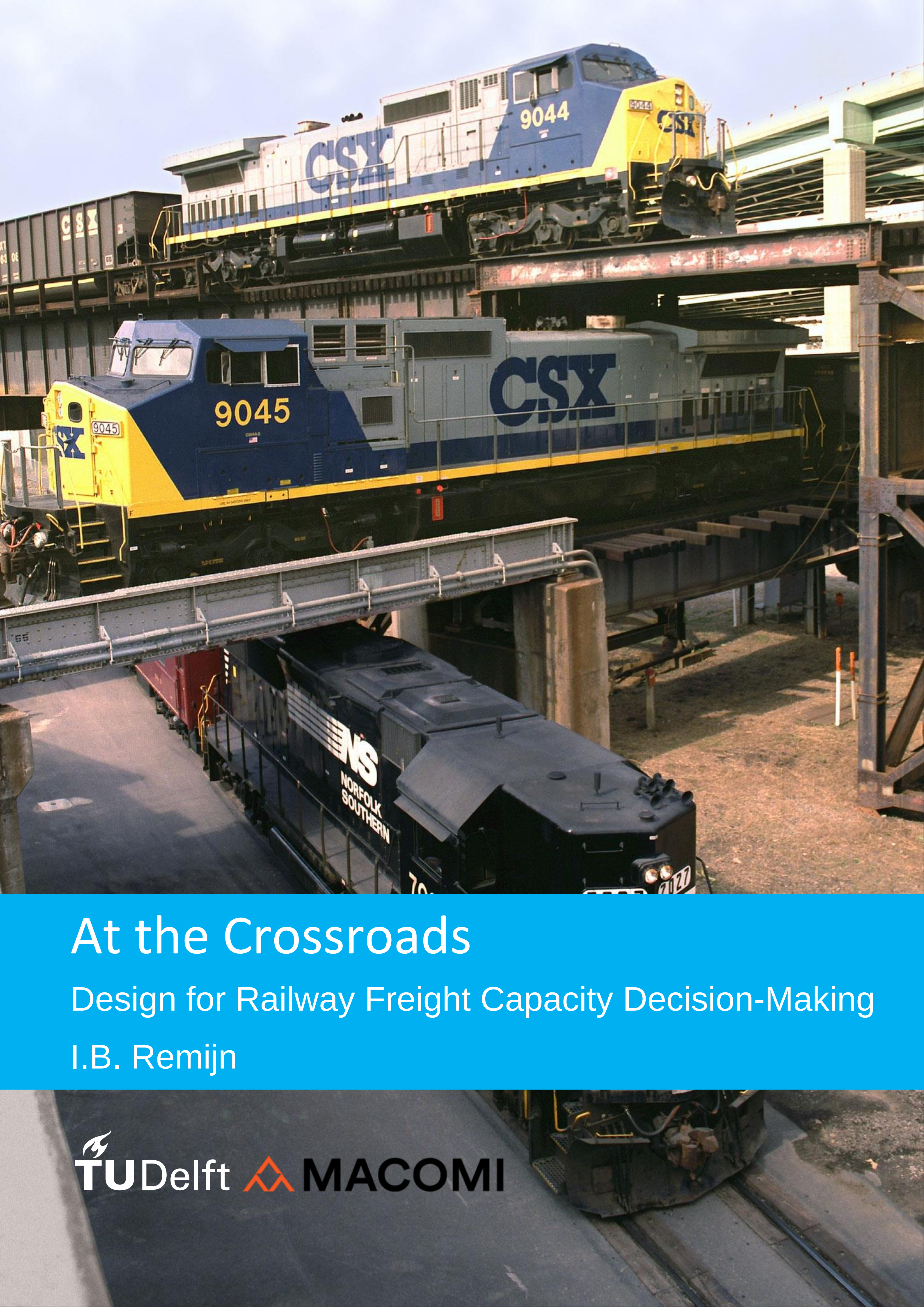

At the Crossroads

Design for Railway Freight Capacity Decision-Making

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At the Crossroads

“I am at the crossroads of decision. This is applied to those who are in doubt and of uncertain mind, hesitating as to which alternative to choose, like travellers who come to a place where three roads meet, and are doubtful about which way to take. …

[Plato] warns us that when we face uncertainty, we should not rush at it with open arms, but stop as if we had come to a crossroad and did not know the way, nor should we push on until some investigation has been made to show where each road leads; ‘like’ he says, ‘a man at a crossroads’.”

Desiderius Erasmus in The Adages, as translated by Margaret Mann Phillips.
Collected Works of Erasmus: The Adages, University of Toronto Press, 1984.

