, STMSW	Urząd Miasta Stołecznego Warszawy, Biuro Drogownictwa i Komunikacji	municipal	mentioned	coal power station
Brussels, IRIS II	Bruxelles Mobilité	regional authority	mentioned	
Brussels, TranMar	Bruxelles Mobilité	regional authority	self-contained	

Table 2.6: Objectives and rail-related measures of transport strategies (source: own)

	London, FP	London, RFS	Paris, PDUIF	Paris, Fret-IdF	Berlin, IWV	Barcelona, PMU	Barcelona, pdM	Milano, PUMS	Rome, PMM	Hamburg, MobP	Warsaw, STMSW	Brussels,IRIS II	Brussels, TranMar
Main objectives:													
Public spending	X	X	X			X	X	X	X	X	–	X	X
Public health	X		X		X	X		X			–	X	
(Road) safety	X		X	X	X	X	X	X	X		–		
Environment	X	X	X	X	X	X	X	X	X		–	X	X
Economic development	X	X		X	X					X	–		X
Rail freight measures:													
Network infrastructure		X	X		X		X			X	–		
Network capacity		X	X	X			X			X	–		
Terminal infrastructure		X	X	X	X		X				–	X	X
Terminal capacity					X						–		
Terminal location		X		X	X						–		X
Freight train operations		X	X	X					X		–		
Freight train technology		X									–		

2.4.4 Results

2.4.4.1 Objectives of rail freight strategies

In general, the purpose of transport strategies issued by public bodies needs to be compliant with public objectives. Objectives can be assigned to (i) efficient public spending, (ii) maintaining or improving public health, (iii) improving (road) safety, (iv) the protection of the environment, and (v) the promotion of economic development. In some strategies objectives refer particularly to freight transport, in others partially or not.

Table 2.6 shows the scope of objectives in the analysed strategies and their freight-relevance. More efficient public spending (i.e. on transport infrastructure) seems to be the major driver of freight transport strategies. Diverting traffic from roads to non-road modes also helps to improve road safety, as well as reducing air pollution, noise and the emission of greenhouse gases.

Economic development is especially important in freight-oriented strategies (e.g. London Rail Freight Strategy) whereas more general strategies rather focus on public health. In general, objectives in transport strategies are usually not explicitly connected to freight transport, especially not to rail freight.

2.4.4.2 Measures and recommendations of rail freight strategies

The measures proposed in transport strategies are manifold. They range from general transport policies to awareness campaigns, development schemes and specific local projects. Irrespective of the degree of particularity, the measures related to rail freight transport can be attributed to one or several of the following aspects:

- Network infrastructure
- Network capacity
- Terminal infrastructure
- Terminal capacity
- Terminal location
- Freight train operations
- Freight train technology

Infrastructural measures range from expanding networks and building new terminals to safeguarding of railway areas from urban development in order to hold them available for future rail freight needs. Especially in safeguarding sites, the planning and dimensioning of railway systems strongly interacts with urban planning and spatial development.

Capacity measures include dedicating capacity to freight, securing train paths from increasing passenger services. Additionally, measures to increase capacity by improving track infrastructure and signalling are included. In terms of rolling stock measures are limited to the technical adaptation of freight trains to passenger trains.

Of major interest to urban planners is infrastructure, capacity and the location of terminals at the interface between rail and road transport. Terminal types range from standard container terminals – partly trimodal (road, inland waterway and rail) – to road–rail crossdocking facilities.

Special solutions are also part of some freight transport strategies. The use of the tramway network for freight is considered in Paris and Brussels; the use of the French high speed railway network for freight is also mentioned (Fret-IdF, PDUIF, TranMar).

The analysis shows that, the less specific a transport strategy, the less likely it is to contain measures directly connected to rail freight transport. Even freight-oriented strategies such as the London Freight Plan do not necessarily contain rail-specific measures; however it is backed up by a specific rail freight plan. Also, in areas with specific freight transport demands, e.g. deep sea ports, strategies seem to contain less specific measures.

Most strategies do not comment on freight train operations and rather focus on infrastructural topics. The physical networks and nodes seem to be of higher priority to public planners than operational aspects.

2.4.4.3 London's rail freight strategy

To highlight the range of measures, the London case is presented in detail. Besides being the largest metropolitan area in Europe, London has the probably most comprehensive rail freight strategy in terms of urban transport. The Rail Freight Strategy of London is part of the London Freight Plan, designed by Transport for London (TfL) a functional body of the Greater London Authority (TfL, 2007a). The proposed solutions include (i) capacity and capability schemes in London, (ii) capacity and capability schemes outside London, (iii) encouraging more efficient use of the network, (iv) terminal development, and (v) other pro-rail policy initiatives.

Capacity and capability schemes aim to increase the available freight routes and therefore improving the reliability and the diversionary capability for freight. The measures include gauge enhancement, increasing the number of available tracks, the strengthening and reconstruction of bridges, headway improvements, electrification and train lengthening. This allows diverting some freight traffic away from busy cross-London routes, and creating additional capacity for passenger services.

More efficient use of the network can be achieved by improving the allocation of train paths. Well-designed track charges support more efficient capacity utilization by encouraging performance of freight trains to be as similar to passenger trains as possible. This may require some technical adaptations of rolling stock. Additionally the availability of alternative routes allows more efficient track maintenance.

The development of new multimodal terminals should allow rail to increase its share in the retail distribution market and support international freight. The location in proximity to highways and main arteries of London is of major importance. Additionally smaller freight terminals concentrating on local markets should be developed.

Pro-rail policy initiatives refer to the liberalization of access to rail infrastructure in continental Europe. This should make the European rail freight market more permeable across national borders. Additionally road pricing will help to create a more level playing field in terms of payment for infrastructure at point of use.

2.5 Conclusion

As this introduction shows, freight transport in urban areas currently faces a number of challenges. Especially the role of railways in urban freight seems to be uncertain.

The structure of the transport industry shows that an isolated view of the rail freight system is insufficient. The many interdependencies between shippers, logistics service providers (LSPs) and carriers are an integral part of today's freight transport environment. Especially in the urban context, *rail freight transport* virtually always implies *multimodal transport*.

The commodity structure of urban freight shows that transport is dominated by dry bulk goods (excavated earth, gravel, sand, wastes and recyclables), followed by palletised goods (mainly food products). Non-containerised cargo thus needs to be included in the considerations of transhipment facilities.

The spatial distribution of freight flows shows a high share of very short trips. The freight volume is mostly distributed among a high number of relations. Both aspects are generally thought to be in disfavour of rail freight transport. On one hand, the focus therefore needs to be on direct traffic on high-volume, longer-distance relations. On the other, technical and operational innovation is indispensable in order to ensure high transport quality.

The analysis of urban freight transport strategies shows that planners mostly agree on the need to take all modes into consideration. Nevertheless, including railways in freight plans does not seem to be custom.

Where rail freight is mentioned, measures seem to be largely infrastructure-oriented. In spite of the call for efficient network usage, train operations and rail vehicles are rarely taken into account. The railway system inherently displays strong dependencies between infrastructure, rolling stock, operations and transport services. Planners however seem to perceive rail freight as a system with inalterable operations and rolling stock. In the long run, rail freight in urban areas will suffer not only from a lack of infrastructure, but also from the widening technological gap between passenger and freight trains.

Some of the strategies reveal a growing awareness of the need to safeguard areas for freight transhipment facilities. Still, public bodies struggle to identify and preserve land suitable for road–rail transhipment. Few have found ways to outline the requirements for freight terminals.

This is partly because it is yet unclear whether railways can reasonably be integrated in urban transport chains. Neither is it clear whether the environmental benefits of rail transport justify investments into the rail freight system, nor has urban planning much experience with rail freight in modern cities, where not production of goods, but consumption is the driver of freight transport.

Chapter 3

Research hypotheses

3.1 Introduction

The interdisciplinary approach of the project entails hypotheses from different domains. They cover aspects from railway technology and productivity, transhipment facilities, system design and framework requirements.

Railway operations and rolling stock technology – in contrast to railway infrastructure – are only marginally present in the debate. It is however crucial for a system-wide approach to rail freight in urban areas.

The need for areas for freight terminals in urban areas is largely acknowledged, but rarely substantiated with proper planning guidelines. The processes and decision-making fundamentals of safeguarding areas for facilities need to be understood.

Understanding the functioning of a rail-based freight system as a whole, the interaction of railways with freight terminals and road transport, helps to quantify costs and impacts. The most important issue is how much land is needed for a rail-based urban freight transport system.

The framework requirements of rail freight in urban areas come from the rail freight system's environment. Rail freight is embedded in an economic environment and in environmental policies and is determined by land use priorities.

The hypotheses are based on the research questions mentioned in Section 1.2.

3.2 Freight railway technology and productivity

What are the effects of adapting freight train operation to densely used railway networks in urban areas?

Since the widespread de-industrialisation of cities, railways in urban areas have experienced a strong shift towards commuter services. As an addition to – or as an alternative for – dedicated urban mass transport systems (e.g. underground railway, light rail or BRT) "heavy" railways are today an essential element of public transport.

For this reason, the technical development of railways has largely been passenger-oriented. Rail freight – having retracted to low-margin niche markets – has developed less rapidly. The widespread use of trainsets in passenger railways has led to higher speeds, higher acceleration and higher deceleration. Improvements in railway signalling have led to ever shorter headways.

As a result, few train paths can be found for freight trains in urban networks. The

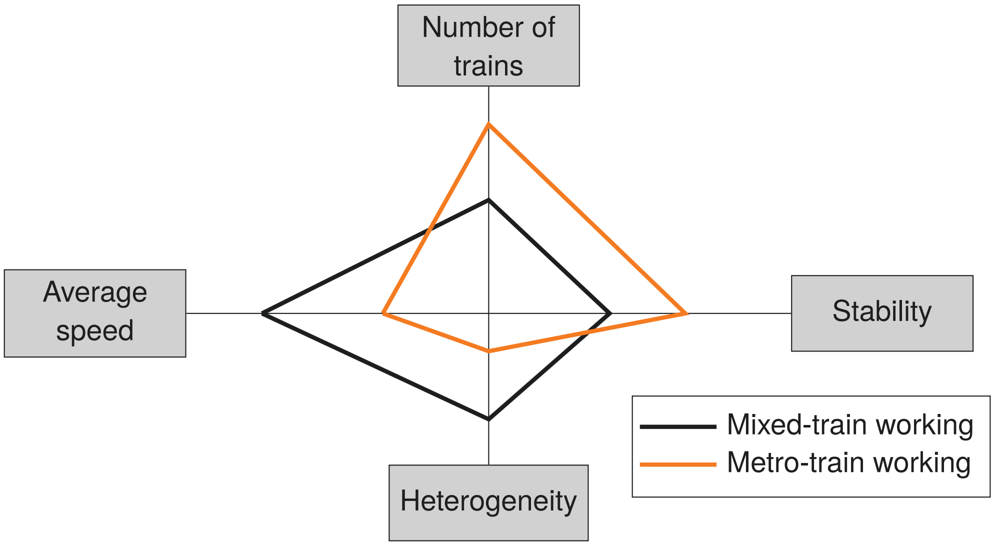


Figure 3.1: Capacity balance (adapted from UIC (2004))

properties of most freight operations require train paths that could only be offered at the cost of passenger services. It is clear that passenger operations should not be compromised by additional freight services.

Capacity – and stability – can be maintained by decreasing the heterogeneity of the network users (Fig. 3.1). Technology of freight trains needs to be developed in order to narrow the gap between passenger and freight services.

> Hypothesis:
>
> There exists railway technology which allows efficient freight train operations in densely used urban networks.

3.3 Rail facilities for freight transhipment

How can areas for the transhipment of goods from rail to road be secured?

It is clear that rail freight in urban areas cannot be a single-mode affair. Railway does not provide a dense enough network to distribute goods to customers, the points-of-sale or the intermediate trade. The transhipment to road transport is necessary.

Freight terminals for the transhipment of goods are an essential part of the multimodal transport chain. Their location determines the length of the main haul and the distribution. Their size and shape determine the throughput and the efficiency of transhipment activities. Their number determines the resilience of the multimodal transport system.

Following the de-industrialisation of cities, many railway facilities have been subject to redevelopment. The conversion for residential and commercial uses is irreversible. Areas for railways are therefore scarce. Public transport has answered this development by increasingly taking networks underground.

Due to higher land demand, this option is only rarely available to rail freight. It is therefore important to preserve areas suited for freight operations. Unused railway areas and lots in industrial estates need to be considered.

Hypothesis:

The areas suited for the transhipment of goods between rail and road can be made available at locations close to the urban core.

3.4 System design of rail freight in urban areas

How much can rail freight contribute to urban freight transport?

Little is known of the limiting factors of an urban multimodal freight transport system. In cities, the freight volume on rail is limited by (i) the share of goods that are shiftable to rail, (ii) the availability of train paths, (iii) the performance of freight transhipment, (iv) the availability of suitable areas for freight terminals, or (v) the availability of road capacity for freight transport. The share of goods that can be shifted to rail is assumed to increase with rail technology adapted to the urban environment. Already now, freight rail undertakings are starting to enter markets that were considered non-viable a few years ago.

The availabilities depend on the infrastructure and land reserves, which differ from city to city. The bigger and denser the city (i.e. in terms of population and economic activity) and the less infrastructure available, the more congestion and the less capacity and areas for freight generally results. This contrasts the rising demand for freight that increasing densities involve. Land use efficiency is thus of major importance for the freight system, in particular for freight terminals. The performance and dimensions of freight terminals largely define the potential of multimodal urban freight transport.

All in all, rail might only be a supplementary element of urban freight transport, providing transports in niche markets. On the other hand, rail freight might be capable of bearing the bigger part of urban freight. Identifying the limitations of a rail freight system in urban areas is therefore crucial.

Hypothesis:

Transport chains in urban areas can have a substantial share of rail transport while fully meeting logistics requirements.

3.5 Framework requirements of rail freight in urban areas

3.5.1 Economic sustainability

At what cost can rail freight be operated in urban areas?

It is obvious that an urban rail freight system will have higher operating costs than conventional rail freight. It is assumed that urban rail freight operations will need technologies involving less human labour and more automation, e.g. in shunting operations. Additionally, train size might be restricted in urban rail freight, making it difficult to exploit economies of scale.

However, due to increasing congestion, railways can provide transport more reliably than road transport. This makes multimodal transport more attractive for shippers.

Hypothesis:

The cost-effectiveness of rail-based urban transport chains is comparable to existing freight distribution systems.

3.5.2 Environmental sustainability

What are the environmental benefits of rail freight in urban areas?

Although emissions from rail transport alone are low, the effects of multimodal transport – the combination of rail and road transport and transhipment – need to be quantified. Negative impacts of freight transport need to be weighed against the environmental benefits and of urban rail freight.

Hypothesis:

Rail-based urban transport chains are environmentally better performing than conventional freight distribution systems.

3.5.3 Land use policy

How can rail freight be considered in urban planning?

Land use policy has a major influence on freight transport, particularly terminals. Areas considered for freight terminals might also be suited to alternative uses. It needs to be determined whether rail freight in urban areas is able to contribute to urban challenges such as efficient land use, reduction of road traffic and more liveable cities.

Hypothesis:

Rail-based urban transport chains give appropriate answers to current and emerging urban challenges.

Chapter 4

Research design

4.1 Introduction

This chapter introduces the approaches to verify the hypotheses. Due to the interdisciplinary character of the study, they need to cover a range of aspects.

The main method used is the analysis of technical, operational and planning processes. Process analysis allows to generalize a problem. This allows, where required, to model the system or object concerned, and to reproduce variations. It also facilitates consistent comparisons. Naturally, the variations are subject to similar conditions as the initially analysed system or object.

4.2 WP2: Freight railway technology and productivity

Capacity consumption is used to evaluate the interaction between freight train technology and productivity. For this reason, train movement is modelled. This allows to estimate the effects of adapting freight trains to operations in urban areas.

The devised model approximates train runs with linear parameters, avoiding detailed modelling of brakes and propulsion, and uses simplified infrastructure parameters. This approximation – basically the trapezoidal rule of the time-speed diagram – is considered to be sufficient for most planning purposes and is also common in commercial train scheduling tools. Focusing on single freight trains, this model however does not take into account detailed timetables, network effects nor the interaction between different train types. The infrastructure parameters are determined by passenger train operations – the predominant users of urban railway networks.

From the modelled train runs, infrastructure occupation and capacity consumption is calculated for main-distant, main-main and moving block signalling systems. The (theoretical) freight capacity is obtained by including potential train load. The model is then used to calculate the effects of improved traction, improved brakes and the variation of train length on freight capacity.

4.3 WP3: Rail facilities for freight transhipment

The planning of freight terminals in urban areas is subject to both private and public planning. Private terminal planning is the process of choosing and evaluating sites, in consideration of the terminal operator's needs. Public planning is the allocation and safeguarding of land resources to freight transport through zoning laws and similar regulation. Especially in urban areas with scarce land resources and numerous actors with contradicting interests, chances are often slim for private and public planning to meet. This leads to unsatisfactory freight transport solutions and missed opportunities for alternative modes.

The processes of both private and public freight terminal planning are analysed. Literature on terminal location choice research is used to identify common private planning processes. Public safeguarding of sites is analysed using public planning guidelines on the local and regional level. National and transnational (rail) freight planning policy and similar initiatives are not considered.

The planning process analysis allows to contrast private terminal location choice with public safeguarding. Comparing planning approaches allows to identify challenges caused by diverging interests, time frames and planning mentalities.

4.4 WP4: System design of rail freight in urban areas

System design is the dimensioning of a rail-based urban freight system. Its key aspect is the urban road-rail freight terminal. The freight quantity potentially handled in the system is determined by terminal performance. Of major interest in spatial planning is the terminal's land use efficiency.

A process analysis of freight handling for a range of transhipment devices is used to derive terminal performance. The performance of conventional transhipment (i.e. of non-containerized goods) is calculated in analogy to the transhipment of containers.

The process analysis includes the space requirements of each freight transhipment device and further dimensions (e.g. storage, rail and road access facilities etc.). This allows to calculate terminal area, and subsequently land use efficiency.

Both the terminal performance and area are combined in a modular approach. The design parameters for the terminal modules are taken from literature and estimations. Lorry and train trip generation is approximated using average values for vehicle capacity utilisation from literature.

4.5 WP5: Framework requirements of rail freight in urban areas

4.5.1 Freight transport scenarios

Freight transport scenarios are used to calculate generic performances of different urban transport systems. The different scenarios are rail-based urban transport, road-only transport, conventional intermodal transport and the use of urban consolidation centres (UCCs). The input parameters are obtained from literature and estimations. Output is the fuel and energy consumption, mileage and capacity for a range of vehicles and commodities. This allows to quantify costs and emissions in the subsequent sections.

4.5.2 WP5.1: Economic sustainability

Exemplary cost functions are calculated to illustrate the potential of rail-based urban transport from a commercial perspective. Cost rates of road and rail transport, as well as transhipment costs are obtained from literature. A cost model is devised on basis of different transport scenarios. The cost model includes the relevant transport costs, but does not consider logistics costs at large.

4.5.3 WP5.2: Environmental sustainability

The environmental impact of rail-based urban transport is evaluated in terms of carbon and greenhouse gas (GHG) emissions, and energy efficiency. Following the methodology of CEN (2012), energy consumption and emissions are calculated for transport services in the scenarios mentioned above. Additionally, energy consumption and emissions of transhipment processes are calculated. Literature research is used to obtain plausible energy and fuel consumption values.

4.5.4 WP5.3: Land use policy

Land use policies strongly shape freight transport, in particular freight terminals, in urban areas. Literature research is used to illustrate planners' attitudes towards freight transport. A database of unused urban sites – former industrial estates, railway facilities, etc. – is the basis of a qualitative analysis.

Chapter 5

Freight railway technology and productivity

Parts of this chapter have previously been published in:

- Fumasoli, T., D. Bruckmann and U. Weidmann (2016) Capacity for freight in urban railway networks—an analytical model for capacity consumption of freight trains in urban networks, in U. Clausen, H. Friedrich, C. Thaller and C. Geiger (eds.) *Commercial Transport: Proceedings of the 2nd Interdisciplinary Conference on Production Logistics and Traffic 2015*, Lecture Notes in Logistics, 385–393, Springer, ISBN 978-3-319-21266-1, and
- Fumasoli, T., D. Bruckmann and U. Weidmann (2015) Operation of freight railways in densely used mixed traffic networks – an impact model to quantify changes in freight train characteristics, *Research in Transportation Economics*, **54**, 15–19, ISSN 0739-8859.

5.1 Introduction

This chapter elaborates the productivity of freight trains on railway lines with mixed traffic in urban areas. Mixed traffic of passenger and freight trains is characterised by diverging train properties. As railway in urban areas is dominated by passenger traffic, there often is a lack of suitable train paths for freight. The hypothesis for this chapter is: *There exists railway technology which allows efficient freight train operations in densely used urban networks.*

Besides improving train operations, capacity for freight can be increased by expanding infrastructure or reallocating capacity in favour of freight services (Weidmann et al., 2014). In the context of rail transport in urban areas, both options are undesirable. Firstly, the expansion of railway infrastructure would allow separating passenger from freight traffic and, as a consequence, to accommodate more freight trains. The construction of railway infrastructure in urban areas however is increasingly costly, due to limited land resources, complex rail networks and comprehensive planning. Re-allocating capacity of mixed traffic networks in favour of freight services would contradict efforts in urban areas to make public transport more attractive. The need for space efficient passenger mass transport, i.e. railways, increases as demand rises in ever denser cities.

Harmonising freight and passenger train operations thus seems to be the primary means to accommodate more freight trains in urban railway networks. It must be mentioned that the technical capabilities of passenger trains determine today's infrastructure and

Table 5.1: Characteristic train parameters in Switzerland (adapted from Frank (2013))

	$l_{train,max}$ m	v_{avg} km/h	a_{acc} m/s^2	a_{dec} m/s^2
Main haul freight trains	750	51 to 86	0.1 to 0.2	−0.5 to −0.4
Express freight trains	500	59 to 105	0.2	−0.6
Passenger trains	300 to 400	68 to 102	0.6	−0.8
Commuter trainsets	100 to 300	37 to 63	0.7 to 1.0	−1.0 to −0.8

operations in urban areas, due to all but an absence of freight services since the extensive de-industrialisation of cities. The attributes of urban railway networks, dominated by passenger traffic, are (i) rigid fixed-interval timetables, (ii) high density train traffic, and (iii) operation of trainsets with high acceleration and braking performance. The analysis of the potential for increasing freight services therefore needs to respect these conditions. In effect, it needs to be determined to what extent the characteristics of freight trains need to be aligned with current passenger trains.

5.2 Urban railway networks and freight operations

From an operational point of view, railway networks can be divided into three main categories: (i) interurban main lines, (ii) regional secondary railway lines and (iii) urban railway lines. *Heavy* railway lines in urban areas need to be distinguished from other urban rail-based transport systems, e.g. rapid transit (underground) or light rail, which are not considered in this study. In contrast to designated systems, urban heavy railway lines are fully interoperable to main line and secondary line operations.

Railway networks with mixed passenger and freight traffic exist for economic and historical reasons, especially when designated infrastructure is not available. In Zurich (Switzerland) for instance, commuter and regional trains share infrastructure with other users on approximately 70 % of the network (Frank, 2013). As a result, mixed traffic networks need to suit a range of users (Table 5.1). Discrepancies in train characteristics lead to longer buffer times and more lost capacity. Depending on infrastructure (signalling systems, block sections) and train operation (speed, variety and order of trains), maximum utilisation (i.e. capacity) is approximately 8 to 12 trains per hour and track in mixed traffic lines, compared to maximum of 24 for a homogeneous usage pattern (Frank, 2013). Under real conditions, the number of passenger trains on main lines with mixed traffic is 4 to 7 trains per hour (Hörl and Dörr, 2011).

Usage patterns in densely used urban networks increasingly shift to the disadvantage of freight trains. To keep braking distances short, freight trains currently need to run at significantly slower speeds than passenger trains. Figure 5.1 illustrates the maximum permissible speeds of different train types, given a presignal distance of 780 m. The rather short presignal distances found in urban networks lead to unfavourable differences of train speeds.

Therefore, harmonising traffic should help to reduce buffer times and increase usable capacity. This means narrowing the range of train characteristics – such as acceleration, deceleration or train length. Speed seems to be less of an issue, since line speed

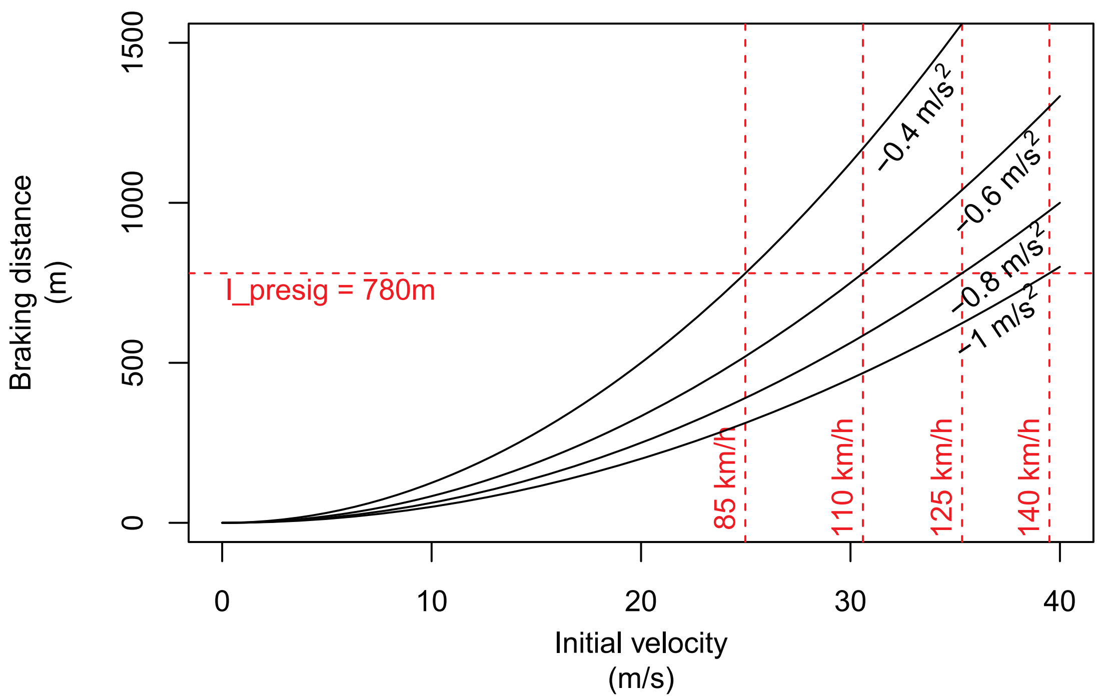


Figure 5.1: Maximum speed of different train types depending on braking distances, based on deceleration values from Frank (2013)

is generally lower in urban networks. However, with passenger services being the predominant network user in metropolitan areas, the operation of freight trains needs to be adapted.

5.3 Definitions

5.3.1 Rail capacity and capacity consumption

In railway transport, capacity generally refers to the *number of trains* per time interval on a defined part of the railway infrastructure. Due to the close dependencies between railway infrastructure and train operations, a single value for capacity does not exist. Many factors other than infrastructure determine the maximum number of trains. UIC (2004) defines capacity as "the total number of possible paths in a defined time window (. . .), in nodes, individual lines or part of the network, with market-oriented quality."

According to UIC (2004) the elements of capacity are:

1. Capacity consumption
   (a) infrastructure occupation
   (b) buffer time
   (c) crossing time
   (d) supplements for maintenance
2. Unused capacity
   (a) usable capacity
   (b) lost capacity

Table 5.2: Recommended values of added infrastructure occupation (UIC, 2004)

Type of line	Peak hour	Daily period
Dedicated suburban passenger traffic	85 %	70 %
Dedicated high-speed line	75 %	60 %
Mixed-traffic lines	75 %	60 %

As Frank (2013) points out, capacity is consumed *directly*, which is the total infrastructure occupation. A train also occupies infrastructure *indirectly*, through rendering infrastructure unusable for other train paths and contributing to the need for maintenance. With the *compression method*, infrastructure occupation of timetabled train paths is added up with minimum headway in between UIC (2004). Additional (theoretical) train paths of similar types are incorporated until no more usable capacity remains.

It is clear that infrastructure occupation can reach 100 % in theory only. For timetable stability and network effects, there is a need for additional buffer times, crossing times and maintenance supplements. (UIC, 2004) provides recommended values of maximum infrastructure occupation times to maintain timetable stability (Table 5.2). For instance, it shows that on mixed-traffic lines, 15 minutes of every hour during peak time the infrastructure should remain unoccupied.

The relevant block section determines the minimum headway of the whole line section (i.e. in between points where trains can pass each other). In case of moving block systems, due to the absence of fixed block sections, much shorter elements become relevant.

5.3.2 Freight capacity

Train frequency is not sufficient to measure the efficiency of rail freight transport. Long (and heavy) freight trains can be more efficient than short freight trains, despite consuming more capacity (and reducing the potential number of trains per hour). Train length and load have a significant influence on train speed and acceleration rates. The train size can thus be traded off for the number of trains (i.e. train frequency).

The concept of *freight capacity* respects this trade-off. Freight capacity expresses the (potential) load transported per time interval (usually in t/h). It can be obtained by summing up the payloads of the (theoretical) number of freight trains per time interval. Load space (e.g. m^3) can be used alternatively.

5.4 Approach

5.4.1 Model structure

The model to calculate generic train runs, infrastructure occupation, capacity consumption and the (theoretical) freight capacity is kept as simple as possible (Fig. 5.2). As Frank (2013) points out, appraisal methods should use (a) as few input parameters as possible, (b) input parameters of adequate accuracy, (c) algorithms of low complexity, and (d) calculation tools easy to acquire and to maintain. Because only theoretical productivities are regarded, it is sufficient that single train runs are considered in the

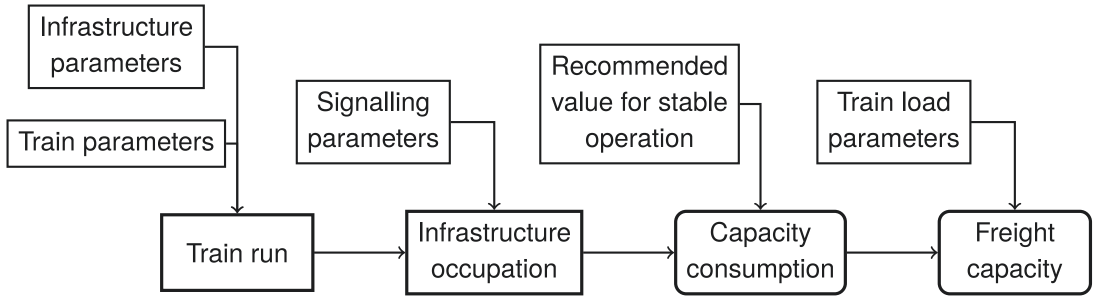


Figure 5.2: Modelling approach to determine capacity consumption and freight capacity of trains adapted to operations in urban areas (source: own)

model. Detailed timetables, network effects nor the interaction between different train types are not included.

In the first step, the model calculates basic train runs for given rolling stock on given infrastructure. Time supplements are added to the technical minimal journey time to account for stochastic variations in train operations. The result is the realistic representation of the train movement in space and time.

The infrastructure occupation is determined by including signalling parameters. Stability requirements define the time the infrastructure should be left unoccupied to ensure stable operations. This results in the (theoretical) capacity consumption, the time period a freight train renders infrastructure elements unusable for other users. The invert of the capacity consumption time, usually expressed in trains per hour, is the (theoretical) line capacity. However, the system performance in a mixed use network cannot be calculated from the capacity consumption time of a single train alone.

The theoretical freight capacity is calculated from capacity consumption and the trainload parameters. This productivity figure is expressed as the load or volume transported per capacity consumption time. The concept of rail freight capacity is elaborated in Section 5.3.2.

5.4.2 Model parameters

To calculate exemplary train runs, track infrastructure is simplified to straight and level double track sections, and curves and gradients are largely ignored. Infrastructure occupation of freight trains is calculated from speed, acceleration, deceleration and train length. These factors can be attributed to the specifics of rolling stock:

- Speed
  - Motive power (traction)
  - Vehicle construction
  - Bogie construction
  - *Achievable deceleration*
- Acceleration
  - Motive power (traction)
  - Coupler and drawgear construction
  - Train weight
- Deceleration
  - Brake technology

  - Train weight
  - Axle load
- Train length
  - Load density

The train run is calculated in a straightforward approach. Approach, journey and clearing times are functions of speed, acceleration, train length, presignal distance, block length and overlap. Linear acceleration and deceleration is used for departing and braking trains, thereby omitting detailed modelling of brakes and propulsion. This approximation – basically the trapezoidal rule of the time-speed diagram – is considered to be sufficient for most planning purposes and is also common in commercial train scheduling tools.

Route setting and route release time depend on the technical response time of the track elements. The visual approach is the time the driver needs to register the signal aspect. Pachl (2016) suggests 6 to 18 s for setting and release and 12 s for the visual approach.

In practice, infrastructure occupation is subject to a range of inaccuracies (e.g. through differing weather conditions), expressed through a constant factor for the variation (f_{var}). The time supplement is 3 to 7 % (UIC, 2004; Pachl, 2016).

For block section signalling, the infrastructure occupation time therefore is:

$$t_{\text{occ}} = t_{\text{form}} + t_{\text{vis}} + f_{\text{var}} \cdot (t_{\text{appr}} + t_{\text{jrn}} + t_{\text{clr}}) + t_{\text{rel}} \tag{5.1}$$

where: t_{occ} = infrastructure occupation time
t_{form} = time for route formation
t_{vis} = time for visual perception
f_{var} = variation factor
t_{appr} = time for approaching the block section
t_{jrn} = journey time in the block section
t_{clr} = clearing time, covering the overlap distance and the length of train
t_{rel} = time for route release

The only difference between conventional main-distant and main-main signalling is the block length.

For the calculation of the infrastructure occupation in moving block signalling systems generally the same parameters are applied. Since block sections do not exist, single track elements are relevant. In the case of trains approaching or leaving freight terminals, this is the entry and exit switch. Instead of a fixed presignal distance, the braking distance (plus a tolerance) determines the approach time.

To obtain the theoretical capacity consumption, the unused capacity and buffer times are allocated to each train run. It is assumed that, by applying the recommended values from UIC (2004) to the infrastructure occupation, a plausible level of capacity consumption is achieved, respecting the precondition of stable operations.

$$t_{\text{total}} = \frac{t_{\text{occ}}}{f_{\text{occ}}} \tag{5.2}$$

where: t_{total} = total time allocated to a freight train (capacity consumption time)
t_{occ} = infrastructure occupation time
f_{occ} = the recommended value of added infrastructure occupation

5.4.3 Theoretical maximum capacity

Theoretical capacities can be calculated from the total time allocated to each freight train. The inverse of the total time per train is the theoretical line capacity (i.e. the maximum number of trains per hour). It considers only the given type of freight train, a pattern that however does not occur in real world situations.

The theoretical freight capacity (tonnes per hour) is obtained by multiplying the theoretical line capacity with the load capacity of the given type of train. Again, this measure is not able to express any real world freight throughput. However, it is used to compare different types of freight trains.

$$C_{\text{line}} = \frac{1}{t_{\text{total}}} \qquad C_{\text{freight}} = \frac{1}{t_{\text{total}}} \cdot L_{\text{train}} \tag{5.3}$$

where: C_{line} = the theoretical line capacity for a given train type
C_{freight} = the theoretical freight capacity for a given train type
L_{train} = the maximum train load

5.4.4 Infrastructure parameters

As mentioned, infrastructure is simplified as much as possible, as curves and gradients are not taken into account. Three types of signalling systems are used in the calculations. (i) main-distant signalling, (ii) main-main signalling, and (iii) moving block signalling.

Main-distant signalling is the most common type of signalling. The line section is divided into blocks, each protected by a main signal (also: stop signal, home signal). The aspect of the main signal is provided in advance by a distant signal (also: approach signal). Braking distances of trains must be within the presignalling distance, otherwise speed need to be reduced on the section.

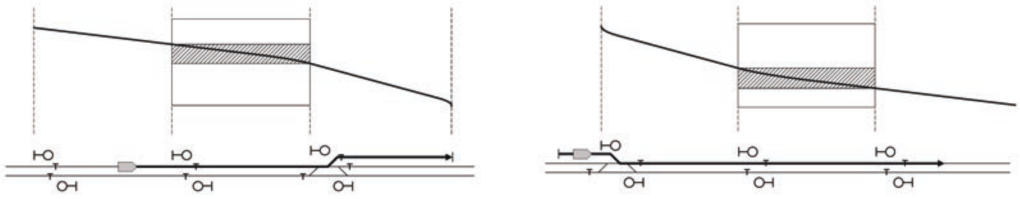
Main-main signalling (also named two-block signalling) follows the same principles as main-distant signalling. Main and distant signals are however congruent, i.e. the length of the block section equals the presignalling distance. Only one type of lineside signal is used, which can display presignalling as well as main signal aspects.

Moving block systems do not use block sections to control the train movement. The distance between trains is instead determined by the braking distance of the following train. Instead of controlling traffic over lineside signals, speed aspects and other information needs to be transmitted to the locomotive driver directly.

5.4.5 Operational setting

The impact of improved rolling stock is modelled for three cases, (i) trains at constant speed, (ii) trains arriving at a terminal, and (iii) trains departing from a terminal.

For block section signalling, sections of identical length are assumed. It gets clear that – given uniform block section lengths – accelerating and decelerating trains occupy the infrastructure for longer periods than a through-running train would (Fig. 5.3).



(a) arrival (b) departure

Figure 5.3: Infrastructure occupation times of arriving and departing trains (source: own)

The model is run with a generic set of infrastructural inputs, i.e. block length, presignal distance, overlap distance and maximum line speed. For this study, input factors are based on Swiss regulations and conditions (VöV, 2014; BAV, 2014).

5.5 Results

Where not mentioned differently, the following calculations are based on main-main signalling with a block section length of 780 m. The maximum switch speed for entering or leaving the siding is 40 km/h. To calculate the freight capacity, the transport of volume goods (average net train load: $0.8\,\mathrm{t/m_{train}}$) is assumed.

Modification of acceleration The calculation of infrastructure occupation shows that by improving acceleration, the theoretical capacity can be improved mainly in the lower range (Fig. 5.4). Improving acceleration capability above approximately 0.4 to $0.5\,\mathrm{m/s^2}$ does not yield significantly higher capacity.

The largest capacity increase is therefore achieved by improving long main haul freight trains. However, this type of train is not the focus of rail freight in urban areas due to the large train length. Additionally, achieving higher acceleration would require comprehensive technical improvements, such as distributed traction, which is currently not standard practice in Europe.

On the other hand, bringing acceleration of an express freight train closer to commuter trains, e.g. from 0.4 to $0.8\,\mathrm{m/s^2}$, reduces capacity consumption by approximately 18.5 s per train, which does not result in a significant capacity increase.

Modification of deceleration Improving train brakes yields similar results. Below a deceleration capability of approximately −0.5 to $-0.4\,\mathrm{m/s^2}$ almost no capacity increase can be achieved (Fig. 5.4). Since almost all freight trains operated already have better braking capabilities, no improvement can be achieved. Improving deceleration from −0.5 to $-1.0\,\mathrm{m/s^2}$ reduces capacity consumption by less than 10 s per train.

Nevertheless, improving train brakes not only influences infrastructure occupation during deceleration, but also the maximum line speed of a train.

Modification of train length The reduction of train length has a more pronounced influence on capacity (Fig. 5.5). For instance, at current acceleration and deceleration

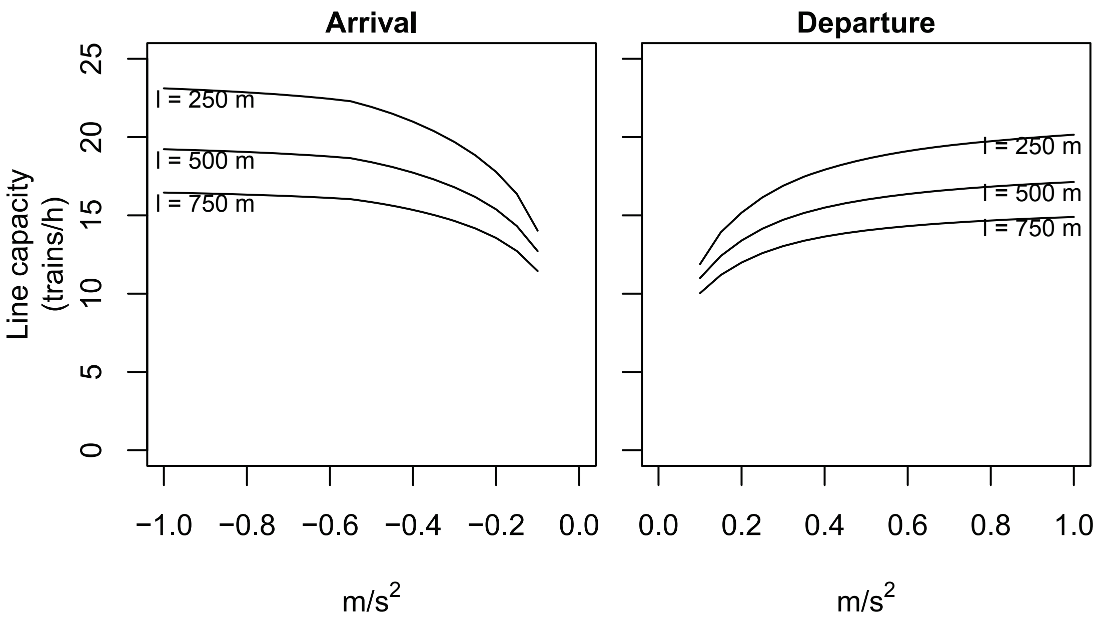


Figure 5.4: Theoretical maximum line capacity in relation to deceleration and acceleration capability. Main-main signalling 780 m; v_{switch} = 40 km/h (source: own)

levels (0.2 m/s^2, −0.4 m/s^2), shortening trains from 750 to 500 m for instance, reduces train headways by approximately 30 s and increases the theoretical line capacity by around 2 trains/h. This however comes along with a reduction of the theoretical freight capacity of around 4000 t/h (assuming transport of volume goods with 0.8 t/m).

In general, it can be observed from Fig. 5.5 that just by decreasing train length, the increase in line capacity does not match the respective decrease in freight capacity.

Comparison of generic train types Figure 5.6 shows the comparison of line capacity and freight capacity for four different freight train types and two signalling systems (main-main and moving block). Freight capacity is based on the transport of volume goods (0.8 t/m). The train types are: (i) a main haul freight train, (ii) an express freight train (both using parameters from Frank (2013)), (iii) an enhanced express freight train with better acceleration and deceleration, and (iv) an even shorter enhanced express freight train.

Not unexpectedly, shorter and more capable trains perform much better concerning line capacity. The comparison of freight capacity shows however that an express freight train with improved acceleration and deceleration (essentially with passenger train characteristics) almost compensates for the significantly shorter train length.

The performance calculation is in line with the results from Bächli (2016). The work of Bächli (2016) used more detailed train run calculation, including real infrastructure examples, more specific traction data and the interplay of train mass and braking characteristics. It showed a peak of freight capacity at a train length of 400 m, given unchanged traction means.

