A three-stage service network design model for synchromodal transport

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Logistics research group

Project

DISpATCh

Digital twin for synchromodal transport

Partners: KU LEUVEN, VUB VRIJE UNIVERSITEIT BRUSSEL

Objective: Facilitate synchromodal transport

Research focus

Support logistics service providers in their transition towards synchromodal transport

"Synchromodal transport is **real-time**, **dynamic** and **optimised** intermodal transport" (Ambra et al., 2019)

How? Decision support model to assist capacity decisions under uncertainty

Research focus

Optimise capacity planning under uncertainty

(1) Which capacity?

- Train slots on the long/medium term
- Trucking capacity in the short term

(2) Which uncertainty?

- Demand volume
- Available train slots over time
- Train slot prices over time

Network assumptions

Train services

- Offered by rail operators
- LSPs can book slots between each terminal pair
- Fixed schedules
- Can be booked in advance

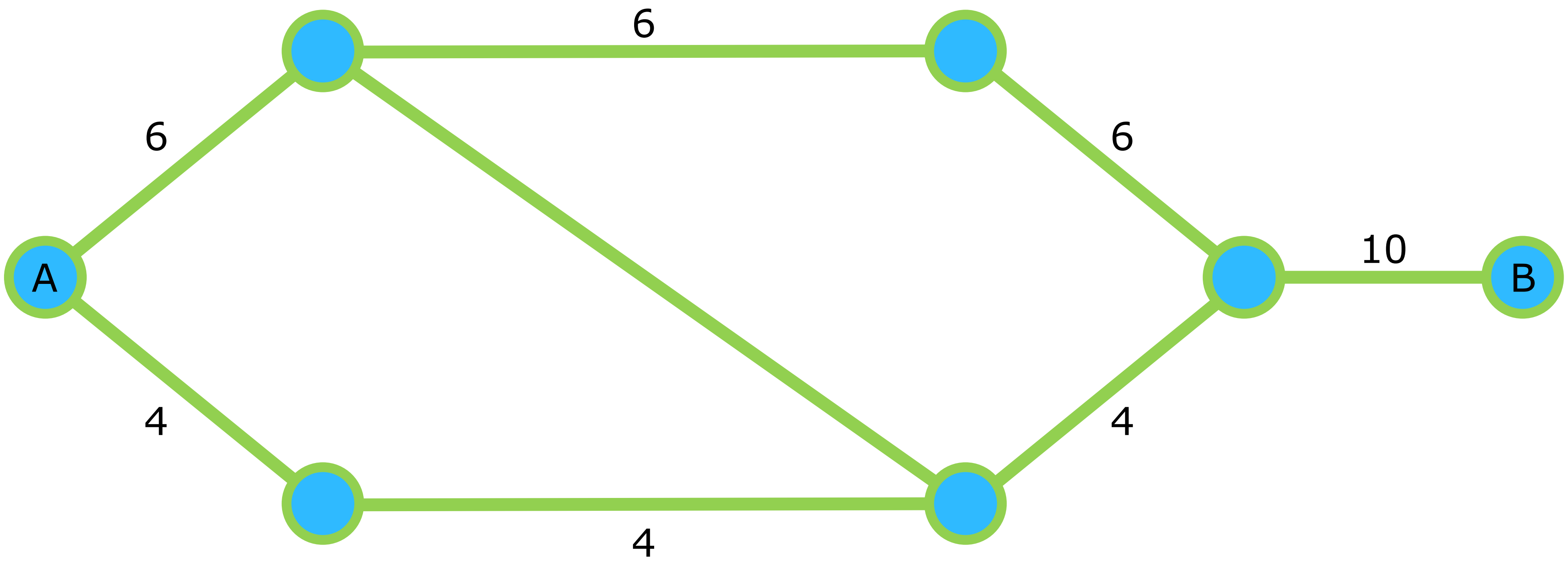
Truck services

- Unlimited number
- More expensive and faster than trains
- Only booked in the short term