At the Crossroads:
Design for Railway Freight Capacity Decision-Making

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by

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Executive Summary

Introduction & Motivation

Growing demand for railway-based transport stresses railway infrastructure on safety, punctuality, and robustness. The Port of Rotterdam and ProRail desire a process of executing simulation model supported capacity studies wherein inputs, methods and outputs are coordinated upfront. However, interorganisational capacity studies are currently conducted ad hoc in lengthy processes, in which there is disagreement about inputs, methods, and outputs of the process. They can be considered misaligned as the internal capacity management processes do not fully fit each organisation's objectives, while also not being sufficiently adaptive towards the dynamic railway capacity context. Alignment is the result of coordination activities between collaborating organisations. An aligned rail freight capacity management process is necessary for the successful matching of demand and supply for rail freight transport services, and can be supported by simulations of the railway capacity. Thus, the question arises: *How to improve the alignment of collaborating organisations on quantitative metrics for railway freight capacity in the Port of Rotterdam with the use of meso-level simulation models?*

This research presents a process design for an interorganisational capacity planning process that has the potential to improve alignment between the collaborating organisations. The principle-based design method presents a novel approach to addressing alignment problems in the domain of decision-model supported capacity planning collaboration between networked organisations. The process design is formulated through a design science method, wherein specific coordination challenges are matched to literature-derived principles regarding technical and interorganisational coordination of capacity planning processes. The design is evaluated against stakeholder defined requirements and through discussion of the proof of concept: an executed capacity study using the formulated design.

Technical Coordination in Capacity Planning Processes

Capacity planning processes are, for their technical part, anchored in the use of railway capacity management performance indicators, a framework for reasoning about the port railway system's capacity dynamics, decision-support tools, and general technical capacity planning principles.

Performance indicators include metrics to monitor the scale, feasibility, stability, robustness, urgency, and economic performance of infrastructure. For rolling stock, travel times and punctuality represent performance. Their dimensions are given by the perspectives on the port railway area: demand or supply of capacity, global system or local subsystem, rolling stock or infrastructural subsystem, yard subsystem or terminal subsystem.

The technical framework presents a technical understanding of the port railway area's subsystems including their dependencies. It provides a platform on which theories can be developed regarding the dynamics of interventions infrastructural subsystems on the broader whole of the network.

Meso-level simulation models are found to best support decision-making for port railway capacity planning as complexity from stochasticity and feedback loops is captured in broad sets of multi-level quantitative performance indicators, in contrast to analytical methods.

The effective and efficient matching of freight transport demand and capacity is structured through the principles of integrality and optimality. Integral planning considers the railway transport system level and the complex effects of interdependencies, e.g. network cascading. Optimal planning requires decisions through unambiguous definitions of performance, use of systematic improvement methods, and root cause analysis.

Coordination of Interorganisational Capacity Planning Processes

In the coordination of activities, the Port of Rotterdam and ProRail are in networked cooperation shaped by loosely coupled activities. Advanced structuring denotes the idea of structuring information exchange and dependent processes *ex ante* with room to manoeuvre, by securing standardisation of process and content interfaces, creating modular interconnected processes, and ensuring structured data connectivity. The dynamic adjustment denotes to the rapid adjustment of inter-organisational processes in response to changes in complex collaboration situations namely the breadth of information shared with collaborators, the quality of information shared with collaborators and deep coordination-related knowledge. The coupling is made through the simulation model which acts as boundary object, a neutral source of data on the performance of the railway system.

Current Capacity Planning Process Challenges

The current capacity planning processes at ProRail and the Port of Rotterdam face coordination challenges that render them misaligned, as occurs in the analysed case study at a shunting yard. The following challenges are addressed in the design of the capacity planning process. Capacity problems and their solutions behave dynamically causing uncertainty regarding cause and effect. There is disagreement regarding magnitude and configuration of volume forecasts used, and the subsequent interpretation of study's operational metric outcomes. Lastly, the process is slowed by a lack of opportunity for hierarchical escalation in decision-making, and experienced difficulty in the follow-up in subsequent processes.

Proposed Capacity Planning Design

By matching the challenges discovered in current capacity management processes with principles set out in the academic literature, a new process design is constructed. The process enables the identification of the current and expected performance of capacity, as well as prominent bottlenecks in the infrastructure. In the process interventions' effectiveness and their cost-efficiency is evaluated. These goals are captured in a design consisting of four macro-processes: strategic overview, bottleneck analysis, intervention effect analysis, and financial-economic analysis. The macro-processes are described through their goals, method of simulation configuration, and interpretation of performance indicators.

Strategic overview process serves to monitor the systems general ability handle transport demand in the face of economic and technical long-term trends and is scoped at the level of the railway system. The process constructs a railway system-wide benchmark reflecting current and future capacity performance. Scenarios describe the current and future configuration of the infrastructure using the capacity framework. These scenarios are converted to assumptions for simulation configuration. In interpretation of the indicators, comparisons across subsystems are drawn to identify malperforming ones.

The goal of bottleneck analysis is twofold, namely, to identify and locate bottlenecks, as well as determining establishing the level of urgency associated with fixing the bottleneck. The analysis is scoped towards problematic subsystems showing high occupation rates and associated delay times. Artificial train volume scenarios are constructed, which probe subsystem's robustness by progressively increasing volumes until a subsystem faces irrecuperable delay revealing the bottleneck.

The goal of intervention effect analysis is to gauge the effectivity & efficiency of possible interventions or solution directions. The analysis is scoped such that it contains the observed bottleneck and subsystems affected by it. Using the capacity framework intervention scenarios are drawn up. The intervention effect analysis uses rigorous factorial experiment design to test the effects and sensitivity.

Financial economic analysis focuses on the use economic capacity expressed in financial metrics to communication to external stakeholders, delineate cost-effectiveness, and stimulate actionable decision-making. It is designed as an addition in this regard to the operational metric-oriented processes.

