STATE-OF-THE-ART ANALYSIS: CONTINUOUS PRE-PLANNING OF REQUIRED TRANSPORTATION CAPACITY FOR THE DESIGN OF SUSTAINABLE FREIGHT TRANSPORTATION NETWORKS

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1. INTRODUCTION

Increasing volatility in transportation demand challenges logistics service providers and carriers to continuously utilise their transportation resources to a high extent (Handfield, 2013, pp. 14–15), (Wittenbrink, 2014, p. 9). Short-term planning horizons and planning uncertainties lead to unfavourable mode choice and reduced capacity utilisation (Lohre, 2007, p. 16), (Zesch *et al.*, 2011, p. 46), (Wittenbrink, 2014, p. 10). Nevertheless mode choice and capacity utilization have significant influence on ecological efficiency of transport (Keller and Helmreich, 2011, pp. 109–126). For logistics service providers, there is a need for an early detection of demand fluctuations to be able to react adequately to them (Hoff *et al.*, 2010a, p. 2058), (Bielli *et al.*, 2011, p. 16), (Bretzke and Barkawi, 2012, p. 262), (Corsten and Gössinger, 2014, pp. 322–324). Advantageous fields of action lie in anticipatory capacity management measures as foresighted mode choice (Zesch *et al.*, 2011, p. 46), (Wittenbrink, 2014, p. 10), (International Union of Railways, 2017, pp. 45–46) synchronisation of order peaks and declines (Bretzke and Barkawi, 2012, p. 260), vertical and horizontal cooperation actions (Bretzke and Barkawi, 2012, pp. 369–370), (Wittenbrink, 2014, p. 328), and the implementation of new pricing and business models (Stölzle, 2010, p. 174).

Hence, we propose a holistic, network orientated model to pre-plan required transportation capacity and to continuously adjust the intermodal fleet size and composition. In order to do so, a research project called “Continuous pre-planning of required transportation capacity for the design of sustainable freight transportation networks” (IPPO) is introduced. In general, the presented approach aims at a reduction of harmful emissions in physical transport by shifting goods transport from road to rail or waterway and lead to more sustainable transport chains by implementing round-trips. Consequently, a newly developed proof-of-concept demonstrator (“IPPO-Demonstrator”) aims at responding to unknown demand fluctuations and decision making by connecting forecasts, planning and optimisation within one integrated model. The core elements of this demonstrator are:

1. Forecasting logic that is based on the client's forecasts, past transport data and factors of influence (e.g. seasonality, economic growth, plant capacity planning, contracts, strategies etc.) in order to determine higher planning security and more specific and finer granularity of planning
2. Planning of transport by connecting generated transport demand with the capacity available in order to predict discrepancies at an early stage
3. Sustainable optimisation of transport planning by using adequate alternatives of action in order to support sustainable modes of transport rail and waterway and thereby increase ecological and economic potential.

The awareness of demand fluctuations at an earlier stage, gives the opportunity to be able to decide between more alternatives of mode change and capacity adjustment and thus operate more sustainably. It is expected that the model will enable logistics service providers and carriers to organise their transportation networks more economically and ecologically sustainable and in a more flexible way.

Figure 1: "IPPO-Demonstrator's" operating environment

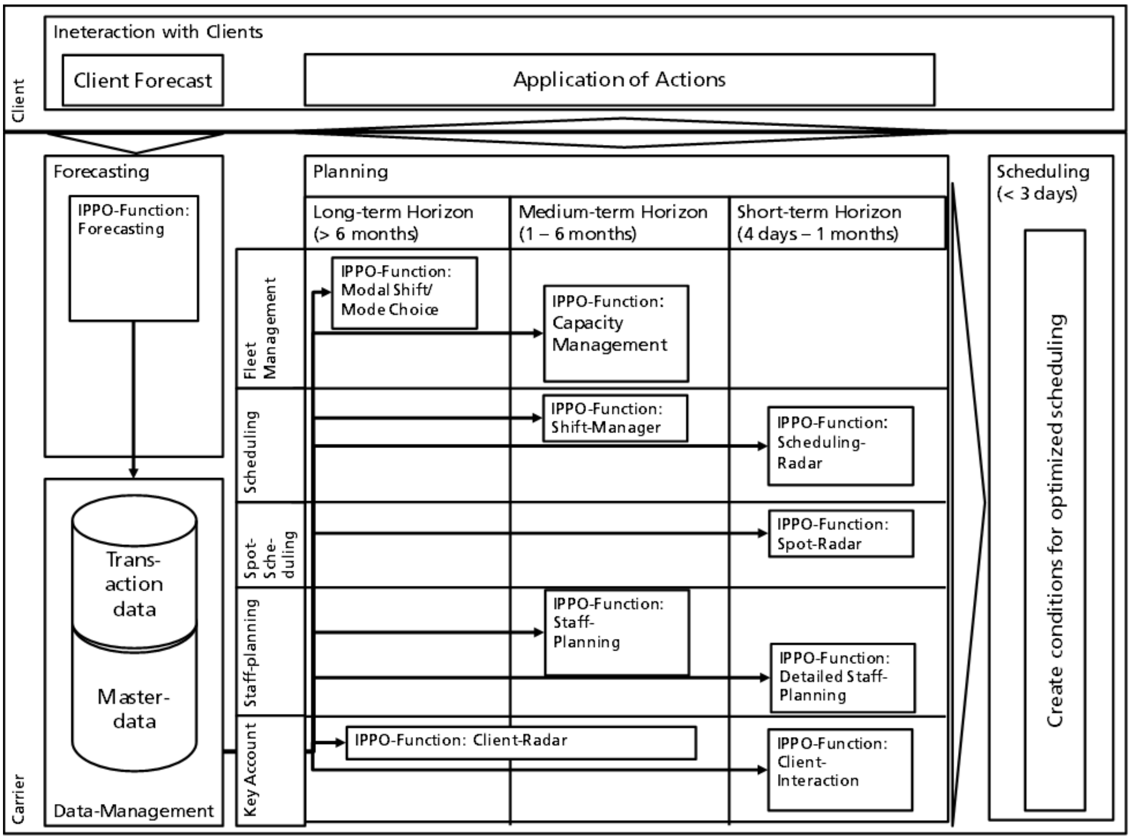

Figure 1 illustrates the basic concept for forecasting and planning processes from the carrier's perspective. It consists of a forecasting function and several planning functions. The forecasting function derives future transport demands from the client's forecasts and from external indicators as input data. The planning section consists of several functions in different time horizons.The concept tries to integrate two perspectives: Capacity demand on one hand, and capacity supply on the other hand. The different functions in the planning section should match projected transport demand and available modes and means of transport.

The paper gives a structured review on intermodal transportation planning problems on strategic, tactical and operational planning levels. Problem types are clustered accordingly and their solution approaches are outlined. For each problem type, involved stakeholders, their planning horizons, regarded actions for capacity adjustment and for transportation mode change as well as defined optimisation parameters are described. Additionally, an overview on solution approaches for each problem type is given.