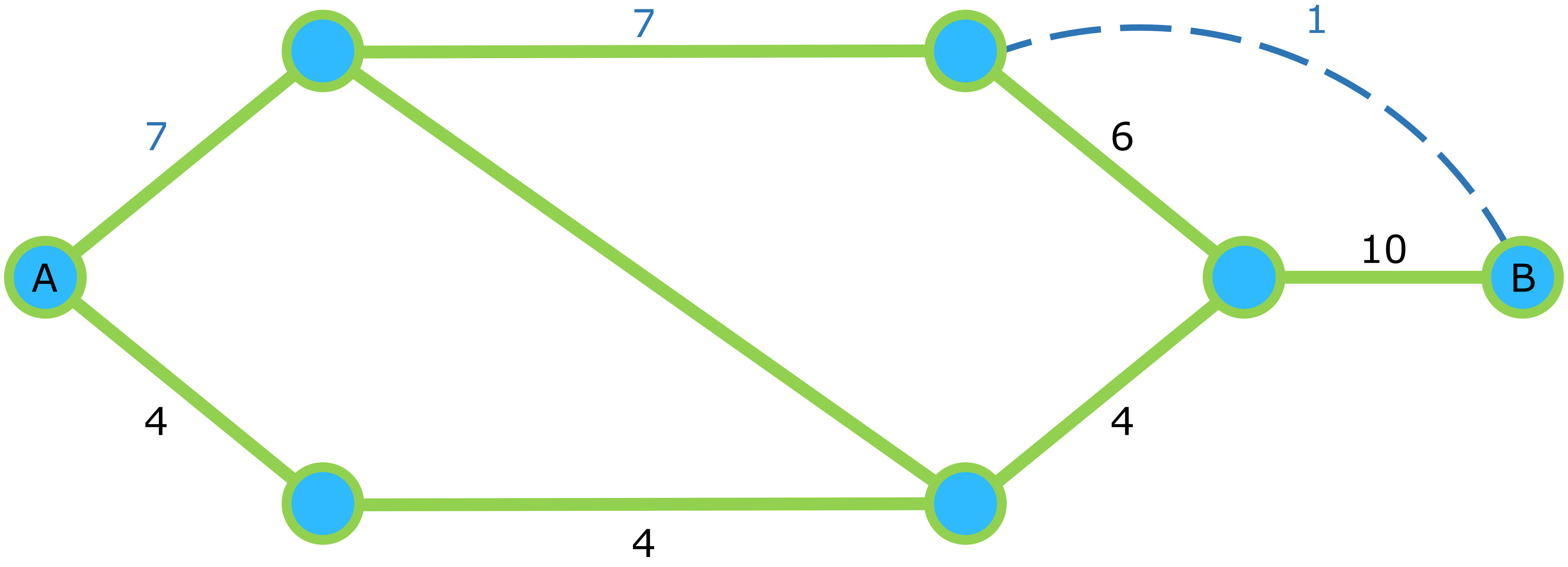
Terminals

- Cost per transhipped container
- Transhipment time

Network example



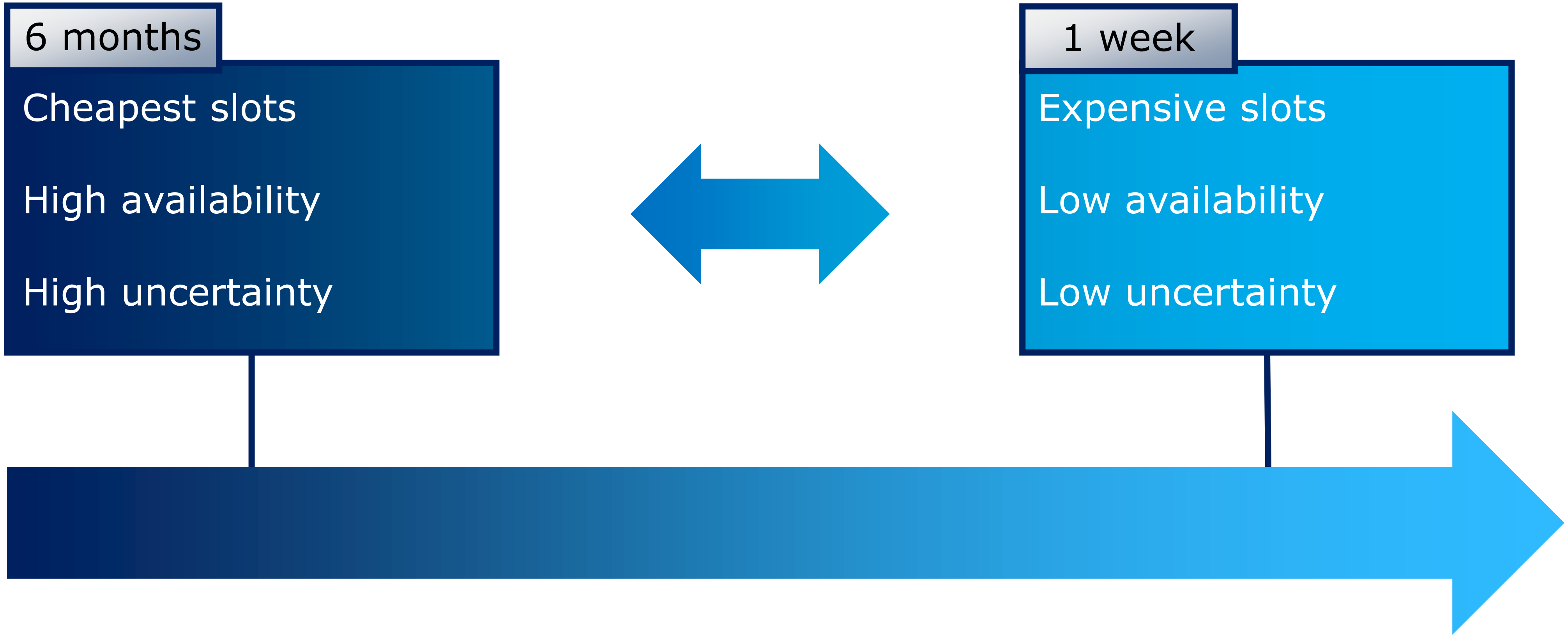
Network example



Literature results

Modelling approach	Capacity and transportation time	Demand	Demand and transportation time
Chance-constrained mixed integer programming			1
Fuzzy chance-constrained mixed integer programming	1		
Mixed integer linear program			1
Simulation optimisation			1
Two-stage chance constrained programming			1
Two-stage robust programming		1	
Two-stage stochastic programming		6	
Total number of studies	**1**	**7**	**4**

Planning timeline



Planning timeline

6 months

- Cheapest slots
- High availability
- High uncertainty

1 month

- More expensive slots
- Intermediate availability
- Less uncertainty

1 week

- Expensive slots
- Low availability
- Low uncertainty

Integer programming model

Objective

Minimise costs

- Train slots at each stage
- Trucking at the operational stage
- Transhipment

Model description

	First stage	Second stage	Third stage
Decisions	Train slots to book	Train slots to book Train slots to cancel	Train slots to book Train slots to cancel Trucks to book Container routing
Uncertainty		Available capacity Total demand in the transport market	Available capacity Demand volume Order sizes Time windows