Evaluation of the proposed design

The process' potential is examined based on stakeholder-derived requirements and a proof of concept. The design is found to address part of the coordination challenges within process requirements posed by the Port of Rotterdam and ProRail. Strengths found include the functioning in terms of performance measurement, root cause analysis facilitation, and testing of alternatives. Structural strengths include the traceability of decision-making and the role of the 'neutral' simulation model. Weaknesses manifest primarily in the use of assumptions, and in the consequent ability to validate and calibrate the model to the situation in practice.

Conclusion

Growing volumes of railway freight necessitate improved alignment of interorganisational capacity planning. The designed interorganisational capacity planning process shows potential to improve alignment. The strategic overview, bottleneck analysis, intervention effect analysis, and financial-economic analysis draw together the shared use and understanding of railway capacity performance indicators, a framework on port railway system's capacity dynamics, and decision-support tools through principles of integrality and optimality. The principles of process maturity and loose coupling address process' performance and place the simulation model as boundary object conducive to collaboration. The process design addresses coordination challenges experienced by clients.

The principle-based design method used, presents a novel approach to addressing alignment problems in the domain of decision-model supported capacity planning collaboration between networked organisations.

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List of Abbreviations

BPGV	Basic Goods Transport Forecast, or *Basis Prognose GoederenVervoer*
CBA	Cost Benefit Analysis
CER	Community of European Railways
EEA	European Environment Agency
ERMTS	European Rail Traffic Management System
EU	European Union
EUC	European Union Commision
KPI	Key Performance Indicator
Min. I & M.	Ministry of Infrastructure and Environment, or *Ministerie van Infrastructure en Mileu*
NS	Nederlandse Spoorwegen
PAS	Programme Approach Nitrogen, or *Programma Aanpak Stikstof*
SD	Standard Deviation
TEU	Twenty Foot Equivalent Unit
UIC	Worldwide Railway Organisation, or *Union Internationale des Chemins de fer*
VUCA	Volatile, Uncertain, Complex, and Ambiguous
WLO	Wellbeing and Environment, or *Welvaart & Leefomgeving*

1. Introduction

In the introduction chapter, we introduce the subject matter of the thesis by providing background information to capacity management in the Port of Rotterdam in section 1.1 Background of Rail Freight Capacity Management in the Port of Rotterdam. Then, the problem state presents a description of the research problem in section 1.2 Problem Statement. Section 1.4 Link to the Study Programme Complex Systems Engineering and Management discusses the relation of this stated problem to the learning goals of the master programme; in which context the thesis is conducted. Section 1.5 Thesis Outline concludes with an outline of the thesis.

1.1 Background of Rail Freight Capacity Management in the Port of Rotterdam

In order to reach ambitious goals for climate, pollution and safety in transport, the European Union endeavoured to promote rail transport as a more sustainable substitute for road transport (EEA, 2019). Transportation activities in the European Union account for over 25% of greenhouse gas emissions (EEA, 2017). While industry, energy supply and residential CO2 emissions have steadily decreased since the 90's, transport emissions have increased with 16% and are still rising (EEA, 2019). Even though demand for rail freight transport is growing across the EU Rail, rail transport's market share has decreased with 3 percentage points against road transport since 2011 (Eurostat, 2019). Therefore, there is a major challenge ahead for the EU to reach goals of 30% market share increases for rail by 2030, as set out in the EU Commission's transport strategy (EUC, 2011).

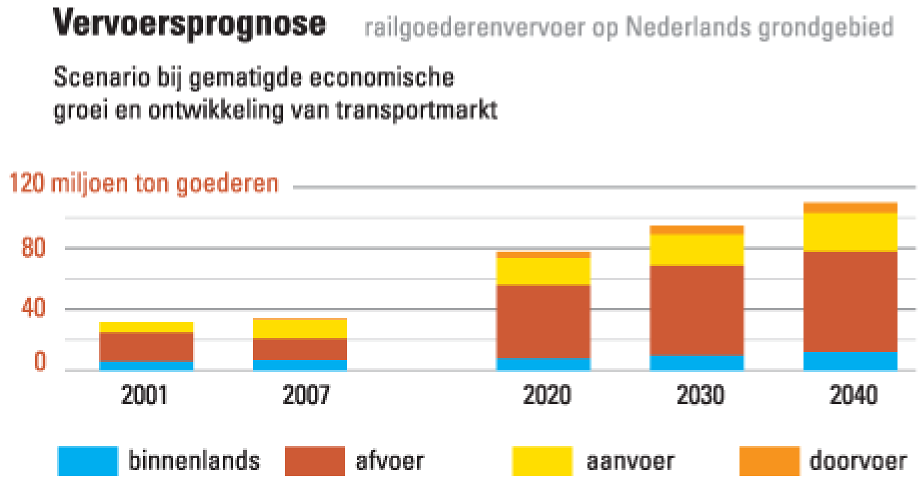


Figure 1 Dutch rail freight volume forecast in million tons, Keyrail (2017), in Dutch.