2. LITERATURE REVIEW

There are several publications giving an overview on recent literature in the field of multimodal transport planning problems, which are discussed in the following:

SteadieSeifi et al. (SteadieSeifi *et al.*, 2014) focus on planning problems from an Operations Research (OR) perspective. They give a structured overview on multimodal transport literature on strategic, tactical and operational levels of planning. Hoff et al. (Hoff *et al.*, 2010a) describe combined fleet composition and routing problems in maritime and road-based transport. Literature of extended and related problems is described and categorised. Bielli et al. (Bielli *et al.*, 2011) focus on recent trends in models of tactical and operational fleet management models. They identify the most relevant problems in fleet management and give an overview on relevant contribution. Reis (Reis, 2014) gives an overview on long distance intermodal services, mainly from the perspective of policy makers. Yaghini and Akhavan (Yaghini and Akhavan, 2012) give a review on network design problems and their application with special regard to rail freight transport planning. Caris et al. (Caris *et al.*, 2008), (Caris *et al.*, 2013) give an overview on planning problems for specific stakeholders along transport chains and on decision support on intermodal transport. Inspired by the given descriptions on multimodal transport problems, we identified publications with implications on the intended forecast supported approach for a continuous pre-planning of required transport capacity for the design of sustainable transport chains. For the identification of best practices and suitable approaches according to continuous preplanning of transport demand and among relevant publications, we have characterized them along seven categories as follows:

1. stakeholders (carrier/service provider, forwarder/client, policy/infrastructure provider)
2. level of planning (strategic, tactic or operational planning level) and planning problems,
3. regarded planning horizon (time span) and demand modelling,
4. capacity adjustment and regarded actions for capacity adjustment,
5. addressed mode of transport (air, rail, road, inland waterway, sea) and mode-change actions,
6. defined models and solution algorithms, and
7. defined optimisation parameters.

2.1. Focused stakeholders

After screening relevant literature, the observed stakeholders are characterised according to the addressed stakeholders and planning tasks similarly to (Caris *et al.*, 2013). All stakeholders who are involved in carrying out transports are subsumed under the category “carrier/service provider”. This category includes stakeholders that can bie associated with carriers themselves, owners of a fleet, railway operators, airlines, public transport operators, CEP-service providers, third-party service providers, terminal operators, network operators and intermodal operators. The category “forwarder/client” includes transport contractors as producers, whole-sale-, retail- as well as e-commerce companies and clients to transport industry in all forms. Papers containing models for a political perspective on infrastructure and network design are labelled with “Policy/Infrastructure provider”. Given this categories, reviewed literature can be allocated as represented in Table 1:

Table 1: Stakeholders

Stakeholder	Publication
Carrier/ service provider	(Couillard and Martel, 1990), (Couillard, 1993), (Bojović, 2002), (Klein, 2006), (Diana *et al.*, 2006), (Hsu and Hsieh, 2007), (Paraskevopoulos *et al.*, 2008), (Bräysy *et al.*, 2008), (Qu *et al.*, 2008), (Godwin *et al.*, 2008), (Andersen *et al.*, 2009), (Katayama *et al.*, 2009), (Pessoa *et al.*, 2009), (Beltran *et al.*, 2009), (Pedersen *et al.*, 2009), (Baldacci *et al.*, 2009), (Bräysy *et al.*, 2009), (Lium *et al.*, 2009), (Schönberger and Kopfer, 2010), (Corman *et al.*, 2010), (Desai and Sen, 2010), (Verma and Verter, 2010), (Cacchiani *et al.*, 2010), (Li and Tao, 2010), (Hewitt *et al.*, 2010), (Lin and Lee, 2010), (Bauer *et al.*, 2010), (Ballis and Dimitriou, 2010), (Hoff *et al.*, 2010a), (Hoff *et al.*, 2010b), (Usha Ramanathan, 2010), (Sayarshad and Tavakkoli-Moghaddam, 2010), (George and Xia, 2011), (Gelareh and Pisinger, 2011), (Anghinolfi *et al.*, 2011), (Andersen *et al.*, 2011), (Merkert and Hensher, 2011), (Moccia *et al.*, 2011), (Chouman and Crainic, 2011), (Meng and Wang, 2011), (Chen and Miller-Hooks, 2012), (Archetti and Speranza, 2012), (Miller-Hooks *et al.*, 2012), (Ayar and Yaman, 2012), (Preuss and Hellingrath), (Crevier *et al.*, 2012), (Meng *et al.*, 2012), (Caris *et al.*, 2012), (Cho *et al.*, 2012), (Domuta *et al.*, 2012), (Meng and Wang, 2012), (Minh *et al.*, 2012), (B. van Riessen *et al.*, 2013), (Wang *et al.*, 2013), (Zhu *et al.*, 2013), (Nguyen *et al.*, 2013), (Shi *et al.*, 2014), (Rahimi-Vahed *et al.*, 2015), (Dožić and Kalić, 2015), (Perez Rivera and Mes, 2015), (Paraskevopoulos *et al.*, 2016), (Braekers and Kovacs, 2016)
Forwarder/ client	(Guélat *et al.*, 1990), (Jin *et al.*, 2010), (Harks *et al.*, 2012), (Kopytov and Abramov, 2012), (Bierwirth *et al.*, 2012), (Pimentel *et al.*, 2013), (Hoen *et al.*, 2014), (Kazan *et al.*, 2015),
Policy/ infrastructure provider	(Arnold *et al.*, 2004), (Jong and Ben-Akiva, 2007), (Yamada *et al.*, 2009), (Pazour *et al.*, 2010), (Bai *et al.*, 2012), (Samimi *et al.*, 2014), (Mitra and M. Leon, 2014), (Reis, 2014), (Arencibia *et al.*, 2015), (Román *et al.*, 2016),

As Table 1 implies, the focus of our research is on planning problems concerning carriers and service providers. We point out that a clear allocation is not always possible. General model descriptions on network design or network flow problems as for example presented in (Minh *et al.*, 2012) or in (Nguyen *et al.*, 2013) can be allocated to two or even all of the stakeholder groups.

2.2. Level of planning problems

After screening relevant literature, the observed stakeholders are characterised similarly to (Caris *et al.*, 2008) and (SteadieSeifi *et al.*, 2014) according to planning level and appropriate planning tasks.

According to their definition, we define strategic planning problems as related to long-term investment decisions on present infrastructures (networks) (SteadieSeifi *et al.*, 2014). Cooperation and alliance strategies can be referred to strategic planning levels (Caris *et al.*, 2008), (Wang *et al.*, 2013) as well. According to (Miller-Hooks *et al.*, 2012), (Chen and Miller-Hooks, 2012) the planning of resilience and risk measures do also refer to strategic planning problems. Additionally, we classify policies and policy measures for the establishment of multimodal transport services, as it refers to network infrastructure evaluation and utilization as strategic planning issues (Caris *et al.*, 2008).