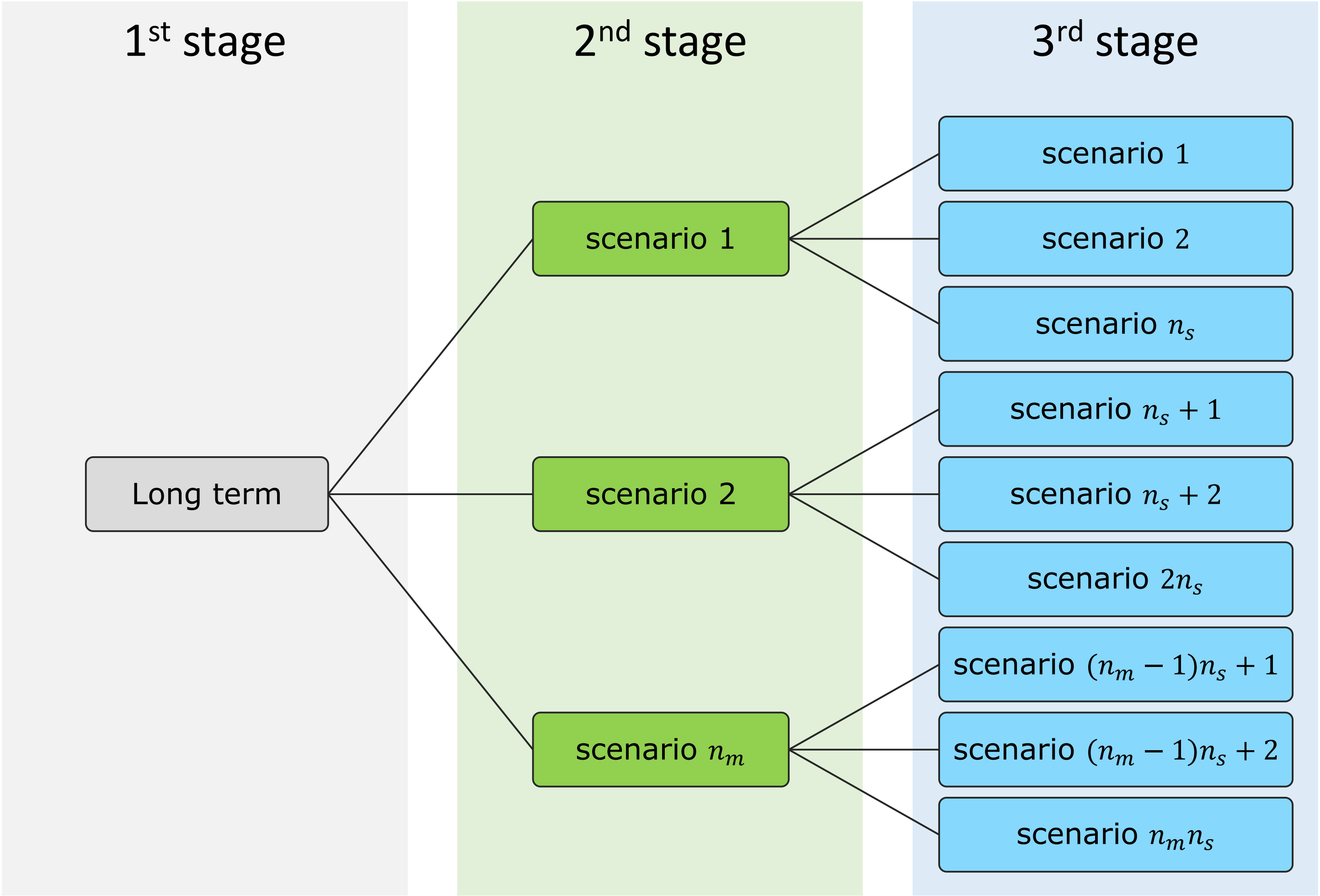
Modelling uncertainty

How is demand modelled?