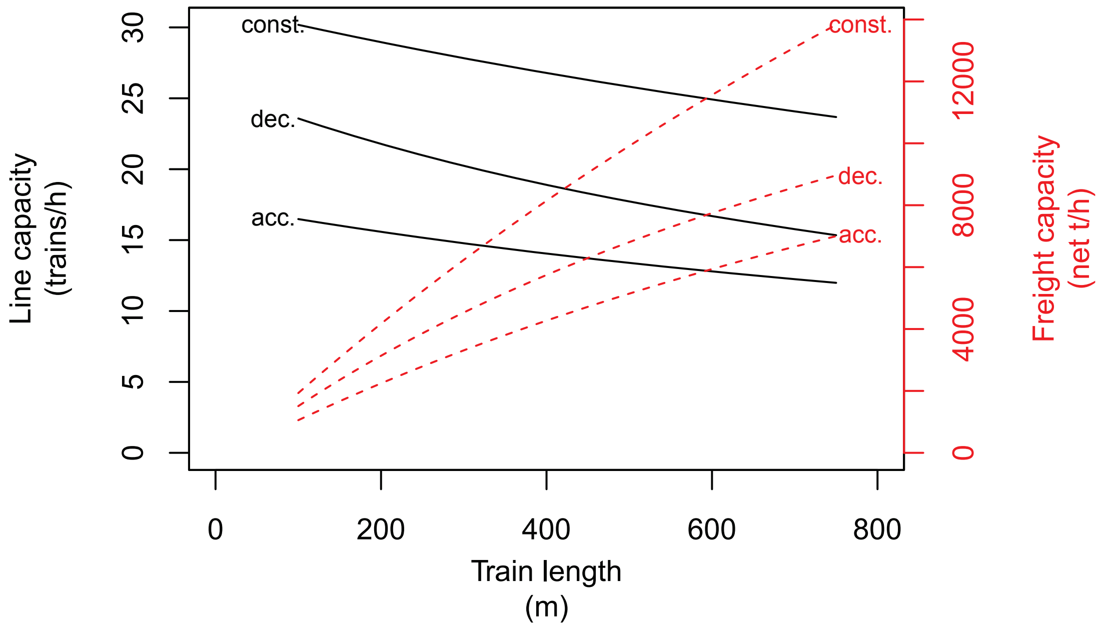


Figure 5.5: Theoretical maximum line capacity (solid) and freight capacity (dashed) in relation to train length. Main-main signalling 780 m; train load capacity 1.8 t/m; acc. 0.2 m/s^2; dec. −0.4 m/s^2; v_{switch} = 40 km/h (source: own)

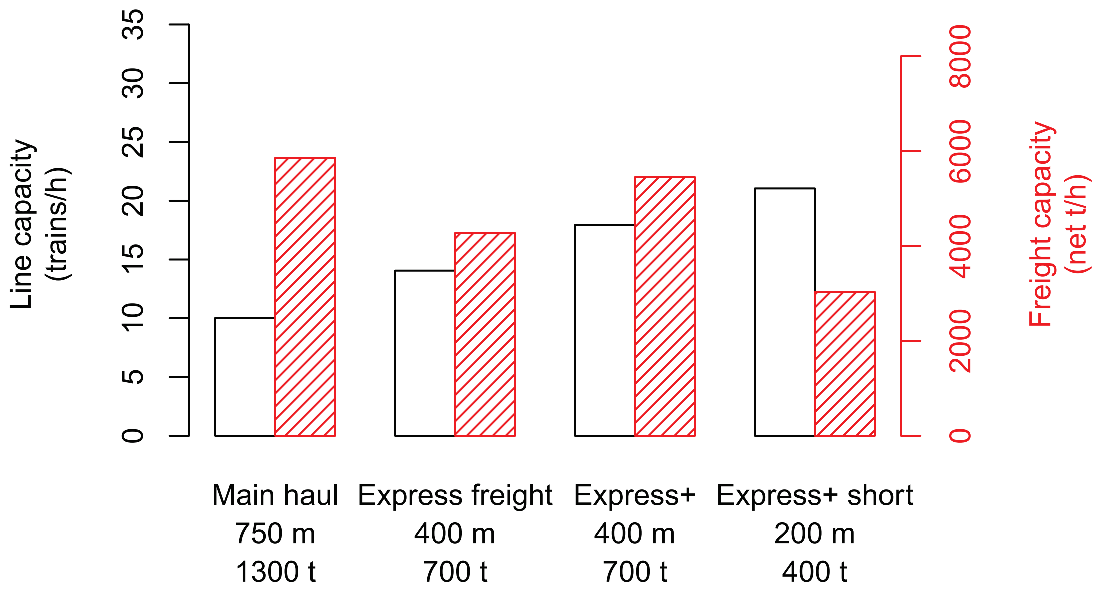
5.6 Conclusion

In this study the infrastructure occupation is analytically modelled in order to determine the effects of rail freight on urban railway networks under different operational assumptions. The results from running the model with exemplary inputs shows that, if a reduction of infrastructure occupation of freight trains is to be achieved, a combination of measures will be needed.

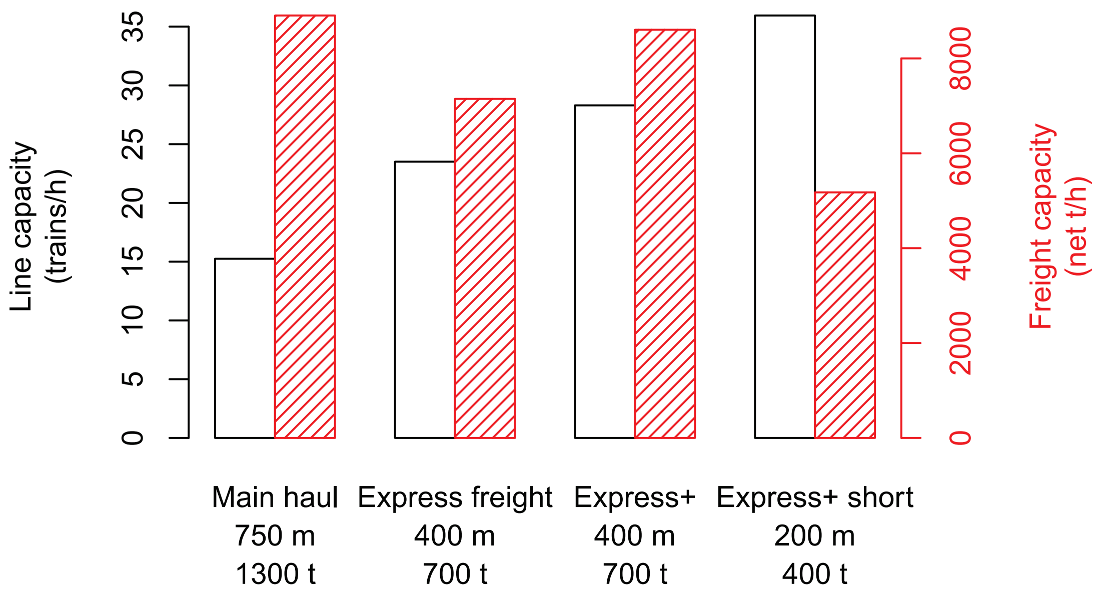
Increasing acceleration shows the biggest potential for reduced infrastructure occupation under current specifications. Acceleration can be improved by increasing tractive power and reducing train gross mass. Corresponding measures include additional or more powerful locomotives, limiting payload, lightweight construction of rail vehicles or shorter trains. However, limitations of acceleration such as drawbar forces or adhesion weight are not regarded in the model. This leads almost inevitably to questions of distributed traction and central couplers, which are still uncommon among European rail freight operators.

On the other hand, increasing deceleration, i.e. introducing better brakes, does not show much potential. Shorter braking distances contribute only to operations in networks with limited presignal distances, allowing freight trains to run at higher line speeds. In networks with overlapping blocks (main-main-signalling) there is little effect. The aforementioned measures to reduce train weight would also contribute to better braking properties.

The operation of shorter trains alone – despite positive effects on train mass and therefore acceleration and deceleration – does not yield benefits. The loss of freight capacity exceeds the potential gain in line capacity. Shorter trains however increase operational flexibility, as the dispatching of short freight trains enjoys the same routing



(a) main-main



(b) moving block

Figure 5.6: Comparison of the theoretical line capacity and freight capacity (shaded) of different freight train types for main-main and moving block signalling. Train load capacity 1.8 t/m; accelerating trains (source: own)

and stabling options as passenger trains. Length-related network access limitations can be avoided.

The level of freight capacity can be maintained with a combination of measures – shortening trains and improving traction. Rolling stock adapted to operation in densely used urban networks can thus provide efficient rail freight traffic.

In consideration of the operational costs, i.e. the significant investments involved in improving rolling stock, the value of reduced infrastructure occupation also needs to be analysed. Not all reduction measures lead to an increased number of available train paths, but rather to an increase of buffer time, an effect which can hardly be monetised. The stabilising effect of increased buffer times is of major interest to railway infrastructure managers (IMs), which also have the possibility to create incentives for improving rolling stock for freight.

The examination of freight railway technology and productivity has some limitations. Although the proposed model provides decision support for strategies in urban rail freight, it does not replace proper scheduling. Where more rail freight is desirable, thorough capacity analysis is still needed. Additionally, the study applies to mixed-use networks only. It does not determine whether or not to separate freight from passenger lines entirely (which would undoubtedly simplify operations significantly).

Nevertheless, the model presents an appropriate way to estimate the technical and operational potential of rail freight in urban areas.

Chapter 6

Rail facilities for freight transhipment

6.1 Introduction

This chapter provides an insight into the planning of facilities for freight transhipment between railway and road. Especially in urban areas, land for freight transport and transhipment is scarce. The hypothesis for this chapter is: *The areas suited for the transhipment of goods between rail and road can be made available at locations close to the urban core.*

Section 6.3 deals with private planning processes to select sites and subsequently develop a freight terminal. It should help to understand how terminals are planned and how the decisions to implement them are made.

Section 6.4 covers public sector planning for the safeguarding of suitable sites. It discusses the basic safeguarding problem and highlights the public sector's instruments to steer development towards a desirable urban freight system. Essentially, the public sector is neither a singular entity, nor do all its objectives aim in the same direction. This must be kept in mind when considering public planning.

In Section 6.5, the challenges of freight terminal planning in urban areas are summarised. The interdependencies between private and public planning in the freight sector are examined.

6.2 Definitions

6.2.1 Actors in freight transhipment

The transhipment process adds another actor to the freight transport process (compare Section 1.4). *Terminal operators* operate transhipment facilities including access (check-in/out), handling equipment, storage management, etc. The terminal operator mostly is – but not necessarily has to be – the owner of the terminal infrastructure.

Carriers and logistics service providers (LSPs) can be both customers and owners/operators of freight terminals. railway undertaking (RU) operate freight train services, *road hauliers* operate trucking services to and from the terminal.

There are various relations to actors not directly involved in the transport process on all network levels (compare Section 2.3.2). The railway infrastructure manager (IM) provides access to the railway network and manages network usage. In Europe, railway infrastructure is either in public ownership or the IM is a public enterprise. Road infrastructure is mostly provided and managed by the *public sector*.

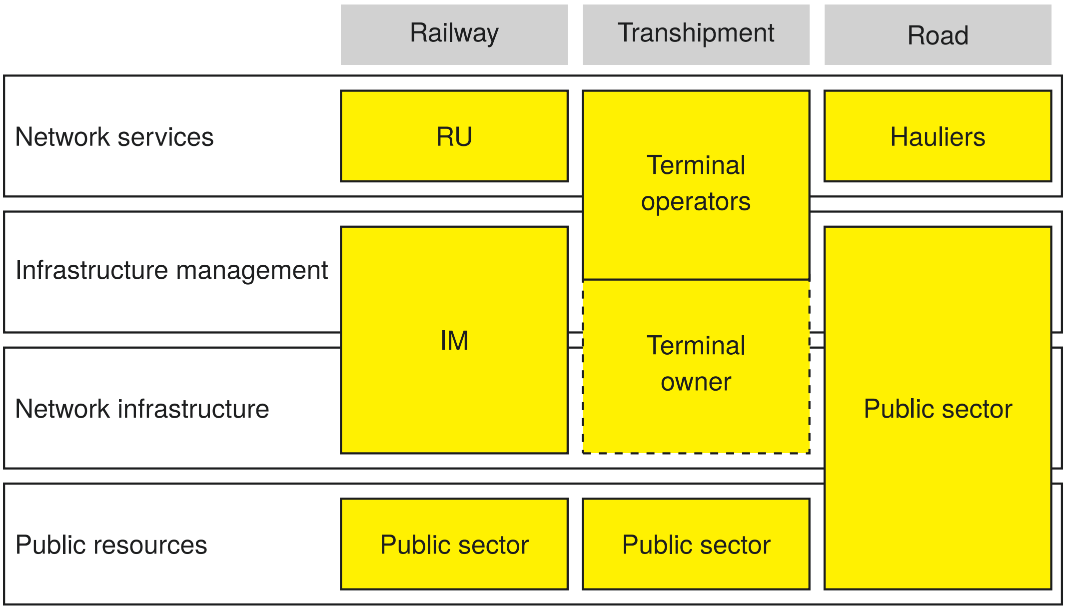


Figure 6.1: Actors in rail–road freight transhipment and transport and the respective network layers (source: own)

In the planning process of freight terminals, the respective network level of the actor plays an important role (Fig. 6.1). In general, the basic layers (public resources and network infrastructure) require longer term planning than the more operative layers (network management and services).

6.2.2 Freight transhipment and terminals

Freight transhipment is the transfer of goods (without changing the good itself) between vehicles or from a vehicle to the shipping/delivery point (or vice versa). Transhipment between vehicles involves some sort of storage or buffer. The facilities providing transhipment between vehicles are interchangeably called freight terminals, freight depots, freight interchange, goods stations and others. Freight terminals are categorized corresponding to the modes used in the respective transport chains (UNECE, 2009, 2001) as follows:

Single mode terminals involve transhipment between vehicles of the same transport mode. The reason for transhipment is usually the different size of vehicles and a break in the operational logic in order to benefit from economies of scale (e.g. main haul and feeder services).

Multimodal terminals involve the transhipment between vehicles of different transport modes, often to connect between networks of different scales (e.g. global to national, national to regional transport).

Intermodal terminals (or container terminal (CT)) are a subcategory to multimodal terminals. Goods are transhipped using intermodal loading units (ILUs), i.e. containers, swap bodies, semi-trailers etc., in order to benefit from the operational advantages in their handling.

In this thesis only transhipment in multimodal terminals between road and railway are regarded. Urban rail freight transport inevitably involves the transhipment to road

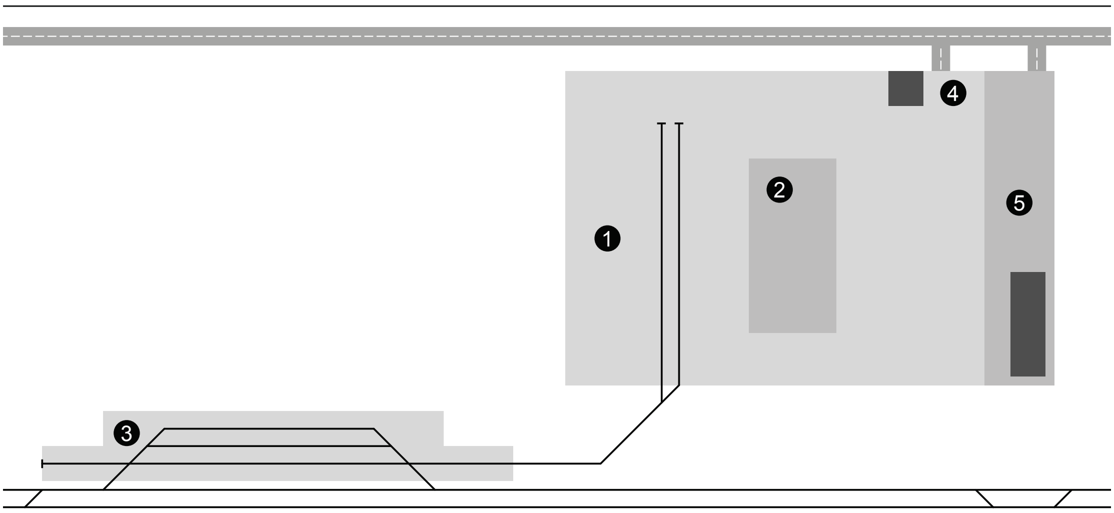


Figure 6.2: Generic road–rail terminal layout: (1) terminal yard, (2) storage/buffer, (3) railway access, (4) road access, (5) auxiliary facilities (source: own)

vehicles, as railway networks do not serve many last-mile customers.

Space requirements of terminals Various factors influence the space requirements for transhipment facilities. There is a large variety of terminals, depending on quantity, the type of goods and cargo, and the type of transport chain. However, most multimodal freight terminals feature the same elements.

Railway access needs to be provided. This requires a set of arrival, departure and stabling sidings in order not to disturb traffic on the main tracks. In common usage, these sidings are not part of the terminal area.

Road access is the entry and exit for lorries. In many cases, the lorries are checked before entering and leaving the terminal. Single-customer terminals might do without check-in/check-out facilities. Since the arrival of lorries is usually not strictly scheduled, the terminal needs to provide waiting areas.

The *terminal yard* is where the transfer of loads between the modes takes place. It needs to provide space for the loading tracks and for industrial trucks or cranes serving the train. Additionally, space is needed for the circulation of lorries to and from their respective loading point.

Buffer and storage areas are needed to account for the variability of freight volume. Additionally rail operations are can be decoupled from lorry traffic.

Additional areas might be needed for *auxiliary functions*. This includes parking spaces for workers, workshop facilities and offices.

For simple single-track modules, Ruesch et al. (2017) provides a guideline of yard widths (Table 6.1). Figure 6.2 shows the generic layout of the terminal elements.

6.3 Private freight terminal planning processes

A number of studies have analysed the processes referred to as *facility location selection*, *location choice*, *facility siting* or *site selection* for freight transport. The procedures are synonymously referred to as *examination process*, *selection process*, *identification*

Table 6.1: Typical sizes of road–rail terminals in Europe (Ruesch et al., 2017)

Type & layout	Track length	Terminal width
Small intermodal terminal with reach stacker operation and container storage	100–200 m	15–40 m
Medium intermodal terminal with reach stacker operation and container storage	200–400 m	40–80 m
Medium to large intermodal terminal with gantry crane and container stack	400–800 m	50–100 m
Small team track and horizontal transhipment terminal	100–200 m	15–40 m
Medium team track and horizontal transhipment terminal	200–400 m	40–80 m

process and other terms. The common processes are summarised in a generic private planning process, which reflects current practice of freight terminal planning.

To highlight freight transport planning processes in Switzerland, *Freight Transport Planning in Urban Areas*, a planning guide elaborated within the Swiss Swiss National Research Programme (NRP) 54 is considered (Ruesch et al., 2013). For comparison, the report *Freight Facility Location Selection – A Guide for Public Officials* from the National Cooperative Freight Research Program (NCFRP) is used, covering a wide variety of freight facilities in the United States.

Generic private planning process The analysed planning processes differ in the wording and sequence of processes. Nevertheless, all location selection procedures display a generic two-step planning structure (Fig. 6.3):

1. Set creation, where a set of potential sites in a specified region is created.
2. Selection, where the set of potential sites is narrowed down to the best suited sites.

The most detailed examinations are conducted in the later stages of the selection process in order to keep planning costs low. Only a small number of potential sites for freight terminals go through detailed cost modelling, risk calculations, environmental impact assessment and feasibility studies.

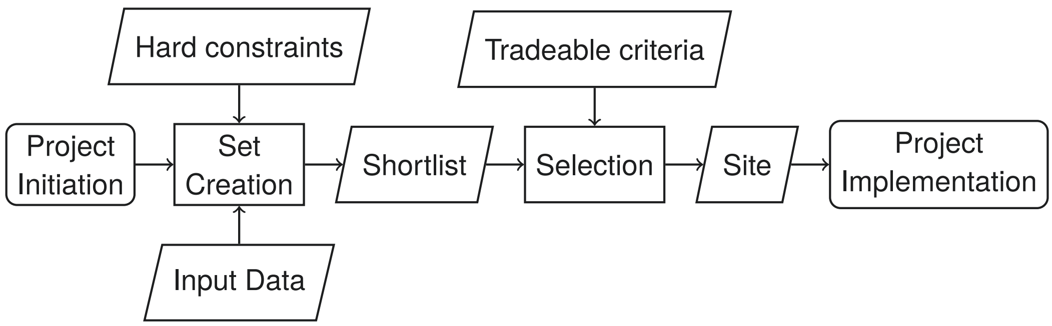
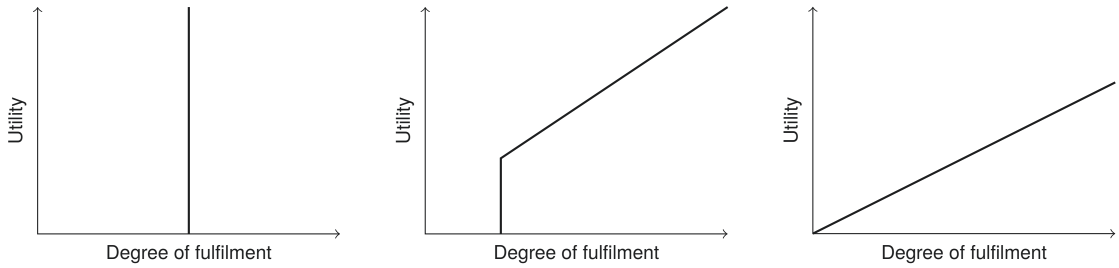


Figure 6.3: Generic two-step location selection (source: own)



(a) Hard constraint (b) Threshold (c) Compensable

Figure 6.4: Illustration of utility functions for hard constraints, threshold and compensable criteria (source: own)

Once a site is selected, the project enters the implementation phase (Fig. 6.5). This requires the approval of the authorities (see public planning) as well as financing.

Criteria are defined for both steps in order to appraise the sites. Depending on the stage of planning process, different rules apply. In the first step (set creation), conditions have to be fulfilled regardless. It is a purely binary choice whether a location belongs to the set of potential sites or not. They are therefore interchangeably referred to as *gateway criteria*, *hard constraints*, *minimum requirements*, *must-haves* or *knock-out criteria*.

In the second step (selection) the remaining sites are ranked. This requires indicators that allow measuring the degree of fulfilment and to assign utility values (Fig. 6.4). By assigning weights it is possible to trade off criteria against each other. They are therefore called *compensable* or *tradeable* criteria (or *nice-to-haves*). Unlike hard constraints, the non-fulfilment of a compensable criterion does not automatically mean the exclusion of the respective terminal site.

By setting threshold values, some indicators have both hard constraints and compensable aspects. Respective criteria can be used in both steps, in the first to obtain a binary decision, in the second to obtain a value for the utility. The most common objectives and criteria (and their respective type) are:

- Integral logistics
  - compatibility with existing solutions — hard constr.
- Proximity to market (costumers, shippers, manufacturers)
  - availability of sites — hard constr.
- Access to transport networks
  - access to road transport corridors — hard constr.
  - access to rail transport corridors — hard constr.
- Efficient road transport
  - road capacity utilisation — threshold
- Efficient rail transport
  - rail capacity utilisation — threshold
- Efficient transhipment
  - terminal size and shape — threshold
  - non-sensitive location — threshold
- Cost environment
  - real estate costs — compensable
  - construction costs — compensable
  - taxes and fees — compensable

– labour costs	compensable
– utility costs	compensable
• Business environment	
– competition	hard constr.
– qualified labour	compensable
– business-friendliness (politics, authorities and community)	compensable
– synergies within the sector (cluster)	compensable
• Operational risks	
– natural hazards	compensable
– timely implementation	threshold

Freight transport planning in urban areas (NRP 54) Against the background of increasing road freight transport in cities, the project *Freight Transport Planning in Urban Areas* within NRP 54 aimed to improve the understanding of freight in urban planning. Its approach is to introduce freight transport considerations into integrated land-use and transport planning. The project therefore describes a generic planning process for logistics locations.

Subject of location planning is the search for areas suited for the development of freight transport facilities. However, location choice often cannot be separated from the facility layout planning. The size and shape of available areas in many cases limit operations on the site.

Ruesch et al. (2013) suggest to conduct location choice in a two-stage process. First to identify the *macro-location* of a facility – i.e. the search for the preferred region for facility locations. Second to assess the *micro-locations* within the chosen macro-location.

Accordingly, the presented location planning process (Fig. 6.6) is applied to both macro- and micro-location choice. The differences are in the level of detail, the weighing and the appraisal methods.

In the first step, *location requirements*, the location criteria are defined. Location criteria and their respective importance are specified individually for each particular project. Basic information needs to be collected and analysed in order to substantiate the requirements.

Minimum requirements – defined for each criterion – set the basis for the *location screening* process. Ruesch et al. (2013) mentions the following criteria for location screening:

- Land availability
  - Real estate costs
  - Suitable size and shape of areas
  - Land reserves (for extensions)
- Transport networks
  - Access to main roads
  - Availability of railway sidings
  - Terminal accessibility
  - Congestion risks
- Market environment
  - Proximity to markets
  - Proximity to manufacturing
  - Synergies within the industry (cluster)
- Construction regulations

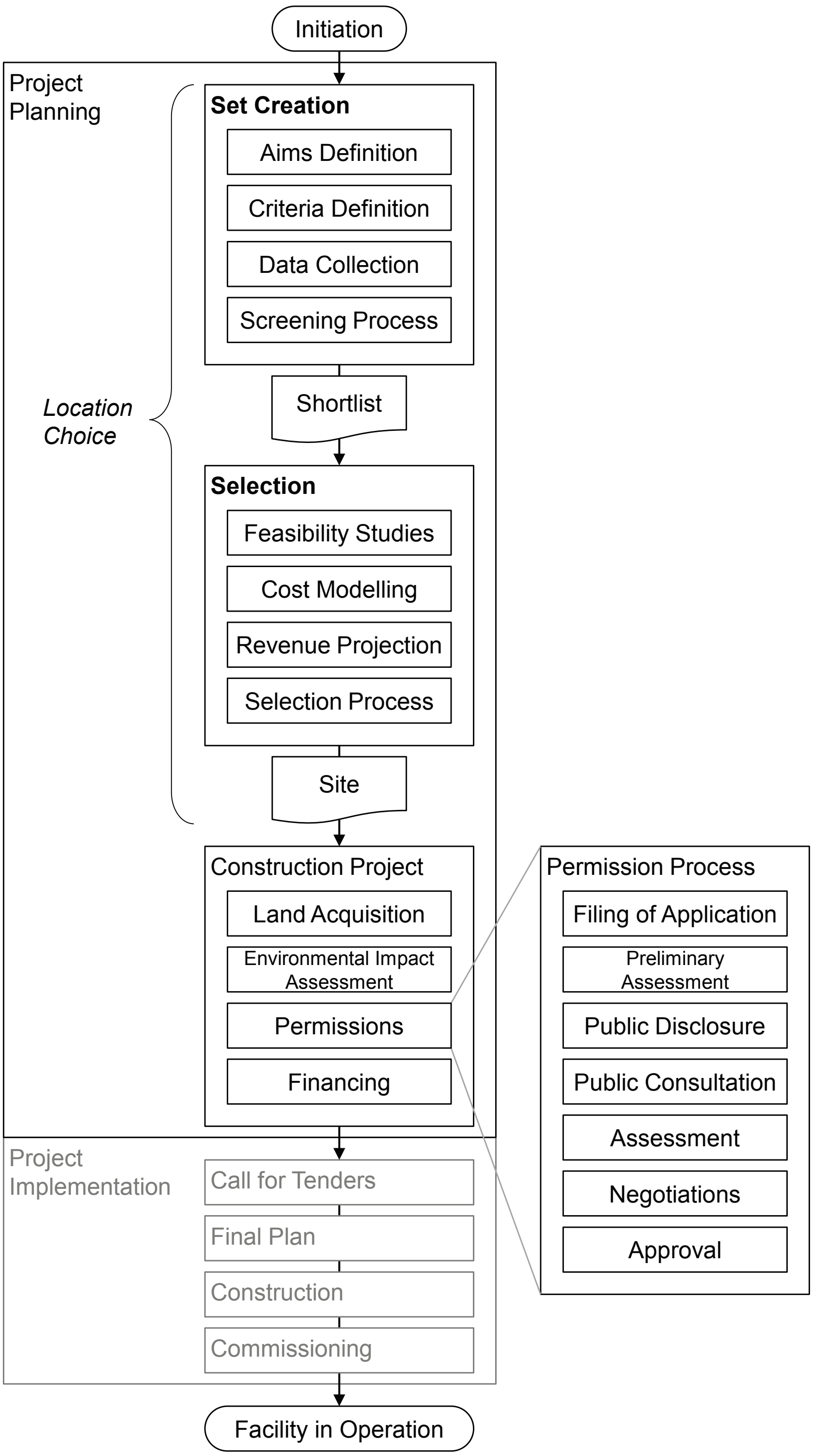


Figure 6.5: Private planning process for freight terminals (source: own)

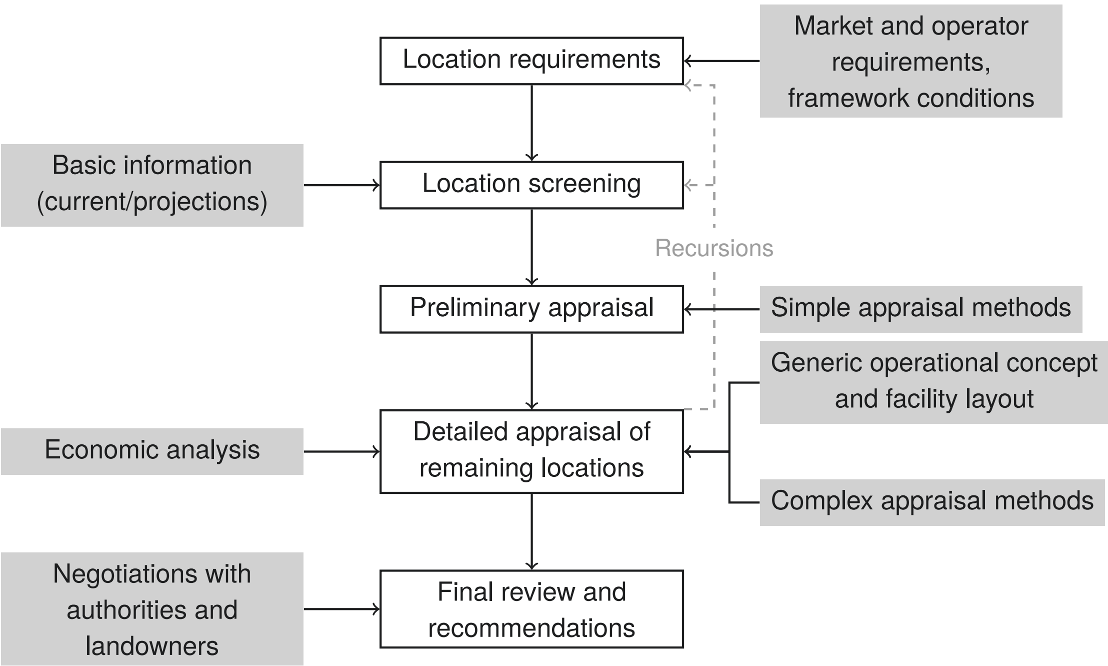


Figure 6.6: Logistics location planning process and inputs (adapted from Ruesch et al. (2013))

- Environmental regulations
- Possibility to operate 24 h
- Taxes and fees
- Business-friendly authorities
- Qualified labour

Information to quantify the chosen criteria can be obtained from publicly available sources, such as zoning laws, land tenure, structure plans, development plans, traffic concepts and land use plans. Market information, e.g. the location of shippers and service providers, is obtained through business intelligence. Locations that do not meet the minimum requirement in at least one criterion are not considered in the further process.

Using only the most important criteria and rather simple methods, the range of potential locations is narrowed down in the *preliminary appraisal*. The remaining sites are subject to *detailed appraisal* using more complex methods. This includes a sensitivity analysis, a risk analysis and a feasibility study. Operational considerations are also taken into account in this step for the first time.

For the *final review* the results from negotiations with authorities and landowners are considered before giving recommendations.

Freight facility location selection – A guide for public officials (NCFRP) This guide is the result of NCFRP project 23 *Economic and Transportation Drivers for Siting Freight Intermodal and Warehouse Distribution Facilities*. It aims to provide public sector decision makers, dealing with siting requests and business attraction, with a better understanding of drivers and impacts in freight facility location (Steele and Hodge, 2011).

The facilities included are distribution centres (DCs), ports, intermodal (i.e. road–

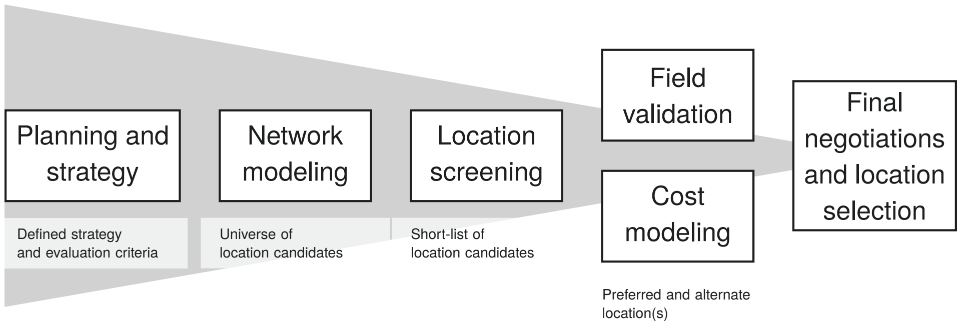


Figure 6.7: Examination process (adapted from Steele and Hodge (2011))

rail) terminals, transload terminals, integrated logistics centres, "freight villages"), hub terminals (i.e. for intramodal reconsolidation) and city terminals.

The report identifies common approaches to facility siting. Basis are interviews with executives from freight intensive businesses. "The location process typically begins with an examination of the overall business needs for the distribution network as a whole, or for the new facility in isolation, and then follows a process (. . .) to narrow the range of alternatives" (Steele and Hodge (2011), Fig. 6.7).

The *planning and strategy* step is about identifying the need for a facility. Causes may be the wish to expand the market, contract or rationalize the distribution network or to change the company's market or methods. Based on these considerations the company's project team will define criteria. The criteria should be divided into "must-haves" and criteria that can be traded off.

Steele and Hodge (2011) specifies the following examples of key criteria and data requirements for site selection:

- Ability to access key markets or customers (required data: market data)
- Interaction with transportation networks
  - Access to key transportation corridors
  - Ability to balance modes
- Labor and workforce needs and costs (labor market health, labor costs, education infrastructure, educational attainment, union presence and activity)
- Total cost environment (freight and logistics costs, labor costs, utilities, facilities costs, taxes)
- Utility requirements (local utility availability and costs)
- Permitting and regulation
- Tax and regulatory environment
- Public sector assistance and incentives
- Climate and natural hazards (data on climate and natural hazards)

Transport-related factors, i.e. the interplay between location and freight costs are examined in the *network modeling* step. It "involves determining the number, size, and broad regional location of facilities required to service customer needs in a cost effective manner (Steele and Hodge, 2011)." It is usually computerized and involves calibration with real-world data and scenario building. The models usually provide a catalogue of recommended areas rather than final sites.

Factors that are not directly transport-related, such as workforce, regulations, utilities and real estate, are examined in the *location screening*. Usually it involves weighting these factors to calculate trade-offs. The screening process results in a short-list of potential sites.

The results from the preceding steps are verified in a *field and site analysis* to refine the location recommendations. Often, local or regional government is involved for the first time in this step. Additionally, a *cost model* is devised to estimate investment and operating costs. The model may also include revenue projections.

In *incentive negotiations* with local or regional governments, (financial) feasibility might be further improved. Public agencies frequently offer tax rebates or subsidies in order to attract business, but increasingly demand some sort of guarantee, e.g. a commitment to long-term job creation.

The process is concluded with the selection of a site and the decision to build the new facility. As rule of thumb, Steele and Hodge (2011) gives planning horizons of:

20 years for significant infrastructure investment (e.g. a port or intermodal facility),
7–10 years for capital or machinery intensive investment, and
3–5 years for commodity based or non-capital intensive.

6.4 Public sector planning for rail freight terminals

In most of Europe, the public sector has a major role in the planning of railway networks. Often railway infrastructure managers (and to a certain extent also rail operators) are in some way state-owned. Therefore, the planning of railway infrastructure is part of public planning. This is in contrast to North America, where "(. . .) rail infrastructure is private, and hence outside the domain of public planning" (Giuliano et al., 2013). European planners thus need to anticipate trends and needs of rail shippers.

Compared to facilities for passenger transport, where public and private planning are usually closely co-ordinated, the public sector is less involved in the planning of freight terminals, unless concerning large projects such as ports or hinterland hubs.

Below, the basic principles in freight terminal planning are introduced, highlighting the importance of safeguarding. On the basis of the *London Rail Freight Strategy*, the safeguarding process for rail freight facilities is examined more closely. Additionally, the *Guidebook for Assessing Rail Freight Solutions* illustrates the processes and challenges of rail freight planning in the United States.

Planning principles and the basic safeguarding problem Public planning is guided by political objectives in the domains economy, society and environment. In accordance with generic economic, social and environmental objectives, sectoral objectives define the desirable development for each planning sector. The desirable development is often documented in a *white paper*, *vision*, *roadmap*, *strategy* or an *action plan*. These documents should lead to concrete measures to support the desirable development, often in the form of legislation, which in turn affects private and public projects.

Since land is the crucial (non-renewable) resource in urban areas, the safeguarding of areas is a well-established measure. Safeguarding withdraws land from the general real estate market and reserves it for a specified purpose. Areas are commonly safeguarded for transport infrastructure, public utilities, affordable housing and green spaces. In urban freight transport too, the safeguarding of areas seems to be necessary.

In the basic safeguarding problem, the public sector has the options to safeguard potential terminal sites or to assign the areas to other uses (Fig. 6.8). The underlying

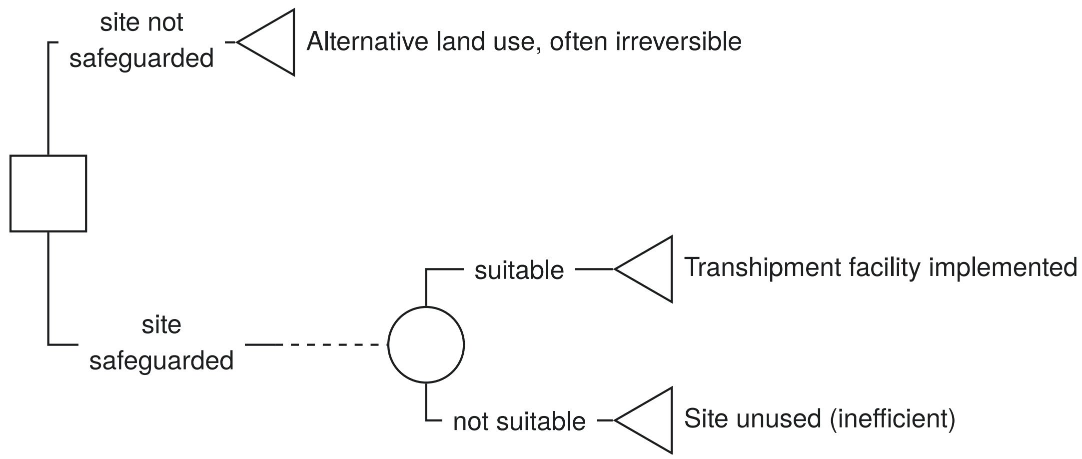


Figure 6.8: The basic safeguarding problem of public planning (source: own)

question is, whether the future use as freight terminal yields higher public benefits than the (potentially more instant) benefits of other uses.

It is however undesirable to hoard land through safeguarding. Hoarding is inefficient and often causes legal disputes, since safeguarding restricts landownership rights. A site is therefore safeguarded only if there is a *reasonable* prospect of developing it. This means that planning for a facility must be already ongoing at the time of deciding to safeguard.

There are possibilities to make safeguarding decisions as robust as possible, i.e. to reduce the risk of the site not meeting its intended purpose. (1) Forecast development as accurate as possible using adequate data and models. (2) Steer development actively towards the desired target state using adequate instruments. (3) Maintain flexibility to rededicate the site if the intended/forecasted development does not materialise.

Safeguarding often concerns existing facilities. In this case, the focus is on the performance of the facility and the possibilities to expand. Given appropriate access to railway and road networks, the potential of existing sites for freight terminals, adapted from Hörl and Dörr (2011) can be categorised as follows:

Unrestricted Mostly unrestricted potential for expansion of the facility within the limits of current legislation (i.e. zoning, environmental restrictions etc.)

Limited Expansion of the facility only possible after rearrangement of lots. Some non-transport users displaced if necessary.

Exhausted High degree of building density, no potential for expansion. Focus on safeguarding existing facility if applicable.

Converted Site converted to non-transport use (reversible/irreversible).

How public planning guidelines deal with rail freight is illustrated using the examples of Transport for London's *London Rail Freight Strategy* (TfL, 2007c) and the *Guidebook for Assessing Rail Freight Solutions to Roadway Congestion* (Bryan et al., 2007).

Safeguarding in the London Rail Freight Strategy The *London Rail Freight Strategy* was issued by Transport for London, the fully integrated transport authority of Greater London. It describes the process local planning authorities should take to safeguard sites for rail freight activities (TfL, 2007c). The planning guide proposes a seven-stage process:

1. Strategic policy review
   - Review London-wide statutory and non-statutory policy and other relevant documents
2. Identification of sites with rail freight potential
   - Refer to TfL site database
3. Generic operational rail constraints
   - Are there any operational rail constraints that need to be overcome?
4. Demand profile
   - Is there a recognised need for rail freight activity in this part of London?
   - Which rail freight sectors have demand?
5. Technical suitability
   - Can the identified demand for rail freight be accommodated on these sites?
   - Do the sites meet the technical specifications required for these particular rail freight sectors?
6. Planning constraints
   - Would safeguarding this land conflict with land use policy designations for the site and surrounding area?
   - Would rail freight activities conflict with land uses in the surrounding area?
7. Formal plan-making process
   - Incorporate and illustrate rail freight site protection policy designations into draft development plan document for formal consideration as part of development plan process.

If a site is not suitable for rail freight, safeguarding for other transport functions should be considered first. A range of databases and additional documents help to identify sites and to determine suitability. Demand forecasting is based on rail freight projections in the sectors construction, forestry, petroleum, automotive, channel tunnel and others (including consumer goods, waste/recyclables and containers). The technical suitability is assessed for three basic types of facilities, co-located facilities (including value-adding processes), break-bulk-facilities (for sorting and storing goods) and transhipment facilities.

NCHRP 586: Guidebook for Assessing Rail Freight Solutions to Roadway Congestion The need to strengthen planning of rail freight is also recognised in the United States. The *Guidebook for Assessing Rail Freight Solutions to Roadway Congestion* (Bryan et al., 2007) is aimed at planners at state and regional level, as well as private sector decision-makers. It encourages public agencies to consider policies, incentive programmes and investment to divert some road freight traffic to rail. The proposed solutions "can be classified into efforts to:"

- "Better rationalize (reconfigure) the center city rail network";
- "Reduce conflicts among road and rail traffic flows";
- "Increase use of rail/truck intermodal transportation";
- "Improve the level of rail service locally available to industry";
- "Upgrade rail facilities to handle taller or heavier railcars".

Figure 6.9 illustrates the proposed decision-making process to identify and assess potential rail freight solutions. The guidebook stresses the importance of a public-private dialogue to implement the solutions found.