Tactical planning problems deal with the efficient use of a given infrastructure network. This includes the configuration of the network flow (e.g. choosing services, associated transport modes, allocation capacities to orders, and planning their frequencies). SteadieSeifi et al. (SteadieSeifi *et al.*, 2014) refer to these issues as Network Flow Planning (NFP), planning decisions addressing the movement of orders (commodities) throughout the network, and Service Network Design (SND), choosing the transport services and modes to move those commodities. Capacity (i.e. Capacity levels of equipment and fleet size) management and measures for dimensioning of resources are referred to as tactical planning problems (Harks *et al.*, 2012), even though the boundaries of planning levels are also blurring in this aspect (Caris *et al.*, 2008). Revenue Management (Pricing strategies) is referred to as tactical planning problems as well (Caris *et al.*, 2008).

Operational planning problems also refer to the best choice of services and the allocation of resources to the demand. As operational problems are also dealing with the routing on intermodal networks, we see NFP and SND in operational planning level. Operational planning problems are dealing with short-term routing and scheduling of resources, oftentimes answering real-time requirements and dealing with dynamicity and stochasticity (Caris *et al.*, 2008), (Hoff *et al.*, 2010a), (SteadieSeifi *et al.*, 2014).

Table 2 summarises relevant publications with their predominant planning problem associated with a planning level.

Table 2: Classification of planning problems

Level of planning	Publication
Strategic planning problems	
Multimodal infrastructure network design and control policy	(Arnold *et al.*, 2004), (Jong and Ben-Akiva, 2007), (Yamada *et al.*, 2009), (Pazour *et al.*, 2010), (Lin and Lee, 2010), (Gelareh and Pisinger, 2011), (Bai *et al.*, 2012), (Pimentel *et al.*, 2013), (Reis, 2014), (Mitra and M. Leon, 2014), (Samimi *et al.*, 2014), (Arencibia *et al.*, 2015), (Román *et al.*, 2016)
Cooperation	(Usha Ramanathan, 2010), (Caris *et al.*, 2012)
Risk Management	(Miller-Hooks *et al.*, 2012), (Chen and Miller-Hooks, 2012)
Tactical planning problems	
Capacity levels of equipment and fleet size	(Couillard and Martel, 1990), (Couillard, 1993), (Bojović, 2002), (Diana *et al.*, 2006), (Hsu and Hsieh, 2007), (Godwin *et al.*, 2008), (Andersen *et al.*, 2009), (Sayarshad and Tavakkoli-Moghaddam, 2010), (Li and Tao, 2010), (Hoff *et al.*, 2010a), (Schönberger and Kopfer, 2010), (Merkert and Hensher, 2011), (George and Xia, 2011), (Kopytov and Abramov, 2012), (Wang *et al.*, 2013), (Hoen *et al.*, 2014), (Rahimi-Vahed *et al.*, 2015), (Dožić and Kalić, 2015), (Perez Rivera and Mes, 2015), (Kazan *et al.*, 2015)
Network flow configuration	(Qu *et al.*, 2008), (Pedersen *et al.*, 2009), (Beltran *et al.*, 2009), (Desai and Sen, 2010), (Jin *et al.*, 2010), (Anghinolfi *et al.*, 2011), (Chouman and Crainic, 2011), (Meng and Wang, 2012), (Meng *et al.*, 2012), (Domuta *et al.*, 2012), (B. van Riessen *et al.*, 2013), (Zhu *et al.*, 2013), (Braekers and Kovacs, 2016),
Pricing strategy	(Klein, 2006), (Crevier *et al.*, 2012),
Operational planning problems	
Multimodal Routing and Scheduling	(Guélat *et al.*, 1990), (Bräysy *et al.*, 2008), (Paraskevopoulos *et al.*, 2008), (Lium *et al.*, 2009), (Katayama *et al.*, 2009), (Pessoa *et al.*, 2009), (Baldacci *et al.*, 2009), (Bräysy *et al.*, 2009), (Cacchiani *et al.*, 2010), (Corman *et al.*, 2010), (Hewitt *et al.*, 2010), (Ballis and Dimitriou, 2010), (Verma and Verter, 2010), (Bauer *et al.*, 2010), (Hoff *et al.*, 2010b), (Moccia *et al.*, 2011), (Andersen *et al.*, 2011), (Cho *et al.*, 2012), (Ayar and Yaman, 2012), (Archetti and Speranza, 2012), (Minh *et al.*, 2012), (Nguyen *et al.*, 2013), (Shi *et al.*, 2014), (Paraskevopoulos *et al.*, 2016)

2.3. Multimodal infrastructure network design and control policy

The section summarizes the identified models and solution approaches, associated to multimodal infrastructure network design and multimodal infrastructure policy. Assigned models do have long-term objectives and do not primarily aim at movable equipment and fleet.

1. Regarded planning horizons and demand modelling

Models in "Multimodal infrastructure network design and control" with reference to capacity adjustment and modal choice have a focus on economic factors, influencing multimodal transport. Therefore, political stakeholders are one of the main focused actors (Arnold *et al.*, 2004), (Jong and Ben-Akiva, 2007), (Yamada *et al.*, 2009), (Pazour *et al.*, 2010), (Reis, 2014), (Samimi *et al.*, 2014), (Mitra and M. Leon, 2014), (Arencibia *et al.*, 2015), , (Román *et al.*, 2016),.

Typical tasks are an evaluation of freight demand on different modes of transport (Jong and Ben-Akiva, 2007), in order to plan infrastructure (Arnold *et al.*, 2004), (Yamada *et al.*, 2009), (Pazour *et al.*, 2010), or to analyse sensitivity of infrastructure users to political or economic measures (Mitra and M. Leon, 2014), (Samimi *et al.*, 2014), (Román *et al.*, 2016). Additional problems are hub location and infrastructure investment problems for logistic service providers (Lin and Lee, 2010), (Gelareh and Pisinger, 2011), (Meng and Wang, 2011) as well as the design of production networks (Pimentel *et al.*, 2013).

Some models do define a certain planning horizon (Jong and Ben-Akiva, 2007), (Reis, 2014), most don't give specifications in this regard. However, there are different types of periodization within the planning horizon, but no reference on a rolling planning problem. Transport demand within the defined planning horizon is mostly defined in a deterministic way and is given as an input to the referred planning model (Arnold *et al.*, 2004), (Jong and Ben-Akiva, 2007), (Yamada *et al.*, 2009), (Pazour *et al.*, 2010), (Reis, 2014), (Samimi *et al.*, 2014), (Mitra and M. Leon, 2014), (Román *et al.*, 2016). There is no forecasting procedure specified, even though some models vary initial transport demand for sensitivity analysis (Reis, 2014) or deal with specified demand functions (Lin and Lee, 2010), (Gelareh and Pisinger, 2011).