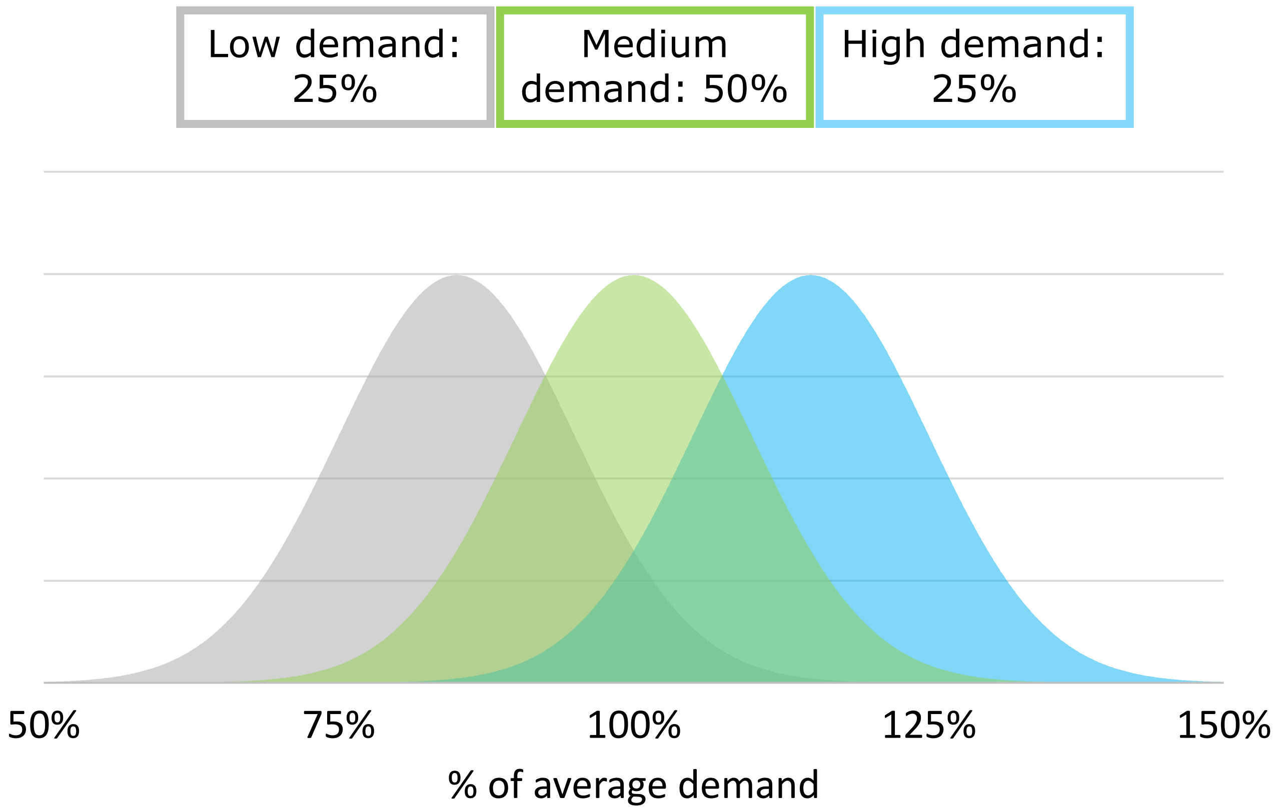
How many train slots are left at each stage?