Both examples – Transport for London's planning guidelines, and the recommendation

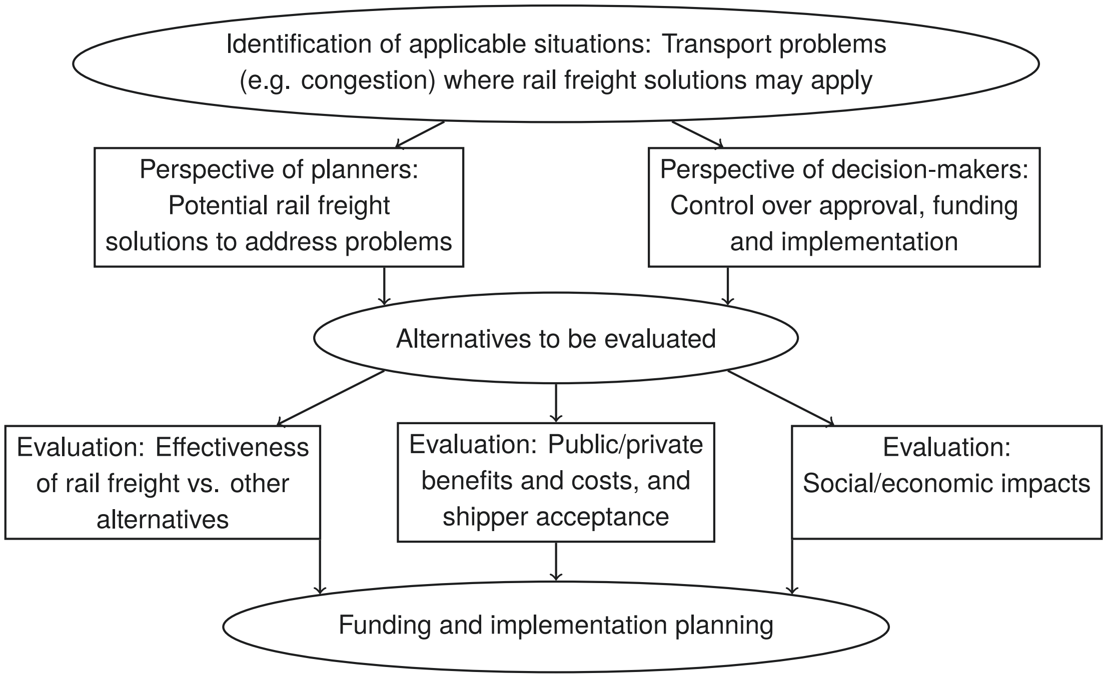


Figure 6.9: Decision-making process for rail freight investment (adapted from Bryan et al. (2007))

from the NCHRP – show that the processes to safeguard sites suitable for rail freight are in principle clear. They also show that rail freight initiatives cause substantial planning efforts.

6.5 Challenges in the planning of urban rail freight facilities

The planning of urban rail freight facilities encounter three main challenges:

- The mutual dependency of the public and private planning processes in areas with limited land availability.
- Intertemporal decision making in safeguarding and the uncertainty of the development of the logistics market and technologies.
- The number, diversity and behaviour of the involved actors.

Mutual dependency The analysis of private and public planning processes shows that – provided that land availability is low – decision making is mutually dependent. Public and private planning processes are contrasted in Fig. 6.10. In order to initiate a safeguarding process, the public sector requires some certainty that a terminal project is viable, in the form of a project proposal for a freight terminal. This is needed to determine the potential public costs, public benefits and impacts of the project during the project appraisal.

The private sector however, is reluctant to bear the costs for detailed terminal planning as long as the question of site availability is unresolved. It is one of the key criteria that needs to be met regardless (hard constraint) and is dealt with early in the planning

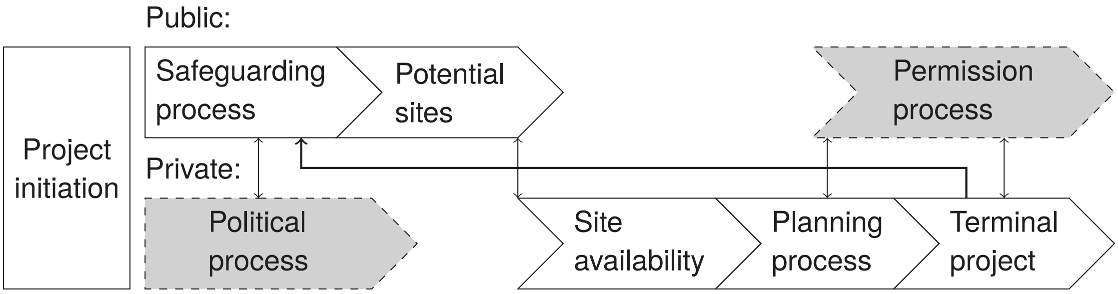


Figure 6.10: The private-public planning dilemma: both the private and public planning processes need each other's outputs as inputs (source: own)

process.

For this reason, and due to diverging planning horizons, opportunities for sustainable urban freight transport are often missed.

It needs to be mentioned that this dilemma between public and private planning does not occur if site availability does not depend on the safeguarding of land. Examples can be found in most green field developments, where undeveloped industrial land is readily available. Particularly in the urban context however, land is scarce and site availability strongly depends on areas held available by the public sector.

Intertemporal decision-making To consider different planning horizons lies in the nature of safeguarding – for any infrastructure. It needs to be decided now if an area is of use in the future. It is also obvious that the future land use requirements are more uncertain than nearer alternatives and that framework conditions, technologies and the market environment can change significantly.

The problem is accentuated by the fact that data availability and quality in the sector still is insufficient. As decision making heavily relies on appropriate forecasting, poor data makes long-term decisions difficult. Holguín-Veras et al. (2012) illustrate that the actors in the freight system have only partial views of the freight system: "In summary, none of the agents involved in freight have sufficient information to fully describe what happens in the system as a whole. This has important implications for data collection efforts, as most surveys rely on the information gathered from the participants in the freight activity" (Holguín-Veras et al., 2012)(Table 6.2).

In general, private actors can only speak for themselves, and the public sector has difficulties emulating the private sector decision making. To alleviate planning, there are initiatives to systematically collect and organize data, e.g. the *London Freight Data Report* (Allen et al., 2013).

Number, diversity and behaviour of actors Decision making in the freight system is shaped by the number, diversity and the behaviour of the involved actors, both in the private and the public sector. Conflicts of objectives among and within private and public actors are an inherent part of freight transport planning and spatial development. Actors weight benefits, costs and risks differently.

The public sector comprises authorities on the national, regional and local level, mostly within the executive (but also in legislative and judiciary). They are responsible

Table 6.2: Partial views of the freight system (Holguín-Veras et al., 2012)

Freight generation:	Shippers/Producers	Carriers	Distribution centers / Warehouses	Consumers of cargo (receivers)	Transportation agencies
Amount of cargo	Yes (1)	Yes (1)	Yes (1)	Yes (2)	No
Number of loaded vehicle-trips	Yes (1)	Yes (1)	Yes (1)	Not always	Partial (3)
Number of empty vehicle-trips	No	Yes (1)	No	No	Partial (3)
Number, frequency, of deliveries	Yes (1)	Yes (1)	Yes (1)	Yes (2)	No
Commodity type	Yes (1)	Not always	Yes (1)	Yes (2)	Partial (4)
Shipment size	Yes (1)	Yes (1)	Yes (1)	Yes (2)	No
Cargo value	Yes (1)	Not always	Not always	Yes (2)	Partial (4)
Land use patterns	Yes (1)	Yes (1)	Yes (1)	Yes (1)	All

(1) Only of the cargo that they handle; (2) For all the cargo they receive.
(3) At key links (no distinction between loaded and empty); (4) Only at some ports of entry.

for transport and economic policies, laws and regulations, issue licences and grant subsidies if applicable and give approval to construction projects.

The private sector in freight transport covers carriers, logistics providers and shippers. The shippers' and carriers' company sizes vary widely.

The range of actors is however not limited to the transport sector, but involves also advocacy groups, unions and professional associations.

Private sector actors have knowledge of their own needs and the full depth of their operations, though limited to the own company. Development is focused on business objectives, i.e. the long term survival of the company. For project appraisal, private actors do not need to take external costs (and external benefits) into account.

The public sector needs to balance social, economic and environmental goals. Compared to companies, public planners have to consider a wider range of issues, e.g. public health and safety, but also economic development and efficient public spending. For this reason, the public sector's appraisal methods take into account the external costs and benefits of a project.

6.6 Conclusion

The analysis of planning procedures shows that an effort is made to better integrate private sector views into public planning. This should in theory enable the qualified safeguarding of areas for freight terminals in urban areas. However, several obstacles need to be overcome.

Since public planners have to take into account a wide range of interests, comprehensive and reliable data is required – but often not available – for appraisal. Just as important are political objectives, defining the desirable development of freight transport in urban areas.

Having a “reasonable prospect” of terminal development as a precondition for safeguarding areas poses a problem for public planners. Even well-suited areas need to be released for other developments if no concrete terminal project is at hand. The private sector is however often reluctant to get committed. The public sector should therefore be given planning instruments that allow the enforcement of long-term safeguarding even in cases where the logistics industry’s demand has not yet been explicitly expressed. In addition to declarations of intent from the freight transport industry, political objectives should be accepted as reason to safeguard areas. This also implies that public planners need to have at their disposal the resources and the knowledge to anticipate the development of freight transport.

At the same time it is necessary to prevent negative side effects. Longer-term unused areas are undesirable, both from an efficiency and a reputational viewpoint. Temporary uses need to be found for safeguarded areas where terminal development is not expected in the near future. Flexibility must be allowed for cases where the intended use does not materialise.

Chapter 7

System design of rail freight in urban areas

7.1 Introduction

This chapter exemplifies the dimensioning of the urban rail freight system. Dimensioning is an essential planning task. The freight system's performance needs to be related to its input quantities in terms of road and rail capacity, and area requirements. The capacities and areas available in urban areas determine the potential of a rail-based freight system. The hypothesis for this chapter is: *Transport chains in urban areas can have a substantial share of rail transport while fully meeting logistics requirements.*

The key aspect of this chapter is the urban road-rail freight terminal. It plays a pivotal role multimodal transport systems, influences its performance and shapes the urban environment. The domains of road and rail capacity will not be covered in detail. The rail freight capacity in urban areas is the subject of Chapter 5. Capacity for heavy goods vehicles (HGVs) is the subject of general road capacity considerations. The effect of freight terminals on local road traffic must be evaluated for individual cases, and with a high level of detail, which is not the intention of this study.

A modular approach to calculate a freight terminal's performance is presented. The performance is calculated in sequence from the single transhipment device to the whole terminal (Fig. 7.1). All in all, this dimensioning approach estimates the space requirements for rail-based freight transport. This should help to evaluate whether the required space is realistically available in urban areas.

In Section 7.2, freight terminal performance and the respective indicators are introduced. The indicators presented are common to container terminals and are applied to rail freight terminals in general.

In Section 7.3, the areas needed for freight terminals are estimated. Each freight handling device has its distinct space requirements, as have different commodities. The terminal area is needed to obtain specific terminal performance measures.

Section 7.4 estimates the freight handling performance. It explains the most common freight handling devices and their respective productivities. Standardized handling rates are calculated in order to make the handling of different commodities comparable.

Operational properties of freight transhipment are included in Section 7.5. The transhipment productivity considers how freight handling resources are deployed. This includes the movement of goods to and from the storage and the handling of empty load units on return trips.

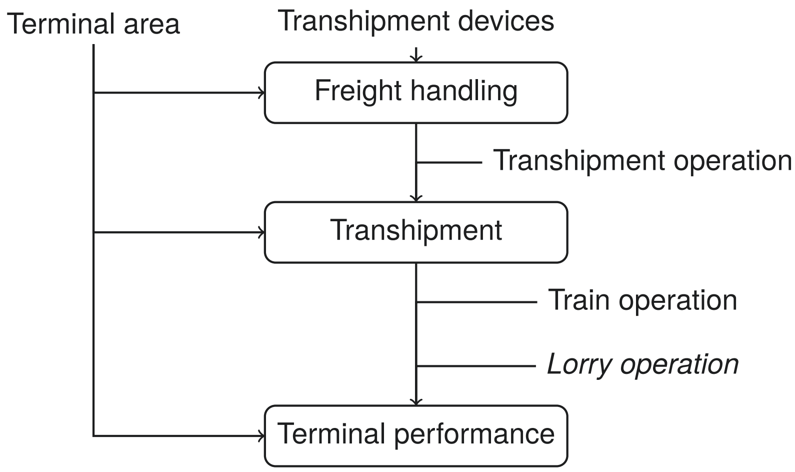


Figure 7.1: Procedure to obtain terminal performance (source: own)

The interaction between transhipment and train operations in the terminal is examined in Section 7.6. The resulting throughput of a terminal is determined by its capabilities to tranship goods, and to handle trains and lorries. The terminal throughput per unit area is the key number relevant to questions of spatial planning.

Section 7.7 provides rules of thumb of the generation of lorry and train trips in urban freight transport. Freight volume (usually in tonnes) needs to be converted to lorries and trains, taking into account load factors and the share of empty trips.

7.2 Freight terminal performance

7.2.1 The importance of terminal performance

Terminal performance is essential for the dimensioning of a multimodal freight transport system. The freight terminal is an additional capacity constraint to the transport system, adding to road and rail capacity constraints. Planners need to know the capabilities and area requirements of freight terminals in order to estimate their dimensions.

Terminal performance is well explored for container terminals (CTs) and bulk ports. The design process for large CTs and ports follows established paths. For smaller terminals, especially for non-containerized transport however, limited data is available and procedures are less clear.

The generic performance of multimodal freight terminals is therefore calculated in analogy to container terminals. An effort is made to adapt performance indicators to non-containerized transport and to estimate generic values for the performance of freight terminals.

7.2.2 Performance indicators

Indicators are a standardised way to express the performance of specific aspects of a freight terminal. The performance indicators distinguish between equipment productivity, transhipment productivity and terminal productivity. Additionally, land use efficiency is obtained by including terminal area. The terminal area includes the space required for each transhipment device, the circulation of trains and lorries, storage or buffer space and additional facilities.

To establish the analogy between CT and conventional freight terminals, the following indicators are considered:

- Equipment productivity
  - Handling rates/capacity — t/h, m^3/h, TEU/h, pallet/h
  - Specific handling capacity — t/h ha, m^3/h ha, TEU/h ha, pallet/h ha
- Transhipment productivity
  - Transhipment capacity — t/h, m^3/h, TEU/h, pallet/h
  - Specific transhipment capacity — t/h ha, m^3/h ha, TEU/h ha, pallet/h ha
- Terminal productivity
  - Terminal throughput — t/h, m^3/h, TEU/h, pallet/h
  - Specific terminal throughput — t/h ha, m^3/h ha, TEU/h ha, pallet/h ha

The *equipment productivity* is the number of transhipment moves (lifts) by the terminal's transhipment equipment and facilities. It depends on the properties of transhipment devices, as well as the goods to be transhipped. Handling rates are calculated from technical properties, the dimensions of the transhipment area and productivity factors. Specific handling rates put the handling performance in relation with the area required.

The *transhipment productivity* considers the need for multiple handling of freight ("double moves") and the handling of empty containers. Transhipment capacity is calculated from the handling rates, the share of direct transhipments and the terminal's operating hours.

The *terminal productivity* is the total amount of goods passing through the terminal. The terminal's (maximum) throughput is determined not only by the transhipment performance, but also by limitations of train and lorry operations inside the terminal.

Especially land-use related indicators pose a problem. While measures using *storage area* seem to be quite reliable and comparable, there often is some uncertainty concerning measures using the *gross terminal area*. For some terminal features – e.g. rail facilities, staff parking spaces etc. – the allocation to the gross area is often unclear. As Tioga (2008) observe, there are frequently disparities between what planners and terminal operators identify as terminal area. Similar obstacles occur with facilities for conventional freight transhipment. In Ruesch (2015), a structured way to allocate areas to different logistics functions – transportation, transhipment and storage – is presented and applied to three case studies. It presents key figures not only for storage density, but also for handling and terminal throughput per unit area.

In general, data collection on terminal size and features vary. Additionally, the factors to which the disclosed terminal capacities or performances refer to are often unclear.

7.2.3 Performance references

Values for (technical) handling rates of container transhipment devices can be obtained from a number of sources. For inland ports (road–rail), Mertel et al. (2012) mentions technical handling rates of 20 to 30 containers/h for gantry cranes and 15 to 20 containers/h for reach stackers. In (marine) container ports, quay cranes reach technical handling rates of around 50 moves/h (Kemme, 2013; Saanen, 2004). However, in operation only 22 to 30 moves/h are achieved.

Storage densities (or yard densities) of container stacks are also well known. Kemme (2013) and Saanen (2004) mention values of 250 TEU/ha for unstacked containers,

Table 7.1: Annual throughput and area of small and medium sized freight terminals (data from Ruesch et al. (2017))

Facility	A_{total}	p_{annual}		p_{spec}	
	m^2	ILU/a	t/a	TEU/ha a	t/ha a
Gossau SG([1,4])	4000	25 000	–	78 125	–
Railport Darmstadt, CT([2,5])	9900	40 000	–	60 606	–
Railport Darmstadt, open([2,6])	7810	–	12 000	–	15 365
Railport Darmstadt, covered	11 580	–	15 000	–	12 953
Intermodal terminal Bludenz([1,5])	11 000	28 000	–	38 182	–
Intermodal terminal Hall([1,5])	28 000	45 000	–	24 107	–

Equipped with ([1]) reach stackers, ([2]) a gantry crane, ([3]) forklift trucks.
([4]) Transhipment of swap bodies: 1.25 TEU/ILU. ([5]) Assumption: 1.5 TEU/ILU.
([6]) Mainly transhipment of pre-slung cargo.

500 TEU/ha when using reach stackers and 1500 TEU/ha under a yard crane. For US ports Tioga (2008) mentions storage densities of 80 to 300 TEU/acre (approximately 200 to 750 TEU/ha).

The specific handling capacity per unit area is the handling capacity divided by the gross terminal area. Figures for container ports by Kemme (2013) and Saanen (2004) show annual container handling capabilities per total area of 23 000 to 50 000 TEU/ha. Assuming an average net-net-load per TEU of 10 t this corresponds to 230 000 to 500 000 t/ha annually. Tioga (2008) mentions a (planned) annual value of 8000 TEU/gross acre (approximately 20 000 TEU/ha).

Terminal throughput per unit area is less easily found. For US ports, Tioga (2008) reports mean annual throughputs of approximately 1000 to 5000 TEU/gross acre (2500 to 12 500 TEU/ha). Many US ports however dedicate substantial areas to rail yards and other uses, which are often not included in the gross terminal area elsewhere.

Maritime container terminals have a distinct storage function and therefore large shares of storage area. This leads to comparably low handling capacities per unit area. It must be assumed that terminals with less extensive storage thus display higher values.

This can be shown by calculating the throughput per unit area from terminals described in Ruesch et al. (2017). It contains the characteristics of a (non-representative) selection of small and medium sized road–rail freight terminals (Table 7.1). However, neither the degree of utilisation, nor the exact allocation of areas is known.

Ruesch (2015) calculated the land use efficiency of logistics facilities in Switzerland. It shows daily throughputs of 900 to 2500 pallets per hectare.

In general, the performance of devices for the transhipment of non-containerized goods is not well documented. Additionally, some sources do not properly disclose whether technical or operational rates are provided. Generic handling rates therefore need to be calculated using basic technical characteristics, while reproducing the handling rates for container transhipment.

7.3 Terminal area

7.3.1 Terminal layout

Freight terminals exist in various layouts, depending on the goods transhipped, the local land availability, the business model of the terminal etc. Generally, a rail freight terminal consists of:

- the terminal yard, including
  - loading tracks,
  - transhipment devices, and
  - space to circulate lorries,
- storage (or buffer),
- access facilities for lorries and trains, and
- additional facilities.

In the terminal yard, the actual transhipment of goods between the train and the lorry (or the storage) takes place. Its dimensions are mainly determined by the length and number of loading tracks and the transhipment devices in operation.

Goods that cannot be transhipped directly between train and lorry are placed in the storage area (or buffer, if the storage time is very short). Storage facilities include container stacks, warehouses, heaps and tanks. Capacity is determined by the type of goods and by the properties of the storage facilities.

The freight terminal requires access facilities at the interface to the transport networks. For railway access, sidings are needed for entry or exit of trains to and from the main tracks. For road access, most freight terminals feature entry and exit gates.

Additional facilities are needed for operations other than transport and transhipment . Offices are needed for terminal administration. The terminal's employees need space to park their private vehicles. Occasionally, terminals feature service facilities for refuelling, cleaning and repairs.

7.3.2 Terminal yard

The terminal yard consists of areas for the loading tracks, for manoeuvring industrial trucks, the lorry loading bay and lorry circulation. In rail freight terminals, the length of the loading tracks is the most relevant dimension. It usually is the determining factor for the overall dimensions and also for the maximum train length that can be dealt with. Is the loading track shorter than the train length, additional shunting is necessary to deliver sets of wagons.

The manoeuvring area depends on the type of transhipment device. The width of the manoeuvring area (also "aisle width") for wheeled transhipment devices, such as reach stackers, forklifts, loaders etc., is determined by their size and turning curves (FEM, 2017). Devices for vertical transhipment, e.g. (gantry) cranes, do not require additional manoeuvring area.

The area for the lorry loading bay depends on the type of lorry and the bay type. Side loading of lorries, e.g. with wheel loaders and reach stackers, requires a single loading lane beside the track. Bays for end loading require space for the lorries to reverse into the bay. The loading bays can be arranged at right angles or diagonally.

Lanes need to be provided for lorries to get to their loading point and back to the exit.

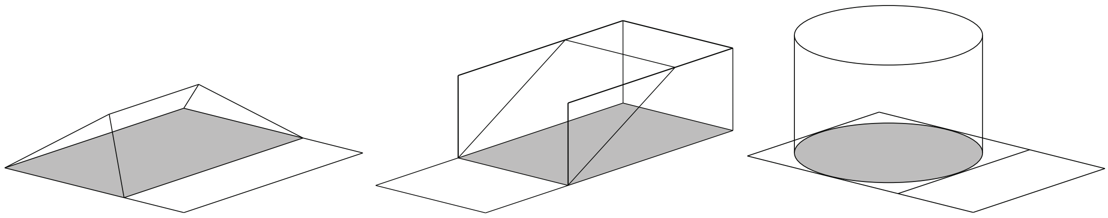


Figure 7.2: Schematic area requirements of dry bulk good storage (source: own)

The total yard area, including loading tracks, can be approximated by Eq. (7.1).

$$A = l_{\text{track}} \cdot (n \cdot w + d_{\text{aisle}} + d_{\text{bay}}) + d_{\text{lane}}) \tag{7.1}$$

where: A = the total area of the terminal yard
l_{track} = the length of the loading track
n = the number of loading tracks
w = the track clearance
d_{aisle} = the width of the loading area
$d_{\text{bay}})$ = the length of the lorry loading bay
d_{lane} = the width of the lorry lanes

7.3.3 Storage area

The size of the storage (or buffer) area is defined by the characteristics of the transhipped goods and the dwell time in the terminal. It depends on the share of direct transhipments (Ruesch et al., 2017). Knowing the total amount of goods shipped, the share of direct transhipments and the average dwell time, the required storage capacity can be calculated with Eq. (7.2).

$$m_{\text{storage}} = M \cdot (1 - q_{\text{direct}}) \cdot t_{\text{dwell}} \tag{7.2}$$

where: m_{storage} = stored amount of goods
M = the daily average amount of goods shipped through the facility
q_{direct} = the share of direct transhipments
t_{dwell} = the average dwell time of the goods in storage

The size of the storage area depends on the type of good and the storage facility. Dry bulk goods can be stored as open heaps, in bunkers or in silos, containers can be stacked and pallets are useful for high rack storage.

The space required for dry bulk goods depends on how bulk is stored (Fig. 7.2). Open heaps, e.g. for sand, gravel or wood chips, require more space than bunkers. Additionally,

Table 7.2: Calculated storage densities of different cargo types (source: own)

Cargo type	Storage density	
Containers:		
Stackable containers	250–1500 ITU/ha	–
Non-stackable containers	100–320 ITU/ha	–
Dry bulk goods(1):		
Open heap	5000–30 000 m^3/ha	2500–60 000 t/ha
Bunker	20 000–45 000 m^3/ha	10 000–90 000 t/ha
Silo	30 000–100 000 m^3/ha	30 000–100 000 t/ha
Pallets(2):		
Single storey	3000–4000 pallets/ha	1500–4000 t/ha
Pallet rack	10 000–20 000 pallets/ha	5000–20 000 t/ha

(1) Light dry bulk: 0.5 t/m^3; Heavy dry bulk: 2 t/m^3
(2) Loaded pallet gross mass: 0.5–1 t/pallet

different goods have different dump angles and densities . Silos are less frequent and might be considered for grain and cement.

The mass density of dry bulk varies significantly, and the storage area can hardly be generalised. For instance, wood chips, paper and domestic waste have densities of 0.5 to 1 t/m^3; Sand, gravel and excavated earth have densities of 1.5 to 2 t/m^3 (see Appendix C, Table C.2).

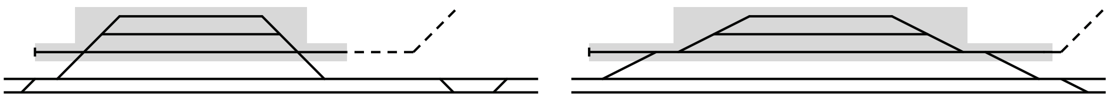
The storage density of containers depends on the stackability and on the handling equipment. Toplift handling allows for denser placing than setting downs containers by lorry, which requires space for manoeuvring. Special attention needs to be paid to the handling of empty containers, which not only generate additional transhipments, but also require storage space.

European standard pallets have a load rating of 1500 kg, but mostly carry not more than approximately 1000 kg. They are commonly used in the transport of lightweight goods, especially in retail trade. Due to high turnover and short dwell times, palletised goods mostly do with small storage space. Larger storage facilities, such as central warehouses, store pallets in racks which allows for much higher storage densities.

7.3.4 Railway access

Rail freight terminals are connected to the railway network via a set of arrival/departure sidings. Direct connection of the loading tracks to the main tracks is not permitted, due to the risk of interrupting main-line traffic during shunting. Incoming trains pulling out from the main tracks need an arrival siding to decouple the locomotive, split up the train if needed and prepare it for shunting to the terminal. Outgoing trains need to be assembled and checked before entering the main tracks.

The area needed for this track infrastructure is not included in the terminal area. It is part of the railway infrastructure and not of the terminal facilities. In some cases, the tracks of a passenger station may serve for receiving freight trains.



(a) compact (b) fast entry/exit

Figure 7.3: Generic track layout for arrival and departure sidings. Fast entry or exit (b) requires flatter switch angles (source: own)

The arrival/departure tracks and the actual terminal need not to be in close proximity. It is not unusual that freight wagons have to be shunted over a significant distance.

Arrival/departure sidings are positioned along the main tracks. The entry and exit speed defines the type of turnouts used and therefore has directly influences the size of the track facilities.

The minimum requirement for the track facilities is one arrival/departure track, one waiting track, one loop track and headshunts. Additional sidings for waiting trains, reserve wagons and repairs might be necessary in medium to large terminals.

The minimal length of the arrival/departure track corresponds to the maximum train length intended for operation in the terminal plus allowances for inaccurate braking, signal visibility etc. A loop track and headshunts are needed to decouple the locomotive and change between pull- and push-operation.

For a rough estimation without preliminary assessment of operational issues, the minimal area required can be approximated using the maximum train length, the switch inclination (depending on the entry speed), track clearance and additions (Eq. (7.3)).

$$A_{\text{rail}} = n_{\text{track}} \cdot w_{\text{track}} \cdot (l_{train} + i_{\text{switch}} \cdot n_{\text{track}} \cdot w_{\text{track}}) + 2 \cdot w_{\text{track}} \cdot (l_{headshunt} + l_{\text{spacing}}) \quad (7.3)$$

where:
- A_{rail} = the total area needed for the track facilities
- n_{track} = the number of tracks
- w_{track} = the track clearance
- i_{switch} = the switch inclination
- l_t = the length of the train
- $l_{headshunt}$ = the length of the headshunts, including buffer and allowances
- l_{spacing} = the spacing between two switches, if necessary

For a compact 3-track set of arrival/departure sidings (entry speed 40 km/h, using Swiss railway standards), an area between 0.55 ha (for a 200 m-train) and 1.38 ha (750 m-train) is necessary. The sidings extend over 570 m to 1120 m along the main track. For fast entry sidings (60 km/h), between 0.68 ha (200 m-train) and 1.51 ha (750 m-train) are needed, extending over 760 m to 1310 m (Fig. 7.3 and Appendix C, Table C.1).

7.3.5 Road access

Depending on procedures and transport volume, the terminal needs to provide a check-in area for lorries. Often the lorries are weighed and occasionally checked for damages. Since the gates can only handle a certain number of vehicles, parking spaces need to be provided for waiting vehicles. The number of gates is mostly dimensioned to a number of vehicles fewer than peak demand. The total number of vehicles in the gate area can be approximated by Eq. (7.4) (Mertel et al., 2012).

$$N = \frac{t \cdot f_{\text{peak}} \cdot d}{n} \tag{7.4}$$

where: N = the maximum number of vehicles in the waiting area (incl. gate)
t = the average total check-in/check-out time per vehicle
d = average number of lorries arriving at the terminal
f_{peak} = peak demand factor
n = the number of gates

The area and the required lane length for the gate is calculated using the maximum vehicle size operating in the terminal.

Examples of gate times vary. For intermodal terminals, Mertel et al. (2012) assumes 5 to 8 minutes each for the technical check of the intermodal loading unit (ILU) and for lorry check-in/check-out. The automation of the check-in/check-out shortens gate times significantly. Smaller terminals and single-user facilities even do entirely without gates.

7.3.6 Terminal module approach

The variety of terminal layouts makes the comparison of terminal performance difficult and unreliable. Therefore, a standardised set of terminal modules is created to obtain comparable figures. Based on findings in Ruesch et al. (2017), the terminal modules consist of areas for the yard and storage space. Two basic module types are distinguished, (1) modules for transhipment with cranes, and (2) modules for wheeled transhipment devices (Fig. 7.4). The use of cranes allows the lifting of load units across several tracks and lanes. In contrast, the use of loading trucks allows only one track to be served. Other transhipment layouts, e.g. conveyors, piping etc. are not considered.

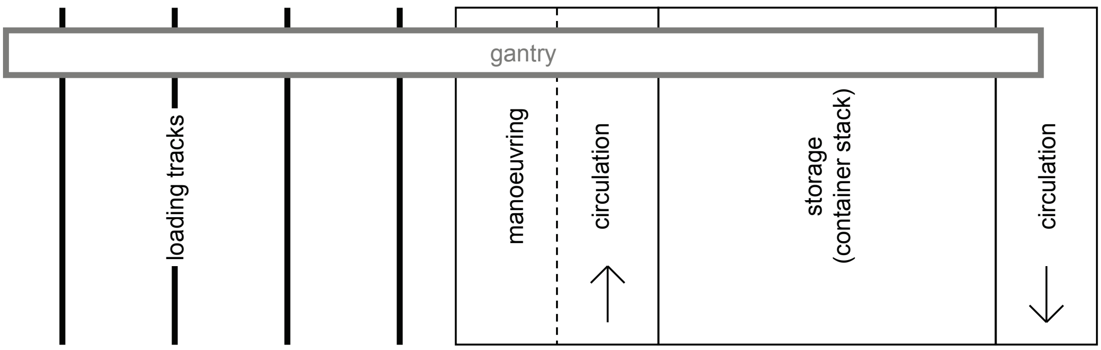
A terminal module is composed of the manoeuvring area of one transhipment device, the loading tracks and the areas required for lorry circulation and goods storage. The module dimensions are thus mainly determined by the transhipment device's aisle width and the operating range.

The operating range is the lateral distance along the loading track, over which a transhipment device operates. (It essentially is the inverse of the number of devices per train length.) Its values are based on assumptions and are subject to high variations. For instance, it is assumed that a reach stacker serves significantly more train-metres than a forklift truck.

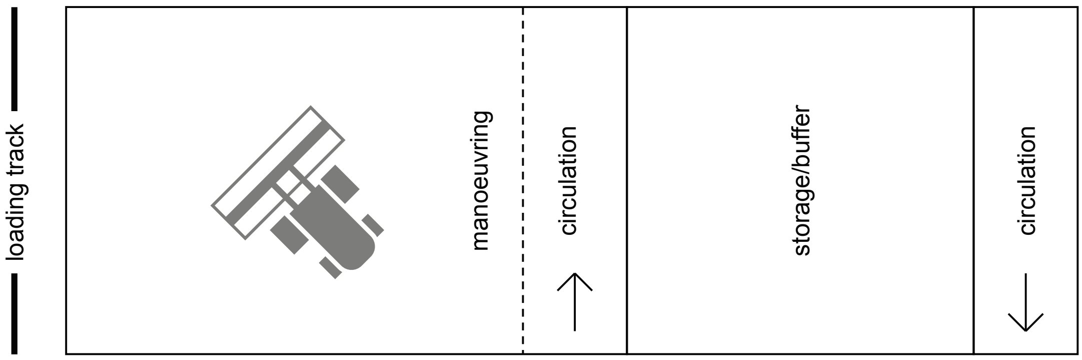
The assumption for the circulation area is two lorry lanes along the module length. Although terminals exist with one-way traffic and entry and exit at opposite ends of the terminal.

Since the required storage area cannot be determined at this stage, default values are used for the storage area width (compare to Fig. 7.4). Table 7.3 shows the space requirements of different transhipment equipment, detailed calculation parameters can be found in Appendix C, Table C.3.

Not shown are additional facilities, such as offices, service facilities, parking spaces, etc. The exact positioning of additional facilities is often determined by residual areas.



(a) with cranes



(b) with wheeled transhipment devices

Figure 7.4: Generic layouts of the modules of rail–road freight terminals (source: own)

In this approach, they are added as a fixed percentage, set to 50 % of the yard area.

Areas needed for railway and road access are not considered in this approach. Entry and exit siding for trains are mostly part of the railway infrastructure, not of the terminal area. The need for lorry gates is diminishing, as information technology helps to exchange data automatically.

7.4 Freight handling

7.4.1 Transhipment devices

The means of transhipment in a freight terminal depend on the type of good and the type of cargo (see Section 2.3.3). In general, (1) continuous and discontinuous handling, (2) wheeled and rail guided devices, and (3) on-site and on-board equipment are distinguished.

Transhipment in intermodal transport Intermodal transport is the transhipment of goods inside intermodal transport units (ITUs) without handling the goods themselves. ITUs include ISO-containers, swap bodies and semi-trailers suitable for intermodal transport. A range of devices is used to tranship ITU.

Gantry cranes span across the loading tracks, the loading lanes and the container stack. The crane can be moved along the loading area on tracks (rail mounted gantry

Table 7.3: Area of exemplary terminal modules (source: own)

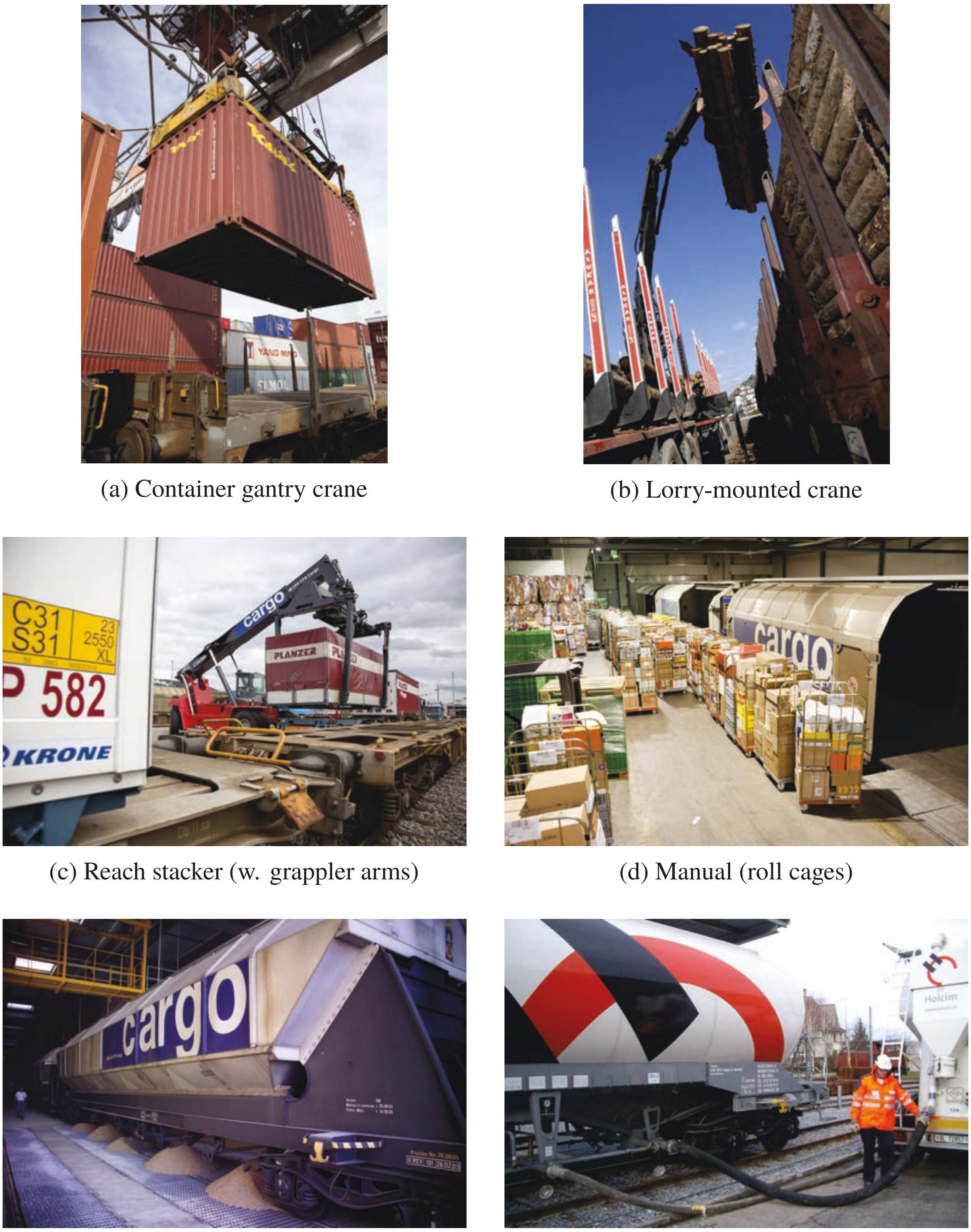
Transhipment device	Load unit	l_{mod} m	d_{trk} m	d_{man} m	d_{bay} m	d_{stor} m	A_{mod}(1) m^2
Manual							
Roll cage	roll cage	25	5	6	11	6	1280
Lowlift pallet truck	pallet	25	5	6	11	6	1280
Industrial trucks							
Forklift single	pallet	50	5	6	11	8	2650
Forklift quad	pallet	100	5	8	11	10	5800
Small wheel loader	1 m^3	50	5	9	4	8	2350
Medium wheel loader	1 m^3	100	5	12	4	12	5550
Large wheel loader	1 m^3	150	5	15	4	16	9600
Reach stacker	TEU	200	5	15	4	8	11 200
Cranes							
RMG	TEU	200	30	0	4	12	15 000
RTG	TEU	200	20	0	4	12	12 000
Industrial crane	coil	50	5	0	4	4	1480
On-board devices							
Loader crane	big bag	50	5	0	4	0	1280
Hooklift hoist	acts	50	5	0	11	0	1800
Container mover	swap body	50	5	0	4	8	1680
Tipper lorry	1 m^3	50	5	0	19	0	2400
Tipper wagon	1 m^3	100	5	0	0	6	2550
Pneumatic pump	1 t	50	5	0	4	0	1280
Continuous systems							
Medium belt conveyor	1 m^3	50	5	0	4	0	1280
Small belt conveyor	1 m^3	50	5	0	4	0	1280
Pump	1 m^3	20	5	0	4	0	510
Pneumatic pump	1 t	100	5	0	4	0	2550

(1) Including area for additional facilities (f_{area} = 50 %) and circulation area (d_{circ} = 8 m).

crane (RMG)) or rubber tyres (rubber tyred gantry crane (RTG)). Manoeuvrability is therefore limited, but for large container terminals (i.e. with several loading tracks) it often is the most efficient way of handling containers.

Among wheeled vehicles for ITU transhipment, *reach stackers* are the most common in road–rail intermodal transport. They can circulate freely across the terminal yard, though the driving surface needs to be reinforced to cope with high wheel loads. Just like cranes they are capable of stacking containers, though to less tiers.

Depending on the type of ITU, the handling devices of both gantry crane and



(a) Container gantry crane

(b) Lorry-mounted crane

(c) Reach stacker (w. grappler arms)

(d) Manual (roll cages)

(e) Bulk chute (grain)

(f) Pneumatic pump

Figure 7.5: Examples of transhipment devices (all pictures: © Photo SBB)

reach stacker are equipped with spreaders and twistlocks (to lift containers and toplift-capable swap bodies) or grappler arms (for most swap bodies and semi-trailers).

Horizontal container transhipment presents an alternative to transhipment by crane or reach stacker. Containers are transhipped with a hoist device on-board the lorry, making on-site transhipment devices obsolete. There are various technologies using different containers and on-board devices. In Europe, roller container system (ACTS) has gained some importance, especially for waste transport in roller containers using lorries with hooklift hoists.

Conventional transhipment Conventional transhipment includes all commodities that are not transported in ITUs. This includes liquid and dry bulk goods, palletized goods, pre-slung goods (including FIBCs, so called "big bags") and general cargo.

Small general cargo with limited size (e.g. boxes, bags) can be transhipped manually, as can wheeled transport units, e.g. roll cages. Manually operated devices, e.g. hand pallet trucks, carts and trolleys support workers handling slightly larger loads.

Pallets, the most important cargo type in trade, are transhipped with a variety of industrial trucks. They range from lowlift *pallet trucks* to large *forklift trucks*. Lowlift pallet trucks (or "pallet jacks") are not able to stack pallets and therefore require level ramps to access wagons and lorries. Forklift trucks are more capable and can be equipped with multiple-pallet handlers. Many forklift trucks can also be used with other attachments, e.g. clamps or hooks.

Dry bulk is often handled with *wheel loaders* or *excavators*. Bucket size and therefore loading capacity depends on the type of good. When transported in *tippers* (lorries) or self-discharging hopper wagons, unloading is done by simply dumping the load through a chute.

For large general cargo, e.g. coils, drums and beams, gantry cranes are used. Size, range and maximum load vary widely.

Lorries with on-board transhipment devices, such as loader cranes, hooklift, pumps and tippers, can use terminals without on-site devices. Unless for direct transhipment, such lorries are not used to unload and load trains.

Dedicated transhipment facilities For some commodities it is appropriate to have purpose-built facilities with specific, large scale transhipment technology. This transhipment equipment is an integral part of the terminal infrastructure and cannot readily be moved.

Large terminals for dry bulk goods, e.g. in mining, quarrying and excavation, operate with stationary *conveyor systems* and chutes for loading and unloading. Terminals for liquid bulk, e.g. fuel depots, require large systems of pumps, piping and tanks. Similarly, for powder substances, e.g. flour or cement, pneumatic pumping is used. Mainly large terminals – e.g. fuel depots for airports, quarries or large industrial complexes – justify investments in capital-intensive stationary transhipment technology.

7.4.2 Handling rates of transhipment devices

The handling rate of a transhipment device is the amount of goods (i.e. the number of containers, pallets, tonnes etc.) moved per operating hour. Its value not only depends on the type of equipment used but also operating conditions in the terminal.

Suppliers of transhipment systems often provide handling rates of their devices. However, the stated rates often refer to operation under ideal conditions or are theoretical values and therefore often need to be reduced to the values valid for long term operation. Kemme (2013) and Saanen (2004) mention different levels for handling rates of quay cranes in seaport container terminals:

Technical	The theoretical maximum possible number of containers handled per hour. It is based on deterministic, physical properties of the crane such as velocity, acceleration and distances.
Operational	Includes stochastic variations of the technical container handling processes, all else under ideal conditions.
Net	The number of crane cycles during net operation time, including interference with other equipment (waiting times).
Gross	The number of crane cycles over longer periods of time (gross operation time). This includes disruptions, such as change of shift and meal breaks, break downs and repair time.

The relation between the different levels is mostly experience-based. The comparison of (theoretical) technical and (observed) gross handling rates shows an efficiency rate of approximately 0.4 to 0.6. Additionally, daily, weekly and seasonal variations of transport volumes are accounted for by factors of 80 to 90 % (Mertel et al., 2012; Tioga, 2008).

For other cargo types than containers, figures on the relation between technical and gross handling rate are rarely available. Observed values barely represent efficient handling rates, since transhipment is not the main activity in many facilities.

An attempt is therefore made to calculate the handling rates for a range of transhipment devices. First, the number of transhipment cycles per hour of operation is calculated, assuming the terminal is running at capacity, i.e. all available transhipment devices are in operation.