The Port of Rotterdam, conscious of the changing transportation environment, has set its own goal to reach a 20% railway market share by 2033 (Port of Rotterdam, 2011). Yet, as shown in Figure 1, growing railway-based traffic puts existing railway infrastructure performance under stress regarding safety, reliability, and affordability (NS, 2016). Capacity utilisation rates have increased over the entirety of the Netherlands, but especially around the Rotterdam area. Nowadays, Dutch railways see the highest usage intensity per km compared to the rest of the EU (IRG-Rail, 2019). There, utilisation rates are increasing steadily towards 90% in 2040, to the effect that the network becomes more vulnerable to failure and train operations sensitive to disruptions (Min. I&M, 2017).

The trend growth in demand for capacity puts considerable pressure on the already costly Dutch capacity supply, especially around the Rotterdam area. The Netherlands is the EU's third largest spender on railway infrastructure with costs of over 400,000 euros per km yearly (CER, 2005). As, rising maintenance costs put pressure railway infrastructures. Maintenance costs have doubled since 1994, mostly due to greater total track length, expansion of supporting infrastructure, and stricter safety rules (Swier, 2014). With the increased utilisation of the railway network, these maintenance costs can be expected to rise even more in the future.

The challenge is how to facilitate the trend of increasing volumes of goods going through the port, within capacity limitations posed by the infrastructure for high performance affordable transportation.

1.2 Problem Statement

Port of Rotterdam and ProRail seek to conduct regular joint capacity studies in order to identify potential bottlenecks in rail freight infrastructure capacity. As capacity studies are a key activity to guarantee safety, reliability, and affordability of freight railway transport in the future, parties desire a process of executing capacity studies wherein inputs, methods and outputs are shared upfront, by design, among collaborating organisations. Yet, Port of Rotterdam and ProRail find that interorganisational capacity studies are currently conducted ad hoc in lengthy processes, in which there is disagreement about inputs, methods, and outputs to the process. In terms of input, controversy exists for example about the sourcing of data from third parties such as terminals or the ministry. Whereas in terms method employed, diverging opinions are found on the decision-support models to use. And lastly, it is found that in the output, metrics used as a proxy for the capacity construct vary, along the organisations' lines.

The trend of increasing amounts of railway freight necessitates the increased frequency of capacity studies from being an occasional project-based occurrence to becoming a regular capacity management task. This increased regularity implies higher requirements to the performance of individual tasks, sequences of tasks and organisation of tasks within the capacity study process as a whole that is currently not met.

Therefore, in terms of the performance of the capacity study process, it is warranted that variation and complicatedness of individual tasks in the capacity study decreases. Where variation of tasks arises through execution of ill-defined tasks driven by tacit expert knowledge, personal preference and situational factors, such as time-constraints and personnel workloads. And complicatedness arises from e.g. the use of specialty tooling, interdependencies among other tasks or task executors for the completion of tasks. The task sequences performance leaves room for improvement in the lack of *ex ante* determinability of sequences. Lacking the ability to pre-specify the ordering of tasks implies that between successive process steps outputs are misalignments with inputs. Overall, there is a lack of plannability and consistency in overarching general capacity study processes. It is found that inputs, methodologies and outputs are not repeatable and comparable across capacity studies, which impedes gaining experience and structural improving of the capacity study process.

Thus, the problem is one of alignment, which according to Henderson and Venkatraman (1993) implies that the internal organisation of capacity management does not fit the organisational objectives while also not being adaptive towards the ever-changing external environment of the organisation. Lederer & Mendelow (1989) posit that the alignment is the result of coordination activities between (parts of) collaborating organisations.

1.3 Research Objective

The problem statement calls for the improvement of alignment of the Port of Rotterdam and ProRail in their joint capacity planning processes, which is both a problem of design and a problem of knowledge. The design problem constitutes the practical objective of this research, which is to propose a process design that brings the joint capacity planning process in line with each organisations' objectives while also improving the process' adaptivity to the dynamic port freight railway system. Designing such a process, however, necessitates answering the knowledge question regarding how to improve the alignment of the collaborating, networked, organisations on railway freight capacity in the Port of Rotterdam. To this end, the research thoroughly investigates the question of how to design capacity planning processes, how to overcome challenges in cooperation, and how stakeholders evaluate the artefact's potential. The research objective therefore encompasses problem investigation, the design of a process artefact and evaluation of this process artefact.

1.4 Link to the Study Programme Complex Systems Engineering and Management

This thesis is written in the context of the study programme Complex Systems Engineering and Management at the Delft University of Technology. It therefore follows that the thesis bears content and shows a developed understanding related to systems, complexity, engineering and management, and design.

The study presented in this report works on the railway system, a system which is a nested interconnected network of engineering infrastructures. Nested in the sense that it is comprised of subsystems such as shunting yards, and transhipment terminals which are interlinked through different types of track. Within the railway networked systems, subsystems are (inter)connected in two related ways. One is connected at the level of structure, denoting the way in which certain parts are physically connected to other parts. The second type of connectedness is at the level of dynamics, the fact that actions at one point in the network have implicit consequences for the outcomes of the system in general, i.e. at large. Meaning that interventions in the capacity of railway systems are taken not in isolation, but with the expectation that the system will react to what us done. As a result, cause and effect relationships are non-obvious, non-intuitive, unrepeatable and unpredictable so any changes made using the *ceteris paribus* assumption can easily cause dynamics across the network in ways that were initially unintended.