2. Capacity adjustment and regarded actions for capacity adjustment

Only a few references regard capacity adjustment as an issue. Typical measures for capacity adjustment within the category of multimodal infrastructure network design and control policy are:

- Integration of hubs and facilities (Lin and Lee, 2010), (Gelareh and Pisinger, 2011), (Meng and Wang, 2011)
- Integration of feeder lines (Gelareh and Pisinger, 2011), (Pimentel *et al.*, 2013)
- Additional rail capacity or reduction of rail capacity (Pazour *et al.*, 2010), (Reis, 2014)

3. Addressed mode of transport and mode-change actions

The evaluation of modes of transport is a big issue in regarded models. We have identified several models, taking into account two or more modes of transport as follows:

- Two modes of transport (Arnold *et al.*, 2004), (Pazour *et al.*, 2010), (Samimi *et al.*, 2014), (Reis, 2014).
- Three or more modes of transport (Jong and Ben-Akiva, 2007), (Yamada *et al.*, 2009), (Arencibia *et al.*, 2015), (Román *et al.*, 2016).

Identified mode choice parameters can be summarised as follows:

- Costs (Arnold *et al.*, 2004), (Jong and Ben-Akiva, 2007), (Yamada *et al.*, 2009), (Samimi *et al.*, 2014), (Mitra and M. Leon, 2014), (Reis, 2014), (Arencibia *et al.*, 2015), (Román *et al.*, 2016).
- Duration/transit time (Pazour *et al.*, 2010), (Samimi *et al.*, 2014), (Mitra and M. Leon, 2014), (Reis, 2014), (Arencibia *et al.*, 2015), (Román *et al.*, 2016).
- Reliability/Punctuality (Reis, 2014), (Arencibia *et al.*, 2015)
- Delays (Mitra and M. Leon, 2014), (Román *et al.*, 2016)
- Capacity and transport volume (Yamada *et al.*, 2009), (Mitra and M. Leon, 2014).
- Value of goods (Samimi *et al.*, 2014)
- Weight of goods (Samimi *et al.*, 2014)
- Type of Industry (Samimi *et al.*, 2014)
- Location (Samimi *et al.*, 2014)
- Safety (Román *et al.*, 2016)
- Frequency (Arencibia *et al.*, 2015), (Arencibia *et al.*, 2015), (Román *et al.*, 2016).
- Flexibility (Reis, 2014), (Arencibia *et al.*, 2015)
- Damages (Arencibia *et al.*, 2015)
- Track & trace (Arencibia *et al.*, 2015)
- Environmental impact (Arencibia *et al.*, 2015)

4. Defined model and solution approach

Table 3 summarises found models and solution approaches:

Table 3: Multimodal infrastructure network design and control policy

Solution approach	**Model/Problem Formulation**	**Reference**
Game theory	Hub location problem	(Lin and Lee, 2010)
Heuristic model	Incapacitated network design problem	(Pazour *et al.*, 2010)
	Forecast infrastructure capacity demand	(Yamada *et al.*, 2009)
	Stochastic capacity planning and dynamic network design problem (SCPDNDP)	(Pimentel *et al.*, 2013)
Genetic algorithm	Hub-and-spoke network problem for infrastructure investment evaluation	(Meng and Wang, 2011)
Mixed integer programming	Fleet deployment and hub location network problem (FDHLN)	(Gelareh and Pisinger, 2011)
	Hub location problem	(Arnold *et al.*, 2004)
(Agent-based-)Simulation	Definition of decision variables for transport mode selection, shipment size	(Reis, 2014), (Jong and Ben-Akiva, 2007), (Samimi *et al.*, 2014),
Latent class model	Analysis of mode choice decision variables	(Román *et al.*, 2016)

5. Defined optimization parameters

Several approaches are formulated as mathematical optimisation problems. The following optimisation objectives have been identified explicitly:

- Maximise revenue/profit (Lin and Lee, 2010), (Gelareh and Pisinger, 2011)
- Minimise investment costs (Yamada *et al.*, 2009), (Meng and Wang, 2011)
- Minimise operative (fix and/or variable) costs (Yamada *et al.*, 2009), (Pimentel *et al.*, 2013)
- Minimise transport duration (Pazour *et al.*, 2010)

2.4. Cooperation

In the problem class of cooperation, we focus on identified models with a primary objective on cooperation in multimodal transport, which are discussed below.

1. Regarded planning horizons and demand modelling

We have found two models giving a special emphasis on cooperation with references to capacity adjustment and modal choice (Puettmann and Stadtler, 2010), (Caris *et al.*, 2012). Both problems refer to cooperation schemes used by logistics service providers on operational day-to-day business. As the authors aim at showing long-term advances of cooperation for decision makers, we classify the issue as a strategic one.

Both models specify a planning horizon; Caris et al. (Caris *et al.*, 2012) define it with one week. Puettmann et al. (Puettmann and Stadtler, 2010) segment the planning horizon in time periods for operational planning with stochastic demand.

2. Capacity adjustment and regarded actions for capacity adjustment

Detected models refer to limited capacity in the owned fleet. Therefore, cooperation should help to increase capacity utilisation and reduce costs. The following measures are addressed:

- Outsourcing of transports (Puettmann and Stadtler, 2010)
- Consolidation for higher capacity utilisation (Puettmann and Stadtler, 2010), (Caris *et al.*, 2012)

3. Addressed mode of transport and mode-change actions

Cooperation is an issue on high capacity modes of transport. Therefore, the focused mode of transport is water in both models (inland waterway and ocean freight).

4. Defined model and solution approach

Table 4 contains exposed models with a primary objective of cooperation in multimodal transport:

Table 4: Cooperation

Solution approach	Model/Problem Formulation	Reference
Scenario generation (combination of several approaches)	Coordination of operations of independent service providers and consolidation of transports	(Puettmann and Stadtler, 2010)
Mixed integer programming		(Caris *et al.*, 2012)

5. Defined optimization parameters

Both models involve mathematical optimisation formulation. The following issues are set as objectives within their models:

- Minimise of operative (fix and/or variable) costs (Puettmann and Stadtler, 2010), (Caris *et al.*, 2012)
- Minimise outsourcing costs (Puettmann and Stadtler, 2010)

2.5. Risk Management

In the problem class of risk management, we summarise models with a primary objective on risk management in multimodal transport, which are discussed below.

1. Regarded planning horizons and demand modelling

Miller-Hooks (Miller-Hooks *et al.*, 2012) et al. and Chen et al. (Chen and Miller-Hooks, 2012) refer to risk management in intermodal transport. Within this category, their focus is on resilience of transport networks and the flow of goods through a network, even though there are disruptions in certain arcs. For their models, there is no planning horizon or periodization specified.