Cycle times, i.e. one complete movement of the transhipment device, are calculated from the process times for picking up and setting down loads, and the average speed of the device. The distance covered by the device is the average lateral distance (along the loading track) and the aisle width for manoeuvring. While the aisle width can be calculated, the lateral distance is based on rough estimations and by the number of load units per metre train length. The dimensions are covered in more detail in Section 7.3.

Secondly, cycles are converted to the load. Each device is able to tranship a certain number of load units. For instance, a container crane lifts 1 to 2 TEU, forklift trucks 1 to 6 pallets and wheel loaders 1 to 6 m^3 per cycle. If needed, load units are converted to tonnes.

Lastly, the technical rates are adjusted. The gross handling rates are calculated with the factors shown above for container terminals. A total efficiency of 40 % is thus assumed for all transhipment devices. This results in gross handling rates of 10 to 20 TEU/h for reach stackers, 30 to 80 pallet/h for forklift trucks and 10 to 80 m^3/h for wheel loaders (Table 7.4).

Continuous transhipment devices, such as conveyors and pumps, do not work in cycles. Nevertheless, the (technical) throughput is converted to gross handling rates using the same factors. Belt conveyors transport 40 to 240 m^3/h, or 20 to 480 t/h; pumps approximately 150 to 250 m^3/h; pneumatic conveyors for powder substances 20 to 30 m^3/h. Table 7.4 shows typical handling rates of different transhipment equipment, detailed calculation parameters can be found in Appendix C, Table C.4.

The relative handling capacity per module is calculated from the handling rates and the area requirements (see Section 7.3). Table 7.4 shows area-specific handling rates of different transhipment equipment, detailed calculation parameters can be found in Appendix C, Table C.4. The calculated relative handling capacity per unit area for bulk goods ranges from 40 to 200 t/h ha. For container handling, the range is 10 to 20 TEU/h ha; for palletized goods, 150 to 250 pallet/h ha.

Table 7.4: Common transhipment devices and calculated gross handling rates in road–rail freight terminals, based on Ruesch et al. (2017); Kemme (2013); Mertel et al. (2012); Tioga (2008); Saanen (2004); Ballis and Golias (2002); Girmscheid (2010)

Transhipment device	n_{spec}	d_u	r_{gross}		$r_{gross, spec}$	
	unit/m	t/unit	unit/h	t/h	unit/h ha	t/h ha
Manual						
Roll cage	5.00	0.2	32	6	251	50
Lowlift pallet truck	2.20	0.4	22	9	174	70
Industrial trucks						
Forklift single	2.20	0.4	30	12	112	45
Forklift quad	2.20	0.4	74	30	127	51
Small wheel loader(1)	2.25	2.0	18	35	75	150
Small wheel loader(2)	4.50	0.5	27	13	113	56
Medium wheel loader(1)	2.25	2.0	30	59	53	107
Medium wheel loader(2)	4.50	0.5	45	22	80	40
Large wheel loader(1)	2.25	2.0	51	102	53	107
Large wheel loader(2)	4.50	0.5	77	38	80	40
Reach stacker	0.15	10.0	18	183	16	163
Cranes						
RMG	0.15	10.0	22	217	14	145
RTG	0.15	10.0	22	223	19	186
Industrial crane	0.40	10.0	10	102	69	689
On-board devices(3)						
Loader crane	2.00	1.5	8	12	63	94
Hooklift hoist	0.15	12.0	3	36	17	200
Container mover	0.12	10.0	3	30	18	179
Tipper lorry(1)	2.25	2.0	104	208	433	867
Tipper wagon(1)	2.25	2.0	206	411	807	1613
Pneumatic pump	4.00	1.0	8	8	63	63
Continuous systems(3)						
Medium belt conveyor(1)	2.25	2.0	240	480	1882	3765
Small belt conveyor(2)	4.50	0.5	40	20	314	157
Pump(4)	4.50	1.0	200	200	3922	3922
Pneumatic pump	4.00	1.0	22	22	86	86

(1) Heavy dry bulk goods
(2) Light dry bulk goods
(3) Cycle times not distance-related
(4) Liquid bulk goods

7.5 Transhipment

7.5.1 Allocation of handling resources

Intermediate storage and empty containers consume part of a terminal's handling capacity. Goods to and from the storage are handled twice (or even more). The return of empty containers, roll cages and pallets generates additional handling demand.

The *transhipment capacity* takes into account how freight handling resources are allocated. It thus expresses the absolute transfer of goods between road and rail. The operational properties of freight transhipment not only cover the number of transhipment devices and the terminal's operating time, but also the share of goods moving through the storage and the handling of empty returns. In a road–rail freight terminal, the following movements occur (Fig. 7.6):

- the direct transhipment between trains and lorries,
- the transhipment to the buffer/storage, and
- the transhipment from the buffer/storage.

Handling rates can be attributed to all movements individually or their combination. The handling rate for direct transhipment (r_{direct}) is usually expressed as a share of the total (q_{direct}). The handling rate to outgoing vehicles is the sum of the direct handling rate and the rate from the storage. For bi-directional terminals (i.e. with freight flows to and from the urban area) the flows in Fig. 7.6, and hence the handling rates, are mirrored.

Two different cases need to be distinguished. Some transhipment devices can be used for all types of transhipments interchangeably. The full handling capacity can be directed to the task most urgent at the time. This is mostly the case in intermodal terminals where the same cranes are used to move containers from and to trains, lorries and the container stack respectively.

In other cases, transhipment devices are limited to a single task, e.g. moving goods from the buffer to the lorry only. The handling capacity cannot be allocated to a different task. Especially transhipment by tipping bulk goods from lorries or wagons is limited to a single direction.

Interchangeable transhipment devices If the transhipment devices can be allocated flexibly to any type of movement, the total handling rate is composed of variable partial handling rates. Shipments going to, or coming from the buffer or storage have to be

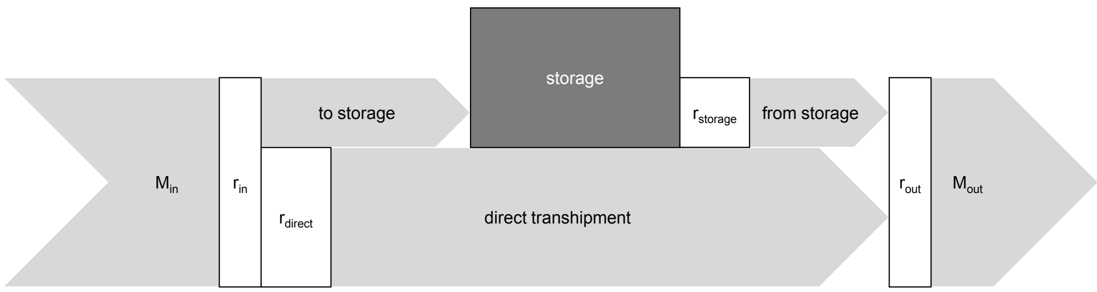


Figure 7.6: Generic transhipment process in road–rail freight terminals (source: own)

moved twice. The transhipment capacity in the long run therefore is (Ruesch et al., 2017):

$$P_{\text{max}} = t_{\text{ops}} \cdot \frac{r_{\text{total}}}{2 - q_{\text{direct}}} \tag{7.5}$$

where: P_{max} = the maximum transhipment capacity
t_{ops} = the terminal's operating time
r_{total} = the total handling rate of the transhipment devices
q_{direct} = the share of direct transhipments

In the short term, the handling resources can be allocated to a single task. An example of interchangeable transhipment devices is a container terminal with several cranes. All cranes can be tasked with unloading a train (to lorries and buffer), by holding back transhipments in the opposite direction and from the buffer to lorries. This however requires that the storage can be fully served in between trains.

Separate transhipment If the transhipment devices are limited to single movements, separate transhipment rates are applied. The terminal handling capacity is therefore limited by the combination of the handling rates. Assuming different, non-combinable transhipment devices, one for incoming goods and one to serve the storage:

$$P_{\text{max}} = t_{\text{ops}} \cdot \min \begin{cases} r_{\text{in}} \\ r_{\text{in}} \cdot q_{\text{direct}} + r_{\text{storage}} \end{cases} \tag{7.6}$$

where: P_{max} = the maximum transhipment capacity
t_{ops} = the terminal's operating time
r_{in} = the total handling rate for incoming goods
q_{direct} = the share of direct transhipments
r_{storage} = the handling rate from the storage

An example of separate handling processes is the transhipment of excavation material (dry bulk), delivered to the freight terminal by lorry and leaving by train. Tipper lorries dump their load either directly into the train's hopper wagons ($r_{\text{in}} \cdot q_{\text{direct}}$) or to the bunker for storage ($r_{\text{in}} \cdot (1 - q_{\text{direct}})$). To load the train from the bunker, a wheeled loader is used. Neither the tipper lorries nor the loader can be used in reverse, limiting the total handling performance of the terminal.

Operating times The terminal's operating time is based on the operation of all available transhipment devices. The operating time needs to be adjusted for non-busy periods, when only part of the devices is in operation. The operating time is thus not necessarily congruent with the terminal's opening hours; it rather expresses the full-load period per day.

Handling of empty load units The handling of empty load units, i.e. containers, pallets and roll cages, consumes a significant part of the handling capacity. It is assumed that in urban freight transport, containers and roll cages generate one additional movement per loaded unit. One in ten pallet lifts is assumed to be the return of empties, generating

0.1 additional movements. The conversion from unit-based transhipment capacities to tonne-based capacities therefore is:

$$P_{\text{tonne}} = P_{\text{unit}} \cdot \frac{1}{1 + f_{\text{empty}}} \tag{7.7}$$

where: P_{tonne} = the transhipment capacity in t/ha a
P_{unit} = the transhipment capacity in units/ha a
f_{empty} = the share of empty load units (per loaded units)

7.5.2 Transhipment capacity

Table 7.5 shows the specific transhipment capacity of various terminal modules. More detailed calculation parameters can be found in Appendix C, Table C.6. Capacities are around 45 000 t/ha a for palletized goods, 80 000 to 300 000 t/ha a for bulk goods (by wheel loader) and 20 000 to 35 000 TEU/ha a for containers (including empties).

The underlying assumptions on operating times and the share of storage transhipments have a big influence on transhipment capacity. The operating time of terminals with pronounced peak loads (e.g. in retail) tends to be short, while less time sensitive goods allow for more evenly distributed loads. High volume facilities need extended operating hours. The daily operating hours are multiplied with 250 working days per year to obtain annual values.

The share of storage transhipments (f_{stor}, the complement of the share of direct transhipments) is only defined for manual transhipment, forklift trucks and cranes. All other devices are limited to storage or direct transhipment only.

Table 7.5: Specific terminal module transhipment capacity (source: own)

Transhipment device	f_{stor}	t_{ops}	p_{spec}	
	–	h/d	units/ha a	t/ha a
Manual				
Roll cage	100 %	6	188 200	18 800
Lowlift pallet truck	100 %	6	130 300	47 400
Industrial trucks				
Forklift single	60 %	6	105 000	38 200
Forklift quad	60 %	6	119 400	43 400
Small wheel loader(1)	–	8	150 400	300 700
Small wheel loader(2)	–	8	225 600	112 800
Medium wheel loader(1)	–	8	107 000	214 000
Medium wheel loader(2)	–	8	160 500	80 200
Large wheel loader(1)	–	8	106 700	213 300
Large wheel loader(2)	–	8	160 000	80 000
Reach stacker	60 %	8	20 400	101 900
Cranes				
RMG	60 %	12	27 100	135 600
RTG	60 %	12	34 900	174 600
Industrial crane	100 %	8	68 900	689 100
On-board devices(3)				
Loader crane	–	8	125 500	188 200
Hooklift hoist	–	8	33 300	200 000
Container mover	–	8	35 800	179 100
Tipper lorry(1)	–	8	866 700	1 733 300
Tipper wagon(1)	–	8	1 613 400	3 226 900
Pneumatic pump	–	8	125 500	125 500
Continuous systems(4)				
Medium belt conveyor(1)	–	12	5 647 100	11 294 100
Small belt conveyor(2)	–	12	941 200	470 600
Pump	–	12	11 764 700	11 764 700
Pneumatic pump	–	8	172 500	172 500

(1) Heavy dry bulk goods (2.0 t/m^3)
(2) Light dry bulk goods (0.5 t/m^3)
(3) Direct transhipment only
(4) One-sided transhipment only

7.6 Terminal throughput

7.6.1 Train operations

Operational constraints of freight trains going to or coming from the loading tracks can be the limiting factor of the terminal productivity. During the changeover of wagons in the loading tracks, the loading and unloading process is halted. The terminal's operating times are thus reduced by the shunting times. Adding transhipment time and the time needed for the technical checks of the wagons, the productivity of train operations inside the terminal is:

$$P_{\text{train}} = \frac{M_{\text{train}}}{T_{\text{tranship}} + T_{\text{shunt}} + T_{\text{check}} + T_{\text{down}}} \tag{7.8}$$

where: P_{train} = the train productivity
M_{train} = the freight quantity per train
T_{tranship} = transhipment time
T_{shunt} = shunting time
T_{check} = time for train checks
T_{idle} = idle (train) time

For the maximum productivity of train operations, minimal idle time is assumed. The number of shunting operations needed is determined by the length of the train and the loading track length. The shunting time is assumed to be a fixed value per shunting movement, irrespective of the number of wagons shunted. It includes dispatching the shunting team and the actual wagon movement.

Additional time is needed to prepare the wagons for shunting, i.e. the check of technical aspects and, if necessary, wagon data. To check hatches and doors, covers and ropes, brakes, couplers, etc. the inspector needs to walk along the whole train. Checking time is thus distance-related.

The actual transhipment time per train is based on handling rates (rather than transhipment capacity). With interchangeable transhipment devices (see Section 7.5) the full handling capacity can be allocated to unloading/loading the train in the short term. Double lifts from storage transhipment can be omitted, however empty returns are included.

Considering this, the minimum transhipment time of a train is:

$$T_{\text{tranship}} = \frac{M_{\text{train}}}{R_{\text{total}}} \cdot \frac{1}{1 + f_{\text{empty}}} \tag{7.9}$$

where: T_{tranship} = transhipment time
M_{train} = the freight quantity per train
R_{total} = the total handling rate of the transhipment devices
f_{empty} = the share of empty load units (per loaded units)

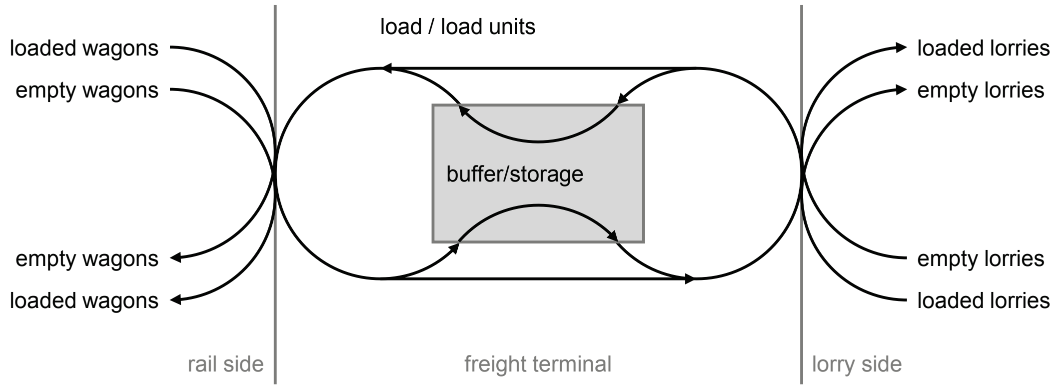


Figure 7.7: Vehicle flows to and from road–rail freight terminals (source: own)

7.6.2 Terminal throughput per unit area

The terminal throughput not only takes into account the transhipment productivity, but also train operations. Lorry operations are not included, since the review of exemplary throughputs suggests that trip densities are not critical. The terminal throughput per unit area is the quintessential measure for terminal's land use efficiency.

To obtain the maximum possible terminal throughput, the above mentioned transhipment capacity is adjusted by the maximum number of trains that can be served. Each terminal consists of one or several modules (of the same type), corresponding to the loading length. The loading length must not be longer that the train length.

A loading length of 200 m results in minimal terminal areas of 0.5 to 1.7 ha. The terminal area is in line with common recommendations of minimum terminal size (e.g. 1 ha in Salkeld et al. (2013); Bruns et al. (2013), 5 to 10 ha in Ruesch (2012)).

Table 7.6 shows the annual throughput per unit area for terminals with loading lengths from 50 to 400 m and a train length of 400 m. For container transhipment, the terminal throughput ranges from 10 000 to 25 000 TEU/ha a. For the transhipment of heavy dry bulk, e.g. excavated earth, gravel and sand, the maximum annual throughput is approximately 160 000 to 250 000 t/ha a. The throughput of light dry bulk (e.g. wood chips, household waste) is 65 000 to 98 000 t/ha a. Light goods on pallets reach approximately 45 000 t/ha a and roll cages 16 000 t/ha a. Detailed calculation parameters can be found in Appendix C, Table C.7.

7.7 Generation of lorry and train trips

Road–rail freight terminals generate lorry and train trips. The *tonne-to-trip* conversion is a basic task of freight transport models. Many models contain a specific logistics sub-model to calculate optimal shipment size and vehicle choice. Here, only a generalised approach is presented to approximate the number of freight trips.

Each terminal visit generates two trips, one arrival and one departure, of either loaded or empty vehicles (Fig. 7.7). The number of lorry and train trips generated depends on the amount of goods, the vehicle's load capacity, the load factor and the empty trip factor.

The *load factor* accounts for the fact that not all good types can fully exploit the vehicle's capacity. Additionally, the *empty trip factor* accounts for the share of empty

Table 7.6: Exemplary specific terminal throughput of road–rail freight terminals, train length 400 m, loading length 50–400 m (source: own)

Transhipment device	l_{trk}	n_{dev}	$A_{terminal}$	$p_{terminal}$	
	m	–	ha	units/ha a	t/ha a
Manual					
Roll cage	200	8	1.0	160 800	16 100
Lowlift pallet truck	200	8	1.0	130 300	47 400
Industrial trucks					
Forklift single	200	4	1.1	105 000	38 200
Forklift quad	200	2	1.2	119 400	43 400
Small wheel loader(1,2)	200	4	0.9	124 300	248 700
Small wheel loader(1,3)	200	4	0.9	194 900	97 500
Medium wheel loader(1,2)	200	2	1.1	91 000	182 000
Medium wheel loader(1,3)	200	2	1.1	141 800	70 900
Large wheel loader(1,2)	200	2	1.9	81 800	163 700
Large wheel loader(1,3)	200	2	1.9	130 300	65 200
Reach stacker	200	1	1.1	11 600	58 000
Cranes					
RMG	400	2	3.0	17 500	87 400
RTG	200	1	1.2	24 800	124 200
Industrial crane	100	2	0.3	68 900	689 100
On-board devices(4)					
Loader crane	200	4	0.5	113 400	170 100
Hooklift hoist	200	4	0.7	13 200	78 900
Container mover	200	4	0.7	13 400	67 200
Tipper lorry	100	2	0.5	417 000	833 900
Tipper wagon	100	1	0.3	780 700	1 561 400
Pneumatic pump	100	2	0.3	119 900	119 900
Continuous systems					
Medium belt conveyor(1,2)	50	1	0.1	1 705 500	3 411 000
Small belt conveyor(1,3)	200	4	0.5	760 800	380 400
Pump	50	3	0.2	3 025 200	3 025 200
Pneumatic pump	200	2	0.5	160 800	160 800

(1) One-directional transhipment. Additional modules needed for opposite direction.
(2) Heavy dry bulk goods (2.0 t/m^3)
(3) Light dry bulk goods (0.5 t/m^3)
(4) Direct transhipment only

Table 7.7: Capacity of lorries and freight wagons (IVE et al., 2016)

Vehicle size/type	m_{empty} t	m_{load} t	n_{TEU} TEU	m_{max} t
Lorries				
≤ 7.5 tonnes	4	3.5	–	7.5
7.5 to 12 tonnes	6	6	–	12
12 to 20 tonnes	9	11	–	20
20 to 26 tonnes	9	17	1	26
26 to 40 tonnes	14	26	2	40
40 to 60 tonnes	19	41	2	60
Trains				
Standard wagon	23	61	–	84
Car wagon	28	21	–	59
Chemistry wagon	24	55	–	79
Container wagon	21	65	2.6	86
Coal and steel wagon	26	65	–	91
Building material wagon	22	54	–	76
Manufactured product wagon	23	54	–	77
Cereals wagon	20	63	–	83

runs generated. Seasonal and daily variations need to be considered for dimensioning the impact on rail and road infrastructure. Table 7.7 provides typical capacities of lorries and freight wagons.

For freight trains, the maximum number of wagons per train is required additionally. This is limited either by the maximum train length, or the maximum train mass. In Europe this generally is 750 m and 2200 t respectively (in mountainous regions less). Table 7.8 shows typical values of wagon lengths and specific wagon capacity per unit length.

Freight transported in ITU, e.g. ISO-containers and swap bodies, needs to be converted to the number of units. Table 7.9 shows typical values for containers in twenty-foot equivalent units (TEUs) (IVE et al., 2016). The ratios to convert TEU into the number of containers vary. Mertel et al. (2012) mentions an average conversion factor of 1.55 TEU/ITU for both continental and maritime transports. In Ickert et al. (2012) 1.2 TEU correspond to a swap body and 2 TEU to a semi-trailer; the average for all transports is 1.5 TEU/ITU. For Eurostat, containers with a length over 20 ft and under 40 ft correspond to 1.5 TEU, and over 40 ft to 2.25 TEU/ITU (UNECE, 2009).

Load factors and empty trip factors The load factor accounts for the fact that not every vehicle can be used to full capacity (by weight). For some goods, the maximum volume of the vehicle is reached before reaching the maximum weight. The load factor is the ratio of the usable capacity for a certain type of good to the maximum payload capacity of a vehicle (IVE et al., 2016). Exemplary load factors are presented in Table 7.10.

Table 7.8: Typical wagon length and specific capacity by train type (IVE et al., 2016; DB Cargo, 2017; SBB Cargo, 2017; Wascosa, 2017)

Train type	Wagon length m	Load capacity per unit length t/m
Standard wagons		
Bulk goods	16	3.8
Average goods	20	1.8
Volume goods	24	2.5
Dedicated wagons		
Car	27	0.8
Chemistry	17	3.2
Container	20	(0.13 TEU/m)
Coal and steel	16	4.1
Building materials	14	3.9
Manufactured products	21	2.6
Cereals	20	3.2

Table 7.9: Container loads by good type (IVE et al., 2016)

Good type	Container t/TEU	Net weight t/TEU	Total weight t/TEU
Bulk goods	2	14.5	16.5
Average goods	1.95	10	11.95
Volume goods	1.9	6	7.9

Since goods flows are not balanced, also empty trips are generated. Although logistics providers and hauliers try to minimize the number and length of empty trips, they cannot be avoided completely. The *empty trip factor (ETF))* is the ratio of the distance of empty trips to the distance of loaded trips (IVE et al., 2016). The ETF depends on the directionality of the good flow, the degree of integration or collaboration in the industry and the properties of the good (good type, cargo type) itself.

Most vehicles are limited to the transport of specific goods, though lorries tend to be more versatile than wagons, which shows in lower ETFs (Table 7.10). Containerized cargo is an exception. It requires only one type of lorry or wagon, regardless of the type of good inside the container. On the other hand, empty containers generate additional handling in freight terminals (see also Section 7.4).

The load factor and the empty trip factor can be combined to express the vehicle's average *capacity utilisation* (CU_{NC}):

$$CU_{\mathrm{NC}} = \frac{LF}{1 + ETF} \tag{7.10}$$

Table 7.10: Exemplary load factors, empty trip factors and capacity utilisation for general cargo in road and rail transport (IVE et al., 2016)

Good type	LF	ETF		CU_{NC}	CU_{NG}
		Road	Rail	Road	Rail
Bulk goods	100 %	60 %	80 %	0.63	0.60
Average goods	60 %	20 %	50 %	0.50	0.52
Volume goods	30 %	10 %	20 %	0.27	0.40

It expresses the ratio of the usable capacity for a certain type of good to the maximum payload capacity on all trips, empty and loaded (IVE et al., 2016).

In rail transport, the ratio of net performance (in net-tonne-kilometres) to gross performance (in gross-tonne-kilometres) is of interest (IVE et al., 2016). In rail freight, capacity utilisation (CU_{NG}) therefore is:

$$CU_{\mathrm{NG}} = \frac{C \cdot LF}{M_{\mathrm{empty}} \cdot (1 + ETF) + C \cdot LF} \tag{7.11}$$

where: CU_{NG} = the net/gross-ratio
M_{empty} = the mass of an empty wagon
C = the load capacity of the wagon
LF = the load factor
ETF = the empty trip factor

Swiss rail freight transport data shows an NG-ratio of approximately 0.45 (Appendix C, Fig. C.1), which indicates a high share of volume goods (Table 7.10).

Average total trips Using the load factor and empty trip factor, the number of lorry and train trips can be approximated. For each mode, the number of trips generated for commodity i is approximated by:

$$N = \sum_i \frac{M_i}{C_i} \cdot \frac{1 + ETF_i}{LF_i} \tag{7.12}$$

where: N = the number of vehicles
M = the amount of freight
C = the load capacity of the vehicle
LF = the load factor
ETF = the empty trip factor

The factors mentioned in Table 7.10 refer to very general average values from transport statistics. For specific terminals, commodities and transport chains, load factors and empty trip factors vary significantly. For each terminal the number of vehicles to and from the terminal needs to be balanced.

7.8 Conclusion

The approach presented shows that a multimodal freight system can be dimensioned reasonably. With a few basic parameters it is possible to calculate the key figures for land use and performance of freight terminals. The calculation requires estimations of the quantity and the type of goods. This also determines which transhipment devices should be considered. In terms of railway operations, rolling stock and train length should be specified. Road transport parameters cover vehicle type and size. All in all, the generic approach provides sufficient data to conduct preliminary estimations.

The exemplary calculations of the land use efficiency and performance of freight terminals suggest that even small facilities can process considerable quantities. Urban areas generate approximately 30 t/a of freight per inhabitant (Dablanc and Rakotonarivo, 2009). Considering the limited potential (compare Section 2.3.7), shifting freight from road to rail is only partially possible. A shift of 5 % would thus need approximately 0.05 to 0.90 m^2 of terminal area per inhabitant, depending on commodity and terminal type.

Some of the underlying assumptions however need to be scrutinized. The calculated handling rates of the transhipment devices should be verified. This would however require extensive surveys of transhipment operations under standardised conditions. Also data on the (net) weight of load units (other than containers) needs collecting.

The handling devices' operating length, i.e. the number of devices over the full train length, has significant influence on both freight handling and terminal area. In the module approach, the *module length* is a fixed value. In practice, the specific number of handling devices varies strongly and dynamically. Depending on freight traffic volume, or in case of failures, some handling devices are out of service. The module length might thus vary over the course of the transhipment process.

In terms of terminal area, the need for storage and additional facilities needs to be clarified case by case. The estimation of freight storage capacity requires knowledge of the underlying logistics system, which might not be available in an early planning stage. It must be noted though that, due to restricted land availability, minimal storage should be the target for urban freight terminals. The extent of auxiliary facilities depends on the operator model. Open access terminals tend to require more facilities for checking vehicles and documents. Single-user terminals, on the other hand, can have lean infrastructure. It also needs to be clarified to what extent transport access facilities need to be accommodated within the terminal.

The operating time of a terminal (in full load hours per working day) directly influences its performance and can potentially take any (plausible) value. In urban freight transport – in contrast to container ports – transhipment often is only the by-product of other logistics processes (e.g. storing, commissioning, distribution, etc.). Operating times in urban freight terminals might thus be rather low.

Train operations within the terminal and to and from the entry/exit sidings should be closer investigated. The use of a fixed value for the shunting times might not necessarily be representative. Here too, local circumstances play a vital role. Also, efforts made to improve shunting operations need to show in the performance figures.

Beyond terminal and transport operations, some factors have been left unconsidered. Operating hours might be limited by regulatory, rather than operational constraints. In an urban environment, restrictions might result from noise regulation and night drive bans for lorries. Furthermore, transport and industry policies might play a role.

Chapter 8

Framework requirements of rail freight in urban areas

8.1 Introduction

Urban rail freight is not only a question of railway capacity and planning and operating freight terminals. A range of framework requirements shape the rail freight system. Firstly, the market environment of freight transport displays strong competition between road hauliers and rail freight companies. Secondly, the state intervenes in this transport market, mainly on grounds of environmental policy. Thirdly, planning policies are based upon environmental goals, amongst others.

This chapter explores some of the external drivers for rail freight in urban areas, in particular, the economic, ecological and planning environments.

Section 8.2 provides the quantitative framework for performance, cost and emission calculations. A set of scenarios is created which is used for the subsequent appraisals.

Section 8.3 deals with the question of the economic viability. Assuming that competitive pricing is the biggest driver for the integration of rail freight into logistics systems, a closer look is taken at the costs of rail freight transport in urban areas.

In Section 8.4, the environmental impact of rail freight transport in urban areas is discussed. Carbon emissions and energy efficiency are used as environmental indicators.

Section 8.5 discusses how rail freight in urban areas is influenced by local and regional planning policies.

8.2 Freight transport scenarios

Transport scenarios are used to appraise the impact of rail-based transports in urban areas. The transport scenarios are the basis for the cost comparisons and environmental impacts in the subsequent sections of this chapter. In each scenario, rail-based urban freight transport is compared to other transport systems. Conventional intermodal transport will not be covered in detail. The scenarios, based on the urban commodity groups (Section 2.3.3), are food/near-food, excavation/construction and waste/recycling (Table 8.2).

Transport systems The following basic transport systems are defined to quantify the output of each scenario (Fig. 8.1):

- Urban multimodal transport (road–rail)
- Road haulage:
  - direct road transport
  - multi-leg road transport via an UCC

The transport distance, transport time, fuel and energy consumption, transhipment time and transport performance is quantified for each mode in each transport system. Only the transport systems applicable to a scenario are quantified, for instance an urban consolidation centre (UCC) makes sense in the food/retail scenario, but not for bulk transports in the construction and waste/recycling scenarios.

Direct road transport is used as reference. The main haul vehicle covers the full transport distance including the last mile to the freight destinations. The distance is split into an urban and a non-urban part, in order to distinguish speed and travel time. The distance covered by direct road transport also represents the *nominal transport distance* (d_{nom}) used as reference.

$$d_{\text{total, direct}} = d_{\text{nom}} = d_{\text{non-urban}} + d_{\text{urban}} \tag{8.1}$$

In the *urban rail* scenario the main haul is by train. Goods are transhipped in an urban rail terminal, from where they are distributed to their destinations. Rail freight does not necessarily take the shortest path, but might be operated in a hub-and-spoke system, resulting in longer distances than by road. For the quantification, the rail transport distance is based on the nominal distance, applying a factor (f_{rail}). Distance is added for last mile distribution by road (d_{distr}).

$$d_{\text{total, urbrail}} = d_{\text{nom}} \cdot f_{\text{rail}} + d_{\text{distr}} \tag{8.2}$$

In *multi-leg road transport* goods are transported via a UCC, regional platform or freight village, where they are transhipped from the main haul vehicle to a distribution vehicle. The main haul is split into an urban and a non-urban part. Dedicated vehicles, better adapted to urban areas, are used for last mile distribution. Usually smaller vehicles

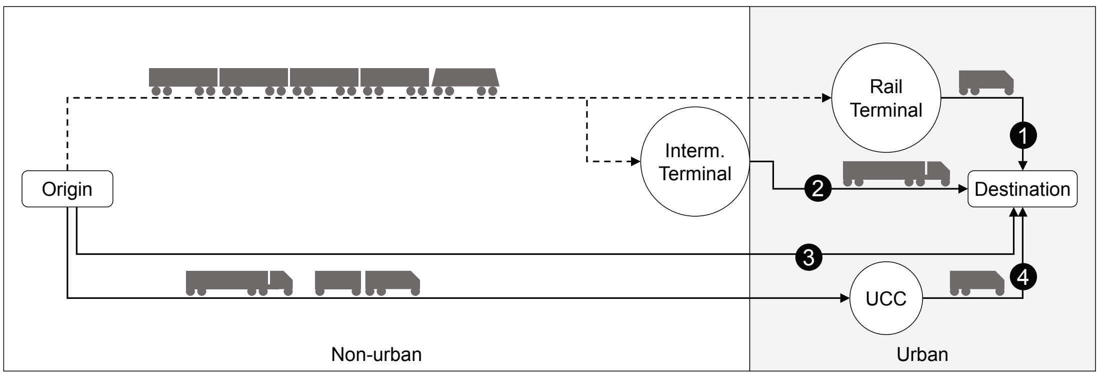


Figure 8.1: Basic urban transport systems: (1) urban rail, (2) conventional intermodal, (3) direct, (4) via UCC (source: own)

are used. The same total transport distance as direct road transport is assumed.

$$d_{\text{total, direct}} = d_{\text{nom}} = d_{\text{main, non-urban}} + d_{\text{main, urban}} + d_{\text{distr}} \tag{8.3}$$

The distances of last mile distribution (and collection) are derived from the urban share of direct transports. A terminal closer to the centre generally decreases road distances for distribution traffic. As shown in Appendix D.1, the freight terminal location has a significant influence on last mile distance. Based on these findings, last mile distances are assumed to be 40 to 60 % of the corresponding urban share of direct transports.

Scenario settings A set of generic transport scenarios is created to provide consistent performance figures. The input parameters are based on values from literature and assumptions. This includes vehicles used, transhipment processes and transport time and distance. The underlying assumptions on vehicle capacity and utilisation are based on IVE et al. (2016). Table 8.2 shows the basic parameters for the transport scenarios.

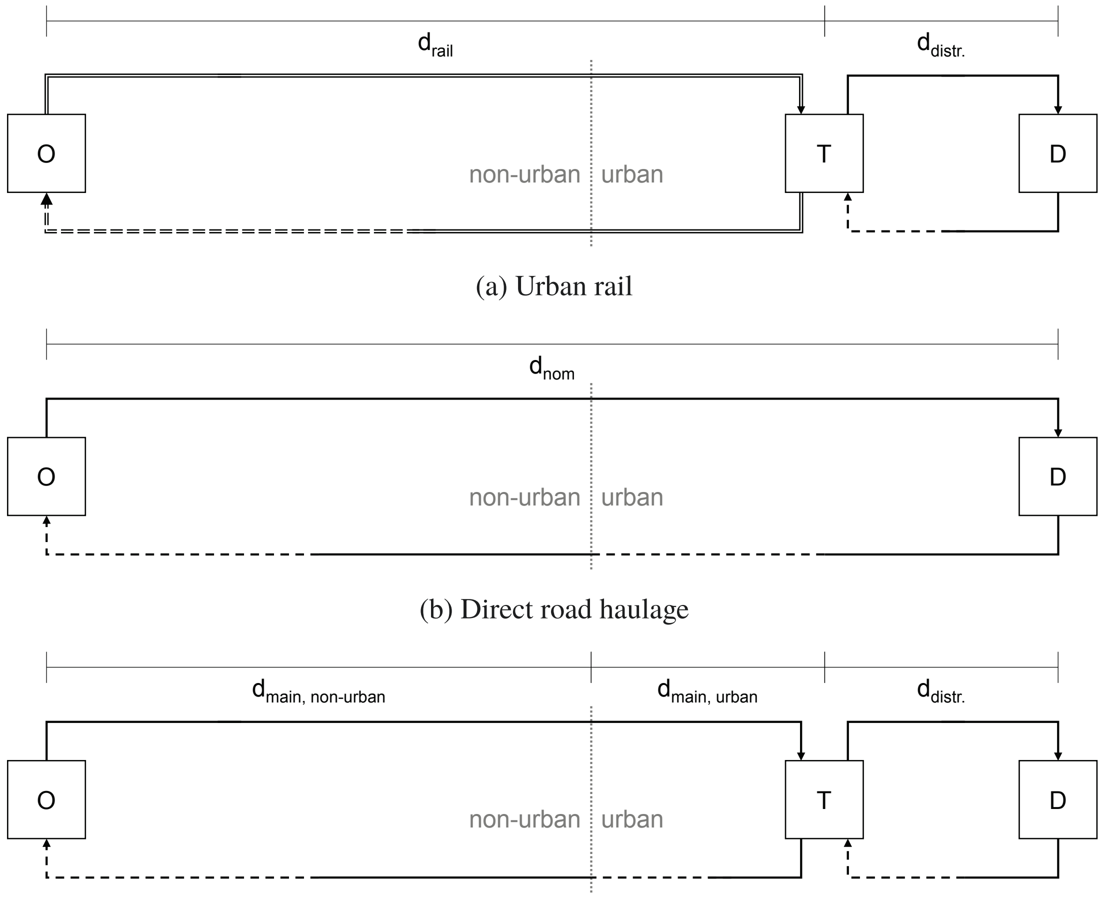
The relevant cargo types for the scenarios are dry bulk and pallets (and other cargo types). For conditions as found in Switzerland the last mile distance is assumed to be in the range of 20 to 60 km for direct transport. From urban terminals (rail or UCC) a range of 10 to 30 km is assumed.

Existing examples of multimodal transport in urban areas are mostly single-ended, i.e. they involve only one pre- or post-haul operation. Goods are transported from/to a larger facility with its own railway siding, such as a central warehouse, production facility or a landfill. Multimodal transports are thus assumed to generate one additional transhipment per freight trip.

The distance of rail transports is not always the shortest path available, especially when operating hub-and-spoke networks. Comparisons of rail and road transport between the same destinations in Switzerland show that typical rail distances are approximately 95 to 200 % of the corresponding road distance, under very unfavourable conditions even more (Appendix D.2, Table D.1). The generic approach of the scenario settings does not allow for detailed routing. It is assumed that urban rail largely does without routing over rail hubs. The transport distances for urban rail (excluding distribution) are fixed to 115 % of the nominal distance (the direct road distance).

Vehicle parameters Table 8.2 shows the vehicles chosen for each scenario and transport system. Vehicles for the main haul are usually heavy combinations (trailers or semi-trailers). For distribution, the vehicle is a single lorry (rigid) for pallets and a combination for bulk goods. The weight shown in Table 8.2 is the maximum permissible gross mass of the vehicles. Road and rail vehicle weight and load capacity are chosen from IVE et al. (2016).

Average HGV speeds are obtained from Keller et al. (2004). For the non-urban leg an average speed of 73 km/h is assumed. The average speed in urban areas is 26 km/h. Speed variations in urban areas are also considered. Lower speed (11 km/h) is assumed for congested conditions. Ideal conditions, i.e. routes mainly via urban main arterials, lead to higher speed (47 km/h). Average train speed for full trains is 56 km/h (Frank, 2013).



(a) Urban rail

(b) Direct road haulage

(c) Multi-leg road (UCC)

Figure 8.2: The concept of the basic vehicle operation systems (VOS). Circulation of shipments between freight origin (O), transhipment (T) and destination (D) (source: own)

For each vehicle in the chain, a *vehicle operating system (VOS)* is defined (CEN, 2012) (Fig. 8.2). Average speed, the minimal turning time and the transhipment time of the vehicle define the minimal cycle time.

For railway, different cycles are assumed for locomotive and the wagons. The locomotive is decoupled from the wagons before transhipment and continues service with another set of wagons (see also Appendix D.3, Fig. D.3). For the wagon cycles, time for shunting and technical checks is added to the minimal turning time. Shunting time is set to 30 minutes each before and after transhipment (in total four times per cycle), and for technical checks 2 to 3 minutes per wagon is assumed.

Fuel consumption is needed for cost modelling as well as emission calculations. Fuel consumption of road vehicles for Switzerland is obtained from Infras (2010). Table 8.1 shows the values used for the fuel consumption of heavy goods vehicles (HGVs). For simplicity, only the values for main roads in built-up areas and motorways under free flow conditions are included. To adjust for different load factors, the fuel consumption is linearly interpolated as is suggested by IVE et al. (2016).

Table 8.1: HGV diesel consumption in Switzerland, free flow traffic, l/100 km (Infras, 2010)

	Main road in built-up areas (speed limit 50 km/h)			Motorway (speed limit 120 km/h)		
HGV type	LF 0 %	LF 50 %	LF 100 %	LF 0 %	LF 50 %	LF 100 %
Rigid						
20–26 t	21.67	27.15	32.74	21.23	23.64	26.04
26–28 t	23.93	29.74	35.67	22.30	25.07	27.75
28–32 t	27.50	34.74	42.17	26.40	30.02	33.31
32–40 t	24.77	33.36	41.98	23.73	27.51	31.30
Combination						
20–28 t	21.79	27.97	34.18	20.98	23.82	26.35
28–34 t	22.39	29.88	37.38	21.15	24.51	27.33
34–40 t	24.46	34.36	44.09	22.23	26.41	30.12

Energy consumption of freight trains is calculated in accordance with IVE et al. (2016):

$$e_{\text{spec}} = 1.2 \cdot m_{\text{gross}}^{-0.62} \tag{8.4}$$

where: e_{spec} = specific final energy consumption (kWh/tkm)
m_{gross} = the gross mass t)

The train gross mass includes the mass of a standard locomotive, which is assumed to be 84 t. Conforming to IVE et al. (2016), the same equation is used for diesel traction, applying an efficiency factor of 37 %.

Table 8.2: Transport scenarios and parameters (source: own)

Scenario	Cargo type	Last-mile distance	Road vehicle type main haul	Road vehicle type distribution	Wagon type
Food and other retail					
- urban rail	pallets and others	10–30 km	–	20–26 t rigid	standard
- direct	pallets and others	20–60 km	26–40 t combination	–	–
- ucc	pallets and others	10–30 km	26–40 t combination	20–26 t rigid	–
Excavation and construction					
- urban rail	dry bulk	10–30 km	–	26–40 t combination	standard
- direct	dry bulk	20–60 km	26–40 t combination	–	–
Waste and recycling					
- urban rail	dry bulk	10–30 km	–	26–40 t combination	standard
- direct	dry bulk	20–60 km	26–40 t combination	–	–

8.3 Economic sustainability

8.3.1 Introduction

The economic environment determines the viability of rail freight transport. Competition between operators – within and across modes – shape the way goods are transported.

Transport price is among the most important decision variables for mode choice, along with reliability (punctuality) and transport time (BVU et al., 2016; Moreni et al., 2008). Demand for rail freight services depends to a large extent on the price competitiveness of multimodal transport chains, compared to road-only transport. For instance, an analysis of prices in domestic transport in Switzerland showed that intermodal transport can partially compete from as little as 60 km and generally from 235 km (Stölzle et al., 2016). This is roughly in line with break-even estimates for Scotland, which were as low as 90 km for rail-only transport, 200 km with a road haul at one end only and 450 km if both a pre- and post-haul is needed (Monios, 2015). Unfortunately, studies using transport price are rare. For this reason, transport costs will be analysed instead.

Although often used interchangeably, transport price and cost need to be distinguished. The transport *price* is the amount actually paid for a transport service (also called *freight rate*). The price is shaped by competition and often distorted by subsidies or market failure. It does not necessarily represent the cost a logistics provider or a haulier bears. In many studies, the transport *cost* is used instead. It includes the cost for vehicles, fuel, labour, taxes etc. and allows to compare similar transport services.

The hypothesis for this section is: *The cost-effectiveness of rail-based urban transport chains is comparable to existing freight distribution systems.*

In this study, an attempt is made to determine transport costs for the scenarios as laid out in Section 8.1. Cost functions are applied to the scenarios.

Multimodal transport potentially faces higher transport costs compared to road-only transports. The combination of modes incurs transhipment costs at the interfaces and requires a higher degree of coordination. Fixed cost and – in Switzerland – labour cost tend to be higher in rail transport.

On the other hand, marginal costs are lower in rail freight transport. Additionally, road hauliers in urban areas face congestion and sometimes road pricing. Congestion increases transport time and therefore labour costs and other time-related costs.

Transport cost also needs to be distinguished from the (generalised) *logistics cost*, used in many freight models. Additional to transport cost (or price), logistics cost also include inventory cost (storage cost), capital cost of goods in transit (pipeline inventory) and order setup cost.