The ideas and competencies are related to both engineering and management as this thesis considers a social-technical process. Not only does capacity management need to take the perspective of physical infrastructures, but also capacity management is the domain of multiple stakeholders Port of Rotterdam, and ProRail, who differ in their goals, views on 'good' performance, interests, and means yet have to work together in order to collectively reach their goals. This implies interdependent activities and decision-making which crystallise into processes of coordination, such as those aimed at agreeing on freight volume forecasts. It follows from for example the swings in freight transport demand, the predictive uncertainty, untraceability of cause and effect, and controversial nature of measures of performance that capacity management is plagued with issues of volatility, uncertainty, complexity and ambiguity, respectively.

However, in the face of these complexities, we can ideate, formulate and implement and evaluate artefacts that intervene in the system. Or to be exact, design processes that help in the sensemaking, planning and controlling of capacity management activities and decisions in the context of a railway system. The coming together of design activities while using the tools and awareness of systems thinking, networks, and VUCA dynamics embodies the high-tech human touch engineer as envisioned in the study programme.

Lastly, railway system capacity management is positioned in the domain of transport and logistics. The transport and logistics view emerge arguably primarily through the questions of transport systems analysis drawn from the design, use and maintenance of railway infrastructure.

1.5 Thesis Outline

In short, the structure of this thesis is as follows. First, a literature review towards railway freight capacity management is undertaken in chapter 2 resulting in a framework for technical capacity in the port railway area, and a list of principles suitable for capacity management process design, including principles for technical capacity coordination processes and process-managerial principles. Where after, in chapter 3, the main research question is presented and further subdivided. Chapter 4 outlines the research' methodology, elaborating upon sub questions posed, the design science method to be employed, and their interlinkage. In chapter 5, a current state analysis is presented regarding the Port of Rotterdam and ProRail. This analysis results in a list of challenges to be met by the capacity management process design. Chapter 6 presents the synthesis of challenges and principles, namely a proposed capacity management process design. This capacity management process design is evaluated in chapter 7s with the organisation mentioned in a proof of concept. Chapter 9 presents a discussion of the research through the perspectives of domain-, empirical researcher, and problem solver. Chapter 10 concludes with a summary of insights gotten during the research.

2. Literature Review on Rail Freight Capacity Management

In chapter 2, a literature study is conducted to gain a deeper understanding of railway freight capacity management. In general, capacity management comprises four elements: indicators for the assessment of capacity performance, the capacity system's technical configuration, decision-support tools, and the capacity planning processes that tie together the previous three elements in order to make decision regarding the infrastructure (Zijm, 2000; Hans *et al.*, 2007). The literature review is divided according to these elements to gain a complete overview of capacity management for railways, which is synthesised into a list of capacity planning coordination principles.

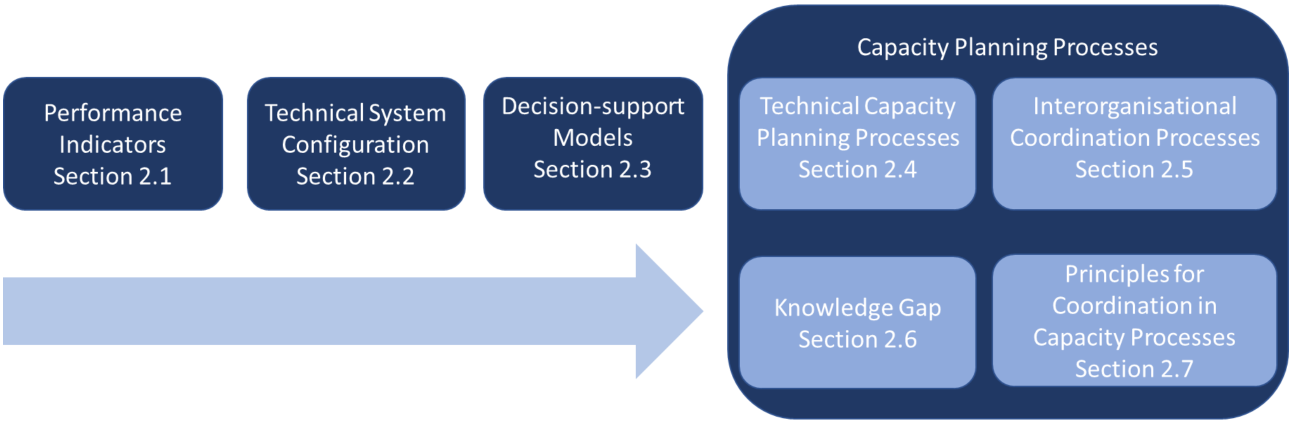


Figure 2 Overview of sections in the literature review chapter.

Section 2.1 Rail Freight Infrastructure Asset Capacity therefore expands upon the current technical understanding related of rail freight capacity determination and the use of indicators. Section 2.2 Technical Framework for Port Rail Capacity Management presents a technical framework for understanding the railway systems technical configuration. Section 2.3 Decision-support Tooling for Railway Capacity outlines the use of decision-support models in railway capacity management. Section 2.4 Railway Capacity Management Process Organisation draws principles for the design of capacity coordination processes from the hierarchical planning and control literature and describes possible use of decision-support tooling. Section 2.5 Interorganisational Coordination in Freight Railway Capacity Management elaborates upon interorganisational collaboration to arrive in joint capacity planning decisions. Section 2.6 Knowledge Gap reflects upon the literature study conducted and distils the found knowledge gap. Concludingly, Section 2.7 Synthesis of Principles for Coordination in Capacity Management synthesises these principles into a list.