2. Capacity adjustment and regarded actions for capacity adjustment

In respect of a proper reaction to disruption in the transport network, both models are taking capacity adjustment measures to enhance limited capacity into account:

- Enhance capacity on certain arcs (Chen and Miller-Hooks, 2012), (Miller-Hooks *et al.*, 2012)

3. Addressed mode of transport and mode-change actions

Miller-Hooks et al. (Miller-Hooks *et al.*, 2012) is focussing on rail transports. Chen et al. (Chen and Miller-Hooks, 2012) is involving intermodal transport on rail, road and air.

4. Defined model and solution approach

Table 5 contains detected models with a primary objective of risk management in multimodal transport:

Table 5: Risk Management

Solution approach	**Model/Problem Formulation**	**Reference**
Stochastic programming	Maximizing resilience of freight transport on (intermodal) networks	(Chen and Miller-Hooks, 2012), (Miller-Hooks *et al.*, 2012)

5. Defined optimization parameters

Both models formulate mathematical optimisation objectives:

- Minimise of transport volume that cannot be delivered from origin to destination in case of disruption (Chen and Miller-Hooks, 2012)
- Maximize network-throughput in case of disruption (Miller-Hooks *et al.*, 2012)

2.6. Capacity level of equipment and fleet size

In this problem class, we focus on identified models dealing with capacity control and dimensioning of movable equipment and fleet, which are discussed below.

1. Regarded planning horizons and demand modelling

Within this category, we set a special focus on dimensioning equipment and fleet size from the perspective of carriers and service providers (Couillard and Martel, 1990), (Couillard, 1993), (Diana *et al.*, 2006), (Hsu and Hsieh, 2007), (Godwin *et al.*, 2008), (Andersen *et al.*, 2009), (Li and Tao, 2010), (Sayarshad and Tavakkoli-Moghaddam, 2010), (George and Xia, 2011), (Merkert and Hensher, 2011), (Wang *et al.*, 2013), (Dožić and Kalić, 2015), (Perez Rivera and Mes, 2015). Most of the models do define a planning horizon, either in an abstract way (time frame is not specified) or in a specified way (time frame is specified). Additionally, some models do differentiate discrete time periods within the planning horizon:

- Single periodic planning: Specified or abstract planning horizon

(Couillard and Martel, 1990), (Couillard, 1993), (Diana *et al.*, 2006), (Hsu and Hsieh, 2007), (George and Xia, 2011), (Merkert and Hensher, 2011), (Wang *et al.*, 2013)
- Multi periodic planning: Specified or abstract planning horizon and periodization within the planning horizon, (Andersen *et al.*, 2009), (Schönberger and Kopfer, 2010), (Sayarshad and Tavakkoli-Moghaddam, 2010), (Li and Tao, 2010), (Perez Rivera and Mes, 2015), (Dožić and Kalić, 2015), (Rahimi-Vahed *et al.*, 2015)

Some authors specify transport demand deterministic as an input-parameter for their models (Andersen *et al.*, 2009), (Sayarshad and Tavakkoli-Moghaddam, 2010), (Li and Tao, 2010), (Wang *et al.*, 2013), (Rahimi-Vahed *et al.*, 2015). Some of the models calculate fleet and equipment size regarding stochastic demand (Couillard and Martel, 1990), (Couillard, 1993), (Diana *et al.*, 2006), (Perez Rivera and Mes, 2015). One example refers to the modelling of future demand with a multiple linear regression approach to determine future transport demand (Dožić and Kalić, 2015).

2. Capacity adjustment and regarded actions for capacity adjustment

The models do take into account capacity limits. Some imply restricted capacity to their means of transport in order to calculate necessary capacity (Diana *et al.*, 2006), (Godwin *et al.*, 2008), (Wang *et al.*, 2013), others even specify measures for capacity adjustment such as:

- Lease means of transport (Couillard and Martel, 1990), (Couillard, 1993), (Rahimi-Vahed *et al.*, 2015)
- Invest in additional means of transport (Rahimi-Vahed *et al.*, 2015)
- Use mean of transport of an alternative fleet (Couillard, 1993), (Couillard and Martel, 1990),
- Postpone/reject transport demand (Couillard and Martel, 1990), (Couillard, 1993), (Andersen *et al.*, 2009), (Schönberger and Kopfer, 2010), (Sayarshad and Tavakkoli-Moghaddam, 2010), (Perez Rivera and Mes, 2015)
- Adjust allocation of means of transports (Hsu and Hsieh, 2007), (Li and Tao, 2010), (George and Xia, 2011), (Dožić and Kalić, 2015)

3. Addressed mode of transport and mode-change actions

None of the addressed publications does imply measures for the change of transport modes for capacity adjustments. All of them do focus on one single mode of transport as listed below:

- Road (Couillard and Martel, 1990), (Couillard, 1993), (Diana *et al.*, 2006), (Li and Tao, 2010), (Schönberger and Kopfer, 2010), (George and Xia, 2011), (Rahimi-Vahed *et al.*, 2015)

- Rail (Godwin *et al.*, 2008), (Andersen *et al.*, 2009), (Sayarshad and Tavakkoli-Moghaddam, 2010)
- Water (Hsu and Hsieh, 2007), (Wang *et al.*, 2013), (Perez Rivera and Mes, 2015)
- Air (Merkert and Hensher, 2011), (Dožić and Kalić, 2015)

Even though in most cases a single mode of transport or no mode of transport is specified, some models take into account inhomogeneous fleets (Couillard and Martel, 1990), (Couillard, 1993), (Hsu and Hsieh, 2007), (Rahimi-Vahed *et al.*, 2015), (Dožić and Kalić, 2015)

4. Defined model and solution approach

Table 6 contains disclosed models dealing with capacity control and dimensioning of movable equipment and fleet:

Table 6: Capacity level of equipment and fleet size

Solution approach	**Model/Problem Formulation**	**Reference**
Mixed integer programming	Capacity control and revenue optimisation	(Schönberger and Kopfer, 2010)
	Service Network Design with Asset Management and multiple Fleet Coordination (SNDAM-mFC)	(Andersen *et al.*, 2009)
	Definition of route specific capacity utilisation	(Dožić and Kalić, 2015)
Linear programming		(Wang *et al.*, 2013)
Queuing theory	Fleet sizing	(George and Xia, 2011)
Dynamic programming		(Couillard and Martel, 1990), (Couillard, 1993), (Li and Tao, 2010)
Stochastic programming		(Diana *et al.*, 2006),
Heuristic model		(Li and Tao, 2010), (Rahimi-Vahed *et al.*, 2015)
Simulation		(Godwin *et al.*, 2008)
Linear programming	Fleet size and mix vehicle routing problem (FSMVRP)	(Hoff *et al.*, 2010a)
Dynamic programming	Anticipatory freight selection	(Perez Rivera and Mes, 2015)

5. Defined optimization parameters

Most of the models do refer to an optimisation problem. The optimisation objective differs, depending on model requirements as listed below:

- Minimise investment costs (Couillard and Martel, 1990),
- Minimise operative (fix and/or variable) costs (Hsu and Hsieh, 2007), (Andersen *et al.*, 2009), (Hoff *et al.*, 2010a), (Sayarshad and Tavakkoli-Moghaddam, 2010). (Perez Rivera and Mes, 2015),
- Minimise costs for outsourcing of transports (Couillard and Martel, 1990)
- Maximize revenue/profit (Li and Tao, 2010), (Sayarshad and Tavakkoli-Moghaddam, 2010), (Schönberger and Kopfer, 2010), (George and Xia, 2011),

- Minimise throughput time (Andersen *et al.*, 2009)
- Minimise costs for lost sales (Li and Tao, 2010), (Sayarshad and Tavakkoli-Moghaddam, 2010)
- Inventory costs (Hsu and Hsieh, 2007)

2.7. Network flow configuration

The problem class of network flow configuration summarises models dealing with the assignment of intermodal means of transport to network arcs and the flow of good through a given network.