8.3.2 Cost structure of freight transport

Road and multimodal transport display very different cost structures. Compared to rail, road transport usually displays low fixed cost and high variable cost.

Fixed costs include the cost of the vehicle (owned or rented/leased) and the cost for administrative duties. Variable costs include labour, fuel/energy and other consumables, maintenance and repair, and access fees. Variable costs depend on operating times, transport distance, the amount transported or transport performance (i.e. *tonne-kilometres*).

Some sources list labour as fixed cost, referring to annual wages (BVU et al., 2016; Fries, 2009). Infrastructure cost is covered by both fixed costs (i.e. taxes) and variable costs (road tolls, parking fees, transhipment rate).

In summary operating costs usually consist of:

- Fixed cost
    - Vehicle cost
        - Depreciation
        - (Opportunity) cost of capital
        - Vehicle taxes and fees
        - Vehicle insurance
    - (Administrative) overhead
    - Vehicle lease/rent
- Variable cost
    - Labour (wages)
    - Fuel/energy
    - Consumables (lubricant, tyres etc.)
    - Maintenance and repairs
    - Access fees (road tolls, parking fees, track charges . . .)
    - Shunting and train formation
    - Transhipment cost

In freight transport, many services are subcontracted and shippers often face make-or-buy decisions. Depending on the degree of vertical integration, the transport operator does not have all means of production (i.e. vehicles, personnel etc.) at his own disposal. For instance, road hauliers haul semi-trailers of other companies; only large incumbent rail operators can afford to have full coverage with shunting teams; and most intermodal terminals are owned and operated by independent terminal operators.

Therefore, the following assumptions are made for this cost analysis. Fixed rates are applied to transhipment services. Rail operators have their own locomotives and personnel, but buy shunting services and use leased wagons. In road transport, full ownership of the lorry (including trailers) is assumed.

For cost calculations, only additional transhipment processes in multi-section transport chains are included. Loading and unloading at the respective endpoints of the transport chain is omitted in the cost calculation.

Cost data sources Mostly, hauliers and logistics providers do not disclose incurred costs nor the prices charged for transport services. However, cost data can be collected from a range of studies and other publicly available sources. Sources for cost calculations (under Swiss conditions) are:

- research reports:
    - Fries (2009)
    - BVU et al. (2016)
    - Stölzle et al. (2016)
- technical reports and standards:
    - NIBA cost rates (BAV, 2012)
    - VSS (2012)
- tariffs:
    - SBB service catalogue (SBB, 2016)

Table 8.3: Commercial vehicles basic operating cost rates for the appraisal of road measures in Switzerland (commercial vehicles) (VSS, 2012)

	wage-unrelated rates CHF/100 km		wage-unrelated rates CHF/h		wage-related rates CHF/h	
	2005	2015(1)	2005	2015(1)	2005	2015(2)
LCV	31.72	32.55	1.33	1.36	33.66	37.72
HGV rigid	37.92	38.91	4.51	4.63	42.1	47.18
HGV combination	45.48	46.67	4.92	5.05	40.89	45.82
Weighted average: HGV	41.70	42.79	4.71	4.83	41.5	46.50
Weighted average: all	35.01	35.93	2.45	2.51	36.24	40.61

(1) adjusted by the consumer price index (CPI). CPI 102.6 (base 2005 = 100)
(2) adjusted by the Swiss wage index (SWI). Nominal SWI 112.1 (base 2005 = 100)

8.3.3 Cost calculation

8.3.3.1 Road transport costs

VSS (2012) is the main source for the calculation of operational cost for road. This Swiss standard contains basic operating cost rates for road vehicles for the appraisal of road measures in Switzerland (Table 8.3). The figures are intended for use within the Swiss road infrastructure appraisal method (NISTRA).

The cost factors are divided into wage-unrelated (distance costs c_{distance} and time costs c_{time}) and wage-related components (c_{wage}). The transport cost for road is obtained by multiplying the factors with the respective quantities:

$$C_{\text{road}} = d \cdot c_{\text{distance}} + t_{\text{total}} \cdot (c_{\text{time}} + c_{\text{wage}}) \tag{8.5}$$

Some cost elements need to be adjusted to the year 2015 using the Swiss consumer price index and wage index. Further costs for road transport are fuel costs and the Swiss heavy vehicle charge (LSVA). Fuel (i.e. diesel) costs are also obtained from VSS (2012) and adjusted with the purchasing power index for petrol products. For the heavy vehicle charge, a performance-weighted average of current values is used.

8.3.3.2 Rail transport costs

Rail operations costs are obtained from the NIBA-documentation (BAV, 2012). NIBA is the appraisal method for rail infrastructure projects. However, the cost figures have not been updated and also need to adjusting, labour cost with the Swiss wage index, other elements with the producer price index (Table 8.4).

Track charges are obtained from SBB (2016) (Table 8.5). For the basic price by weight the flat rate is used instead of the price by wear (which would require detailed knowledge of the rolling stock used).

To account for the high quality of train paths required for reliable operations in urban networks, factors are applied accordingly. Energy price contains a network load factor for running trains during peak hours. The train path price contains factors for peak hour

Table 8.4: Railway operating cost rates for the appraisal of rail measures in Switzerland (freight trains) (BAV, 2012)

Cost item	Unit	2010	2015	
Time-dependent locomotive	CHF/h	60	64.7	(1)
Distance-dependent locomotive	CHF/km	1.30	1.40	(1)
Time-dependent wagon	$\text{CHF/h}_{\text{wagon}}$	0.70	0.75	(1)
Labour costs (loco driver)	CHF/h	100	103.7	(2)
Distance-dependent wagon	$\text{CHF/km}_{\text{wagon}}$	0.10	0.11	(1)
Wagon lease	CHF/wagon	40	40	

(1) adjusted by the producer price index (PPI) for rail freight services. PPI 107.8 (base 2010 = 100)
(2) adjusted by the Swiss wage index (SWI). Nominal SWI 103.7 (base 2010 = 100)

demand and for the train path quality.

The railway transport costs are obtained by multiplying the cost factors with respective quantities. For each full cycle, two stops and six shunting operations are assumed. Train handling (shunting and technical checks) requires additional personnel, which is set to two persons.

$$\begin{aligned} C_{\text{rail, ops}} = {} & t_{\text{loco}} \cdot c_{\text{labour}} + t_{\text{handling}} \cdot c_{\text{labour}} \cdot N_{\text{pers}} + c_{\text{lease}} \cdot N_{\text{wagon}} + t_{\text{loco}} \cdot c_{\text{time, loco}} \\ & + d_{\text{loco}} \cdot c_{\text{dist, loco}} + t_{\text{wagon}} \cdot c_{\text{time, wagon}} \cdot N_{\text{wagon}} + d_{\text{wagon}} \cdot c_{\text{dist, wagon}} \cdot N_{\text{wagon}} \end{aligned} \tag{8.6}$$

$$\begin{aligned} C_{\text{rail, infra}} = {} & d_{\text{total}} \cdot c_{\text{path}} \cdot f_{\text{peak}} \cdot f_{\text{quality}} + (d_{\text{loaded}} \cdot m_{\text{gross, loaded}} + d_{\text{empty}} \cdot m_{\text{gross, empty}}) \cdot c_{\text{weight}} \\ & + e_{\text{spec}} \cdot c_{\text{electricity}} \cdot f_{\text{load}} + N_{\text{stop}} \cdot c_{\text{stop}} + N_{\text{shunt}} \cdot c_{\text{shunt}} \end{aligned} \tag{8.7}$$

$$C_{\text{rail, total}} = C_{\text{rail, infra}} + C_{\text{rail, ops}} \tag{8.8}$$

8.3.3.3 Transhipment costs

Transhipment cost are obtained from BVU et al. (2016). The values mentioned are valid for Germany, for which reason they are converted to Swiss Francs and adjusted by purchasing power (Table 8.6).

8.3.3.4 Total costs

Total cost is obtained by adding up the partial costs of the full transport chain for each transport system (Section 8.2). For direct road transport and multi-leg transport via UCC, the main vehicle's path needs to be split into a non-urban and urban part to account for

Table 8.5: Railway infrastructure charges in Switzerland (SBB, 2016)

Cost item	Unit	Value
Minimum train-path price	CHF/km_{train}	1.50
Peak-hour demand coefficient	–	2
Train-path quality (category B)	–	1
Basic price by weight	CHF/tkm_{gross}	0.0033
Electricity price	CHF/kWh	0.12
Network load factor (energy)	–	1.2
Stop surcharge	CHF/stop	2
Shunting	CHF/movement	6.96

Table 8.6: Road–rail transhipment costs by cargo (BVU et al., 2016)

Cargo type	EUR/t	EUR/ILU	CHF/t(1,2)	CHF/ILU(1,2)
Dry bulk	2.50	–	2.97	–
Pneumatic conveying	2.50	–	2.97	–
Liquid bulk	2.80	–	3.33	–
Pallets	7.50	–	8.91	–
General cargo	14.00	–	16.64	–
ILU	–	20.00	–	23.77

(1) mean annual exchange rate 2015, 1.07 (CHF/EUR) (source: SNB)
(2) adjusted by purchasing power (transport services), ratio 1.11 (source: BFS)

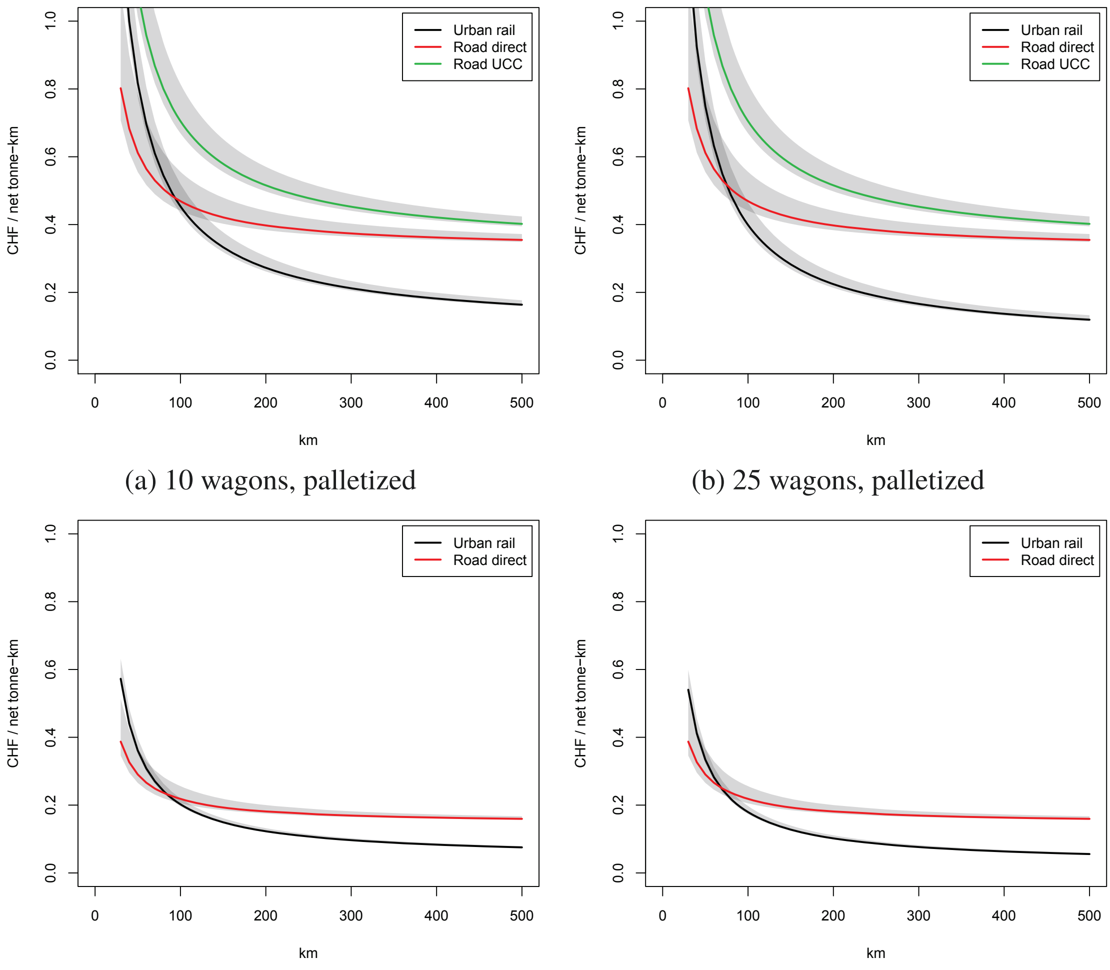
different speed and fuel consumption values.

$$C_{\text{direct}} = C_{\text{road, direct}} \tag{8.9}$$

$$C_{\text{urban rail}} = C_{\text{rail}} + C_{\text{road, distr.}} + C_{\text{transhipment}} \tag{8.10}$$

$$C_{\text{multi-leg}} = C_{\text{road, main}} + C_{\text{road, distr.}} + C_{\text{transhipment}} \tag{8.11}$$

To compare values between the scenarios, relative costs are obtained by dividing total costs by tonne-kilometres. In order to compare the same transport service, the tonne-kilometres used for this calculation refer to the nominal distance, not the distance actually covered.



(a) 10 wagons, palletized

(b) 25 wagons, palletized

(c) 10 wagons, bulk

(d) 25 wagons, bulk

Figure 8.3: Exemplary transport cost functions for the transport of palletized and bulk goods (source: own)

8.3.4 Results

Total transport costs are calculated over a distance range of 50 to 500 km (Fig. 8.3). The transport cost functions for palletized goods (food/retail) show that urban rail transport can compete with direct road transport from a distance of approximately 100 km. Urban rail transport of bulk goods (construction and waste/recycling) can compete with direct road transport from a distance of approximately 70 to 85 km.

Rail transport costs depend on the train size. Pictured are train sizes of 10 and 25 wagons, which corresponds to train lengths of approximately 180 to 420 m for (heavy) bulk and 260 to 620 m for volume goods.

In case of road network congestion, shown in Fig. 8.3 with shaded areas, transport costs increase.

8.3.5 Discussion

The calculated cost functions show that multimodal transport can offer cost-competitive transport services. The numbers also conform to observations from particular cases in Switzerland. Due to heavy congestion in the Geneva region, Swiss retailer *Coop* largely serves its Geneva branches via rail. Coop's own rail transport subsidiary operates trains over a 70 km distance and distributes the goods. In Zurich, a large earth-moving company owns a fleet of hopper wagons and operates its own shunting locomotives to transport excavated material from down-town construction sites to landfills roughly 30 to 50 km outside. However, these cases are rather unique and comparisons with more common cases and Stölzle et al. (2016) suggest that the critical distance of multimodal transport in Switzerland is usually longer.

It must be noted that the calculations do not consider some important factors. Firstly, the calculations assume trains for single origin-destination pairs. On one hand, this means that the ability to bundle enough freight is required. Only few, large shippers actually have the required freight volumes to fill a full "company train". On the other hand, in a hub-and-spoke network larger trains can be operated, which decreases costs per tonne transported, but is less attractive due to longer transport times.

Secondly, logistics cost are not represented. Increased transport time and the bundling of loads incur costs for increased inventory and the inconvenience of receiving goods later or having to prepare outgoing shipments earlier. It must be assumed that these costs add disproportionately to urban rail freight.

Meaningful cost values affecting modal choice can thus not be provided, although the cost functions return plausible transport costs.

8.4 Environmental sustainability

8.4.1 Introduction

In the current debate on environmental sustainability of transportation, freight transport is getting more attention. It should therefore be analysed what railways can contribute to low-emission freight transport in the urban context. This is in line with political consensus to reduce carbon and greenhouse gas emissions, and to shift freight to rail in order to reduce congestion.

Hypothesis: *Rail-based urban transport chains are environmentally better performing than conventional freight distribution systems.*

The whole transport chain needs to be regarded to analyse the environmental sustainability of urban transport. Both energy consumption and carbon emissions (per net tonne-kilometre) of electric freight trains are lower than of HGV. Generic figures based on IVE et al. (2016) for average conditions in Switzerland, shown in Fig. 8.4, suggest that only shunting operations with diesel locomotives perform worse than HGV.

However, urban rail freight is a question of combined transport. Hence, the total energy consumption and carbon emissions of the combination of different modes is crucial. Additionally, freight transhipment needs to be considered.

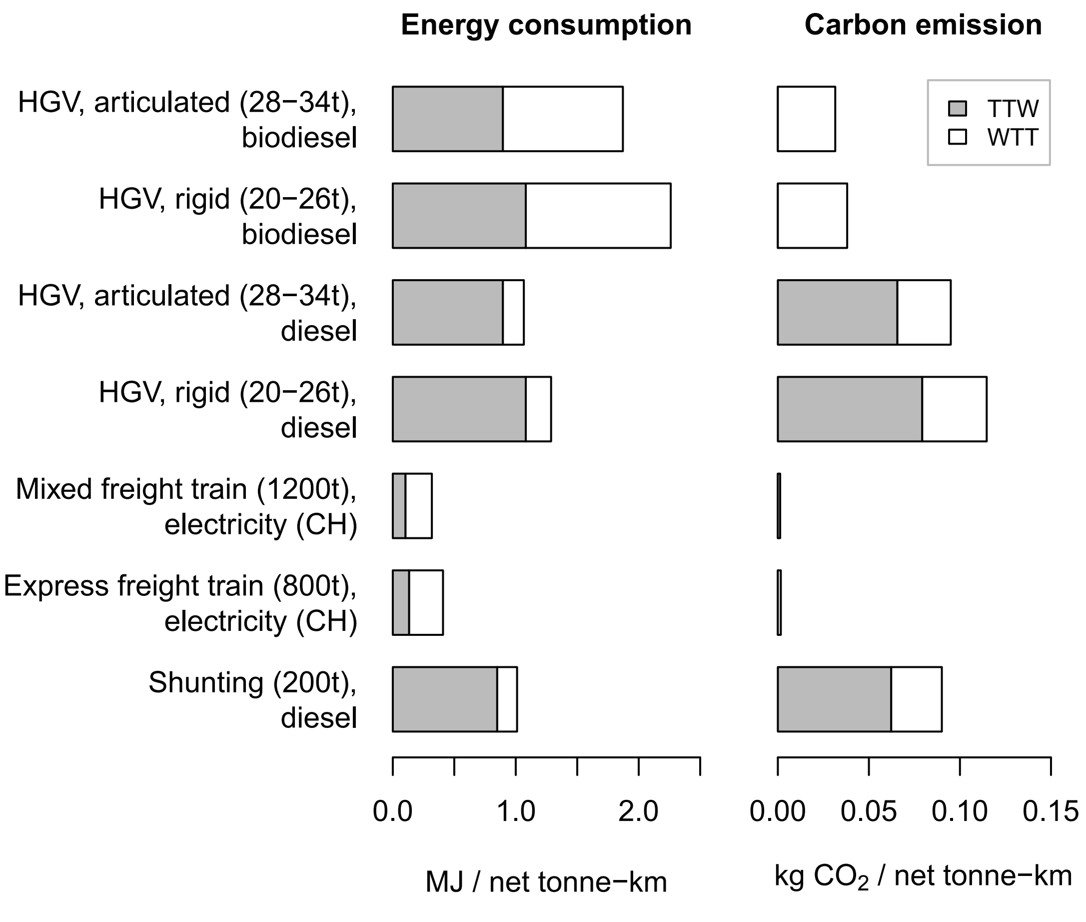


Figure 8.4: Generic energy consumption and carbon emissions in different modes (adapted from Fumasoli (2016b))

Table 8.7: Energy and emission factors based on CEN (2012); IVE et al. (2016)

Type		Energy factor	CO_2-factor	
			TTW	WTW
		MJ/MJ_{TTW}	kg_{CO_2}/MJ	kg_{CO_2}/MJ
Fuels:				
	Gasoline	1.17	0.073	0.088
	Diesel	1.19	0.073	0.089
	Bio-diesel	2.09	0.000	0.017
Electricity:				
	Switzerland	3.07	0.000	0.004
	EU28	3.62	0.000	0.130

8.4.2 Energy consumption and emission calculation

Based on the predefined scenarios (Section 8.2) the energy consumption and greenhouse gas emissions are calculated in accordance with CEN (2012). This European Standard defines the relevant factors and methods for both tank-to-wheel (TTW) and well-to-wheel (WTW) evaluations for transport services. The calculation of the relevant electrical energy and fuel consumption values are described in Section 8.2.

TTW evaluates energy consumption during vehicle operation for a given transport service. For road transport this is the actual amount of fuel consumed, e.g. litres of diesel (converted to MJ). For electric trains it is the consumption of electric energy at pantograph. It is also referred to as *final energy* demand.

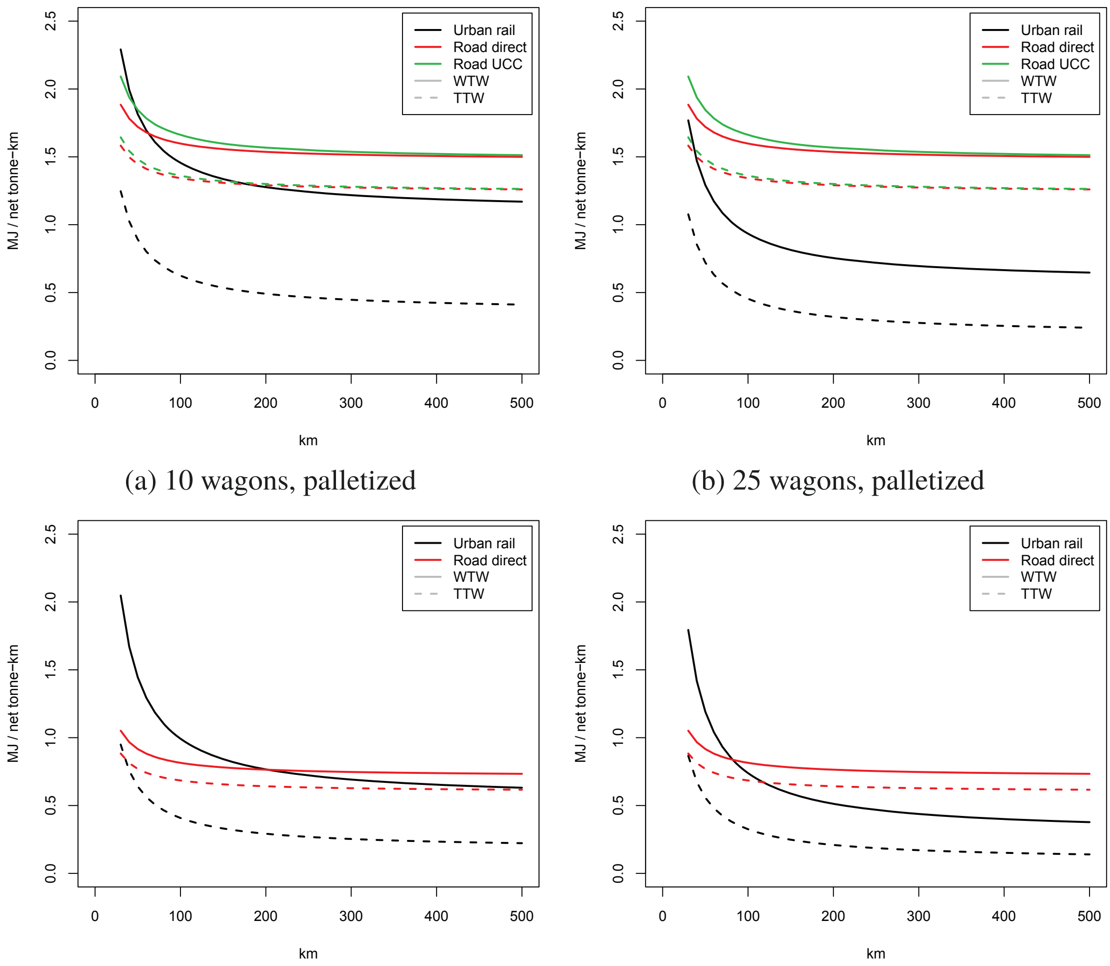
To obtain *WTW* values, the energy consumption of upstream processes needs to be added to TTW. These *well-to-tank (WTT)* values include extraction, processing and the transport of the fuel. Correspondingly, generation and transmission losses are included for electricity. It is also referred to as the consumption of *primary energy*.

From the energy consumption the respective carbon and greenhouse gas (GHG) emissions are calculated. Carbon emissions vary with the fuel and electricity mix chosen.

Energy factors for electricity (for railway transport) are larger than for fuels (Table 8.7). However, the actual energy consumption varies significantly, due to the different motor efficiency, rolling resistance and net-tonne/gross-tonne ratio of the vehicles. Despite the large energy factor, electric traction profits from the high efficiency of electric motors (approximately 90 %, including converter). Electricity also offers the possibility of regenerative braking. Internal combustion engines, in contrast, have an efficiency of approximately 35 %).

Although not part of the standard, the transhipment process is also included in the calculations. IVE et al. (2016) contains the final energy consumption for transhipment, albeit pointing out large uncertainties. A factor of 15.84 MJ/TEU is used for container transhipment, 4.68 MJ/t for dry bulk and 2.16 MJ/t for other cargo. Electricity powered transhipment is assumed for all processes. Energy consumption and emissions are calculated only for *additional* transhipments. Loading and unloading at the origin and destination are not considered.

Diesel traction is used for shunting operations at each end of the rail transports. For



(a) 10 wagons, palletized (b) 25 wagons, palletized

(c) 10 wagons, bulk (d) 25 wagons, bulk

Figure 8.5: Specific energy consumption for the transport of palletized and bulk goods (source: own)

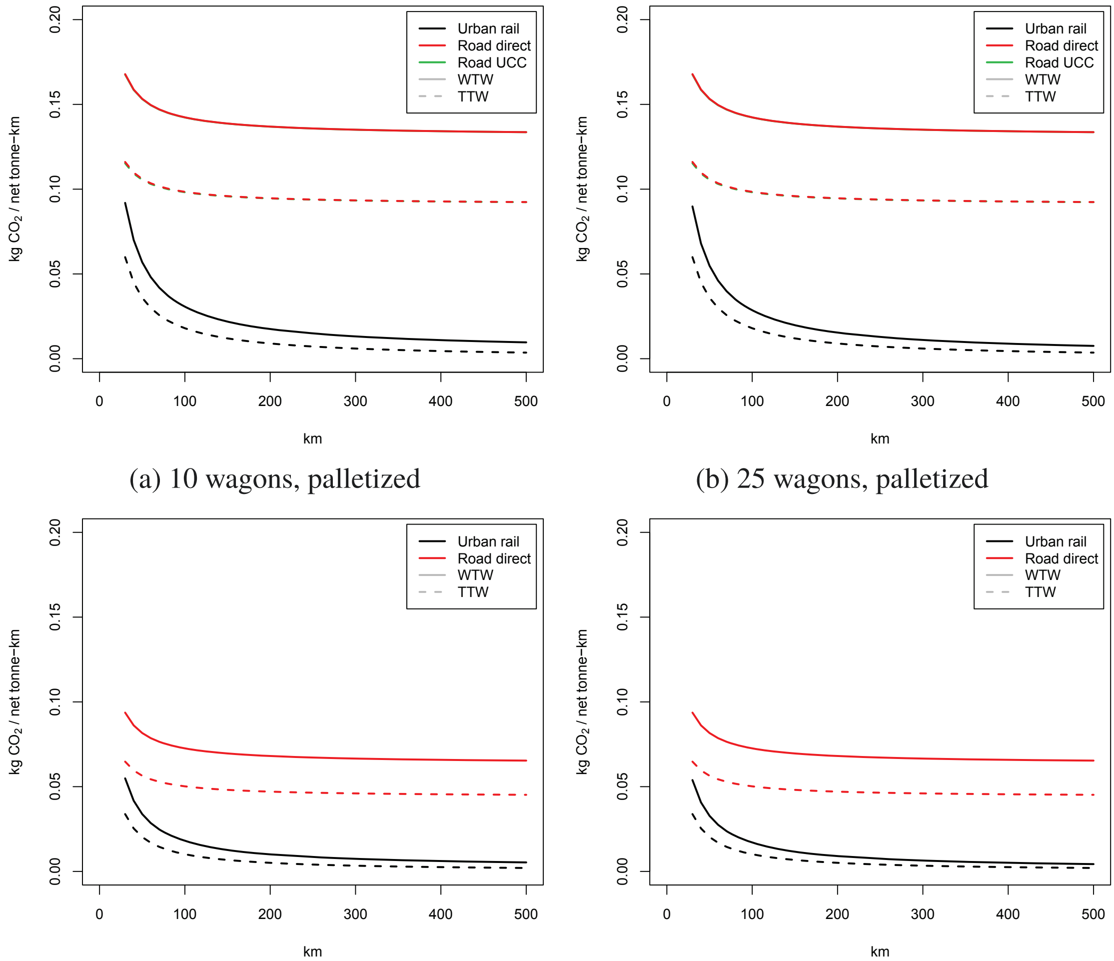
simplicity, shunting movements of 200 t-units over 5 km are assumed for each shipment.

Total energy consumption and GHG emissions are obtained by adding up the partial consumptions and emissions of the full transport chain. To compare values between the scenarios, relative consumption and emissions are obtained by dividing the totals by tonne-kilometres. In order to compare the same transport service, the tonne-kilometres used for this calculation refer to the nominal distance, not the distance actually covered.

8.4.3 Results

8.4.3.1 Energy consumption

The energy consumption of urban freight clearly shows that in some cases road transport is more energy efficient than multimodal transport (Fig. 8.5). For palletized goods, multimodal transport is mostly more energy efficient. For bulk goods, depending on train size, road transport is more efficient below 100 to 200 km. Despite the higher energy demand for the transhipment, the transport of bulk is generally more energy efficient than volume goods (per net-tonne).



(a) 10 wagons, palletized
(b) 25 wagons, palletized
(c) 10 wagons, bulk
(d) 25 wagons, bulk

Figure 8.6: Specific carbon emissions for the transport of palletized and bulk goods (source: own)

8.4.3.2 Carbon and GHG emissions

Total carbon emissions from multimodal transport of palletized and bulk goods (including road distribution) are much lower than from road transports across all distances (Fig. 8.6). Train size is of minor importance to carbon emissions of urban rail; differences are hardly observable. Since the use of (largely carbon-free) electricity is assumed for transhipment, it does not affect carbon emissions of multimodal transport.

GHG emissions (in CO_2-equivalents) differ only slightly from carbon emissions. The results for palletized and bulk goods are shown in Appendix D.5, Fig. D.4.

8.4.4 Discussion

The results of the calculations show that, in terms of carbon and GHG emissions, multimodal transport is highly favourable. Multimodal transport emits around 10 to 50 % of the WTW carbon emissions of road transport. Owing to largely carbon free electricity generation in Switzerland, the only carbon source in multimodal transport is the distribution by road. In terms of energy efficiency, the advantages of multimodal transport are less clear. Due to the unfavourable energy factors of electricity, the well-to-wheel energy consumption is partially worse than of road transports.

In order to get clearer ideas of the total energy demand of multimodal transport, transhipment processes need to be further analysed. As pointed out in IVE et al. (2016), there are large uncertainties in the energy consumption of transhipment.

Some potential for improved energy efficiency and emissions lie in improving railway rolling stock. Lightweight construction of freight wagons is yet uncommon. The reduction of the wagon's empty weight, respectively the increase of the payload, should improve efficiency significantly (Fumasoli, 2016a).

The shift to electric powered road transport – already at hand in passenger transport – is expected to spread to freight transport. Freight terminals in proximity of the urban core could stimulate the use of electric vehicles in last-mile distribution. "In cities, switching to cleaner transport is facilitated by the lower requirements for vehicle range (. . .)" (EC, 2011).

Electric lorries have not been considered in the analysis, but certain aspects can be anticipated. Assuming largely carbon free sources for electricity, carbon and GHG emissions of road transport are significantly reduced. Energy efficiency however remains more or less constant. While combustion engines have a low efficiency but use an energy efficient fuel, electric motors are highly efficient but electricity itself is not.

An additional effect is the loss of load capacity due to the weight of the batteries, especially if long haul transport is to be electrified. Prototypes of electric lorries show that the batteries outweigh the reduced drive train and the absence of a fuel tank (e-Force, 2015; IVECO, 2017). This mainly has an effect on weight-limited transports, especially liquid and dry bulk goods.

8.5 Land use policy

8.5.1 Introduction

Local planning policies play a vital role for freight transport. The safeguarding of areas for freight transport (already discussed in Chapter 6) also needs to evaluate alternative uses for the areas considered. Areas generally well suited for rail uses might be considered for other uses by local governments and the railway infrastructure manager. However, an ill-considered conversion of rail areas should be prevented.

Against the background of a variety of needs and desirabilities for (urban) space, potential freight uses need to be carefully checked against alternatives. The case for safeguarding and using areas for freight transport must therefore be proven for each location. This requires careful appraisal of all impacts and weighing local and common (i.e. regional, national, international, etc.) interests.

The hypothesis for this section is: *Rail-based urban transport chains give appropriate answers to current and emerging urban challenges.*

As shown in Section 8.4, multimodal freight transport contributes to overarching goals, such as the reduction of GHG emissions. On the local level however, different priorities prevail. Of major importance are the mitigation of congestion, air pollution and noise, but also shortages of land (for residential, business or public uses). The process of allocating land for specific uses is mainly political.

Literature research is used to evaluate the planning priorities for large areas in cities. Planning guidelines are searched for statements concerning freight uses.

Data from a survey on unused areas (Hofer et al., 2008) – former industrial estates, railway facilities, military areas and airports – is analysed. The corresponding reports reveal the approaches to land use priorities by planners dealing with unused areas.

8.5.2 Freight in land use planning

The status of freight transport in planning is often unclear. The purpose of land use planning is to allocate space for (Gilgen, 2012):

- free space
- settlements
  - residential areas
  - commercial areas
  - industrial areas
- transport infrastructure
- public facilities
- utilities

Transport infrastructure only applies to road and rail infrastructure but not transhipment facilities. Freight terminals are usually assigned to industrial areas. This corresponds to the widely spread view that freight transport, in contrast to passenger transport, is a purely private commercial matter.

Freight facilities are controversial. Although necessary for the supply of goods, the perception of negative features of freight transport prevails. Freight facilities are known to require rather large areas, generate traffic and emit noise.

In a survey among 20 public sector representatives in Ruesch et al. (2013), the following conflicts in terminal location planning were identified:

Table 8.8: Employment density in facilities of the transport, manufacturing and service sectors, FTE/ha (FGSV, 2006)

Type	Employment density
Transport sector	–
- Transhipment facilities (e.g. road–rail)	1–8
- Forwarding hub	25–80
- Distribution centre	15–100
- Freight village	20–40
Trade/Warehousing/Sales	10–50
Recycling facilities (medium to large)	<10–70
Manufacturing	
- Small scale production (high-tech, laboratories, . . .)	50–150
- Industrial production	50–100
Service sector	
- Office blocks (e.g. financial services)	200–1800
- Other services and commerce	100–600

- Traffic volume
- Noise
- Lorries parking in the neighbourhood
- Ecological conflicts
- Disagreement on planning requirements
- Disagreement on planning processes
- Requests for infrastructure improvements
- Impaired townscapes
- Public utilities

Furthermore, freight facilities create only moderate added value, since employment density is very low (Table 8.8). It ranges between 1 and 8 full time equivalents per net hectare of building area (FGSV, 2006), and only low skilled labour is required. Since the prospect of generating tax revenue is low, communities have little incentive to support the locating freight terminals.

8.5.3 Planning priorities in Switzerland

The database of a survey on unused areas (Hofer et al., 2008) contains former industrial estates, railway facilities, military areas and airports. By definition, the database contains only sites with areas above 10 000 m^2. The sites are less than 50 % occupied by its original use or completely unused. The database has not been updated since 2009 and the actual status of the sites is not known. The database is linked to spatial data and evaluated for railway areas.

According to the survey there were 24 abandoned or underused railway areas close to urban centres with a total area of 133 ha. The areas of the sites range from 10 000 to 280 000 m^2. It must therefore be assumed that these sites are generally suitable for further railway uses, including rail freight.

Of the sites with known development plans, most were designated for conversion to residential and commercial uses (office and retail space). Additional uses include schools, cultural facilities, public administration and an exhibition centre. Literature on rededicating areas likewise suggests a focus on housing and office spaces (BAFU, 2009; Scherrer and Tobler, 2009; Jaccaud et al., 2013).

Putting emphasis on housing and office spaces in the development of large unused sites is however questionable. Studies suggest that the demand for housing and office space in Switzerland can largely be covered by internal reserves.

Nebel et al. (2012) calculated reserves in zoned areas of 6700 to 22 500 ha, of which only 700 to 5500 ha refer to the rededication of unused sites. Adding the floor space reserves in built up areas, there is enough space for a population increase in Switzerland of approximately 600 000 to 1 700 000 (without reserves from unused sites). A similar conclusion was drawn by Fahrländer et al. (2008).

8.5.4 Land use allocation process

In Switzerland land use allocation is as much a planning task as a political process. It is therefore crucial that – especially complex and rather unpopular – planning concerns enjoy strong advocacy. Advocacy can be provided by one or several protagonists in the matter affected, or in the words of Stead and Cotella (2011), by an "advocacy coalition".

It is however not always clear who should take the leading role. In an example for passenger transport, Scholl et al. (2016) suggest that the Swiss Federal Railways (SBB) should take the lead by providing a "permanent point of contact".

In freight transport, by contrast, a coordinating role of SBB is not accepted by many stakeholders. This can mainly be attributed to the competitive situation between SBB as a rail freight operator as well as railway infrastructure manager, and road hauliers and logistics service providers (LSPs) respectively.

Advocacy in (multimodal) freight transport is further complicated by the diverse and opposed interests. According to (Ruesch et al., 2013) the main interests of the actors in freight transport are:

- Shippers
  - maintain/improve accessibility
  - maintain delivery capabilities
  - small transport costs
  - high transport quality
  - improve competitiveness
  - portfolio optimisation
- LSP and hauliers
  - satisfaction of customer expectations
  - cost-effectiveness of logistics and transport services
  - efficient delivery
  - use of freight consolidation/bundling
  - use of synergies
- Public sector
  - high availability of the transport system
  - competitive locations for businesses

  - securing supply capabilities
  - liveable urban spaces
  - low environmental impact
  - high transport safety
- Population/Residents
  - high quality of living
  - high availability of goods and services
  - low annoyance through delivery vehicles

It is not to be expected that effective advocacy can be provided by a single actor. The forming of advocacy coalitions is therefore crucial to multimodal freight transport.

8.5.5 Discussion

The planning environment for freight facilities in urban areas in Switzerland is shaped by pressure from urban development. However, since ample internal land reserves exist, the development pressure seems to be unsubstantiated. Especially demand for residential and office spaces can largely be covered by existing reserves within zoned areas.

Following the (political) emphasis on residential use, planners often take no notice of opportunities for freight transport. The lack of advocacy for freight transport in general, and terminals in particular, seems to have two main reasons.

Firstly, although public planning on government level advocates the use of environmentally friendly modes of transport and efficient land use, this does not translate well to effective planning on the local level. Local policy-makers largely perceive freight as unattractive. Positive impacts of multimodal freight transport rarely show locally.

Secondly, some public planners see freight transport as a matter of the private sector. Since profitability is low and investments are high, the private sector however does not prioritise freight terminals in urban areas either. Additionally, private stakeholders are diverse and fragmented, and largely lack planning impact.

In order to improve the perspectives of multimodal freight transport in urban areas, awareness for the challenges of freight transport faces must be raised. Additionally, ways must be found to make freight transport less unattractive on the local level. Planning instruments and regulation inducing attractive solutions to freight transport must be found.

8.6 Excursus: Digitalization and automated vehicles

8.6.1 Introduction

Digitalization changes logistics and freight transport. While logistics centres have long invested in automation, the transport sector is just starting. Especially in road transport, much effort goes into automation. It is yet unclear, how automated driving will shape freight transport, and what potential for digitalization lies in railway operations. The automation of freight handling is also an emerging field, especially in container transhipment.

The characteristics of the transport infrastructure have an essential influence on automation. Some transport infrastructures can largely be separated from external influences (e.g. mainline and underground railways). Others accommodate largely uniform transport vehicles (e.g. airways, motorways). Still others have to deal with mixed use (e.g. urban roads, trams, waterways).

8.6.2 Automated driving in road transport

8.6.2.1 General challenges

The automation of road vehicles can take many forms. The level of automation is defined by the degree of control a human driver has over the vehicle (under normal operation). It ranges from very basic driving assistance to fully automated, i.e. autonomous, vehicles without any control by a person (including remote control). For automation, the vehicle must be equipped with systems that can intervene in propulsion and steering. Routing and warning systems are a basic requirement (and often already existent) but are not per se automation.

Due to the highly heterogeneous transport infrastructure, the challenges in road transport lie mainly in:

- the exact positioning of the vehicle in the lane,
- detection of other road users, in particular pedestrians and cyclists, and
- the reaction to unforeseen situations.

If normal operation cannot be upheld, driving systems can either hand back control to the driver (or a remote controller in an operations centre) or perform a safe reaction. In the first case, the driver (or operator) is required to be present at all times and capable of acting. In the second, the system's safety mechanism leads to a safe operational state (often an emergency stop).

The degree of automation depends on the system's capabilities in vehicle operation (steering, acceleration and braking), detection of the driving environment and the type of fall-back level. The commonly distinguished degrees of automation for road vehicles range from "no automation" to "full automation" (Table 8.9).

8.6.2.2 Automated and autonomous driving in road freight transport

Current developments in the freight transport sector focus on advanced driver assistance systems (e.g. for enabling "platooning"). Advanced automation could substantially change the profile of lorry drivers. In the case of assisted driving and partial automation, the role of the driver remains largely unchanged.

Table 8.9: Degrees of automation for road vehicles (ITF, 2015)

Level		Description
0	No automation	The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems
1	Driver assistance	The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task.
2	Partial automation	The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task
3	Conditional automation	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene
4	High automation	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene
5	Full automation	The full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver

With conditionally and highly automated operation, the driver can handle other tasks than driving (e.g. acquisition, invoicing, etc.) during the trip. With conditional automation however, the driver must be in the seat during the entire journey and able to respond in time. In highly automated operation, the driver can completely hand over control to the system on certain sections of the route (e.g. motorways). Drivers can take over administrative tasks or spend their rest period, thus largely eliminating lorry downtimes.

With full automation, road freight transport changes fundamentally. The presence of a driver is unnecessary, which saves on labour costs. Due to the lack of a driver, the handling of goods needs modifications. Either loading and unloading of vehicles is also automated, or appropriate personnel must be available at the destinations.

8.6.3 Automation of railways

Concerning automation, railway differs fundamentally from road transport. Track guidance reduces the number of variables considerably. Train movement is predetermined by train control. Only a few decisions remain at the vehicle level, e.g. speed, acceleration and deceleration, as well as departure times and – in the case of passenger transport – the opening and closing of doors.

The technical prerequisites for further automation of modern railway systems are already largely in place. The safety level of railway systems with automatic train protection (ATP) is already very high. Railway operations centres increasingly use algorithm-based routing and prioritisation. Adaptive train operation (i.e. the transmission of the optimum speed to the locomotive driver) currently being developed, has potential applications in automation.

A distinction must be made between automatic train operation (ATO) and automatic train control (ATC). The aim of ATO is to automate decisions at vehicle level. The system assumes the function of the locomotive driver. ATC automates decisions at the network level. It refers to the automation of the operating centres, i.e. route setting (train signalling). Further functions include automation of dispatching, traffic monitoring and intervention. Elements of customer information can also be automated. In principle, train control and train operation can be automated independently.

With ATC and ATO respectively, railway infrastructure companies expect to reduce the number of dispatchers, train operators the number of drivers. The role of the driver as "first response" in the event of train failures still needs to be clarified.

Fully automated railway systems currently exist in underground passenger rail systems. These systems largely use uniform rolling stock and eliminate external factors from their networks (no mixed traffic, no level crossings etc.).