2.1 Rail Freight Infrastructure Asset Capacity Performance

Freight capacity of a railway system is defined as the ability of (part of) the railroad system to satisfy transportation demand for freight (Fernandez *et al*., 2003). As, such it can be considered the supply side in capacity management, defined by Slack *et al.* (2013) as the activities that efficiently and effectively coordinate a) the demands of the market and b) the ability of the operation's resources to supply.

Dingler (2010) poses that no ultimate measurements of capacity exist, as there are a plethora of factors influencing the capacity. Therefore, there is a necessity to take on different specific perspectives, in a sense different sets of lenses to look at railway freight capacity. Jensen *et al.* (2017) identify freight capacity from the two perspectives of a) infrastructure and b) the mode of transport. From both perspectives, two ways emerge for rail transport decision-makers to increase the capacity for transporting railway freight, namely through expanding the total available capacity in their physical elements, or to make more efficient use of these elements through operating strategies (Lai & Barkan, 2011). The distinction in perspectives in railway freight capacity, as well as corresponding examples, are summarised in Table 1. For a brief overview of the railway physical elements as well as their interconnections, see Figure 3.

	Physical Elements	**Operating Strategies**	**Source**
Transport Ground Infrastructure	Track, (shunting) yards, switches and signals.	Adjustments to degree of utilisation, operating speed, infrastructure operating hours, spatial efficiency.	(Weatherford *et al*., 2008), (Hillestad *et al*., 2013), (Ghijsen *et al*., 2007), (Khadem & Landex, 2013), (Kahn Ribeiro *et al*., 2012).
Mode of Transport	Rolling stock: locomotives (and their motive power), and cars.	Increasing length of trains, optimising fill rates, virtual coupling, load unit sharing.	Weatherford *et al*. (2008), McClellan (2006), (Fernandez *et al*., 2003), (Lai & Barkan, 2011).

Table 1 Overview of factors influencing railroad capacity determination.

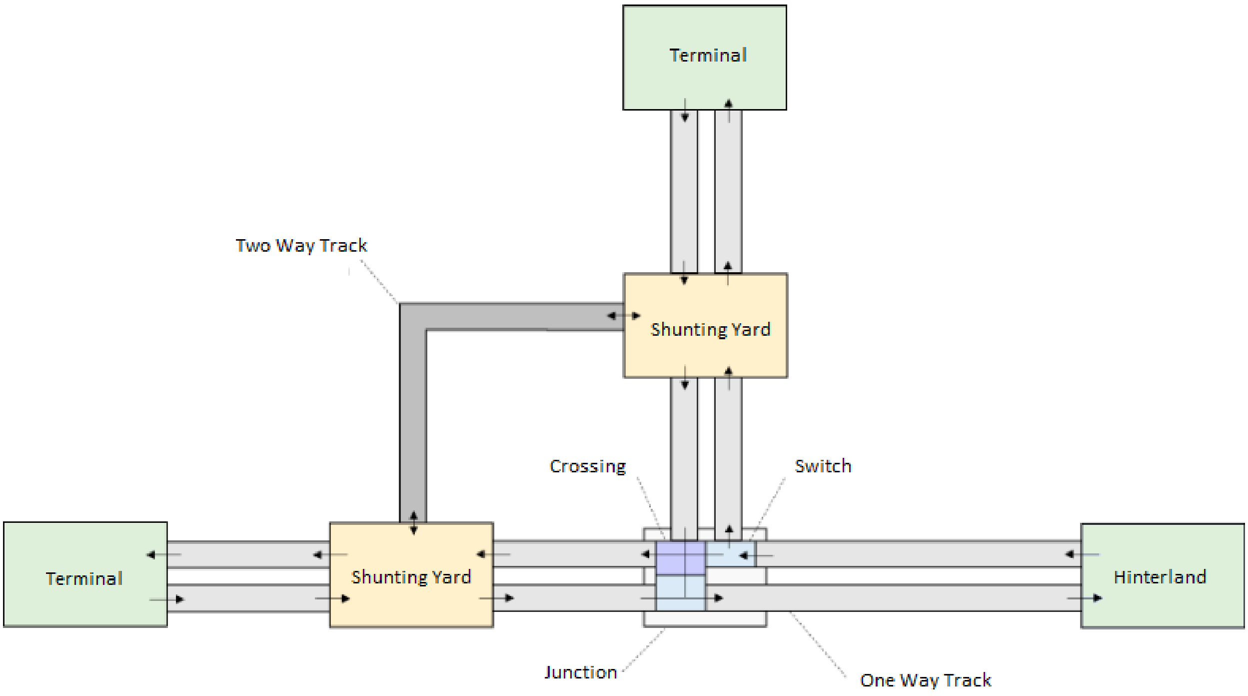


Figure 3 Schematic overview of the physical network infrastructures present (Macomi, N.d).