What are the train slot prices at each stage?

Scenario tree



Demand modelling

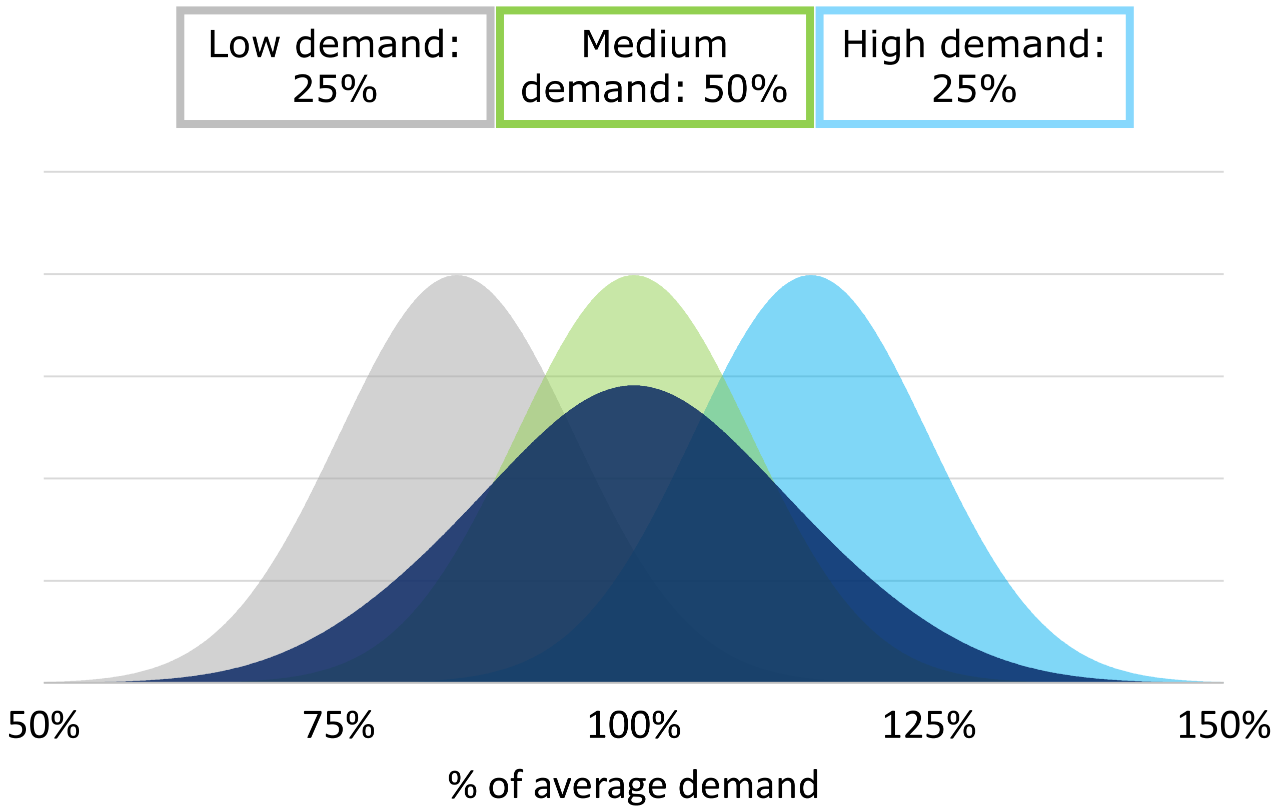


Each terminal pair has its own average demand

2nd stage demand distributions depend on the **total demand in the market**

Each market state has its own probability

Demand modelling



Each terminal pair has its own average demand

2nd stage demand distributions depend on the **total demand in the market**

Each market state has its own probability

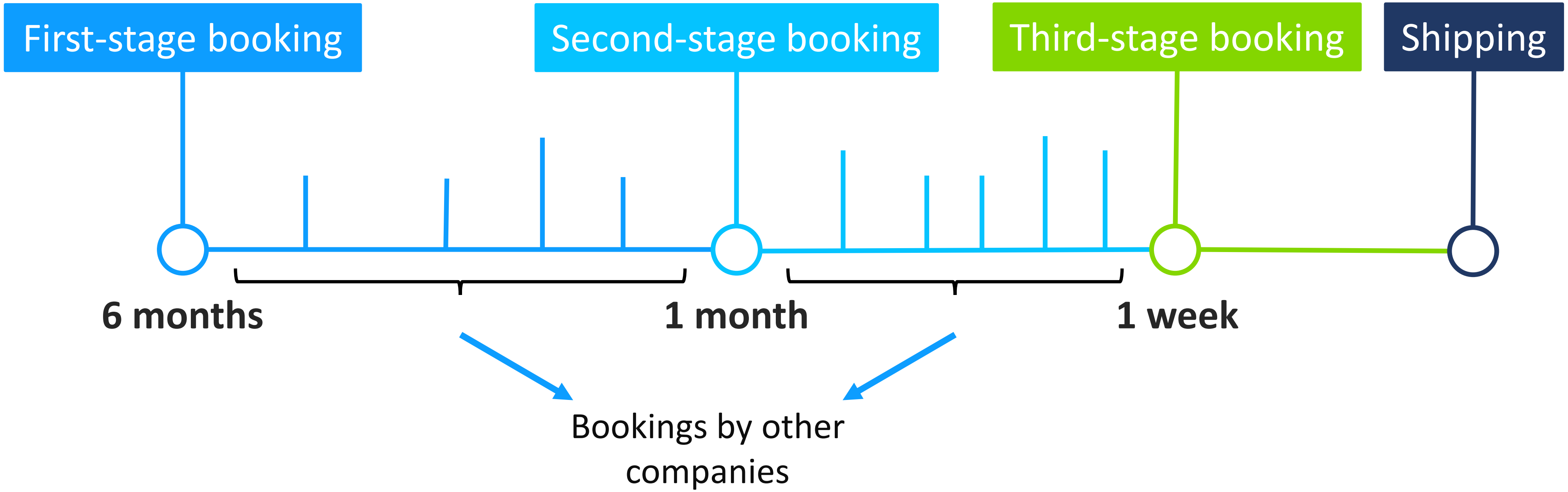
Long-term demand distribution is the weighted sum of the 2nd stage distributions