1. Regarded planning horizons and demand modelling

The problem class of network flow configuration addresses carriers (Qu *et al.*, 2008), (Beltran *et al.*, 2009), (Anghinolfi *et al.*, 2011), (Moccia *et al.*, 2011), (Meng and Wang, 2012), (Meng *et al.*, 2012), (Zhu *et al.*, 2013), (Braekers and Kovacs, 2016), as well as shippers (Jin *et al.*, 2010), (Kopytov and Abramov, 2012), (Bierwirth *et al.*, 2012), (Hoen *et al.*, 2014), (Kazan *et al.*, 2015), and the flow of good through a specified network. Again, authors diverge with single and multi-periodic models.

- Single periodic planning: Specified or abstract planning horizon (Pedersen *et al.*, 2009), (Jin *et al.*, 2010), (Meng *et al.*, 2012), (Bierwirth *et al.*, 2012), (Hoen *et al.*, 2014).
- Multi periodic planning: Specified or abstract planning horizon and periodization within the planning horizon (Meng and Wang, 2012), (Zhu *et al.*, 2013), (B. van Riessen *et al.*, 2013), (Braekers and Kovacs, 2016).

While Eksioglu et al. (Jin *et al.*, 2010) take annual forecasts into account, the rest of the authors define demand ether deterministic or in a stochastic way.

2. Capacity adjustment and regarded actions for capacity adjustment

Models in the class of network flow configuration refer to capacity adaption in regard of the network flow configuration (routing, grouping). Therefore, measures for capacity adjustment are not specifically addressed. Capacity limitations concerning means of transport or fleet size are still regarded (Beltran *et al.*, 2009), (Anghinolfi *et al.*, 2011), (Meng and Wang, 2012), (Meng *et al.*, 2012), (Zhu *et al.*, 2013), (B. van Riessen *et al.*, 2013).

3. Addressed mode of transport and mode-change actions

Especially in regard of grouping problems, models address changes in the mode of transport (Qu *et al.*, 2008), (Beltran *et al.*, 2009), (Jin *et al.*, 2010), (Anghinolfi *et al.*, 2011), (Kopytov and Abramov, 2012), (Bierwirth *et al.*, 2012), (B. van Riessen *et al.*, 2013), (Hoen *et al.*, 2014), (Kazan *et al.*, 2015).

Therefore, authors take into account multiple criteria for transport mode selection as follows:

- Cost (Qu *et al.*, 2008), (Beltran *et al.*, 2009), (Jin *et al.*, 2010), (Kopytov and Abramov, 2012), (Bierwirth *et al.*, 2012), (B. van Riessen *et al.*, 2013), (Kazan *et al.*, 2015),
- Externalised cost (Beltran *et al.*, 2009)
- Revenue (Hoen *et al.*, 2014)
- Safety (Kazan *et al.*, 2015)
- Time/Speed (Qu *et al.*, 2008), (Anghinolfi *et al.*, 2011), (Kopytov and Abramov, 2012), (B. van Riessen *et al.*, 2013), (Kazan *et al.*, 2015)
- Reliability (Kopytov and Abramov, 2012)
- Capacity (Kazan *et al.*, 2015)
- Ecology (Kopytov and Abramov, 2012)
- Warehousing (Qu *et al.*, 2008)
- Social Aspects (Qu *et al.*, 2008)

4. Defined model and solution approach

Table 7 summarises models dealing with the flow of commodities through a given network and the assignment of (intermodal) means of transport:

Table 7: Network flow configuration

Solution approach	**Model/Problem Formulation**	**Reference**
Integer linear programming	Fleet deployment	(Meng and Wang, 2012)
Stochastic programming		(Meng *et al.*, 2012)
Heuristic model	Transit network design	(Beltran *et al.*, 2009)
	Service network design	(Zhu *et al.*, 2013)
Lagrangian relaxation	Transport mode selection	(Hoen *et al.*, 2014)
Fuzzy Logic		(Kazan *et al.*, 2015)
Analytic Hierarchy Process (AHP)		(Kopytov and Abramov, 2012)
Integer linear programming		(Jin *et al.*, 2010), (Bierwirth *et al.*, 2012)
Simulation		(Qu *et al.*, 2008)
Linear programming		(B. van Riessen *et al.*, 2013)

5. Defined optimization parameters

Most of the models do refer to an optimisation problem. The optimisation objectives differ, depending on model requirements:

- Minimise duration (Anghinolfi *et al.*, 2011)
- Minimise operative (fix and/or variable) costs (Beltran *et al.*, 2009), (Jin *et al.*, 2010), (Bierwirth *et al.*, 2012), (Meng and Wang, 2012), (Zhu *et al.*, 2013), (Braekers and Kovacs, 2016).
- Maximize revenue (Meng *et al.*, 2012), (Hoen *et al.*, 2014).

2.8. Pricing strategy

In this problem class, we focus on found models focussing on revenue management according to restricted capacity and transport demand.

1. Regarded planning horizons and demand modelling

Two models do focus on pricing strategies (Klein, 2006), (Crevier *et al.*, 2012) of carriers/logistic service providers. Klein (Klein, 2006) defines a multi periodic planning problem. Depending on demand, remaining time within the current time period and remaining capacity bid prices are adjusted. Demand is modelled stochastically. Crevier et al. (Crevier *et al.*, 2012) integrate price policy into capacity management as well, whereas demand is modelled deterministically.

2. Capacity adjustment and regarded actions for capacity adjustment

For both models, it is essential having limited capacity of means of transport. As a measure in terms of capacity management, adjusted prices regulate demand for scarce resources.

3. Addressed mode of transport and mode-change actions

Both models do not address a switch of transport modes. Crevier et al. (Crevier *et al.*, 2012) are focusing on rail transport, while Klein (Klein, 2006) is focusing on air transport.