2.1.1 Infrastructure Capacity in Rail Freight Transport

In the perspective of infrastructure, Nooteboom & Rodrigue (2003) note that The Netherlands has little opportunity to increase capacity on the short to midterm, because of restrictions to improve utilisation of current capacity and difficult nature of infrastructure expansion.

Although technically, increasing the total available capacity might prove key in facilitating a rail model shift on the long run, realisation on the short to midterm (Khadem & Landex, 2013). The solution space in the technical domain includes enlarging the availability in supply of railway routes and the presence of alternative routes in case of disruption (ACM, 2018). Enlarging the availability in supply of railway routes is difficult to counter railway bottlenecks as it is time, capital, and land-area intensive (Nooteboom & Rodrigue, 2003). Shih *et al.* (2014) note, however, that the presence of alternative routes in case of disruption is conducive to improving railway operations as it allows for greater reliability of rail transport, in case of accidents, failures or maintenance operations.

Capacity increase through further increased utilisation of infrastructure is expected to yield only little growth in train movements, as nowadays Dutch railways see the highest usage intensity per km compared to the rest of the EU (IRG-Rail, 2019). There utilisation rates are steadily increasing towards 90% in 2040, to the effect that the network becomes maximally loaded and more vulnerable to failure while train operations sensitive to disruptions (Min IenM, 2017). The lack of improvement opportunity here arose due to utilisation improvements being historically popular in The Netherlands (Landex & Kaas, 2009). Van Oort *et al.* (2015) attribute the brunt of these improvements to decreasing the minimal distance in between different trains enabled by past improvements in infrastructure (utilisation) management IT systems.

Capacity metrics regarding the performance of infrastructure include feasibility, stability, robustness and resilience, which are pictured in Table *2* Classification of capacity metrics (Goverde & Hansen, 2013). Feasibility is measured through occupation rates, and whether the train schedule can be theoretically processed in the allocated, planned time. Stability is defined by Delorme et al. (2008) as the ability of infrastructure subsystems return to their undelayed states. Stability is therefore expressed as the delay times accrued on the infrastructure, specifically waiting to be dispatched to different subsystem present on the itinerary (Goverde & Hansen, 2013). Occupation rates together with delay (waiting time) are typical performance indicators derived from the comparison of the railway system to a network of queues (Huisman, 2002; Niessen, 2014). Delorme et al. (2008) further suggest looking at statistically tested difference in delay scenarios. Kroon (2001) operationalises this aspect for determining the stability of a timetable by measuring the time necessary for recuperation i.e. the settling time. Robustness of the infrastructure is determined through its ability to withstand external influences, especially increases in traffic. This can be measured in the maximum copiable amount of traffic at a location before the tipping point. The tipping point being the point where secondary delays grow such that the location cannot process the traffic. This point is different from the deterministic theoretical capacity at full utilisation gotten from the division of operating hours by yard or terminal process times, or 24 hours divided by the sum of average traversal time of a track and minimal follow-up time. The tipping point lies provides a lower capacity threshold as stochasticity is explicitly considered.

	Deterministic	**Stochastic**
Macroscopic	Stable	Robust
Microscopic	Feasible	Resilient

Table 2 *Classification of capacity metrics (Goverde & Hansen, 2013).*

2.1.2 Mode Capacity in Rail Freight Transport

In the perspective of the mode of transport, decision-makers typically look at the total available freight capacity in freight cars or rolling stock, and their utilisation rates. Authors, such as Jensen *et al.* (2017) and Hernández *et al.* (2011) suggest that increasing the utilisation of freight cargo cars emerges as the most promising avenue for capacity improvement.

Increasing the capacity of freight cargo cars and rolling stock can be achieved in various ways. A new trend lays in extending train length towards 740 metres allowing more freight cars to be linked on one train. Additionally, new types of cars can be introduced that allow for larger quantities of cargo to be transported. Yet, not all corridors in the Port's hinterland support these innovations (ACM, 2018). In determining rail transport capacity, looking at utilisation rates of freight cargo carts presents an increasing opportunity for improvement now. In the USA, it was found that freight cars travel empty for 40% of the time on average (Mendiratta, 1982). Some reasons for this lay in the directionally unbalanced traffic's necessity to be compensated, furthermore empty rides are induced by specialization of freight cars for specific loads or products, operational constraints and rules (Dejax & Crainic, 1987).

Apart from volumetric capacity, performance of trains can be measured through their throughput time (or travel time), and punctuality (Goverde & Hansen, 2013). With throughput time being the time, a train needs to fulfil the itinerary in the railway system. Punctuality being the reliability or the variation with which trains can do so. Punctuality is expressed as average delay per train signals how well the stability and robustness of the infrastructure as well as train traffic management practices have been able to absorb delay.

2.2 Technical Framework for Port Rail Capacity Management

In this section a technical framework detailing the interconnections of infrastructural subsystems is presented. In section 2.2.1 Framework Introduction, the frameworks purpose is introduced. Section 2.2.2 Demand Patterns expands upon the demand side of railway freight. Section 2.2.3 Port Railway Sub-systems introduces infrastructure and rolling stock composition. These are detailed in individual sections: 2.2.4 Terminals, 2.2.5 Branch Line Freight Trains, 2.2.6 Shunting Yards, 2.2.7 Main Line Freight Trains, and 2.2.8 Main Line. Section 2.2.9 Conclusion summarises the findings.