Available number of train slots

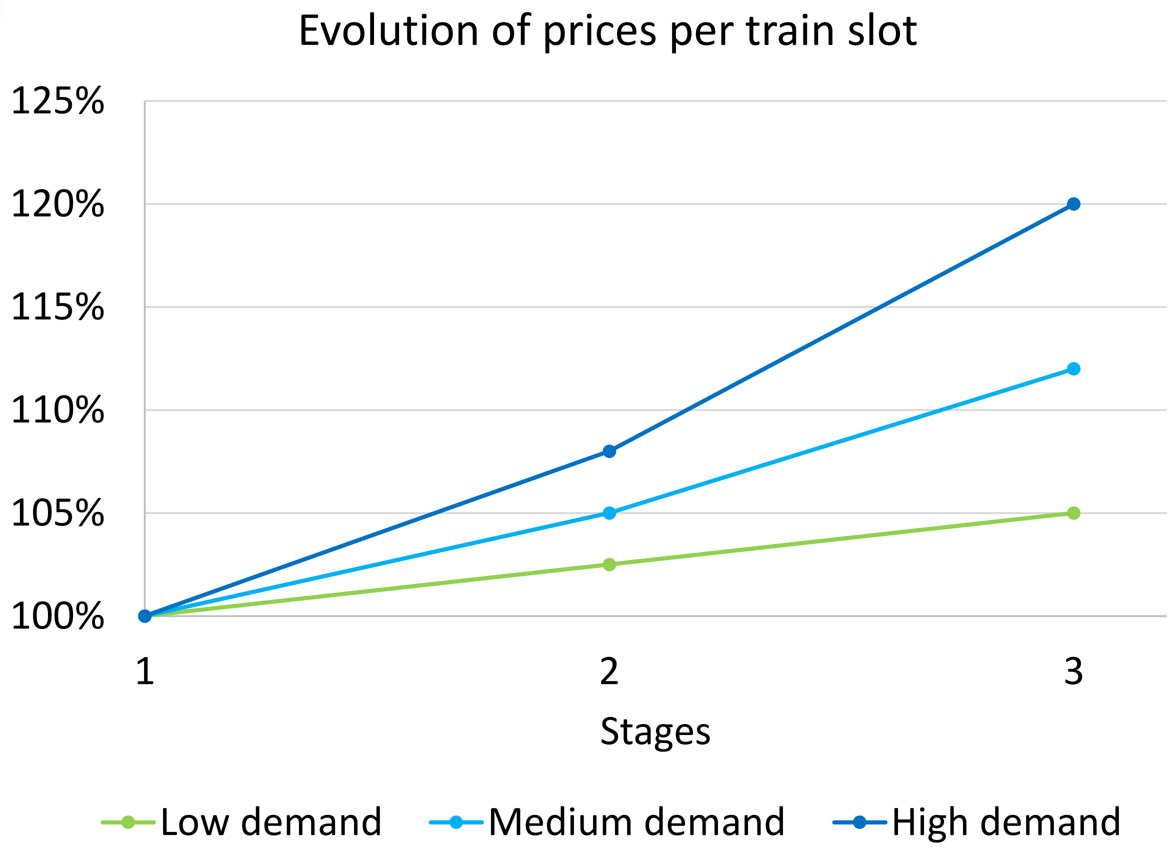
Fixed in the first stage

Second and third stages:

- Stochastic capacity decrease per connection
- Distribution mean depends on the market state



Train slot prices



Fixed increase compared to initial prices

Depends on the market state

Methodology

Exact commercial solver with a time limit

Sensitivity analyses:

- Fictional instances
- Comparison between 2-stage and 3-stage models
- Common random numbers to reduce variance

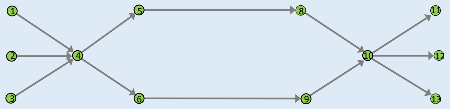
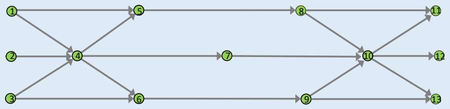
3rd stage scenarios

Number of scenarios	25	50	100	200	500
Average cost	452282.0	453877.9	453468.4	452381.1	452570.6
Standard deviation	1997.19	1931.96	984.70	1260.99	708.51
95% c.i.	1428.70	1382.04	704.41	902.06	506.84
Relative 95% c.i.	0.32%	0.30%	0.16%	0.20%	0.11%

2nd stage scenarios

Number of scenarios	5	10	15
Average cost	452748.1	453250.8	453712.9
Standard deviation	220.00	175.65	128.98
95% c.i.	157.38	135.02	119.29
Relative 95% c.i.	0.035%	0.030%	0.026%