Automated train operations and control are in early development stages for mainline railways. Several stages of development are conceivable in freight transport. The first step could be the automation of direct trains between large formation and transhipment facilities (i.e. marshalling yards and container terminals (CTs)). In the second step, local freight trains with intermediate stops are also automated. They are automatically guided to transfer tracks, where the local shunting team uncouples and couples wagons as required. In the last step, delivery to sidings is automated. This requires fully automatic couplers as well as either automatic shunters or self-propelled railway carriages. However, the question of technical checks on the wagons and locomotive remains open.

8.6.4 Automated freight handling

Automation also takes hold of freight handling. Many seaport CTs already use automated guided vehicles (AGVs) between quay cranes and the container stack. Increasingly, crane operation is automated too. Also warehousing heavily depends on automated systems, as do large bulk terminals. In these cases however, external influences in the freight handling area can largely be eliminated.

In non-containerized freight, automation is yet uncommon. Loading and unloading of trains and lorries with forklifts, wheel loaders, cranes etc., is still labour-intensive.

8.6.5 Shifting comparative advantages

As a result of automation, comparative advantages of road and rail freight are expected to shift. Due to the higher share of labour costs, the reduction of (driving) personnel will benefit road transport more. However, automation technology (e.g. sensing and positioning) adds to vehicle costs. In this respect, the railway systems seems to offer better conditions for automation. The pricing of risk and liability is also not to be neglected. Further automation of freight handling might make multimodal transport more attractive, if transhipment costs – and potentially also transhipment time – can be reduced.

8.7 Conclusion

Despite the desirable environmental effects, framework conditions are not entirely in favour of urban rail freight. From the examination of the economic sustainability, the environmental sustainability and land use, it seems that rail freight in urban areas is not viable without public support, both financial and regulatory.

The economic considerations suggest that the bigger part of urban rail freight needs financial support. Only few freight transport relations reach big enough freight quantities to justify regular rail services. Especially rail services over short distances struggle to compete against road transport.

At the same time, the environmental benefits of urban rail freight do not seem to be clear enough to justify public support. In a multimodal freight transport system, the environmental benefit of railways is only partially passed on to the full transport chain.

Incentives to improve energy efficiency and GHG emissions in freight transport focus on lorries. Due to the already good environmental performance, potential efficiency gains in rail freight are moderate. Mainly single-mode road transport thus benefits from efficiency gains.

Under these circumstances, the perception in land use planning of freight transport in general, and rail freight in particular, is unlikely to change. For a lack of quantifiable and widespread benefits, incentives for rail freight in urban areas largely lack legitimation. Public decision makers will therefore hesitate to allocate funds to the rail freight system and to adjust land use policy.

There are policy fields other than environmental and economic, justifying the use of railway for freight in urban areas. For reasons of reliability, it might be favourable to have two different land transport systems available. It gives the possibility to resort to an alternative transport mode in case of disruptions. Railways also offer more space-saving network infrastructure than high-capacity roads and thus contribute to efficient land use.

Some aspects of the framework requirements for rail freight in urban areas remain unclear. The quantification of costs and emissions has its limitations.

In terms of transport costs, the potential for bundling loads has not been regarded in detail. In Switzerland, the railway's ability to bundle loads – to the cost of transport time – is an essential part of the nation-wide wagonload system. Furthermore, the generic transport scenarios do not allow to cover individual cases with a high rail potential, despite seemingly unsuitable distances or quantities.

In terms of energy efficiency and GHG emissions, similar limitations occur. The values for both vehicle capacity usage and fuel consumption used in the model are approximations. The large range of vehicles (both on road and rail) and drivetrains is only partially reproduced.

Both models quantifying the costs and the emissions are based on generic transport scenarios. It seems that by means of scenarios, not the full range of urban transport chains can be covered. A more dynamic approach to simulate transport chains might be desirable.

Chapter 9

Case study

9.1 Introduction

The aforementioned approaches to rail freight productivity, spatial planning and system dimensioning are illustrated in the case study. The key figures are exemplified using the example of the metropolitan area of Zurich.

Zurich is Switzerland's largest agglomeration with a population of 1.3 million and 900 000 employed (BFS, 2017b,a). The City of Zurich alone has a population 390 000 and 460 000 employed.

Section 9.2 examines the freight flows to and from the urban core of the Zurich agglomeration. The further sections follow the structure of the work packages (compare Section 1.3). In Section 9.3, the structure and operational conditions on the railway network in the Zurich area are presented. Section 9.4 provides an insight on how potential logistics sites are safeguarded. Section 9.5 aims to dimension the potential throughput and land use of the case study sites. In Section 9.6, the economic, environmental and urban planning impacts of freight terminal use on the case study sites are discussed.

Table 9.1: Annual freight volumes by commodity group to and from the urban core of the Zurich area (source: own; data: BFS GTS)

Commodity group	Total freight volume t/a	Median volume t/a	Median distance km	Gini –
Construction	4 746 000	16 200	27	0.59
Food/retail	3 254 000	900	70	0.74
Waste/recycling	1 453 000	3700	23	0.72
Liquid	1 276 000	12 400	48	0.55
Containers	666 000	1500	27	0.73
General trade	3 363 000	800	66	0.77

9.2 Freight flows in Zurich

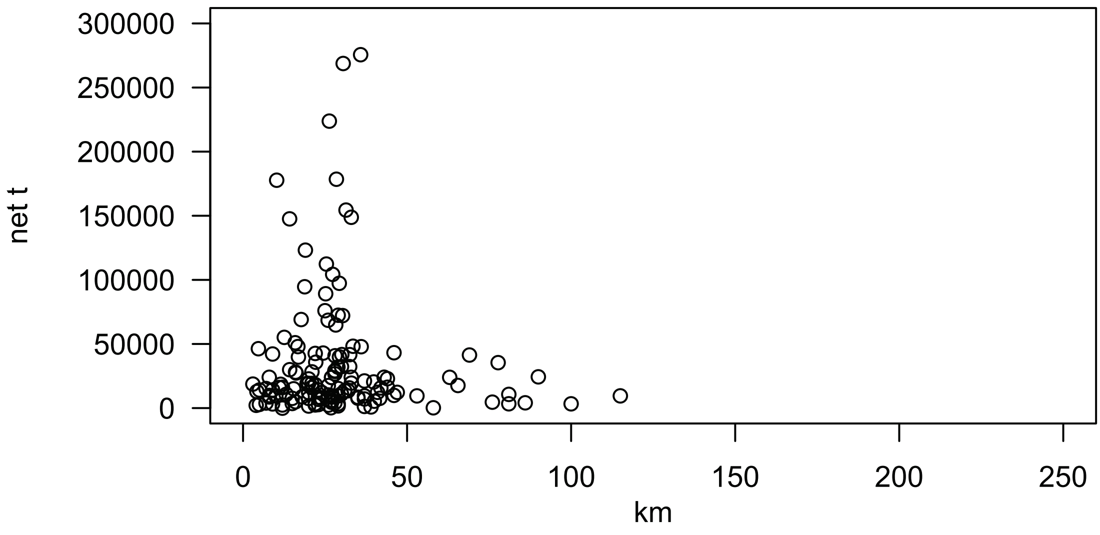
Table 9.1 shows the total annual freight volume, the median volume and distance per trip as well as the distribution of freight volume among all trips (Gini-coefficient) for each commodity group in the region of Zurich. All freight trips in OD-pairs with (at least) one end in the urban core were evaluated. Figure 9.1 shows for the respective annual freight volume and average transport distance for each OD-pair (on municipal level, compare Section 2.3.4).

The largest volume is in construction material, followed by general trade and food and other retail. General trade contains a variety of cargo types of unknown handling properties (compare Section 2.3.3). It is therefore not further considered for multimodal freight terminals.

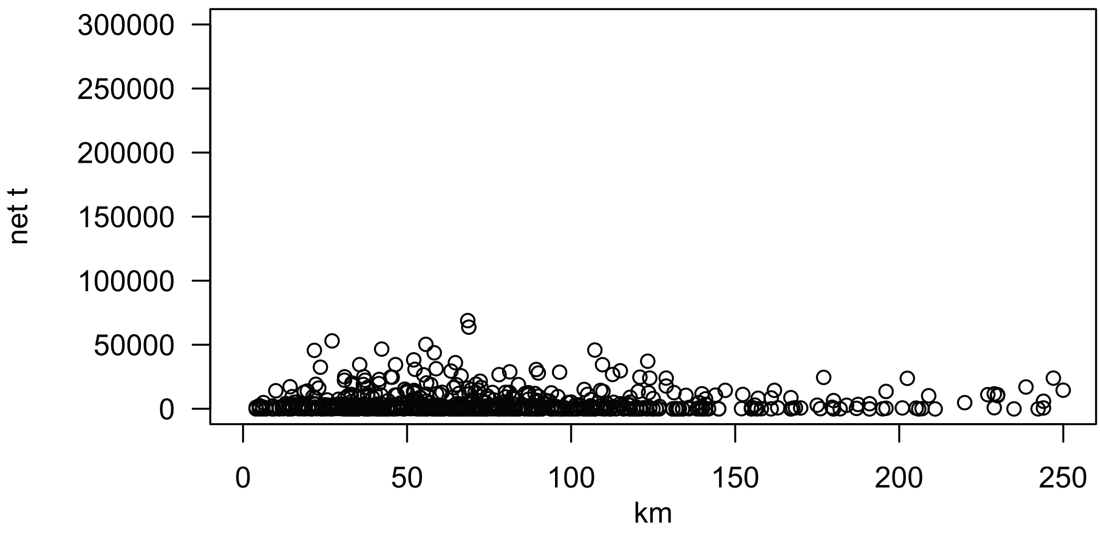
Construction material is generally transported over short distances. Additionally, the Gini (compare Section 2.3.7) coefficient implies that the freight volume is more dispersed among the OD-pairs than in other commodity groups (except hazardous liquids).

Food and other retail goods combine a large volume with longer transport distances. Flows are also more concentrated on few high-volume OD-pairs.

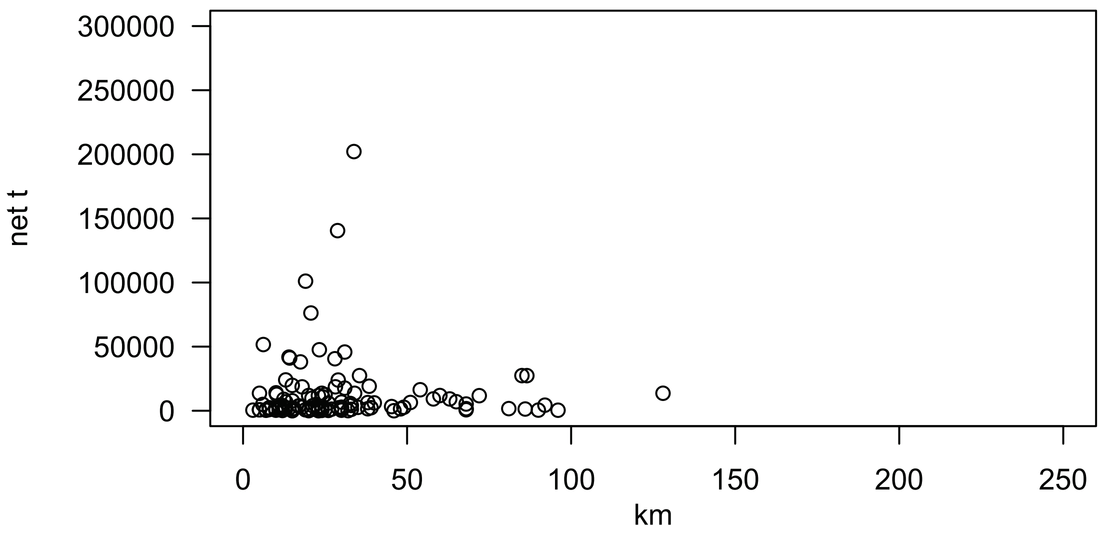
Waste and recycling goods, as well as containerized goods, are also concentrated, but display very short distances. For waste, this can largely be explained with the presence of two waste incineration plants within the urban core. Containers are presumably transported as pre- and post-haul of combined transport.



(a) construction material



(b) food and retail goods



(c) waste and recycling goods

Figure 9.1: Freight flows per OD-pair of the commodity groups construction material, food/retail and waste/recycling goods in the region of Zurich (source: own)

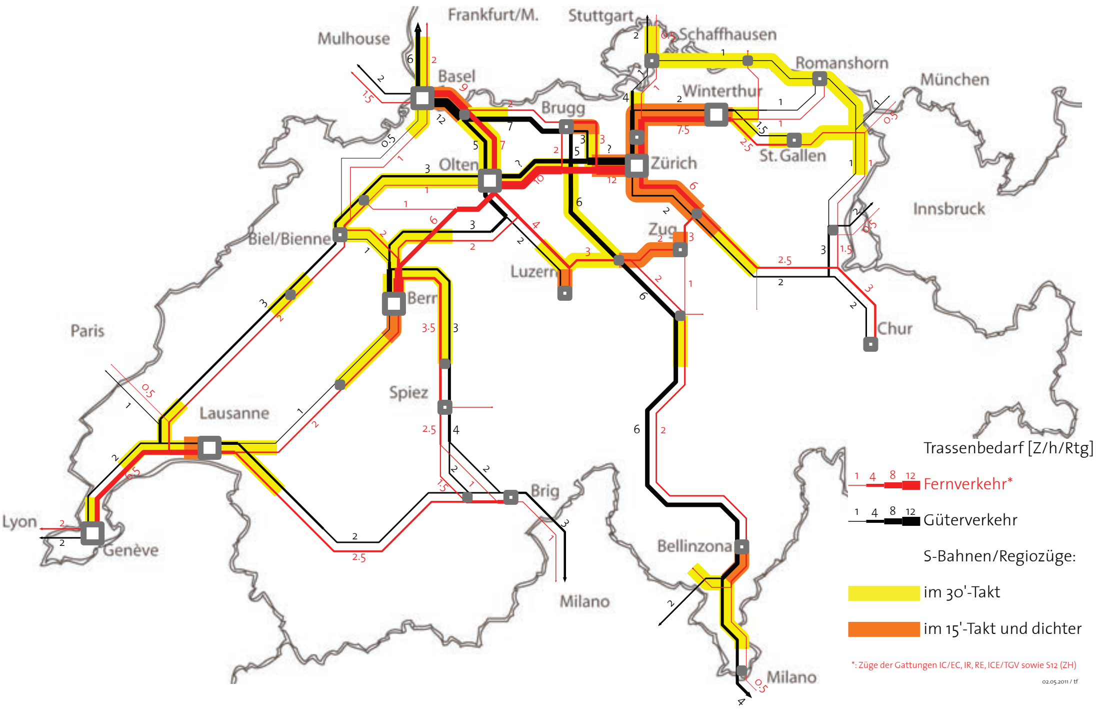


Figure 9.2: Train paths for commuter services, long distance passenger trains and freight trains in Switzerland in 2010 (Weidmann et al., 2014)

9.3 Railways in the Zurich area

The Canton of Zurich has a standard gauge railway network length of approximately 500 km. The railway network has a dual function. Firstly, Zurich is the major railway hub for intercity traffic from and to eastern Switzerland. High economic activity and the location of Switzerland's main airport make it a major destination. Secondly, Zurich's railway system serves as a metropolitan and suburban commuter transport system. Partly due to the absence of a proper underground railway system – according projects were rejected in the 1970s – the system needs to cope with high commuter train frequencies (Weidmann et al., 2012b).

Nevertheless, a respectable number of freight trains cross through the urban core of Zurich. They are partly serving rail shippers located in the region and partly – due to the lack of diversionary routes – they are transit freight services to and from eastern Switzerland (SBB, 2017a; Weidmann et al., 2014). All train categories use the same infrastructure. Figure 9.2 shows the overlap of train paths for commuter services, long distance passenger trains and freight trains in Switzerland. The highlighted parts of the network show commuter services running in intervals of 15 minutes or less.

9.4 Safeguarding of terminal locations

The Office of Transport of the Canton of Zurich has analysed potential locations for logistics uses (Salkeld et al., 2013). The affinity to logistics uses was determined by evaluating the sites' motorway accessibility, proximity to main arterials, proximity to

Zurich airport and the sensitivity to noise. Railway accessibility was a qualitative parameter, but not included in the score. Sites with a high logistics affinity score are in theory suitable to logistics uses. In practice, site-specific properties need to be regarded.

In the most urbanised parts of the agglomeration of Zurich – City of Zurich, Limmattal and Glattal – a range of potential sites exist. Especially in the City of Zurich the evaluated sites are however under big pressure from urban development for housing and offices.

The cantonal structure plan specifies a number of (existing) sites for road-rail transhipment (ARE ZH, 2015). The structure plan is binding for public bodies involved in infrastructure planning. Its entries are thus safeguarded in public planning. Two of those sites are chosen. The sites of *Zurich Hardfeld* and *Zurich-Mülligen* are situated at the western mainline of Zurich (Fig. 9.3). Hardfeld is approximately 2.5 km from Zurich's city centre, Mülligen approximately 5 km.

A part of Hardfeld is currently used as a collection point for recyclables. The rest mainly serves as storage and car park for various firms and for stabling rail vehicles. The site's historic track layout is rather inconvenient for rail operations. Serving the rather short sidings requires many shunting movements. Ongoing planning of Swiss Federal Railways (SBB) and the city of Zurich supports development for logistics uses.

Mülligen is a former shunting yard. Part of the track facilities serve two adjacent logistics facilities, a mail sorting centre of Swiss Post and a transport hub of a major Swiss haulier. The remaining tracks are used for stabling commuter trains between peak hours. The mail sorting centre can be served by trains with a length of up to 300 m, the transport hub with 200 m.

Both sites have an area of approximately 6 ha each. For the area of the Mülligen site, the existing transport hub is included and a set of arrival/departure tracks is subtracted.

9.5 Terminal performance

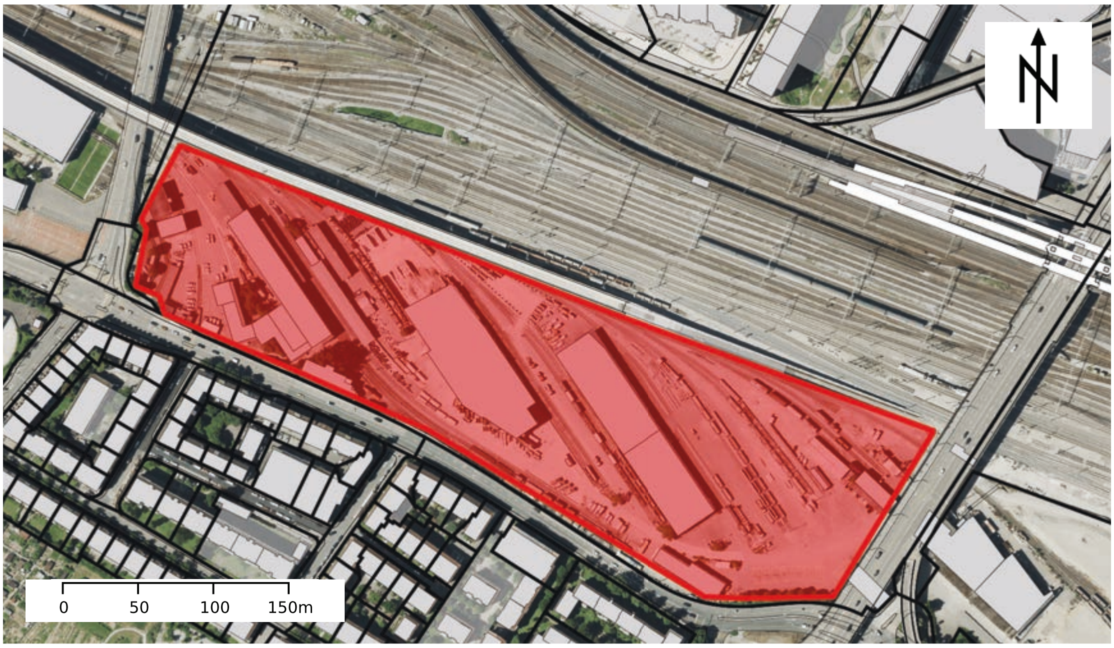
9.5.1 Terminal layouts

The two case study sites have an area of approximately 6 ha each. Using the module approach (Section 7.3.6), no detailed terminal layouts are needed to calculate the potential of the two sites for urban rail freight.

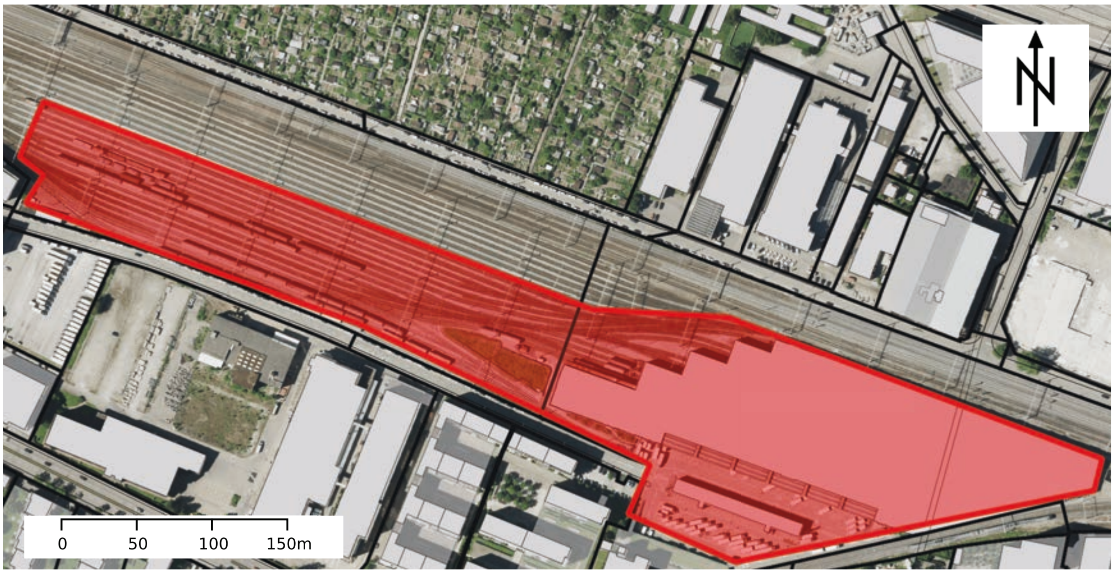
As an example for the case study, one of the sites is used as cross-dock for food and other retail goods. It is assumed that the goods are palletised and large forklift trucks are used.

The other site is used for bulk goods, both construction material (e.g. gravel, sand and excavated earth) and waste/recycling goods (e.g. recovered paper and cardboard, scrap metals and bio-waste). It consists of modules for the transhipment by wheel loaders and for receiving tipper lorries and wagons. In the construction material hub (approximately 4 ha), tipper wagons are discharged to the storage, whereas tipper lorries partly discharge to rail wagons directly. Similarly, in the waste and recycling hub (approximately 2 ha) tipper lorries discharge both to the storage and to rail wagons directly. A small ACTS-section is added for containerised recycling goods.

The food and retail terminal is assumed to receive trains of 400 m length, the bulk terminal 200 m respectively. Based on Section 7.3, Table 7.3, the food/retail terminal can accommodate up to approximately 10 forklift-modules. The bulk terminal accommodates approximately 8 modules for wheel loaders, 4 modules for tipper lorries, one for tipper



(a) Zurich, Hardfeld



(b) Zurich-Mülligen

Figure 9.3: Potential terminal locations in Zurich (source: GIS ZH)

wagons and 2 ACTS-modules (Table 9.2). Due to the modular character of the approach, the terminal layout could of course take numerous other forms.

9.5.2 Potential throughput

The specific terminal throughputs are based on Section 7.6, Table 7.6. Table 9.2 shows the estimated average potential annual throughput for each site. The performance of the modules for wheel loaders are not included, since it concerns transhipment to and from the storage only. The terminal throughput is thus not directly affected by it.

Annual throughput is approximately 252 000 t/a in food/retail, 798 000 t/a in con-

Table 9.2: Throughput estimates for the case study sites (source: own)

Transhipment device	p_{spec} t/ha a	A_{site} m^2	n_{mod} –	l_{load} m	P_{annual} t/ha
Site 1: Retail cross-dock					
Forklift quad	43 000	58 000	10	1000	252 000
Site 2a: Construction material hub					
Medium wheel loader	182 000	33 300	6	600	–
Tipper lorry	834 000	4800	2	100	400 000
Tipper wagon	1 561 000	2600	1	100	398 000
Site 2b: Waste and recycling hub					
Medium wheel loader	71 000	11 100	2	200	–
Tipper lorry	282 000	4800	2	100	135 000
Hooklift (ACTS)	79 000	3600	2	100	28 000

Table 9.3: Lorry trip generation estimates for the case study sites (source: own)

Commodity group	m_{main} t/lorry	m_{distr} t/lorry	LF_{lorry} –	ETF_{lorry} –	f_{main} lorry/d	f_{distr} lorry/d
Site 1:						
Food/retail	26	17	0.3	0.1	180	270
Site 2a:						
Construction	26	26	1.0	0.6	250	250
Site 2b:						
Waste/recycling	26	17	1.0	0.6	30	50
ACTS	24	12	1.0	0.6	10	20

struction and 163 000 t/a in waste/recycling. This corresponds to 8 %, 17 % and 11 % of the respective total freight volumes in the region (Table 9.1).

9.5.3 Lorry and train trips

The number of lorry trips generated is calculated from average load factors and empty trip factors (Table 9.3). The same generic vehicle types are assumed as in Section 8.2. Long distance transports are by 40 t-combinations with a payload capacity of 26 t. For the distribution of food/retail, 26 t-rigids with a payload capacity of 17 t are assumed. The load factor for bulk goods is 100 %, for food/retail 30 %.

Table 9.3 shows the total lorry trips generated by multimodal urban freight terminals. With the above-mentioned throughputs, approximately 470 main haul trips per day are taken off the road. The terminals however generate 590 distribution trips per day.

Train trip estimation uses specific train loads (including load factors), train length

Table 9.4: Train trip generation estimates for the case study sites (source: own)

Commodity group	c_{train} t/m$_{\text{train}}$	l_{train} m	m_{train} t/train	ETF_{train} –	f_{train} train/d
Site 1:					
Food/retail	0.88	400	350	0.2	4.3
Site 2a:					
Construction	4.50	200	900	0.8	8.0
Site 2b:					
Waste/recycling	2.25	200	450	0.8	2.2
ACTS	1.80	400	720	0.8	0.3

and the empty trip factors. The specific train load (c_{train}) is slightly changed compared to Section 8.2. Train length (l_{train}) refers to the loading length, excluding the locomotive. The empty trip factors are for bulk good 80 % and for palletised goods 20 %.

Table 9.4 shows the total number of freight train trips generated by urban multimodal urban freight terminals. On average, approximately 15 train trips are generated per day.

9.6 Framework conditions

9.6.1 Transport characteristics

The comparison of the above-mentioned throughput values with annual freight flows in Zurich (Section 9.2) illustrates the challenges of rail in urban freight transport. Figure 9.4 shows the minimal freight volume and distance required to reach a modal shift of a given percentage, provided that the most suitable OD-pairs (high freight volumes and transport distances) are shifted first (compare Fig. 9.1). The contour lines show the share of freight volume (in net-tonnes) of all OD-pairs above the indicated distance and annual freight volume.

Very short rail distances result from shifting freight to multimodal transport, especially in construction material and waste/recycling goods. A 20 %-shift in construction material, or a 10 %-shift in waste/recycling, result in minimal (total) distances of approximately 40 km. At least, freight in both commodity groups is concentrated on a few high-volume OD-pairs.

The transport of food/retail goods displays longer distances. For instance, a 10 %-shift in the transport of food and retail goods could be achieved if it is possible to cover all OD-pairs with a minimal freight volume of approximately 20 000 t and a minimal transport distance of 100 km. Compared to bulk goods, the annual freight volumes (per OD-pair) in food and retail are however smaller. This implies that bundling loads across several OD-pairs is essential to run freight trains efficiently.

9.6.2 Economic impact

Short transport distances and dispersed freight volumes are in disfavour of multimodal transports. Comparing the transport characteristics above with cost functions from Section 8.3 shows that additional costs (per net-tkm) are to be expected.

The minimal transport distance of bulk goods (construction material, waste/recycling) lies well below the break-even distance of approximately 85 km. Additional cost for multimodal transport is up to 0.1 CHF/net-tkm, depending on train size. High volume OD-pairs however allow for efficient train operations. The potential for cost-efficient transport (i.e. above the break-even distance) lies below 5 % of the annual freight volume for both commodity groups.

In the transport of food and retail goods, a substantial number of OD-pairs display distances longer than the break-even distance of 100 km. Up to approximately 20 % of the annual freight volume potentially allows for cost-efficient multimodal transport. Food/retail however largely lacks high volume relations. Since the exact location of the freight trips has not been analysed, the potential of bundling loads cannot be evaluated. It must be assumed though that bundling loads incurs additional costs.

9.6.3 Environmental impact

The environmental impact of shifting freight to multimodal transport is evaluated using GHG-emissions (CO_2 and CO_2-equivalent) and energy consumption (per net-tkm). Transport characteristics shown above are compared to the energy and emission model from Section 8.4.

At the minimal (total) distance of 40 km, energy consumption in construction material and waste/recycling is 0.3 to 0.5 MJ/net-tkm higher for multimodal transport. The reason for this is the comparably high proportion of distribution by road compared to the main haul by rail. The energy and emission model (Section 8.4) assumes smaller (and thus less efficient) vehicles for distribution traffic. The respective carbon emissions are approximately 0.05 kg (CO_2)/net-tkm lower compared to road transport.

For trains of 200 to 600 m length, energy consumption in food/retail is 0.1 to 0.6 MJ/net-tkm lower for multimodal transport. The respective carbon emissions are approximately 0.1 kg (CO_2)/net-tkm lower compared to road transport. The high dispersion of freight volume among OD-pairs however makes bundling loads essential. The effects of bundling processes on energy consumption and GHG-emissions have however not been evaluated.

9.6.4 Planning

While urban planning on the site of Hardfeld is ongoing, the development of the Zurich-Mülligen is unclear. Both sites share a location close to the main railway tracks, with a mixed industrial, residential and commercial surrounding. Both sites display high accessibility to public transport and good connections to the main road network.

The slightly more peripheral location of the Mülligen-site however shows in some of the key parameters (Table 9.5). A perimeter analysis shows that Hardfeld displays higher densities of both population and employment. The share of employment in the construction industry is lower, however in transport and logistics it is higher.

Owing to their locations, both sites are subject to desirabilities from various actors. The major alternatives to the use as urban freight terminals are (i) residential and

Table 9.5: Perimeter analysis for Zurich-Mülligen and Hardfeld (source: GIS ZH)

Parameter	Unit	Mülligen	Hardfeld	Cantonal average
Population (2015)				
Total population	P	4522	6565	
Population density	P/ha	57.6	83.6	( )
Employment (2013)				
Total employment	P	4867	5515	
Total employment	FTE	3860	4746	
Employment density	P/ha	49.1	60.4	( )
Employment by sector (2013)				
Trade	%	11.7	9.5	13.7
Financial and insurance services	%	19.9	16.3	10.8
Freelance (services)	%	10.2	34.2	10.7
Manufacturing industry	%	2.9	3.2	9.9
Health care and social services	%	3.8	2.6	10.6
Construction industry	%	10.1	1.9	6.5
Other services	%	5.4	5.4	6.2
Information and communications	%	5.4	1.5	5.9
Education	%	0.7	1.3	5.8
Transport and logistics	%	4.9	14.8	5.2
Other sectors	%	24.9	9.4	14.7

Radius 500 m; Coordinates (LV95): Mülligen 2 678 505 / 1 249 684; Hardfeld 2 680 997 / 1 248 712

commercial uses, (ii) free space (i.e. parks), and (iii) public uses (i.e. schools, administration etc.).

Residential, commercial and industrial lots adjacent to the sites were analysed GIS ZH). In close vicinity of Hardfeld, land is fully utilised and no floor space reserves remain. In the surroundings of the Mülligen-site however, some lots are not fully utilised and reserves of around 18 000 m^2 are available (Appendix E, Table E.1). This indicates that especially Hardfeld is under pressure to be converted to residential and commercial uses.

The availability of free spaces is a major characteristic of "quality of life" in cities. The government of the City of Zurich aims to provide 8 m^2 of (accessible) free space per person living in the city, and 5 m^2 per person employed (Weber et al., 2006). Both sites, Mülligen and Hardfeld, are in areas of the city with low availability of free space. The sites could thus (partially) be used to mitigate these shortages.

An analysis of the demand for public facilities has not been conducted. Nevertheless, the areas might (partially) be considered for schools, administration buildings, etc.

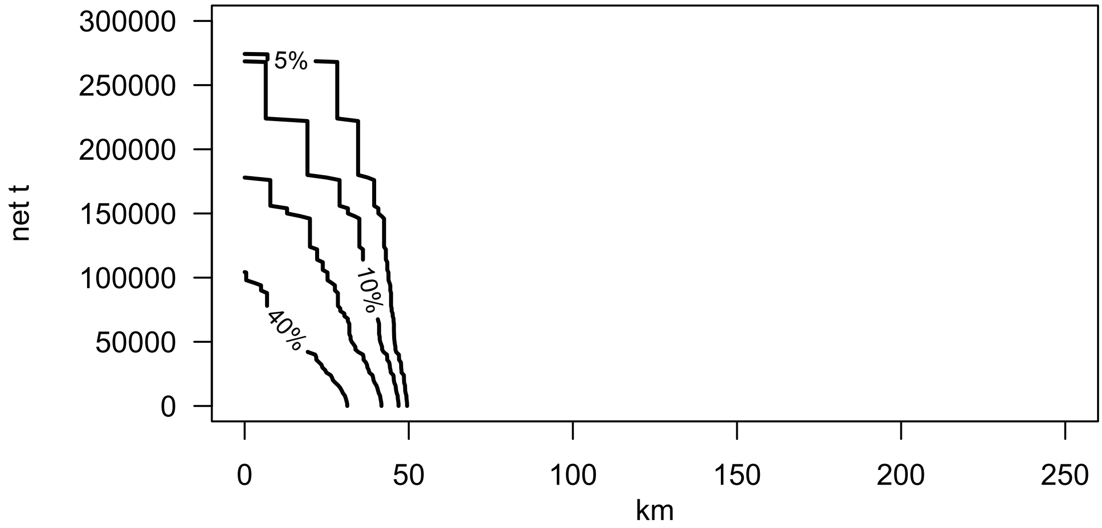
9.7 Conclusion

The case study shows that the analysed sites offer enough capacity to shift a substantial amount of goods from road to rail transport. Of the biggest commodity groups, 10 to 20 % of the freight volume could be transhipped close to the city centre and distributed to their destinations. The structure of the good flows in the Zurich area however indicates that shiftable loads will be hard to find. In urban transport of construction material and waste/recycling goods there are some high-volume relations, but distances are very short. In food and retail goods, longer distances are covered, but the freight volume is more dispersed. Both effects lead to higher costs and in some cases to unfavourable energy consumption.

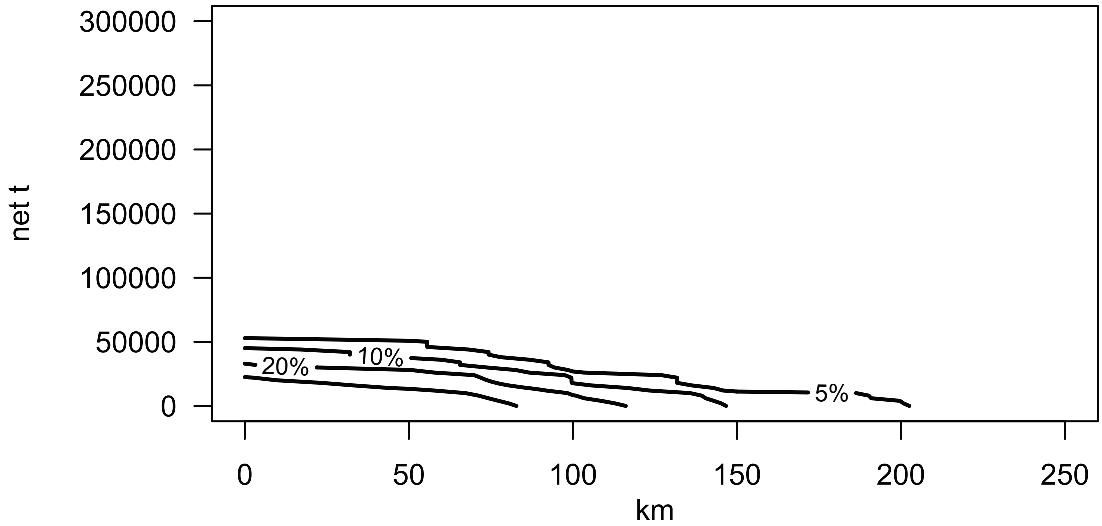
In order to achieve even moderate goals for modal shift in urban freight transport, rail freight transport and the corresponding terminals need to be incentivised. Funding needs to be found and used efficiently to attract shippers, hauliers and train operators. It seems, however, that environmental reasons are not sufficiently supporting widespread use of multimodal freight transport in the agglomeration of Zurich.

The results also indicate that under certain conditions, urban rail freight can be competitive in individual cases, which is confirmed by examples in Switzerland (Section 8.3). A bigger effort is however required to identify these cases and to create an appropriate environment for rail freight. Considering this, detailed studies of freight operations prior to selecting sites for safeguarding are probably inevitable.

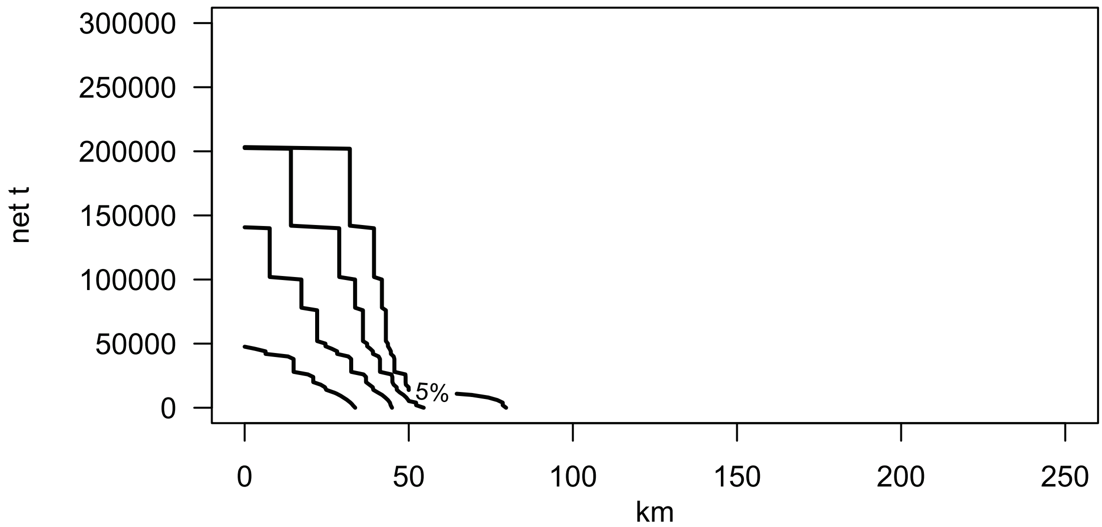
In Zurich's case, the willingness to safeguard the site of Hardfeld for logistics uses deserves acclaim. No detailed plans for the site have yet been published. The size and location of the Hardfeld site however implies that it has the potential for becoming an example of an urban freight terminal. To accommodate additional uses – non-logistic or logistics uses other than transhipment – storeys need to be added above (and below) the transhipment area to make best use of the land available. It must be assumed that – given the appropriate processes and planning instruments can be found – the success of Hardfeld will substantially shape attitudes – of planners, logistics and railway companies alike – towards rail freight in urban areas in Switzerland.



(a) construction material



(b) food and retail goods



(c) waste and recycling goods

Figure 9.4: Freight flows of the commodity groups construction material, food/retail and waste/recycling goods in Zurich and the respective minimal distance and volume (source: own)

Chapter 10

Synthesis

10.1 Introduction

In this chapter, the main findings from each work package are presented. The validity and application range of the results is discussed.

Methodological considerations – challenges that have emerged, rejected methods and promising approaches – are discussed. Suggestions for further research are made.

10.2 Key results

This study intends to evaluate the potential and the implications of railways as an alternative freight transport system in urban areas. Below, the key results are summarised.

What are the effects of adapting freight train operation to densely used railway networks in urban areas?

Rail freight can be adapted to railway operations in urban areas by shortening trains, improving braking and traction and by reducing train weight. The results show that increasing acceleration displays the biggest potential to reduce infrastructure occupation. This can be achieved by improving traction and limiting the gross train mass (which in turn depends on the train length, load capacity and tare mass of the train).

Although displaying similar characteristics, increasing deceleration does not yield the same direct effect on infrastructure occupation. Improving brakes however positively contributes to operations in networks with limited presignal distances, allowing freight trains to run at higher line speeds.

Shortening trains has some effect on infrastructure occupation. The involved loss of load capacity however cannot be compensated by the gain in train numbers. Only with a combination of measures it is possible to maintain the capacity. Freight trains of 400 m length with improved traction and braking can thus provide the same freight capacity as conventional 750 m long freight trains.

Shorter freight trains have further advantages. The need for higher train frequencies leads to steadier freight flows and decreases load peaks at the freight terminal. Additionally, the dimensions of terminal facilities are smaller.

How can areas for the transhipment of goods from rail to road be secured?

The analysis of private and public planning processes shows that – land scarcity provided, as is usually the case in urban areas – decision making for freight terminals faces a couple of challenges. Firstly, the cross dependency between safeguarding potential terminal sites and initializing private terminal projects leads to hold-ups. Secondly, the lack of overview and insufficient data quality (including forecasts) impedes long-term planning and hence safeguarding. Thirdly, divergences of objectives and standards between public and private actors (and within) weaken freight transport initiatives, which require a high degree of co-ordination. The resulting uncertainty – along with the considerable planning costs involved – leads to a lack of willingness to safeguard suitable sites and to initialize terminal projects.

The public sector therefore needs planning instruments to safeguard potential terminal areas on the basis of political objectives. This allows to ensure the availability of land for freight transport, even in cases where the logistics industry's demand has not yet been explicitly expressed. Public planners thus need to have the appropriate planning resources and the freight logistics knowledge at their disposal.

How much can rail freight contribute to urban freight transport?

Performance calculations show that efficient terminal throughput can be expected at approximately 160 000 to 250 000 t/ha a for heavy dry bulk, 65 000 to 98 000 t/ha a for light dry bulk and for (palletized) volume goods 38 000 to 48 000 t/ha a. Even small facilities can thus process considerable quantities, efficient operations provided. Assuming freight generation of approximately 30 t/a per inhabitant, a modal shift of 5 % would require 0.05 to 0.90 m^2 of terminal area per inhabitant, depending on commodity and terminal type.

The performance values depend on a few sensitive factors. Firstly, the assumed number of transhipment devices (per train length) strongly influences the (specific) handling performance. Especially small, inexpensive transhipment vehicles – e.g. forklift trucks, but also manual labour – can be added to or removed from a terminal as required. This fundamentally changes the performance per unit area.

Secondly, the performance is very sensitive to the terminal's operating hours. Although the operating times are adjusted for non-busy periods, some uncertainties remain of what should be considered *efficient* specific terminal throughput. The terminal's degree of utilisation therefore heavily depends on the reference value for operating times.

Thirdly, the factors applied to the handling rates need to be scrutinised. The factor of the variability of freight volume of 0.8 to 0.9 (Kemme, 2013; Tioga, 2008; Saanen, 2004) seems rather high. Obviously, the variability of freight distribution does not follow the same laws as intermodal transport.

Fourthly, the approach using terminal modules does not allow to account for scales of productivity and land use efficiency. Larger terminals have more transhipment devices at their disposal, allowing to minimize downtimes due to maintenance.

Lastly, the empty trip factors (ETFs) chosen might not represent the conditions in urban freight transport. The values in IVE et al. (2016) are averages calculated from system-wide data. Especially for freight distribution the ETF might generally be closer to 100 % (not only for bulk goods). However, the ETF affects multimodal and road transport likewise.

At what cost can rail freight be operated in urban areas?