4. Defined model and solution approach

Models summarised in Table 8 focus on revenue management according to restricted capacity and transport demand:

Table 8: Pricing strategy

Solution approach	Model/Problem Formulation	Reference
Mixed integer programming	Pricing and network capacity management problem	(Crevier *et al.*, 2012)
Heuristic model		(Klein, 2006)

5. Defined optimization parameters

Both models aim to maximize the revenue or the regarded carrier.

2.9. Multimodal Routing and Scheduling

Identified modes of (intermodal) routing of commodities and means of transport, fleet deployment and the assignment of means of transport to demand are summarised in the class of multimodal routing and scheduling.

1. Regarded planning horizons and demand modelling

This problem class engages with the determination of a path through a network (routing) (Bräysy *et al.*, 2008), (Paraskevopoulos *et al.*, 2008), (Baldacci *et al.*, 2009), (Bräysy *et al.*, 2009), (Pessoa *et al.*, 2009), (Hewitt *et al.*, 2010), (Hoff *et al.*, 2010b), (Verma and Verter, 2010), (Moccia *et al.*, 2011), (Chouman and Crainic, 2011), (Andersen *et al.*, 2011), (Cho *et al.*, 2012), (Ayar and Yaman, 2012), (Minh *et al.*, 2012), (Archetti and Speranza, 2012), (Domuta *et al.*, 2012), (Nguyen *et al.*, 2013), (Paraskevopoulos *et al.*, 2016) or the assignments of means of transport to transport jobs and the design of schedules (scheduling) (Lium *et al.*, 2009), (Cacchiani *et al.*, 2010), (Bauer *et al.*, 2010), (Ballis and Dimitriou, 2010), (Shi *et al.*, 2014). Usually, operative planning problems have a short planning horizon. For most models, there is even no defined specific planning horizon.

2. Capacity adjustment and regarded actions for capacity adjustment

Especially capacitated routing problems and fleet size and mix vehicle routing problems do consider limited capacities of the means of transport (Guélat *et al.*, 1990), (Bräysy *et al.*, 2009), (Baldacci *et al.*, 2009), (Hewitt *et al.*, 2010), (Andersen *et al.*, 2011), (Minh *et al.*, 2012), (Paraskevopoulos *et al.*, 2016). However, besides the best possible resource utilisation, no specific capacity measures are implemented.

3. Addressed mode of transport and mode-change actions

Several models address the routing through multimodal networks, in this regard they can be defined as multimodal planning problems (Hoff *et al.*, 2010b), (Moccia *et al.*, 2011), (Verma and Verter, 2010), (Cho *et al.*, 2012), (Ayar and Yaman, 2012), (Domuta *et al.*, 2012).

4. Defined model and solution approach

Detected models summarised in Table 9 have a focus on (intermodal) routing and fleet assignment to transport demand:

Table 9: Multimodal routing and scheduling

Solution approach	Model/Problem Formulation	Reference
Dynamic programming	Weighted Constrained Shortest Path Problem (WCSPP)	(Cho *et al.*, 2012)
Evolutionary Algorithm	Multicommodity Network Design Problem (MCNDP)	(Paraskevopoulos *et al.*, 2016)
Heuristic model		(Katayama *et al.*, 2009)
Successive resource decomposition	Fixed charge network flow problem	(Hewitt *et al.*, 2010)
Heuristic model	Dynamic fleet management problem	(Shi *et al.*, 2014)
	Fleet size and mix Vehicle routing problem with time Windows	(Bräysy *et al.*, 2009)
	Split delivery vehicle routing problem	(Archetti and Speranza, 2012)
	Time-dependent multi-zone multi-trip vehicle routing problem (TMZT-VRPTW)	(Nguyen *et al.*, 2013)
	Heterogenous fleet vehicle routing problem (HFVRP)	(Pessoa *et al.*, 2009)
	Capacitated multicommodity fixed-cost network design problem with design –balance constraints	(Minh *et al.*, 2012)
	Multimodal routing problem with timetables and time windows	(Moccia *et al.*, 2011)
	Fleet size and mix vehicle routing problem with time windows	(Bräysy *et al.*, 2008)
	Heterogenous Fleet Vehicle Routing Problem with Time Windows	(Paraskevopoulos *et al.*, 2008)
	Rerouting fleet during operations	(Corman *et al.*, 2010)
Stochastic Programming	Multi-period service network design problem	(Lium *et al.*, 2009)
	Stochastic service network design problem	(Hoff *et al.*, 2010b)
Mixed integer programming	Intermodal Multicommodtiy Routing Problem with Scheduled Services (IMR-S)	(Ayar and Yaman, 2012)
	Service Network Design with Design-Balanced Requirements	(Chouman and Crainic, 2011)
	Fleet size and mix Vehicle routing Problem with fixed costs	(Baldacci *et al.*, 2009)
Integer Programming	Service Network design with asset management constraints	(Andersen *et al.*, 2011)

5. Defined optimization parameters

Most of the models do refer to a mathematical optimisation problem. Objectives are formulated as follows:

- Minimise operative (fix and/or variable) costs (Paraskevopoulos *et al.*, 2008), (Bräysy *et al.*, 2008), (Baldacci *et al.*, 2009), (Lium *et al.*, 2009), (Pessoa *et al.*, 2009), (Bräysy *et al.*, 2009), (Hoff *et al.*, 2010b), (Hewitt *et al.*, 2010), (Verma and Verter, 2010), (Moccia *et al.*, 2011), (Chouman and Crainic, 2011), (Cho *et al.*, 2012), (Archetti and Speranza, 2012), (Nguyen *et al.*, 2013), (Ayar and Yaman, 2012), (Minh *et al.*, 2012), (Paraskevopoulos *et al.*, 2016).
- Maximize revenue/profit (Archetti and Speranza, 2012), (Shi *et al.*, 2014)
- Minimise total distance (Bräysy *et al.*, 2009), (Archetti and Speranza, 2012), (Domuta *et al.*, 2012)

- Minimise travel time (Cho *et al.*, 2012)
- Minimise risk (Verma and Verter, 2010)
- Minimise warehousing costs (Ayar and Yaman, 2012)
- Minimise Emissions (Bauer *et al.*, 2010)

3. CONCLUSION

3.1 Interpretation

In this section, most important findings concerning our research and our future research objectives are summarised.

1. Horizontal Integration of mode choice and fleet sizing

Our intention is to develop an appropriate method for different fleets on different modes of transport simultaneously instead of successive planning.