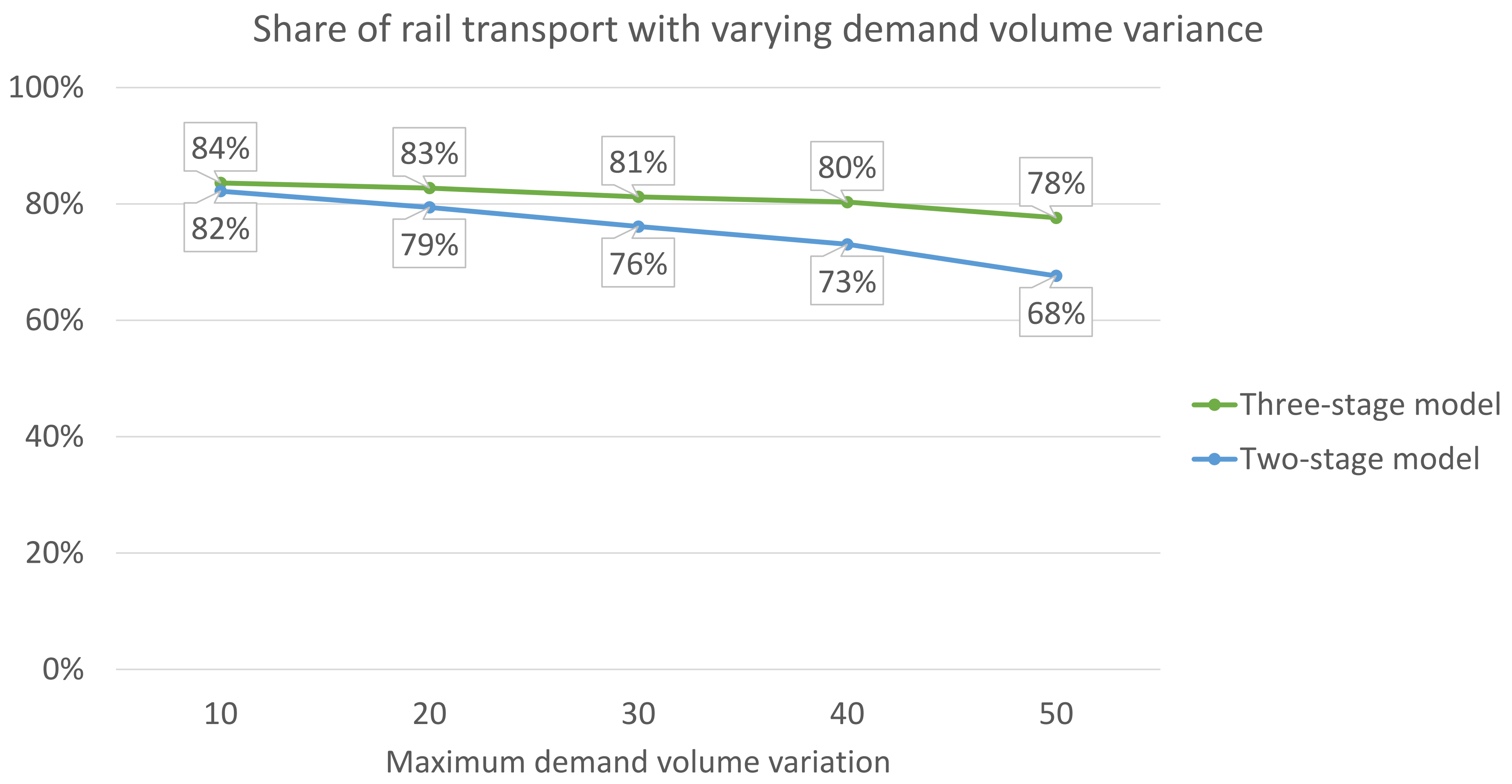
Sensitivity analyses

Network # train services	 4	 7
Capacity/demand ratio	1.2	1.7
Train/truck cost ratio	50%	70%
Demand volume variance	20%	50%

Experimental results

Measure	2-stage model	3-stage model	Difference
Average cost	€ 433,671.28	€ 428,217.48	-1.60%
Average cost over lower bound	€ 26,663.91	€ 21,210.10	-20.45%
Average distance by train in km	281,602.3	292,271.4	3.79%
Average distance by truck in km	73,942.5	65,077.0	-11.99%

Experimental results



Model contributions

More realistic compared to academic literature

Better decision-making

What-if analyses

- Impact of demand uncertainty
- Effect of network changes
- Effect of other input parameters (truck/train cost ratio, demand volume/capacity ratio, prices, …)

Thank you for your attention

Questions are welcome

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Research group website:
https://www.uhasselt.be/en/onderzoeksgroepen-en/research-group-logistics

Literature results

REFERENCE	TRANSPORT MODES	STOCHASTICITY	APPROACH
Lium et al. (2009)	Unspecified	Demand	Two-stage stochastic programming
Hoff et al. (2010)	Unspecified	Demand	Two-stage stochastic programming
Crainic et al. (2011)	Unspecified	Demand	Two-stage stochastic programming
Bai et al. (2014)	Unspecified	Demand	Two-stage stochastic programming
Meng et al. (2015)	Barge, rail, road	Demand	Two-stage stochastic programming
Demir et al. (2016)	Barge, rail, road	Demand and transportation time	Mixed integer linear program
Layeb et al. (2018)	Barge, rail, road	Demand and transportation time	Simulation optimisation
Sun et al. (2018)	Rail, road	Capacity and transportation time	Fuzzy chance-constrained mixed integer programming
Zhao et al. (2018)	Rail, ship	Demand and transportation time	Two-stage chance constrained programming
Zhao et al. (2018)	Rail, ship	Demand and transportation time	Chance-constrained mixed integer programming
Wang and Qi (2019)	Unspecified	Demand	Two-stage robust programming
Wang et al. (2019)	Unspecified	Demand	Two-stage stochastic programming