In terms of transport costs, multimodal urban freight transport in Switzerland can compete with direct road transport from a distance of approximately 80 to 100 km, depending on train size and commodity group. In case of road network congestion, critical distance might even be lower.

The cost estimations have some shortcomings caused by the scenarios, which do not contain some aspects of the transport chain. For instance, (separate) shunting operations for rail transport are not incorporated in detail.

Furthermore, the model considers transport costs only, and not the total logistics costs. Although the cost functions return plausible transport costs, they can thus not reproduce the cost decisions of shippers and logistics service providers (LSPs). It must be assumed that logistics costs (e.g. inventory costs), which are not regarded in the study, add disproportionately to multimodal freight.

What are the environmental benefits of rail freight in urban areas?

In terms of carbon and greenhouse gas (GHG) emissions, multimodal transport performs much better than road haulage. Multimodal transport emits around 10 to 50 % of the well-to-wheel (WTW) carbon emissions of road transport. Taking Swiss electricity generation as a basis, rail transport enables largely emission-free transport.

Owing to high WTW energy factors of electricity (and low ones for diesel fuel), the energy efficiency of multimodal transport is partially lower than of road transport. Below a transport distance of 100 to 200 km, energy efficiency of road transport of bulk goods is more efficient than multimodal transport.

Transhipment is the weak point of the emission calculations. The transhipment processes are still not well understood in terms of energy consumption. The values for energy consumption of transhipment processes, as mentioned in IVE et al. (2016), are rather uncertain.

The expected use of electric lorries in distribution, and possibly also main haul, opens another gap. Electric lorries would certainly shift the reference for emissions and energy consumption. However, little freight-specific information can currently be found.

How can rail freight be considered in urban planning?

The urban planning environment in Switzerland is strongly emphasising residential and commercial land use. Unused and underused (railway) areas are generally designated for housing and offices although ample reserves of zoned areas exist. The pressure from urban development on areas suited to freight terminals therefore seems unsubstantiated.

Despite the economic necessity for freight transport, negative perception – noise, pollution, heavy traffic – mostly prevails. More efforts therefore have to be put into establishing and promoting freight transport compatible to the urban environment. This takes advocacy to raise awareness, as well as suitable planning instruments to seize opportunities for sustainable freight transport in urban areas.

The results from the work packages provide answers to the research question: *Can rail freight systems be designed to allow for the integration into urban supply chains in modern economies and which conditions need to be met?*

From the results it is concluded that railway has the potential to complement the urban freight system with an alternative transport system. In summary, neither can rail freight be an all-purpose solution to urban freight transport, nor is it completely unfit for the urban environment. As the general framework conditions for rail freight in urban areas remain difficult, the challenge lies in identifying the (few) cases, where urban rail freight meets ideal conditions.

Public planners will therefore have to be able to identify sites with a high potential, and to safeguard these sites for the freight transport sector. Potential terminal owners and operators need to put more effort into designing terminals with high throughput and high land use efficiency. Carriers (on road and rail) and LSPs should cooperate to find multimodal transport solutions meeting the logistics demands of the shippers. This partly relies on the ability of railway undertakings (RUs) to renew rolling stock and adapt freight train operations to the conditions in urban railway networks. Shippers should invest in rail access where possible and, when relying on external carriers, should be encouraged to have a say in the mode choice.

10.3 Methodological considerations

Freight data The estimation of the freight volumes to and from urban areas has some shortcomings. To obtain nationwide, annual freight volumes, the data from the survey sample is grossed up. The grossing factors provided by Swiss Federal Statistical Office (BFS) do not necessarily correspond to the spatial distribution of the freight trips. They are based on the Swiss HGV register and customs statistics. To get a better picture of the spatial relevance of the data, in Fig. A.1 emphasises the OD-pairs with more than 20 trips recorded in the sample. The analysis of the freight trip sample should be reviewed.

Train run calculations In the Master thesis of Bächli (2016) a more detailed approach to train run calculations for the estimation of rail freight productivity was tested. In particular, traction performance was based on proper examples of locomotives (instead of generic acceleration terms) and an attempt made to better include the properties of brakes (instead of generic deceleration terms). The results in this study largely confirm the results from the Master thesis, showing that the approach taken to calculate train runs is sufficient.

Terminal performance and areas Process analysis was used to estimate terminal performance and land use efficiency. This approach is prone to large variances in the results, when ranges are applied to all input factors.

Alternatively, surveys of freight terminals could be used, using benchmarking to obtain values of efficient terminal operations. However, no standards exist so far on how to measure terminal performance and areas in a reproducible way for a range of commodities and terminal types. This virtually makes it necessary to conduct a comprehensive survey from scratch.

Terminal operations variation and dynamics The design of transhipment modules and terminal units is a straightforward approach to estimate the (potential) performance of a freight terminal. A set of simple key figures can thus be provided to planners. Limitations exist in terms of the dynamics and variation of terminal operations.

The presented modules each use one (typical) transhipment device and commodity type only. Additionally, fixed handling rates are assumed.

Usually, variations of transhipment devices (e.g. the size and performance of wheel loaders), commodities (e.g. the mass density of bulk goods) etc. occur. Instead of using exemplary cases of typical devices and commodities, representative averages should be calculated. This requires comprehensive surveys of a range of terminal types.

Alternatively, (micro-) modelling of terminal operations could be used to account for variations and dynamics. This is already common for large container terminals. However, increased complexity is not appropriate in early planning stages and would increase planning costs.

Transport scenarios The transport scenarios, too, each use one typical vehicle only for each transport system. As with terminal operations, representative average values could be used.

Cost estimations The estimation of transport costs is presumably not sufficient to explain the decision-making of shippers and LSPs. For a better understanding of the freight system, the full logistics costs might be more appropriate. This requires more detailed scenarios that include specific logistics processes.

Environmental impact The environmental impact was analysed by calculating the energy consumption and emissions of freight transport according to CEN (2012) (plus transhipment processes). Other methods are available to estimate the environmental impact in more detail. For instance, a *life-cycle assessment* would allow to estimate impacts "from-cradle-to-grave", including land-use, the use of natural resources and energy (Fries, 2009). This requires more detailed scenario-making and the availability of life cycle inventory data.

10.4 Research perspectives

The study shows that freight transport in urban areas – especially involving rail freight – raises a number of questions. In trying to answer the research questions, a range of open issues were encountered.

First and foremost is the need to improve freight data. Especially rail freight data is hardly available (mostly due to business privacy concerns) and if, data is recorded in a different manner from road transport. Data on freight terminals (of non-containerised goods) is even more in need for standardisation. Methods need to be developed to uniformly record terminal area and performance.

Connected to freight terminal data, – secondly – deeper insight into cargo handling is required. The laws of terminal handling performance, i.e. the relation between number of devices, freight volume and handling performance, needs to be better understood.

Thirdly, the energy consumption of cargo handling should be further analysed. This should include not only gantry cranes and reach stackers, given the importance of non-containerised freight in urban freight transport.

Fourthly, the introduction of electric drivetrains to road transport needs to be investigated. Only from a few prototypes of electric lorries data on energy consumption (especially on the recuperation of braking energy) and on the trade-off between battery weight, vehicle range and load capacity can be gathered. As the industry's efforts advance in electric drivetrains for buses in public transport, reliable results can also be expected in freight transport in the near future.

Lastly, freight transport will not escape the emerging transformation of the transport sector caused by digitalization and automation. A better picture is needed of the potentials of automation as well as estimations of its impact. Both elements are essential for taking action to steer development in the desired direction.

Filling these gaps would help planners, in both the public and private sector, to deal with rail-based freight transport in urban areas. Policy recommendations and planning advice should be developed to ensure sound and integral end-to-end planning of multimodal freight.

Bibliography

Alessandrini, A., P. Delle Site, F. Filippi and M. Salucci (2012) Using rail to make urban freight distribution more sustainable, *European Transport – Trasporti Europei*, **50**, ISSN 1825-3997.

Allen, J., M. Browne and A. Woodburn (2013) London freight data report: 2013 update, *Technical Report*, Transport for London (TfL), London, July 2013.

ARE (2015) Aggregierte Methode Güterverkehr (AMG) – Methodenbeschrieb, *Technical Report*, Swiss Federal Office for Spatial Development (ARE), Berne, September 2015.

ARE ZH (2015) *Kanton Zürich Richtplan : Beschluss des Kantonsrates (Festsetzung) : Stand 18. September 2015*, Kanton Zürich, Amt für Raumentwicklung (ARE ZH), Zurich, URL `http://www.are.zh.ch/internet/baudirektion/are/de/raumplanung/kantonaler_richtplan/richtplan.html`.

Bächli, I. (2016) Schienengüterverkehr auf hochbelasteten Mischverkehrsstrecken, Master Thesis, IVT, ETH Zurich.

BAFU (2009) Leitfaden Zwischennutzung, *Guideline*, Federal Office for the Environment (BAFU), Bern.

Ballis, A. and J. Golias (2002) Comparative evaluation of existing and innovative rail–road freight transport terminals, *Transportation Research Part A: Policy and Practice*, **36** (7) 593–611, August 2002.

BAV (2012) eNIBA: Elektronisches Rechentool für NIBA : Version 2012.1, excel calculation tool.

BAV (2014) *Ausführungsbestimmungen zur Eisenbahnverordnung (AB-EBV)*, Swiss Federal Office of Transport (BAV), Bern, URL `https://www.bav.admin.ch/bav/de/home/rechtliches/rechtsgrundlagen-vorschriften/ab-ebv.html`.

BAV (2016) NIBA: Nachhaltigkeitsindikatoren für Bahninfrastrukturprojekte, *Guideline*, Federal Office of Transport (BAV), Bern, December 2016.

BFS (2016) Amtliches Gemeindeverzeichnis der Schweiz – MS-Excel Version, spreadsheet, June 2016, URL `https://www.bfs.admin.ch/bfs/de/home/grundlagen/agvch.assetdetail.256599.html`.

BFS (2017a) City statistics portraits 2016: agglomerations, *Technical Report*, Swiss Federal Statistical Office (BFS), Neuchâtel, March 2017.

BFS (2017b) City statistics portraits 2016: core cities, *Technical Report*, Swiss Federal Statistical Office (BFS), Neuchâtel, March 2017.

BFS (2017c) Die Raumgliederungen der Schweiz 2016 – MS-Excel Version, spreadsheet, March 2017, URL `https://www.bfs.admin.ch/bfs/de/home/statistiken/querschnittsthemen/raeumliche-analysen/raeumliche-gliederungen.assetdetail.2118475.html`.

BFS (2017d) Räumliche Typologien, webpage, URL `https://www.bfs.admin.ch/bfs/de/home/statistiken/querschnittsthemen/raeumliche-analysen/raeumliche-gliederungen/raeumliche-typologien.html`.

Browne, M., J. Allen and M. Attlassy (2007) Comparing freight transport strategies and measures in London and Paris, *International Journal of Logistics Research and Applications*, **10** (3) 205–219, September 2007.

Browne, M., J. Allen, A. Woodburn and M. Piotrowska (2014) The potential for non-road modes to support environmentally friendly urban logistics, *Procedia – Social and Behavioral Sciences*, **151**, 29–36, ISSN 1877-0428.

Bruckmann, D., T. Fumasoli and J. Grotrian (2012) Innovationen im Wagenladungsverkehr, in C. Laesser, T. Bieger and R. Maggi (eds.) *Jahrbuch ... Schweizerische Verkehrswirtschaft*, 21–32, IMP-HSG.

Bruckmann, D., T. Fumasoli and A. Mancera (2014a) Innovationen im alpenquerenden Güterverkehr, *Final Report*, Swiss Federal Office of Transport (BAV), IVT, ETH Zurich, Zurich, August 2014.

Bruckmann, D., T. Fumasoli, M. Saeednia and U. Weidmann (2014b) Reduktion des Energieverbrauchs im Schienengüterverkehr, in C. Laesser, T. Bieger and R. Maggi (eds.) *Jahrbuch ... Schweizerische Verkehrswirtschaft*, 41–52, IMP-HSG.

Bruckmann, T. and T. Fumasoli (2012) Prozessorientierte Ansätze für eine qualitative Nutzenermittlung von Innovationen im Schienengüterverkehr, paper presented at the *III. Internationales Fachsymposium Moderner Schienengüterverkehr*, 25–31, Berlin, March 2012.

Bruns, F., M. Hofer, P. Ruggli and R. Salkeld (2013) Infrastruktur Landverkehr 2030 : Modul 2: Logistikstandorte Siedlungs-/Verkehrsplanung, *Final Report*, Cargo Forum Schweiz, VAP, BPUK, KÖV and Logistikcluster Region Basel, Ernst Basler+Partner, Zurich, June 2013.

Bryan, J., G. Weisbrod and C. D. Martland (2007) Rail freight solutions to roadway congestion–final report and guidebook, *Guidebook*, NCHRP, **586**, AASHTO, FHA, Transportation Research Board, Washington, D.C.

BVU, TNS and KIT (2016) Entwicklung eines Modells zur Berechnung von modalen Verlagerungen im Güterverkehr für die Ableitung konsistenter Bewertungsansätze für die Bundesverkehrswegeplanung, *Final Report*, Bundesverkehrswegeplan (BVWP) 2030, **FE 96.1002/2012**, Federal Ministry of Transport and Digital Infrastructure (BMVI), Karlsruhe Institute of Technology, August 2016.

CEN (2012) *Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers)*, Brussels, September 2012.

Dablanc, L. and D. Rakotonarivo (2009) The impacts of logistics sprawl: How does the location of parcel transport terminals affect the energy efficiency of goods' movements in Paris and what can we do about it?, paper presented at the *6th International Conference on City Logistics*, vol. 2 of *Procedia Social and Behavioral Sciences*, 6087–6096, Puerto Vallarta, Mexico, June 2009, ISSN 1877-0428.

DB Cargo (2017) Güterwagenkatalog, webpage, January 2017, URL `http://gueterwagenkatalog.dbcargo.com`.

Dijkstra, L. and H. Poelman (2014) *A harmonised definition of cities and rural areas: the new degree of urbanisation*, European Commission Directorate-General for Regional and Urban Policy (DG REGIO), URL `http://ec.europa.eu/regional_policy/sources/docgener/work/2014_01_new_urban.pdf`.

Dinwoodie, J. (2006) Rail freight and sustainable urban distribution: Potential and practice, *Journal of Transport Geography*, **14** (4) 309–320.

e-Force (2015) *E-FORCE 18t Electric Truck : Technical Specifications*, e-Force One AG, Fehraltdorf, URL `http://eforce.ch/wp/wp-content/uploads/2016/06/E_FORCE_Fact_Sheet_D_2015n.pdf`.

EC (2001) Directive 2001/12/ec of the european parliament and of the council of 26 february 2001 amending council directive 91/440/eec on the development of the community's railways, *Directive*, **2001/12**, European Commission, Brussels, February 2001.

EC (2011) White paper : Roadmap to a single european transport area – towards a competitive and resource efficient transport system, *Commission Communication*, **144**, European Commission, Brussels, March 2011.

Eurostat (2016) Transport database, webpage, May 2016, URL `http://ec.europa.eu/eurostat/web/transport/data/database`.

Eurostat (2017a) Gisco: Geographical information and maps, webpage, March 2017, URL `http://ec.europa.eu/eurostat/web/gisco`.

Eurostat (2017b) Territorial typologies for european cities and metropolitan regions, webpage, URL `http://ec.europa.eu/eurostat/statistics-explained/index.php/Territorial_typologies_for_European_cities_and_metropolitan_regions`.

Fahrländer, S., S. Fuchs, C. Heye, T. Unternährer and B. Weilenmann (2008) Bauzonen Schweiz : Wie viele Bauzonen braucht die Schweiz?, *Final Report*, Swiss Federal Office for Spatial Development (ARE), Fahrländer Partner AG, Zurich.

FEM (2017) *Industrial trucks – 90 degree stacking aisle width*, European materials handling federation FEM, Product Group Industrial Trucks, Brussels, fourth edn., January 2017, URL `http://www.fem-eur.com/wp-content/uploads/2016/03/IT-4.005.pdf`.

FGSV (2006) *Hinweise zur Schätzung des Verkehrsaufkommens von Gebietstypen*, Forschungsgesellschaft für Strassen- und Verkehrswesen, Arbeitsgruppe Verkehrsplanung, Köln.

Frank, J. P. (2013) Methodik zur Effizienzbeurteilung der Kapazitätsnutzung und -entwicklung von Bahnnetzen, Ph.D. Thesis, ETH Zurich, Zurich.

Fries, N. (2009) Market potential and value of sustainable freight transport chains, Ph.D. Thesis, ETH Zurich, Zurich.

Fumasoli, T. (2010) Die automatische Kupplung im Einzelwagenladungsverkehr der Schweiz, Master Thesis, IVT, ETH Zurich.

Fumasoli, T. (2016a) Inputpapier – Massnahmen städtischer Schienengüterverkehr, unpublished project input paper, NFP71 Energy-efficient and CO2-free Urban Freight Logistics.

Fumasoli, T. (2016b) Verlagerung Schiene – Umschlagsanlagen, unpublished project factsheet, NFP71 Energy-efficient and CO2-free Urban Freight Logistics.

Fumasoli, T., D. Bruckmann and U. Weidmann (2015) Operation of freight railways in densely used mixed traffic networks – an impact model to quantify changes in freight train characteristics, *Research in Transportation Economics*, **54**, 15–19, ISSN 0739-8859.

Fumasoli, T., D. Bruckmann and U. Weidmann (2016) Capacity for freight in urban railway networks—an analytical model for capacity consumption of freight trains in urban networks, in U. Clausen, H. Friedrich, C. Thaller and C. Geiger (eds.) *Commercial Transport: Proceedings of the 2nd Interdisciplinary Conference on Production Logistics and Traffic 2015*, Lecture Notes in Logistics, 385–393, Springer, ISBN 978-3-319-21266-1.

Fumasoli, T. and U. Weidmann (2016) The state of urban rail freight strategies in European cities, paper presented at the *95th Annual Meeting of the Transportation Research Board*, Washington, D.C., January 2016.

Galonske, N., J. Hildebrandt, A. Zanardelli, L. Deiterding, A. Magnien, P. Mantell, M. Hennigson, L.-O. Fällbom and E. Feyen (2016) User-friendly access to information about last-mile infrastructure for rail freight, *Final Report*, **MOVE/B2/827-2013**, European Commission, Directorate-General for Mobility and Transport, Brussels, November 2016.

Gilgen, K. (2012) *Kommunale Raumplanung in der Schweiz*, vdf, Zürich, ISBN 978-3-7281-3472-1.

Girmscheid, G. (2010) *Leistungsermittlungshandbuch für Baumaschinen und Bauprozesse*, fourth edn., Springer, Berlin/Heidelberg/New York, ISBN 978-3-642-13795-2.

Giuliano, G., T. O'Brien, L. Dablanc and K. Holliday (2013) Synthesis of freight research in urban transportation planning, *NCFRP Report*, **23**, National Cooperative Freight Research Program, Transportation Research Board, Research and Innovative Technology Administration, Washington, D.C.

Goebel, V. and F. Kohler (2014) Raum mit städtischem Charakter 2012 : Erläuterungsbericht, *Technical Report*, **1474-1200**, Swiss Federal Statistical Office (BFS), Neuchâtel.

Hacon (2017) Railfreightlocations pilot portal data, e-mail, March 2017, URL `www.railfreightlocations.eu`.

Häfeli, U., T. Arnold, D. Matti, M. Ruesch, S. Bohne, T. Schmid, T. Fumasoli and D. Bruckmann (2016) Trends und Massnahmen in der urbanen Logistik – Ergebnisse einer Online-Befragung, in C. Laesser, T. Bieger and R. Maggi (eds.) *Schweizer Jahrbuch für Verkehr*, 23–44, IMP-HSG, St. Gallen.

Häussermann, H. (2007) Phänomenlogie und Struktur städtischer Dichte, in V. M. Lampugnani, T. K. Keller and B. Buser (eds.) *Städtische Dichte*, 19–30, Verlag Neue Zürcher Zeitung, Zurich, ISBN 978-3-03823-291-9.

Hesse, K. and U. Clausen (2012) Eco-efficient logistics, *it – Information Technology Methoden und innovative Anwendungen der Informatik und Informationstechnik*, **54** (1) 24–33.

Hofer, M., M. Lehmann and M. Malek (2008) Die Brachen der Schweiz : Reporting 2008, *Technical Report*, Swiss Federal Office for Spatial Development (ARE), Wüest & Partner AG, Zurich, November 2008.

Holguín-Veras, J., M. Jaller, I. Sanchez-Diaz, J. Wojtowicz, S. Campbell, H. Levinson, C. Lawson, E. L. Powers and L. Tavasszy (2012) Freight trip generation and land use, *NCFRP Report*, **19**, National Cooperative Freight Research Program, Transportation Research Board, Research and Innovative Technology Administration, Washington, D.C.

Hörl, B. and H. Dörr (2011) Metro.Freight.2020 : Transportmittelauswahl für die mittelbetriebliche Wirtschaft – Strategie zur Stärkung und effizienten Nutzung der Schieneninfrastruktur in Ballungsräumen, *Final Report*, iv2splus, **820689**, Austrian Research Promotion Agency (FFG), Austrian Ministry for Transport, Innovation and Technology BMVIT, Zurich, June 2011.

Ickert, L., M. Maibach, C. Bieler, D. Bruckmann and T. Fumasoli (2012) Grossterminalstudie : Beurteilung der Terminalprojekte Gateway Limmattal und Basel-Nord, *Final Report*, Swiss Federal Office for Transport (BAV), Bern, June 2012.

Infras (2010) Handbook emission factors for road transport (HBEFA) 3.1, database, URL `http://www.hbefa.net`.

ITF (2015) Automated and autonomous driving: Regulation under uncertainty, *Corporate Partnership Board Report*, OECD, International Transport Forum (ITF), Paris.

IVE, Infras and ifeu (2016) Ecological transport information tool for worldwide transports : Methodology and data update, *Technical Report*, EcoTransIT World Initiative (EWI), Berne and Hannover and Heidelberg, June 2016.

IVECO (2017) *Technische Beschreibung : Euro VI – Fahrgestelle 4x2 : AD/AT 190 S 31-40 P*, IVECO, URL `http://www.iveco.com`.

Jaccaud, J.-P., S. Lufkin, A. Schaer, V. Easton, J. Fornet, V. Kaufmann and K. Littlejohn (2013) Densification des friches ferroviaires urbaines, *Final Report*, NRP 54, Swiss National Science Foundation, LAMU and LaSUR, EPFL, Lausanne.

Jahn, H. and J. Krey (2014) Berliner Verkehr in Zahlen 2013, *Brochure*, Senatsverwaltung für Stadtentwicklung und Umwelt, Abteilung Verkehr, Berlin, January 2014.

Keller, M., P. de Haan, W. Knörr, S. Hausberger and H. Steven (2004) *Handbuch Emissionsfaktoren des Strassenverkehrs 2.1 : Dokumentation*, Bundesamt für Umwelt, Wald und Landschaft (BUWAL), Bern.

Kemme, N. (2013) *Design and Operation of Automated Container Storage Systems*, Physica-Verlag HD, ISBN 978-3-7908-2885-6.

Knieps, G. (2007) *Netzökonomie : Grundlagen – Strategien – Wettbewerbspolitik*, first edn., Gabler, Wiesbaden, ISBN 978-3-8349-9231-4.

Liebherr (2017) *Wheel Loaders L 526 – L 546*, Liebherr-Werk Bischofshofen GmbH, Bischofshofen, URL `https://www.liebherr.com/en/deu/products/construction-machines/earthmoving/wheel-loaders/details/69145.html`.

Maes, J. and T. Vanelslander (2010) The use of rail transport as part of the supply chain in an urban logistics context, paper presented at the *12th World Conference on Transportation Research*, Lisbon, July 2010.

Mertel, R., M. Gaidzik, K. Petri, V. Präg, K.-U. Sondermann and S. Karcher (2012) Empfehlungen zur Bemessung, Dimensionierung und Gestaltung von modernen KV-Umschlaganlagen, *Handbook*, BÖB, DUSS, IPN and VDV, Frankfurt am Main and Hannover, September 2012.

Monios, J. (2015) Integrating intermodal transport with logistics: a case study of the UK retail sector, *Transportation Planning and Technology*, **38** (3) 347–374, February 2015.

Moreni, G., J. Wichser, G. Abay, C. Petz and N. Fries (2008) Modal Split Funktionen im Güterverkehr, *Research Report*, Forschungsprojekt SVI 2004/081, **1229**, Vereinigung Schweizerischer Verkehrsingenieure (SVI), Swiss Federal Department for Environment, Transport, Energy and Communication UVEK, Swiss Federal Roads Authority, Zurich, December 2008.

Nebel, R., B. Scholl, K. Widler and K. Hollenstein (2012) Schweizweite Abschätzung der inneren Nutzungsreserven, *Final Report*, Swiss Federal Office for Spatial Development (ARE), IRL, ETH Zurich, Zurich.

OECD (2012) *Redefining "Urban": A New Way to Measure Metropolitan Areas*, Organisation for Economic Co-Operation and Development (OECD), April 2012.

OSM (2017) OpenStreetMap, webpage, May 2017, URL `http://www.openstreetmap.org/directions`.

Pachl, J. (2016) *Systemtechnik des Schienenverkehrs: Bahnbetrieb planen, steuern und sichern*, eighth edn., Springer Fachmedien Wiesbaden, Wiesbaden, ISBN 978-3-658-12986-6.

Ripert, C. and M. Browne (2009) La démarche exemplaire de paris pour le transport de marchandises en ville, *les Cahiers Scientifiques du Transport*, **55**, 39–62.

Ruesch, M. (2012) Raumplanerische Sicherung von Logistikflächen im Raum Basel – Herausforderungen und Lösungsansätze, *Input Paper*, HKBB and Logistikcluster Region Basel, RappTrans, Zurich, September 2012.

Ruesch, M. (2015) Flächeneffiziente Logistik, *Final Report*, HKBB and Logistikcluster Region Basel, RappTrans, Zurich, October 2015.

Ruesch, M., T. Fumasoli, S. Schneider, A. Diolaiuti, P. Khaligh, D. Bruckmann and K. Sänger (2017) Multifunctional small and medium freight facilities, *Research Report*, Forschungsprojekt VSS 2011/807, **1612**, Swiss Association of Road and Transport Professionals (VSS), Swiss Federal Department for Environment, Transport, Energy and Communication UVEK, Swiss Federal Roads Authority, Zurich, August 2017.

Ruesch, M., C. Petz, P. Hegi, U. Haefeli and P. Rütsche (2013) Güterverkehrsplanung in städtischen Gebieten, *Handbook*, NRP 54, Swiss National Science Foundation, Rapp Trans AG, Interface Politikstudien, IRL ETH Zurich, Bern.

Saanen, Y. A. (2004) An approach for designing robotized marine container terminals, Ph.D. Thesis, TU Delft, Delft, December 2004.

Salkeld, R., T. Schiesser, M. Hofer and P. Ruggli (2013) Logistikstandortkonzept Kanton Zürich, *Final Report*, Kanton Zürich, Amt für Verkehr AFV, Ernst Basler+Partner, Zurich, March 2013.

Savy, M. and J. Burnham (2013) *Freight Transport and the Modern Economy*, Routledge.

SBB (2013) *Geometrische Gestaltung der Fahrbahn für Normalspur*, Schweizerische Bundesbahnen, Bern.

SBB (2016) *List of Infrastructure Services 2017*, SBB and BLS and SOB and Thurbo and HBS, Bern, September 2016.

SBB (2017a) Ausbauschritt AS2025, Stand 05.2017 : Angebotskonzept, *Concept*, SBB AG, Infrastruktur, Fahrplan und Netzdesign, Bern, June 2017.

SBB (2017b) Verkehrsleistung auf dem Normalspurnetz SBB Infrastruktur, Güterverkehr : 2001–2016, e-mail, February 2017.

SBB Cargo (2017) Wagentypen-Suche, webpage, January 2017, URL `http://www.sbbcargo.com/de/angebot/wagen-waren/wagentypen-suche.html`.

Scherrer, I. and G. Tobler (2009) Konzept zur Siedlungsentwicklung nach innen, Arbeitshilfe zur Erarbeitung der Agglomerationsprogramme, *Final Report*, Federal Office for the Environment (BAFU), Bern.

Scholl, B., M. Soltaniehha, M. Niedermaier and R. Sonderegger (2016) Challenges and chances for SBB in small and mid-sized communities: Railway stations and spatial development in small and mid-sized communities in Switzerland, *Final Report*, SBB Research Fund, IRL, ETH Zurich, Zurich.

Stead, D. and G. Cotella (2011) Differential Europe: Domestic actors and their role in shaping spatial planning systems, *disP – The Planning Review*, **47** (186) 13–21.

Steele, C. W. and D. Hodge (2011) Background research material for freight facility location selection: A guide for public officials (NCFRP report 13), *Web-Only Document*, **1**, National Cooperative Freight Research Program, Transportation Research Board, Research and Innovative Technology Administration, Washington, D.C.

Stölzle, W., E. Hofmann and K. Oettmeier (2016) Logistikmarktstudie 2016, *Final Report*, GS1 Switzerland, Bern.

TfL (2007a) London freight plan : sustainable freight distribution: a plan for London, *Technical Report*, Transport for London (TfL), London, November 2007.

TfL (2007b) London rail freight strategy, *Technical Report*, Transport for London (TfL), London, August 2007.

TfL (2007c) London rail freight strategy : Planning policy toolkit, *Technical Report*, Transport for London (TfL), London, April 2007.

Tioga (2008) Improving marine container terminal productivity : Development of productivity measures, proposed sources of data, and initial collection of data from proposed sources, *Final Report*, CHCP, Cargo Handling Cooperative Program, The Tioga Group, Inc., Moraga, CA, July 2008.

UIC (2004) *Capacity*, International Union of Railways (UIC), Paris, June 2004.

UIC (2017) *DIUM CH : Uniform distance table for international freight traffic: list of railways stations – list of the railways places of acceptance/delivery*, International Union of Railways (UIC), Paris, July 2017, URL `http://uic.org/dium`.

UNDESA (2016) *The World's Cities in 2016*, United Nations, Department of Economic and Social Affairs, Population Division.

UNECE (2001) *Terminology on Combined Transport*, United Nations Economic Commission for Europe (UNECE), URL `http://www.unece.org/fileadmin/DAM/trans/wp24/documents/term.pdf`.

UNECE (2009) *Illustrated Glossary for Transport Statistics*, United Nations Economic Commission for Europe (UNECE), URL `http://www.unece.org/fileadmin/DAM/trans/main/wp6/pdfdocs/glossen4.pdf`.

US Census (2011) *Urban Area Criteria for the 2010 Census*, Department of Commerce, Bureau of the Census, August 2011, URL `http://www2.census.gov/geo/pdfs/reference/fedreg/fedregv76n164.pdf`.

VöV (2014) *Vorsignaldistanzen*, Verband öffentlicher Verkehr (VöV), Bern, second edn.

VSS (2012) *Kosten-Nutzen-Analysen im Strassenverkehr : Betriebskosten von Strassenfahrzeugen*, Winterthur, February 2012.

Wascosa (2017) Kesselwagen, webpage, January 2017, URL `http://www.wascosa.ch/wagenpark/kesselwagen/`.

Weber, C., E. Tschannen, R. Winkler, S. Graf and I. Bähni (2006) *Das Grünbuch der Stadt Zürich*, Grün Stadt Zürich, Zurich, URL `https://www.stadt-zuerich.ch/gruenbuch`.

Weidmann, U., D. Bruckmann, T. Fumasoli, S. Herrigel and S. Schranil (2015) Innovationen im Bahnsystem: SBB-Fonds für die Forschung zum Management im Verkehrsbereich, *Monograph Series*, **173**, Institute for Transport Planning and Systems (IVT), ETH Zürich, Zurich.

Weidmann, U., P. Frank, T. Fumasoli and S. Moll (2012a) Optimale Netznutzung und Wirksamkeit der Instrumente zu deren Lenkung, *Monograph Series*, **158**, Institute for Transport Planning and Systems (IVT), ETH Zürich, Zurich.

Weidmann, U., W. Huber and T. Fumasoli (2012b) Metrotram : Eine Perspektive für Zürich, *Monograph Series*, **157**, Institute for Transport Planning and Systems (IVT), ETH Zürich and Hochparterre, Zurich.

Weidmann, U., J. Wichser, D. Bruckmann, P. Frank, T. Fumasoli, M. Ruesch, P. Hegi, N. Schick and T. Wieczorek (2014) Anforderungen der Güterlogistik an die Netzinfrastruktur und die langfristige Netzentwicklung in der Schweiz : Forschungspaket UVEK/ASTRA Strategien zum wesensgerechten Einsatz der Verkehrsmittel im Güterverkehr der Schweiz, Teilprojekt C, *Research Report*, **1448**, Swiss Federal Department for Environment, Transport, Energy and Communication and Swiss Federal Roads Authority, Bern.

Appendix A

WP1: Freight transport in urban areas

Table A.1: Correspondence of AMG commodity groups and NST divisions (ARE, 2015)

Commodity group	NST division	
Agricultural products	1	Products of agriculture, hunting, forestry and fishery
Fuels and crude petroleum	2	Coal and lignite; crude petroleum and natural gas
	7	Coke and refined petroleum products
Mining and quarrying products	3	Metal ores and other mining and quarrying products
Food products	4	Food products
Chemical products and synthetics	8	Chemical products
Building material and glass	9	Other non metallic mineral products
Basic metals and metal products	10	Basic metals and metal products
Manufactured and semi-finished products	5	Textiles and textile products; leather and leather products
	6	Wood products (except furniture); paper products
	11	Machinery and equipment
	12	Transport equipment
	13	Furniture; other manufactured goods
Waste	14	Secondary raw materials; wastes
Grouped goods, parcels and others	15	Mail, parcels
	16	Equipment utilized in the transport of goods
	17	Goods being moved for repair
	18	Grouped goods
	19	Unidentifiable goods
	20	Other goods

Table A.2: Examples of truck to rail diversion potential by commodity (SCTG codes) (adapted from Bryan et al. (2007))

Code	Product	Diversion
1	Live animals and fish	0%
2	Cereal grains	40%
3	Other agricultural products	80%
4	Animal feed and products of animal origin, n.e.c.	80%
5	Meat, fish, seafood, and their preparations	20%
6	Milled grain products and preparations, bakery products	40%
7	Other prepared foodstuffs, and fats and oils	40%
8	Alcoholic beverages	40%
9	Tobacco products	0%
10	Monumental or building stone	0%
11	Natural sands	40%
12	Gravel and crushed stone	80%
13	Other non-metallic minerals n.e.c.	80%
14	Metallic ores and concentrates	20%
15	Coal	20%
17	Gasoline and aviation turbine fuel	20%
18	Fuel oils	40%
19	Coal and petroleum products, n.e.c.	80%
20	Basic chemicals	80%
21	Pharmaceutical products	0%
22	Fertilizers	80%
23	Chemical products and preparations, n.e.c.	20%
24	Plastics and rubber	40%
25	Logs and other wood in the rough	20%
26	Wood products	80%
27	Pulp, newsprint, paper, and paperboard	80%
28	Paper or paperboard articles	20%
29	Printed products	0%
30	Textiles, leather, and articles of textiles or leather	20%
31	Non-metallic mineral products	20%
32	Base metal in primary or semi-finished forms and in finished basic shapes	40%
33	Articles of base metal	20%
34	Machinery	20%
35	Electronic and other electrical equipment and components, etc.	20%
36	Motorized and other vehicles (including parts)	40%
37	Transportation equipment, n.e.c.	0%
38	Precision instruments and apparatus	0%
39	Furniture, mattresses and mattress supports, lamps, etc.	20%
40	Miscellaneous manufactured products	20%
41	Waste and scrap	80%
43	Mixed freight	20%

Table A.3: Freight volume from and to urban areas (DEGURBA 1) in Switzerland, 1000 t (data: BFS GTS)

		Cargo type								
NST-division	Total	Liquid bulk	Dry bulk	Large containers	Other containers	Palletised goods	Pre-slung goods	Mobile self-propelled units	Other mobile units	Other cargo types
Agricultural and forestry products	3402.5	290.0	592.6	355.6	102.2	1135.3	292.7	170.1	0.0	464.0
Coal, crude petroleum and natural gas	59.9	55.8	3.6	0.0	0.0	0.4	0.0	0.0	0.0	0.1
Metal ores, mining and quarrying products	18 038.2	137.0	16 124.7	554.6	506.4	380.1	81.7	0.0	0.0	253.7
Food products	9482.6	240.1	253.1	296.3	17.1	6458.9	7.8	0.0	0.0	2209.4
Textiles and leather products	256.7	0.0	0.0	14.0	18.2	138.3	4.8	0.0	0.0	81.5
Wood and paper products	1763.3	1.5	17.3	32.8	97.9	1014.3	332.8	0.0	0.0	266.7
Refined petroleum products	5306.8	5068.7	19.5	50.3	15.9	105.7	0.1	0.0	0.0	46.8
Chemical products	2173.2	778.1	5.3	255.3	31.7	907.8	94.0	0.0	0.0	101.0
Other non metallic mineral products	8636.0	3513.3	2383.3	572.5	109.7	918.9	747.7	0.0	0.0	390.7
Basic metals and metal products	2722.5	0.0	39.6	281.0	117.9	631.1	1423.5	0.0	0.0	229.5
Machinery and equipment	736.6	0.0	0.0	264.7	12.5	278.0	16.9	41.5	0.6	122.3
Transport equipment	335.8	0.0	0.0	13.5	16.4	119.3	10.6	138.0	4.1	34.0
Furniture and other manufactured goods	1038.0	0.0	0.0	5.5	25.6	788.6	28.9	1.5	0.2	187.8
Secondary raw materials, wastes	6943.4	274.1	2794.0	1896.2	764.4	313.8	98.0	20.2	0.0	782.8
Mail, parcels	1127.1	0.0	0.0	7.2	28.9	270.5	7.4	0.0	0.0	813.2
Equipment utilized in the transport of goods	2867.4	0.0	10.6	884.3	228.1	1318.4	9.9	0.0	0.0	416.2
Goods being moved for repair	1986.8	0.0	0.0	63.5	26.5	150.0	583.8	792.2	86.2	284.7
Grouped goods	1888.7	0.0	7.8	227.7	35.4	1395.5	10.6	0.0	0.0	211.7
Unidentifiable goods	512.8	17.2	0.0	209.5	2.9	138.5	0.6	0.0	0.0	144.1
Other goods	79.0	16.7	0.0	2.2	5.0	18.8	7.2	0.0	0.0	29.1
Total	69 357.6	10 392.5	22 251.1	5986.7	2162.6	16 482.0	3758.7	1163.4	91.1	7069.4

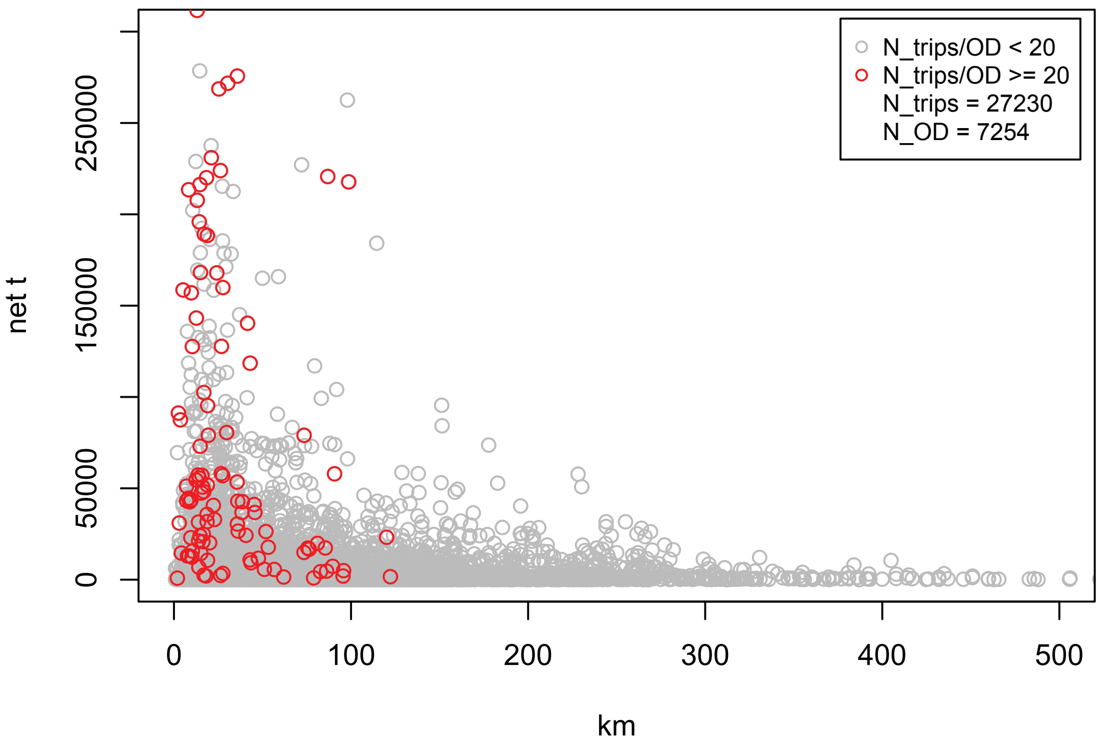


Figure A.1: Freight flows in Switzerland by OD-pair (municipalities), for all regions and commodities, transported by HGV. Highlighted: OD-pairs with more than 20 trips sampled (source: own, data: BFS GTS)

Appendix B

WP3: Rail facilities for freight transhipment

Table B.1: ITE land use classes related to freight (Holguín-Veras et al., 2012)

Land Use Code	Land Use Category
010	Waterport/Marine Terminal
021	Commercial Airport
022	General Aviation Airport
030	Truck Terminal
130	Industrial Park
150	Warehousing
151	Mini-Warehouse
152	High-Cube Warehouse
254	Assisted Living
731	State Motor Vehicles Department
732	United States Post Office
760	Research and Development Center
813	Free-Standing Discount Superstore
815	Free-Standing Discount Store
816	Hardware/Paint Store
860	Wholesale Market
890	Furniture Store
931	Quality Restaurant

Table B.2: NIBA objectives and monetised indicators for cost-benefit analysis (CBA) and non-monetised (DES) indicators, adapted from BAV (2016)

Objectives/Indicators	Type
ENVIRONMENT: - *mitigate local, national and international environmental impacts*	
1 reduce air pollution	
1.1 air pollution	CBA
2 reduce noise exposure	
2.1 noise levels in residential areas	CBA
2.2 noise levels in protected and recreational areas	DES
3 reduce soil sealing	
3.1 soil sealing	CBA
4 reduce pressure on natural habitats and landscapes	
4.1 unfragmented areas	CBA
4.2 landscape and townscapes	DES
- *reduce atmospheric pollution*	
6 reduce damage to the climate	
6.1 emissions of greenhouse gases	CBA
- *preserve natural resources*	
8 reduce consumption of fossil fuels	
8.1 external costs of energy consumption	CBA
8.2 consumption of fossil fuels	DES
ECONOMY: - *establish a good ratio between direct costs and benefits*	
10 minimise direct costs of the project	
10.1 operating costs passenger traffic	CBA
10.2 operating costs goods traffic	CBA
10.3 operating costs infrastructure	CBA
10.4 energy costs	CBA
10.5 maintenance costs	CBA
10.6 average annual capital costs	CBA
11 maximise direct benefits of the project	
11.1 travel time savings for passenger traffic	CBA
11.2 travel time savings for goods traffic	CBA
11.3 benefit of additional rail traffic (passengers)	CBA
11.4 benefit of additional rail traffic (goods)	CBA
12 optimal implementation of the project	
12.1 timetable stability	DES
12.2 implementability in stages	DES
12.3 impacts during construction	DES
- *optimise indirect economic effects*	
14 improve accessibility as an integral part of the economic advantages (. . .)	
14.1 sustainability of large-scale development	DES
15 support balanced regional economic development	
15.1 sustainability of small-scale development	DES
16 increase know-how	
16.1 know-how gained	DES
SOCIETY: - *foster solidarity*	
20 safety/security	
20.1 traffic casualties and injuries	CBA
24 fair distribution of costs and benefits	
24.1 distribution of travel time savings (by cantons)	DES