Reis et al. (Reis, 2014) analyse market potential for intermodal rail transport in short distances. Pazour et al. (Pazour *et al.*, 2010) calculate necessary rail route length to meet certain transport demand. Both models refer to strategic political decisions with a focus on rail transport. Puettmann et al. (Puettmann and Stadtler, 2010) and Caris et al. (Caris *et al.*, 2012) concentrate on the grouping of transport demands for high capacity utilisation on maritime or inland waterway transport. Hooks et al. (Miller-Hooks *et al.*, 2012) regard capacity increase on different arcs of a network in case of disruption on a strategic level. Specific measures for multimodal capacity increase are not defined. Two important contributions for fleet sizing are delivered by Couillard (Couillard and Martel, 1990), (Couillard, 1993). He concentrates on an inhomogeneous fleet on road transport and calculates plans for fleet sizing measures within a defined planning horizon. A recent model for fleet sizing in road transport is developed by Rahimi-Vahed et al. (Rahimi-Vahed *et al.*, 2015). Sayarshad et al. (Sayarshad and Tavakkoli-Moghaddam, 2010) solve a multi-periodic model of a rail-car fleet sizing problem. Schoenberger et al. (Schönberger and Kopfer, 2010) focus on road transport, but do not refer to fleet sizing measures. They rather propose to postpone freight when capacity limits are reached. Rivera et al. (Perez Rivera and Mes, 2015) focus on freight selection on inland waterways. Andersen et al. (Andersen *et al.*, 2009) developed a model for the management of multiple fleets in road transport. Dožic et al. (Dožić and Kalić, 2015) introduce a model for fleet deployment in air transport. Li et al. (Li and Tao, 2010) determine optimal fleet sizes for car rental companies. Hsu et al. (Hsu and Hsieh, 2007) allocate vessels according ship type and ship size on maritime transport.

Fleet size and mix vehicle routing problems (Bräysy *et al.*, 2008), (Baldacci *et al.*, 2009), (Bräysy *et al.*, 2009), refer to vehicle routing problems with a limited number of vehicles of an heterogeneous fleet and do not take adjustment measures into account. Service and transfer network design problems do refer to the scheduling and allocation of resources within a network (Andersen *et al.*, 2009), (Beltran *et al.*, 2009), (Pedersen *et al.*, 2009) or the routing of commodities through a network (Gelareh and Pisinger, 2011), (Chouman and Crainic, 2011), (Andersen *et al.*, 2011), (Paraskevopoulos *et al.*, 2016) with restricted capacity, or refer to abstract (costs per arc) capacity adjustment without taking into account specified measures (Lium *et al.*, 2009), (Hoff *et al.*, 2010b).

For a sustainable mode choice model, *we propose to help carriers referring to customer demands and available capacity adjustment measures on different modes of transport simultaneously.* None of the reviewed models supports this idea to sufficient extent.

2. Integration of Forecasting, Fleet-Sizing and Choice of Mode of Transport

For a sustainable mode choice and fleet-sizing model, we refer to future customer transport demands on a multimodal transport network. Hoff et al. (Hoff *et al.*, 2010a) discuss the integration of future demand in fleet-sizing and mix issues is necessary in future research. Measures to adjust fleet capacity in order to meet future transport demand are underrepresented in recent research activities. This fact is also underlined by SteadieSeifi et al. (SteadieSeifi *et al.*, 2014), who criticise that there are no models concerning restricted transport capacity on strategic planning level as well as on tactical level in a sufficient way.

These statements imply an integration of demand forecasting and capacity adjustment of the favourable mode of transport from the perspective of a carrier/logistics service provider. We, therefore, propose a multi-periodic model for a rolling pre-planning of required transport capacity on different modes of transport. From our perspective, none of the evaluated models is presented in such a holistic and dynamic setting. Dožic et al. (Dožić and Kalić, 2015) introduce a model which is established on long-term forecasts on route specific transport demands based on historic demands for airline fleet composition. Additionally, several multi periodic planning models for road or for rail are presented. E.g. Li et al. (Li and Tao, 2010) introduce a multi periodic fleet sizing model for a car rental company to derive a proper transfer policy. Sayarshad et al. (Sayarshad and Tavakkoli-Moghaddam, 2010) solve a rail-car fleet sizing problem with deterministic demand input. Jin et al. (Jin *et al.*, 2010) propose a mode selection method for shippers, which introduces quantity discounts for transport consolidation and grouping based on randomly generated forecast instances. Van Riessen et al. (B. van Riessen *et al.*, 2013) focus on multimodal routing with restricted capacity and given demand with one week of planning horizon.

Rivera et al. (Perez Rivera and Mes, 2015) develop a "look ahead policy" for the selection and postponement of freight. Ayar et al. (Ayar and Yaman, 2012) solve a multi periodic routing problem with random transport demand. Schoenberger et al. (Schönberger and Kopfer, 2010) develop a model to postpone freight when capacity limits are reached. Therefore, they implement forecasting scenarios for future requests. In this regard, they analyse the different forecast qualities to planning objectives.

From our perspective, *none of the presented models evaluates the integration of forecasts of transport demand and the continuous pre-planning of capacity needs and the ecological and economic impact of this procedure*.

3. Integration of Routing, Fleet-Sizing and Choice of Transport Mode

Capacity demand of a mean of transport is directly depending on the routing and individual capacity utilisation of used means of transport (including empty mileage) (Keller and Helmreich, 2011). We found one attempt by Rahimi-Vahed et al. (Rahimi-Vahed *et al.*, 2015) to minimise the maximum quantity of needed vehicles in a given planning horizon by a modular approach of scheduling and routing of vehicles by given deterministic transport demands.

From our perspective, *routing is one basic aspect for capacity calculation including loaded and empty mileage.*

4. Integration of cost and emission objectives

Most authors formulate mathematical objective functions, some refer to simulation models (Jong and Ben-Akiva, 2007), (Schönberger and Kopfer, 2010), (Reis, 2014), and others refer to multi-criteria decision support processes (Kopytov and Abramov, 2012). After deep analysis of identified objectives, various models refer to costs or revenue; almost none of them includes environmental aspects specifically. Kopytov et al. (Kopytov and Abramov, 2012) describe a mode-choice model including environmental impact as a decision criteria. Beltran et al. (Beltran *et al.*, 2009) formulate a model for the allocation of a fleet of a limited amount of ecological friendly vehicles, with the objective of minimised costs, including externalities. Bauer et al. (Bauer *et* *al.*, 2010) formulate a multi-commodity capacitated network design problem for rail transport, incorporating emissions in their objective function.

We see a *significant need for the integration of ecological aspects in an integrated fleet-size and mode choice model in order to reduce environmental impact* – especially as a measure of not-met emission targets of the European Commission (European Comission, 2001), (Keller and Helmreich, 2011).

3.2 Implications for our future research

Our findings lead to several implications for future research, which are specified as follows:

- Analysis of impact of forecasting and forecasting quality of future transport demand on the quality of capacity adjustment measures.
- Analysis of ecological and economic impact of horizontally integrated fleet sizing and transport mode choice for a holistic evaluation of multimodal capacity adjustment measures.
- Analysis of economical and economic impact of vertical integration of routing information and transport demand on specific routes to strategic decision processes (e.g. investments, fleet sizing, order acceptance)
- Analysis of trade-off between ecological and economic effects on integrated modal choice and fleet size actions with ecological objective formulation.

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