Appendix C

WP4: System design of rail freight in urban areas

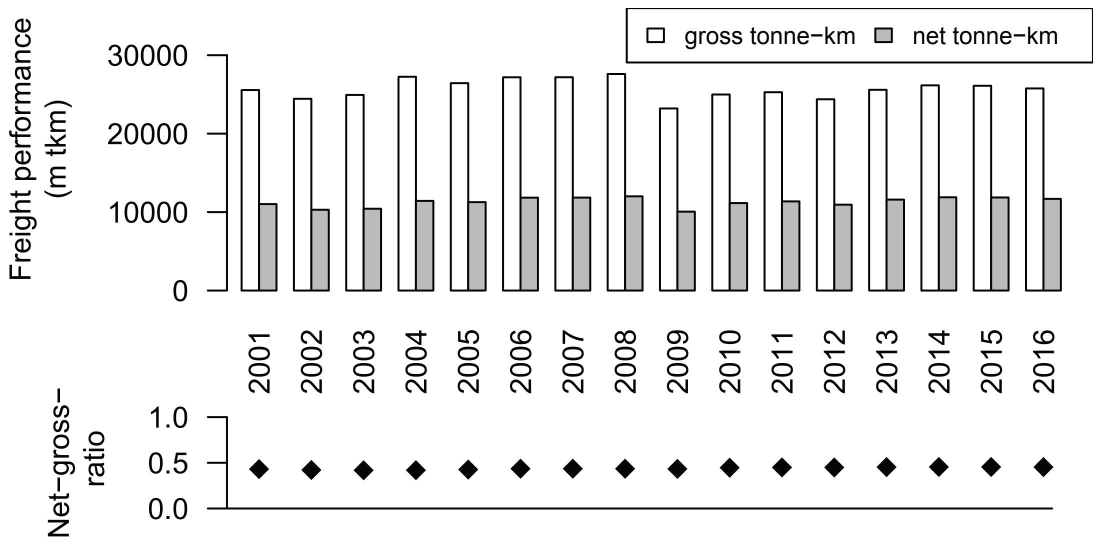


Figure C.1: Rail freight performance and net-gross-ratio in Switzerland, 2001–2016 (SBB, 2017b)

Table C.1: Turnout dimensions in Swiss railway infrastructure (SBB, 2013; BAV, 2014)

Type	Turnout speed	Turnout length		Spacing
		Constructive	Clearance	
	km/h	m	m	m
EW 185-1:9	40	26.546	41.746	11
DW 185-1:9	40	32.600	63.000	–
EW 300-1:12	50	33.275	54.478	15
EW 500-1:14	60	42.074	66.800	18

Table C.2: Bulk material densities (Liebherr, 2017)

Material	Type	Density t/m^3
Gravel	moist	1.9
	dry	1.6
	crushed stone	1.5
Sand	dry	1.5
	wet	1.9
Gravel and Sand	dry	1.7
	wet	2
Sand / Clay		1.6
Clay	natural	1.6
	dry	1.4
Clay / Gravel	dry	1.4
	wet	1.6
Earth	dry	1.3
	wet	1.6
Topsoil		1.1
Basalt		1.95
Granite		1.8
Sandstone		1.6
Slate		1.75
Bauxite		1.4
Limestone		1.6
Gypsum	broken	1.8
Coke		0.5
Slag	broken	1.8
Glass waste	broken	1.4
	solid	1
Compost	dry	0.8
	wet	1
Wood chips / Saw dust		0.5
Paper	shredded / loose	0.6
	recovered paper / cardboard	1
Coal	heavy material density	1.2
	light material density	0.9
Waste	domestic waste	0.5
	bulky waste	1

Legend Table C.3:	
l_mod	Module length
n_trk	Tracks per module
d_clr	Track clearance
d_trk	Loading track width
d_man	Manoeuvring width
d_circ	Circulation width
d_bay	Loading bay width
d_stor	Storage area width
d_total	Total module width (incl. tracks)
A_yrd	Yard area per module
A_stor	Storage area per module
f_area	Additional area
A_mod	Area per module

Legend Table C.4:	
type_wag	wagon type
n_spec	Units per train-metre
n_mod	Units per module
n_cycle	Units per cycle
c_mod	Cycles per module
l_avg	Average distance
v_dev	Device speed
l_lat	Average lateral distance
l_trans	Average transverse distance
v_gan	Gantry speed
v_tro	Trolley speed
t_cycle	Cycle travel time
t_proc	Total cycle process time
t_tot	Total cycle time
Table C.5:	
r_tech	Technical handling rate
f_tg	Technical-gross factor
m_unit	Unit load
r_gross	Gross handling rate
r_spec	Specific handling capacity

Legend Table C.6:	
f_stor	Share of storage transhipments
f_empty	Share of empty returns
p	Transhipment capacity
p_spec	Specific transhipment capacity
t_ops	Operating time (full load hours)
t_year	Working days

Table C.3: Exemplary terminal area calculation (source: own)

Transhipment device	Load unit	l_mod	n_trk	d_clr	d_trk	d_man	d_circ	d_bay	d_stor	d_total	A_yrd	A_stor	f_area	A_mod
		m	–	m	m	m	m	m	m	m	m^2	m^2	–	m^2
Manual														
Roll cage	roll cage	25	1	5	5	6	8	11	6	36	750	150	1.5	1275
Lowlift pallet truck	pallet	25	1	5	5	6	8	11	6	36	750	150	1.5	1275
Industrial trucks														
Forklift single	pallet	50	1	5	5	6	8	11	8	38	1500	400	1.5	2650
Forklift quad	pallet	100	1	5	5	8	8	11	10	42	3200	1000	1.5	5800
Small wheel loader	1 m^3	50	1	5	5	9	8	4	8	34	1300	400	1.5	2350
Small wheel loader	1 m^3	50	1	5	5	9	8	4	8	34	1300	400	1.5	2350
Medium wheel loader	1 m^3	100	1	5	5	12	8	4	12	41	2900	1200	1.5	5550
Medium wheel loader	1 m^3	100	1	5	5	12	8	4	12	41	2900	1200	1.5	5550
Large wheel loader	1 m^3	150	1	5	5	15	8	4	16	48	4800	2400	1.5	9600
Large wheel loader	1 m^3	150	1	5	5	15	8	4	16	48	4800	2400	1.5	9600
Reach stacker	TEU	200	1	5	5	15	8	4	8	40	6400	1600	1.5	11 200
Cranes														
RMG	TEU	200	6	5	30	0	8	4	12	54	8400	2400	1.5	15 000
RTG	TEU	200	4	5	20	0	8	4	12	44	6400	2400	1.5	12 000
Industrial crane	coil	50	1	5	5	0	8	4	4	21	850	200	1.5	1475
On-board devices														
Loader crane	big bag	50	1	5	5	0	8	4	0	17	850	0	1.5	1275
Hooklift hoist	ACTS	50	1	5	5	0	8	11	0	24	1200	0	1.5	1800
Container mover	swap body	50	1	5	5	0	8	4	8	25	850	400	1.5	1675
Tipper lorry	1 m^3	50	1	5	5	0	8	19	0	32	1600	0	1.5	2400
Tipper wagon	1 m^3	100	1	5	5	0	8	0	6	19	1300	600	1.5	2550
Pneumatic pump	1 t	50	1	5	5	0	8	4	0	17	850	0	1.5	1275
Continuous systems														
Medium belt conveyor	1 m^3	50	1	5	5	0	8	4	0	17	850	0	1.5	1275
Small belt conveyor	1 m^3	50	1	5	5	0	8	4	0	17	850	0	1.5	1275
Pump	1 m^3	20	1	5	5	0	8	4	0	17	340	0	1.5	510
Pneumatic pump	1 t	100	1	5	5	0	8	4	0	17	1700	0	1.5	2550

Table C.4: Freight handling parameters for road–rail freight terminals, based on Ruesch et al. (2017); Kemme (2013); Mertel et al. (2012); Tioga (2008); Saanen (2004); Ballis and Golias (2002); Girmscheid (2010)

Transhipment device	type_wag	n_spec unit/m	n_mod units	n_cycle unit/cycle	c_mod cycles	l_avg m	v_dev m/s	l_lat m	l_trans m	v_gan m/s	v_tro m/s	t_cycle s	t_proc s	t_tot s
Manual														
Roll cage	covered	5.00	125	1.0	125	12.3	0.7					18	10	45
Lowlift pallet truck	covered	2.20	55	1.0	55	12.3	0.7					18	30	65
Industrial trucks														
Forklift single	covered	2.20	110	1.0	110	18.5	2.0					9	30	49
Forklift quad	covered	2.20	220	4.0	55	33.0	2.0					17	45	78
Small wheel loader	bulk heavy	2.25	113	1.0	113	21.5	2.0					11	60	82
Small wheel loader	bulk light	4.50	225	1.5	150	21.5	2.0					11	60	82
Medium wheel loader	bulk heavy	2.25	225	2.0	113	37.0	2.0					19	60	97
Medium wheel loader	bulk light	4.50	450	3.0	150	37.0	2.0					19	60	97
Large wheel loader	bulk heavy	2.25	338	4.0	84	52.5	2.0					26	60	113
Large wheel loader	bulk light	4.50	675	6.0	113	52.5	2.0					26	60	113
Reach stacker	flat	0.15	30	1.5	20	65.0	3.0					22	75	118
Cranes														
RMG	flat	0.15	30	1.5	20			10.0	30.0	2.0	0.6	60	40	100
RTG	flat	0.15	30	1.5	20			10.0	20.0	1.5	0.4	57	40	97
Industrial crane	coil	0.40	20	1.0	20			2.5	5.0	0.5	0.3	22	120	142
On-board devices														
Loader crane	open top	2.00	100	1.0	100								180	180
Hooklift hoist	acts	0.15	8	1.0	8								480	480
Container mover	flat	0.12	6	1.0	6								480	480
Tipper lorry	bulk heavy	2.25	113	13.0	9								180	180
Tipper wagon	bulk heavy	2.25	225	30.0	8								210	210
Pneumatic pump	powders	4.00	200											
Continuous systems														
Medium belt conveyor	bulk heavy	2.25	113											
Small belt conveyor	bulk light	4.50	225											
Pump	liquid bulk	4.50	90											
Pneumatic pump	powders	4.00	400											

Table C.5: Calculated handling rates in road–rail freight terminals

Transhipment device	r_tech, c cycles/h	r_tech, u units/h	f_tg –	m_unit t/unit	r_gross, u units/h	r_gross, t t/h	r_spec, u units/h ha	r_spec, t t/h ha
Manual								
Roll cage	80.0	80.0	0.4	0.2	32.0	6.4	251.0	50.2
Lowlift pallet truck	55.4	55.4	0.4	0.4	22.2	8.9	173.8	69.5
Industrial trucks								
Forklift single	74.2	74.2	0.4	0.4	29.7	11.9	112.0	44.8
Forklift quad	46.2	184.6	0.4	0.4	73.8	29.5	127.3	50.9
Small wheel loader	44.2	44.2	0.4	2.0	17.7	35.3	75.2	150.4
Small wheel loader	44.2	66.3	0.4	0.5	26.5	13.3	112.8	56.4
Medium wheel loader	37.1	74.2	0.4	2.0	29.7	59.4	53.5	107.0
Medium wheel loader	37.1	111.3	0.4	0.5	44.5	22.3	80.2	40.1
Large wheel loader	32.0	128.0	0.4	2.0	51.2	102.4	53.3	106.7
Large wheel loader	32.0	192.0	0.4	0.5	76.8	38.4	80.0	40.0
Reach stacker	30.4	45.6	0.4	10.0	18.3	182.5	16.3	163.0
Cranes								
RMG	36.2	54.2	0.4	10.0	21.7	217.0	14.5	144.7
RTG	37.2	55.9	0.4	10.0	22.3	223.4	18.6	186.2
Industrial crane	25.4	25.4	0.4	10.0	10.2	101.6	68.9	689.1
On-board devices								
Loader crane	20.0	20.0	0.4	1.5	8.0	12.0	62.7	94.1
Hooklift hoist	7.5	7.5	0.4	12.0	3.0	36.0	16.7	200.0
Container mover	7.5	7.5	0.4	10.0	3.0	30.0	17.9	179.1
Tipper lorry	20.0	260.0	0.4	2.0	104.0	208.0	433.3	866.7
Tipper wagon	17.1	514.3	0.4	2.0	205.7	411.4	806.7	1613.4
Pneumatic pump		20.0	0.4	1.0	8.0	8.0	62.7	62.7
Continuous systems								
Medium belt conveyor		600.0	0.4	2.0	240.0	480.0	1882.4	3764.7
Small belt conveyor		100.0	0.4	0.5	40.0	20.0	313.7	156.9
Pump		500.0	0.4	1.0	200.0	200.0	3921.6	3921.6
Pneumatic pump		55.0	0.4	1.0	22.0	22.0	86.3	86.3

Table C.6: Calculated transhipment capacity in road–rail freight terminals (source: own)

Transhipment device	f_stor –	f_empty –	p_u units/h	p_t t/h	p_spec, u units/h ha	p_spec, t t/h ha	t_ops h/d	f_yearly d/a	p_u units/a	p_t t/a	p_spec, u units/ha a	p_spec, t t/ha a
Manual												
Roll cage	1.0	1.0	16.0	1.6	125.5	12.5	6	250	24 000.0	2400.0	188 235.3	18 823.5
Lowlift pallet truck	1.0	0.1	11.1	4.0	86.9	31.6	6	250	16 615.4	6042.0	130 316.7	47 387.9
Industrial trucks												
Forklift single	0.6	0.1	18.6	6.7	70.0	25.5	6	250	27 835.1	10 121.8	105 037.9	38 195.6
Forklift quad	0.6	0.1	46.2	16.8	79.6	28.9	6	250	69 230.8	25 174.8	119 363.4	43 404.9
Small wheel loader	0.0	0.0	17.7	35.3	75.2	150.4	8	250	35 337.4	70 674.8	150 372.0	300 744.0
Small wheel loader	0.0	0.0	26.5	13.3	112.8	56.4	8	250	53 006.1	26 503.1	225 558.0	112 779.0
Medium wheel loader	0.0	0.0	29.7	59.4	53.5	107.0	8	250	59 381.4	118 762.9	106 993.6	213 987.2
Medium wheel loader	0.0	0.0	44.5	22.3	80.2	40.1	8	250	89 072.2	44 536.1	160 490.4	80 245.2
Large wheel loader	0.0	0.0	51.2	102.4	53.3	106.7	8	250	102 400.0	204 800.0	106 666.7	213 333.3
Large wheel loader	0.0	0.0	76.8	38.4	80.0	40.0	8	250	153 600.0	76 800.0	160 000.0	80 000.0
Reach stacker	0.6	1.0	11.4	57.0	10.2	50.9	8	250	22 816.9	114 084.5	20 372.2	101 861.2
Cranes												
RMG	0.6	1.0	13.6	67.8	9.0	45.2	12	250	40 684.9	203 424.7	27 123.3	135 616.4
RTG	0.6	1.0	14.0	69.8	11.6	58.2	12	250	41 896.6	209 482.8	34 913.8	174 569.0
Industrial crane	1.0	0.0	5.1	50.8	34.5	344.6	8	250	10 164.7	101 647.1	68 913.3	689 132.6
On-board devices												
Loader crane	0.0	0.0	8.0	12.0	62.7	94.1	8	250	16 000.0	24 000.0	125 490.2	188 235.3
Hooklift hoist	0.0	1.0	3.0	18.0	16.7	100.0	8	250	6000.0	36 000.0	33 333.3	200 000.0
Container mover	0.0	1.0	3.0	15.0	17.9	89.6	8	250	6000.0	30 000.0	35 820.9	179 104.5
Tipper lorry	0.0	0.0	104.0	208.0	433.3	866.7	8	250	208 000.0	416 000.0	866 666.7	1 733 333.3
Tipper wagon	0.0	0.0	205.7	411.4	806.7	1613.4	8	250	411 428.6	822 857.1	1 613 445.4	3 226 890.8
Pneumatic pump	0.0	0.0	8.0	8.0	62.7	62.7	8	250	16 000.0	16 000.0	125 490.2	125 490.2
Continuous systems												
Medium belt conveyor	0.0	0.0	240.0	480.0	1882.4	3764.7	12	250	720 000.0	1 440 000.0	5 647 058.8	11 294 117.6
Small belt conveyor	0.0	0.0	40.0	20.0	313.7	156.9	12	250	120 000.0	60 000.0	941 176.5	470 588.2
Pump	0.0	0.0	200.0	200.0	3921.6	3921.6	12	250	600 000.0	600 000.0	11 764 705.9	11 764 705.9
Pneumatic pump	0.0	0.0	22.0	22.0	86.3	86.3	8	250	44 000.0	44 000.0	172 549.0	172 549.0

Table C.7: Calculated theoretical train capacity in road–rail freight terminals (source: own)

Transhipment device	l_train	T_transh	t_shunt	T_shunt	t_check	T_check	p_rail, u	p_rail, t
	m	h	h/man.	h	h/m	h	units/h	t/h
Manual								
Roll cage	400	15.63	1	2	0.001 67	0.67	109.3	10.9
Lowlift pallet truck	400	5.46	1	2	0.001 67	0.67	108.3	39.4
Industrial trucks								
Forklift single	400	8.15	1	2	0.001 67	0.67	81.4	29.6
Forklift quad	400	6.55	1	2	0.001 67	0.67	95.4	34.7
Small wheel loader	400	12.73	1	2	0.001 67	0.67	58.4	116.9
Small wheel loader	400	16.98	1	2	0.001 67	0.67	91.6	45.8
Medium wheel loader	400	15.16	1	2	0.001 67	0.67	50.5	101.0
Medium wheel loader	400	20.21	1	2	0.001 67	0.67	78.7	39.3
Large wheel loader	400	8.79	1	2	0.001 67	0.67	78.6	157.1
Large wheel loader	400	11.72	1	2	0.001 67	0.67	125.1	62.6
Reach stacker	400	6.57	1	2	0.001 67	0.67	6.5	32.5
Cranes								
RMG	400	2.77	0	0	0.001 67	0.67	17.5	87.4
RTG	400	5.37	0	0	0.001 67	0.67	9.9	49.7
Industrial crane	400	7.87	1	4	0.001 67	0.67	12.8	127.6
On-board devices								
Loader crane	400	25.00	1	2	0.001 67	0.67	28.9	43.4
Hooklift hoist	400	10.00	1	2	0.001 67	0.67	4.7	28.4
Container mover	400	8.00	1	2	0.001 67	0.67	4.5	22.5
Tipper lorry	400	4.33	1	4	0.001 67	0.67	100.1	200.1
Tipper wagon	400	4.38	1	4	0.001 67	0.67	99.5	199.1
Pneumatic pump	400	100.00	1	4	0.001 67	0.67	15.3	15.3
Continuous systems								
Medium belt conveyor	400	3.75	1	8	0.001 67	0.67	72.5	145.0
Small belt conveyor	400	11.25	1	2	0.001 67	0.67	129.3	64.7
Pump	400	3.00	1	8	0.001 67	0.67	154.3	154.3
Pneumatic pump	400	36.36	1	2	0.001 67	0.67	41.0	41.0

Table C.8: Calculated terminal throughput in road–rail freight terminals (source: own)

Transhipment device	l_trk m	l_trk, tot m	n_dev –	p_terminal, u units/h	p_terminal, t t/h	p_max, u units/h	p_max, t t/h	A_term ha	p_spec, max, u units/h ha	p_spec, max, t t/h ha	p_spec, max, u units/ha a	p_spec, max, t t/ha a
Manual												
Roll cage	200	200	8	128.0	12.8	109.3	10.9	1.02	107.2	10.7	160 793.2	16 079.3
Lowlift pallet truck	200	200	8	88.6	32.2	88.6	32.2	1.02	86.9	31.6	130 316.7	47 387.9
Industrial trucks												
Forklift single	200	200	4	74.2	27.0	74.2	27.0	1.06	70.0	25.5	105 037.9	38 195.6
Forklift quad	200	200	2	92.3	33.6	92.3	33.6	1.16	79.6	28.9	119 363.4	43 404.9
Small wheel loader	200	200	4	70.7	141.3	58.4	116.9	0.94	62.2	124.3	124 335.3	248 670.7
Small wheel loader	200	200	4	106.0	53.0	91.6	45.8	0.94	97.5	48.7	194 941.4	97 470.7
Medium wheel loader	200	200	2	59.4	118.8	50.5	101.0	1.11	45.5	91.0	90 985.2	181 970.4
Medium wheel loader	200	200	2	89.1	44.5	78.7	39.3	1.11	70.9	35.4	141 781.1	70 890.6
Large wheel loader	200	200	2	102.4	204.8	78.6	157.1	1.92	40.9	81.8	81 836.8	163 673.6
Large wheel loader	200	200	2	153.6	76.8	125.1	62.6	1.92	65.2	32.6	130 340.3	65 170.2
Reach stacker	200	200	1	11.4	57.0	6.5	32.5	1.12	5.8	29.0	11 594.6	57 973.1
Cranes												
RMG	400	2400	2	27.1	135.6	17.5	87.4	3.00	5.8	29.1	17 483.4	87 417.2
RTG	200	800	1	14.0	69.8	9.9	49.7	1.20	8.3	41.4	24 846.6	124 233.1
Industrial crane	100	100	2	10.2	101.6	10.2	101.6	0.30	34.5	344.6	68 913.3	689 132.6
On-board devices												
Loader crane	200	200	4	32.0	48.0	28.9	43.4	0.51	56.7	85.0	113 394.8	170 092.1
Hooklift hoist	200	200	4	12.0	72.0	4.7	28.4	0.72	6.6	39.5	13 157.9	78 947.4
Container mover	200	200	4	12.0	60.0	4.5	22.5	0.67	6.7	33.6	13 432.8	67 164.2
Tipper lorry	100	100	2	208.0	416.0	100.1	200.1	0.48	208.5	417.0	416 963.6	833 927.3
Tipper wagon	100	100	1	205.7	411.4	99.5	199.1	0.26	390.3	780.7	780 699.4	1 561 398.8
Pneumatic pump	100	100	2	16.0	16.0	15.3	15.3	0.26	59.9	59.9	119 895.1	119 895.1
Continuous systems												
Medium belt conveyor	50	50	1	240.0	480.0	72.5	145.0	0.13	568.5	1137.0	1 705 487.6	3 410 975.1
Small belt conveyor	200	200	4	160.0	80.0	129.3	64.7	0.51	253.6	126.8	760 831.3	380 415.6
Pump	50	50	3	600.0	600.0	154.3	154.3	0.15	1008.4	1008.4	3 025 210.1	3 025 210.1
Pneumatic pump	200	200	2	44.0	44.0	41.0	41.0	0.51	80.4	80.4	160 760.0	160 760.0

Legend Table C.7:	
l_train	Maximum train length
T_transh	Theoretical transhipment time
t_shunt	Shunting time unit
T_shunt	Total shunting time
t_check	Checking time
T_check	Total checking time
p_rail	Train capacity
Table C.8:	
l_trk	Loading track length
l_trk, tot	Total loading length
n_dev	No. of modules
p_terminal	Terminal transhipment capacity
p_max	Maximum terminal throughput
A_term	Terminal area
p_spec, max	Specific maximum terminal throughput

Table C.9: Total railway transport in Europe, 1000 t (Eurostat, 2016)

Country	2007	2008	2009	2010	2011	2012	2013	2014
European Union (28 countries)	1 828 913	1 796 955	1 465 412	1 596 235	1 708 130	:	:	:
European Union (27 countries)	1 813 149	1 782 104	1 453 761	1 584 033	1 696 335	:	:	:
Germany	361 116	371 298	312 087	355 715	374 737	366 140	373 738	365 003
France	111 214	108 536	86 126	85 045	91 789	87 539	88 989	87 411
United Kingdom	104 383	103 180	87 666	89 241	100 364	115 225	117 769	108 531
Switzerland	:	69 864	61 848	63 989	65 038	60 270	64 999	65 375

Table C.10: Railway share of total transport in Europe, 1000 t (Eurostat, 2016)

	2007	2008	2009	2010	2011	2012	2013	2014
European Union (28 countries)	:	9.2%	8.6%	9.3%	9.9%	:	:	:
European Union (27 countries)	9.3%	9.2%	8.6%	9.3%	9.9%	:	:	:
Germany	9.9%	10.0%	9.5%	10.7%	10.5%	10.5%	10.6%	10.0%
France	4.5%	4.6%	4.1%	3.9%	4.1%	4.0%	4.1%	4.2%
United Kingdom	5.2%	5.5%	5.7%	5.5%	5.9%	6.6%	7.2%	6.7%
Switzerland	:	19.4%	17.9%	18.5%	17.7%	16.7%	18.0%	17.7%

Appendix D

WP5: Framework requirements of rail freight in urban areas

D.1 Effect of the freight terminal location

Two types of last-mile freight tours are considered (Fig. D.1): (i) The *TSP*-type transport cycle covers all freight destinations in sequence. It is applicable to less-than-truckload (LTL) transports, where all destinations are served in a single trip. The shortest route is calculated using the "nearest neighbour" algorithm. (ii) The *return-trip*-type consists of single trips from the freight terminal to the freight destinations and back again. It is applicable to all sorts of full truckload (FTL) transports. The order of the destinations is irrelevant.

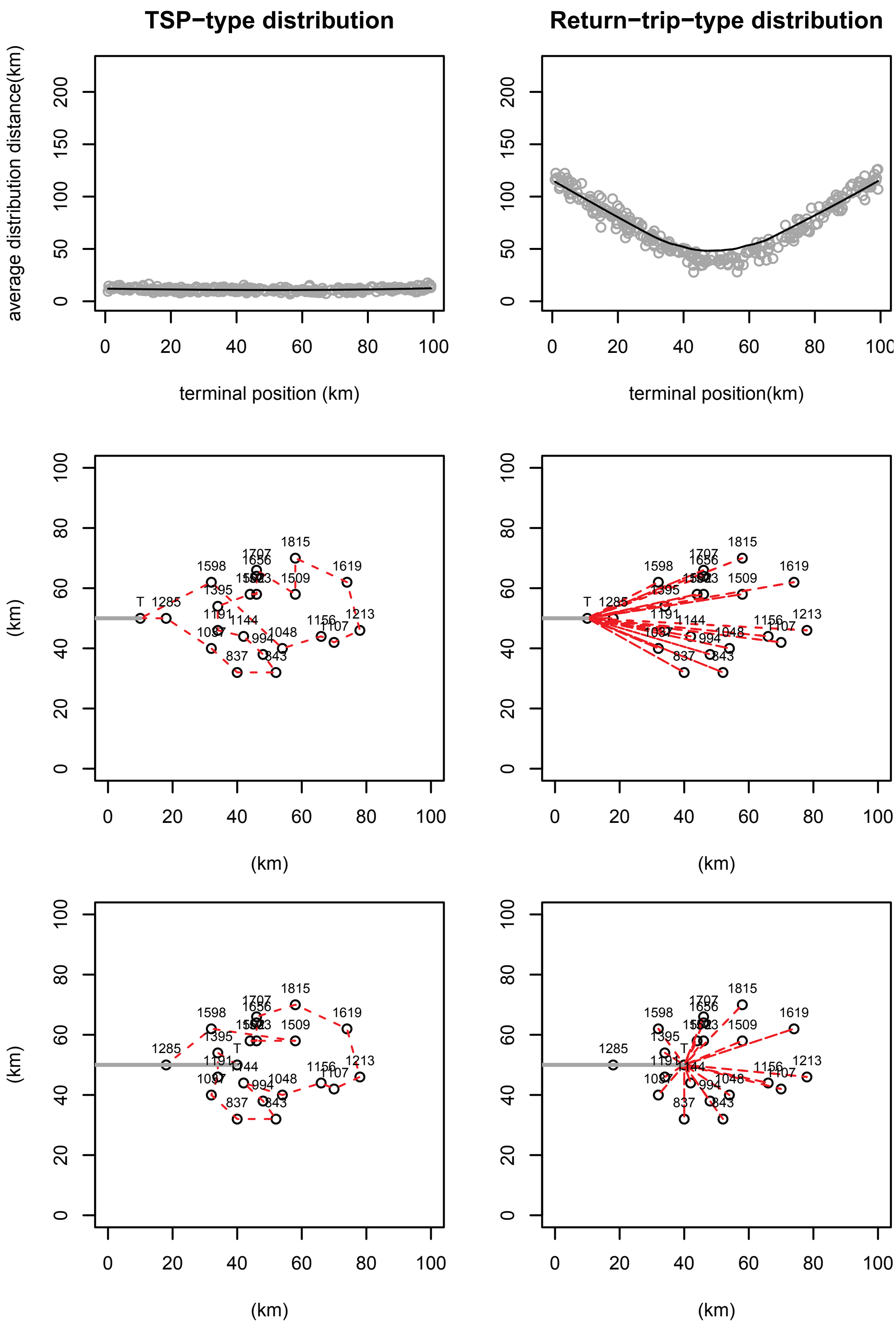


Figure D.1: Estimation of distribution distances as a function of the terminal location (20 destinations, 100 km × 100 km, 256 calculation runs). Examples of generic last-mile distribution tours based on a rectangular grid network (source: own)

D.2 Comparison of road and rail distances

Table D.1: Rail distances for direct transport and via rail hubs, in percentages of the shortest road distance (UIC, 2017; OSM, 2017)

From	To	Hub([1])	Rail direct	Via hub
Estavayer-le-Lac	Genève-La-Praille	LT	93 %	94 %
Härkingen Post	Genève-La-Praille	LT	95 %	95 %
Zürich Mülligen	Härkingen Post	RBL	96 %	96 %
Daillens	Genève-La-Praille	LT	96 %	97 %
Gossau SG	Härkingen Post	RBL	98 %	99 %
Dagmersellen	Zürich Mülligen	RBL	100 %	100 %
Pratteln	St. Gallen St. Fiden	RBL	96 %	101 %
Frauenfeld Paketpost	Basel SBB GB	RBL	98 %	107 %
Buchs SG	Zürich Mülligen	RBL	95 %	112 %
Schönenwerd SO Ost (Spw)	Zürich Mülligen	RBL	115 %	115 %
Emmenbrücke	Basel SBB GB	RBL	101 %	136 %
Dagmersellen	Cadenazzo	RBL	119 %	146 %
Emmenbrücke	Schönenwerd SO	RBL	78 %	165 %
Zürich Herdern	Hüntwangen-Wil	RBL	93 %	190 %
Cornaux	Niederglatt	LT	112 %	227 %
Schönenwerd SO Ost (Spw)	Basel SBB GB	RBL	96 %	234 %
Buchs SG	St. Gallen St. Fiden	RBL	102 %	357 %

([1]) LT: Lausanne-Triage, RBL: Zürich RB Limmattal

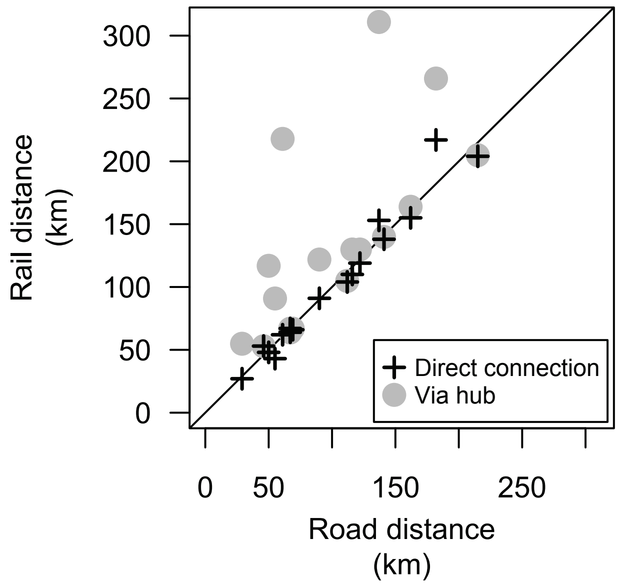
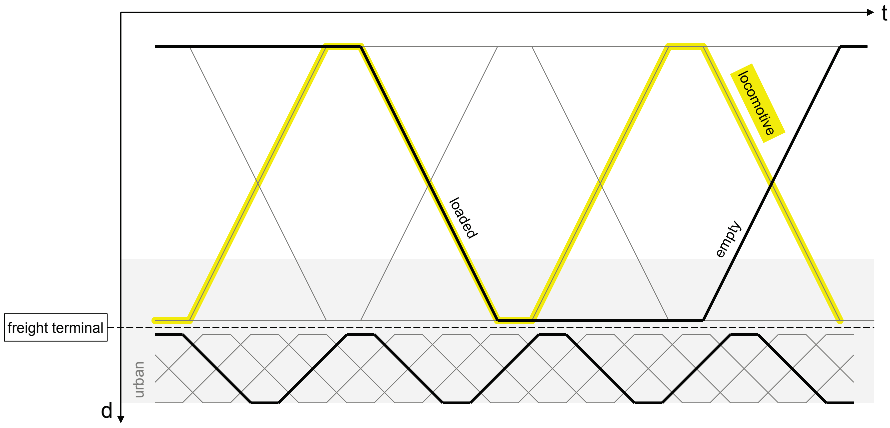
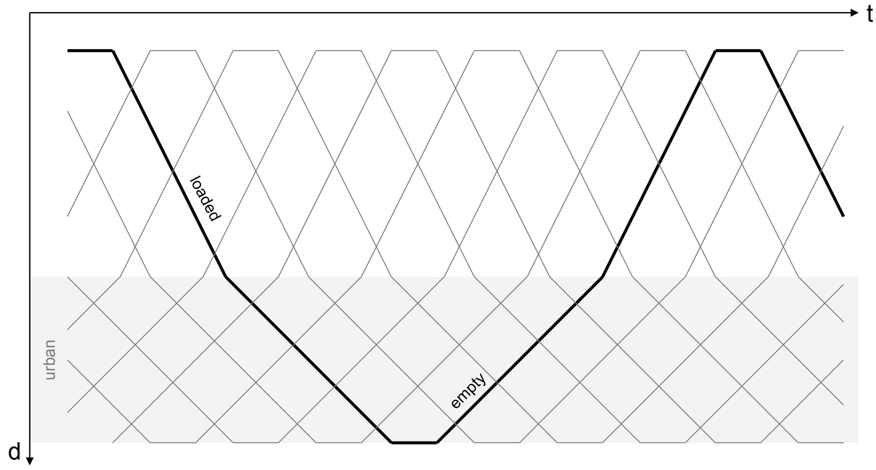


Figure D.2: Comparison of road and rail distances in Switzerland, obtained from UIC (2017); OSM (2017) (source: own)

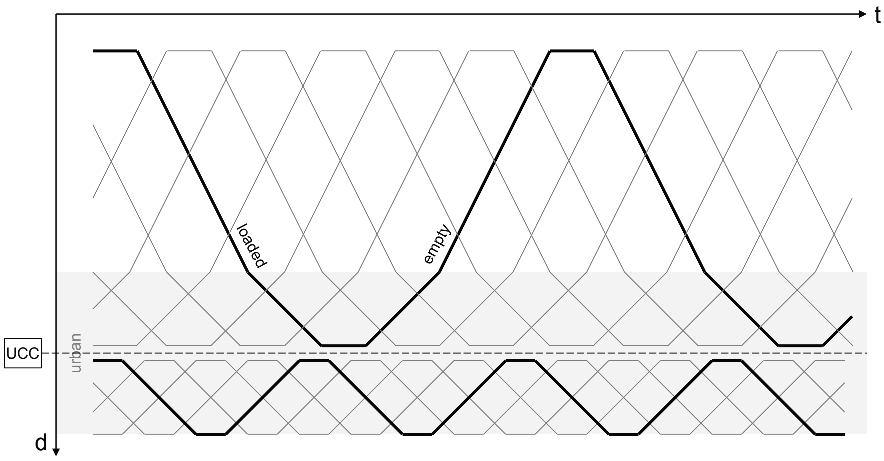
D.3 Vehicle operating systems and cycles



(a) Urban rail



(b) Direct road haulage



(c) Multi-leg road (UCC)

Figure D.3: Vehicle cycles for each VOS (source: own)

D.4 HBEFA fuel consumption data

Table D.2: Average HGV diesel consumption in Switzerland, all road classes and traffic situations, l/100 km (Infras, 2010)

HGV type	LF 0 %	LF 50 %	LF 100 %
Rigid			
20–26 t	23.91	28.96	34.37
26–28 t	25.22	30.73	36.63
28–32 t	28.69	35.49	42.69
32–40 t	27.12	35.15	43.35
Combination			
20–28 t	23.68	29.54	35.49
28–34 t	24.14	31.38	38.30
34–40 t	26.01	35.56	44.79

Table D.3: HGV diesel consumption in Switzerland, main road in built-up areas (speed limit 50 km/h), l/100 km (Infras, 2010)

	Free flow traffic			Stop-and-go traffic		
HGV type	LF 0 %	LF 50 %	LF 100 %	LF 0 %	LF 50 %	LF 100 %
Rigid						
20–26 t	21.67	27.15	32.74	49.83	57.14	64.76
26–28 t	23.93	29.74	35.67	50.66	58.68	66.71
28–32 t	27.50	34.74	42.17	51.47	61.87	72.24
32–40 t	24.77	33.36	41.98	55.60	67.02	78.75
Combination						
20–28 t	21.79	27.97	34.18	47.01	55.25	64.13
28–34 t	22.39	29.88	37.38	47.86	58.04	68.58
34–40 t	24.46	34.36	44.09	55.05	68.25	81.95

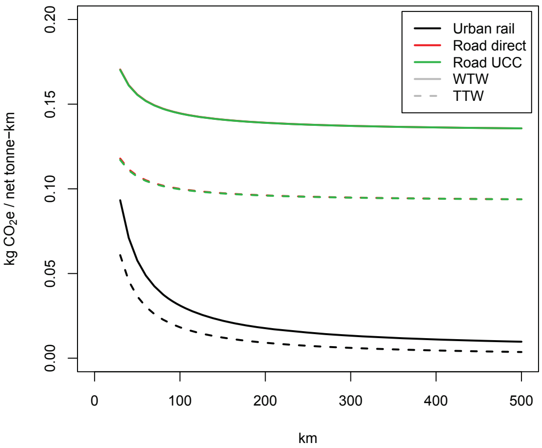
Table D.4: HGV diesel consumption in Switzerland, motorway (speed limit 120 km/h), l/100 km (Infras, 2010)

	Free flow traffic			Stop-and-go traffic		
HGV type	LF 0 %	LF 50 %	LF 100 %	LF 0 %	LF 50 %	LF 100 %
Rigid						
20–26 t	21.23	23.64	26.04	40.40	48.67	57.53
26–28 t	22.30	25.07	27.75	41.55	50.40	59.84
28–32 t	26.40	30.02	33.31	43.68	55.07	66.99
32–40 t	23.73	27.51	31.30	45.40	58.47	71.88
Combination						
20–28 t	20.98	23.82	26.35	39.24	48.81	58.61
28–34 t	21.15	24.51	27.33	40.14	51.83	63.64
34–40 t	22.23	26.41	30.12	45.45	60.61	75.74

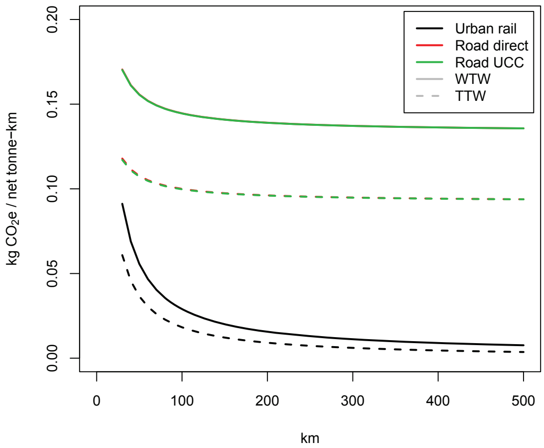
Table D.5: HGV diesel consumption in Switzerland, rural main road (speed limit 80 km/h), l/100 km (Infras, 2010)

	Free flow traffic			Stop-and-go traffic		
HGV type	LF 0 %	LF 50 %	LF 100 %	LF 0 %	LF 50 %	LF 100 %
Rigid						
20–26 t	20.15	24.33	28.49	45.61	53.37	61.42
26–28 t	21.55	26.09	30.57	46.32	54.66	63.49
28–32 t	24.08	29.92	35.55	47.36	58.13	69.32
32–40 t	22.98	29.50	35.72	50.98	62.91	75.42
Combination						
20–28 t	19.58	24.41	29.05	43.11	52.03	61.18
28–34 t	20.02	25.87	31.26	44.03	54.90	65.96
34–40 t	22.08	29.60	36.58	50.94	65.00	79.02

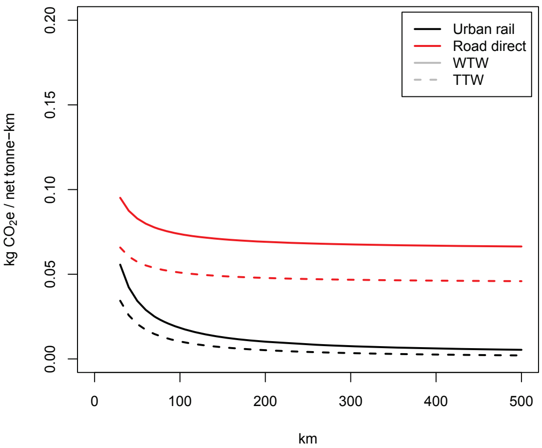
D.5 GHG emissions



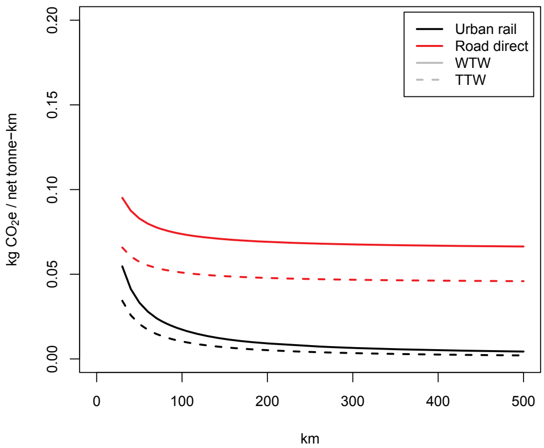
(a) 10 wagons, palletized



(b) 25 wagons, palletized



(c) 10 wagons, bulk



(d) 25 wagons, bulk

Figure D.4: Specific GHG emissions for the transport of palletized and bulk goods (source: own)

Appendix E

Case study

Table E.1: Analysis of parcels adjacent to the case study sites (source: GIS ZH)

Lot ID	Floor-space reserve	Area utilisation	Densities		
			Population	Employment	Total
	m^2	–	pers./ha	pers./ha	pers./ha
Muelligen:					
7545	5196	60.0–79.9%	217	197	414
7835	−853	≥ 80%	239	20	259
7836	2015	≥ 80%	258	180	438
8550	907	≥ 80%	111	477	588
8792	−41 914	≥ 80%	32	1614	1647
7830	383	≥ 80%	459	( )	481
7834	9483	0.1–19.9%	59	( )	60
6783	8993	40.0–59.9%	92	9	101
6780	3041	60.0–79.9%	166	( )	171
7543	10 289	60.0–79.9%	143	15	158
8551	−1763	≥ 80%	86	343	429
7832	2797	60.0–79.9%	276	( )	284
7833	19 360	40.0–59.9%	158	8	165
Hardfeld:					
6110	−2561	≥ 80%	434	294	729
5797	−1908	≥ 80%	537	143	680
5796	544	≥ 80%	413	83	496
6013	−766	≥ 80%	399	( )	406
5549	−4026	≥ 80%	( )	780	839
6012	−4556	≥ 80%	385	( )	391
5795	382	≥ 80%	435	( )	485
6010	−1022	≥ 80%	324	( )	351
5794	4419	60.0–79.9%	246	235	481
5548	−2324	≥ 80%	174	( )	174
6009	−8672	≥ 80%	271	34	305
5793	−1135	≥ 80%	475	21	496