2.2.1 Framework Introduction

The ideas forwarded by previous reviews on railway freight capacity management can be transplanted to fit the port railway freight system. The synthesis is expressed in a framework, a structure containing a general set of the variables and their conceptual relations. The framework can be thought of as a grammar and syntax for railway freight capacity managers and scholars, who can use the framework to build capacity management theories, i.e. hypothesized causal relations between elements of the port railway system. The framework is presented in the following paragraph outlining the capacity structure of a port railway system, which is built on the literature review (in the previous section), and expert interviews conducted (Appendix B Interviews).

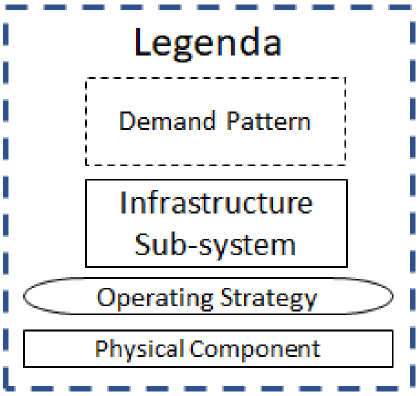


Figure 4 Legend of the technical capacity framework

We keep the matrix-like distinction between a) transport ground infrastructures and the mode of transport, and b) physical structures and their operation from section 2.1.2 Mode Capacity in Rail Freight Transport. In our vocabulary displayed in Figure 4, the port railway system that is comprised of several subsystems, which in other literature is referred to as infrastructural works or elements, such as yards, or terminals. These subsystems themselves are built of components, such as track, signalling equipment and switches. The way in which the (sub)system and its components is operated, i.e. used, is referred to here as the Operating Strategy. The framework is presented in steps, first outlining the subsystems, then their components. Afterwards, the factors governing capacity levels are described in progressive detail. These points have been diagrammatically captured in Figure 7.

2.2.2 Demand Patterns

Demand patterns act as triggers for the subsequent usage of capacity, as it activates different transport service processes which supply transport services across time and space to cater to demand. Demand as a factor for capacity can be overlooked or its effects understated in traditional capacity studies, yet without specifying demand in a more detailed manner, one cannot form an accurate assessment of capacity (Versteegt, 2004). Fazi (2014) unravels part of the demand's influence on capacity through the enactment of scheduling, routing and bundling of freight volumes. In summary, the principal components associated with demand's influence on capacity are the timing of demand, i.e. its scheduling, its origin and destination relation, as well as characteristics such as the type of good, their corresponding volume, and bundling (Van Binsbergen & Visser, 2001).

Scheduling is the determination of the itinerary, set of locations to be visited, at a specified frequency in a certain time window (Veenstra & Zuidwijk, 2016). Although some logistics operations are run continuously 24/7, others distinctly are not, but instead operate according to prespecified operating time windows. These operating windows can be determined for windows in the span of a day, for example by sticking to local office hours. Additionally, the observation of weekends, Sunday rest, (bank) holidays or the alike can lead to the operation being limited to less than the amount of days in the year. Operating time windows affect capacity in two ways: a) limiting theoretical demand for capacity to windows less than 24 hours a day, or 365 days a year, b) may cause misalignment in the operating time windows at subsequent stages of the supply chain (Behdani *et al.*, 2014). Limitation of theoretical demand for capacity is in other words the decision to limit demand for transport capacity to time windows thereby decreasing the utilisation of existing infrastructural assets (Appendix B, interview 21/02). This thereby causes a loss in the available capacity. The misalignment occurs as a consequence of the consecutive demand and capacity operating windows along the stages of the transport chain (Behdani *et al.*, 2014). This misalignment of operating windows causes waiting for railway freight services in the form of e.g. trains waiting on yards as a result, or travel speeds being reduced. All in all, these misalignments also cause deviations from the theoretical capacity, decreasing utilisation of infrastructural assets, but at the scope of the system rather than its components. Frequency denotes the concept that the sources for demand of transport services combine their transport request over time, creating a certain critical mass of goods to be sent off for shipping. An explanation of why this behaviour occurs, can be sought in the existence of economic order quantities supplemented with the need to keep safety stock inventory for the supply chain activities of private parties (Veenstra & Zuidwijk, 2016). The parties aim at minimization of the total costs comprised of ordering, inventory, and transport costs, and therefore arrive at local optimal quantities for shipping. Whereas the previous two operation factors related to the time aspect of transport, the itinerary instead focuses more on the place aspect of transport. The itinerary here refers to the set of places the goods need to arrive at, at some point in their travel. Intuitively, a train making many stops in port railway area can be thought of as having a higher demand for capacity, and thus burdens capacity more than trains making fewer stops along their way.

Goods origin and destination are key factors in determining the routes. The routes which are general descriptions between the entry and exit of the railway system. As well as the exact pathways chosen, which is the set of goods take across port railway infrastructure.

The types of good transported also has an influence over the specific level and use of infrastructure capacity, as goods' characteristics differ across their archetypes (Konings, 1996). For example, TEU are handled and transported using special purpose handling equipment, cars, and even trains, but beyond that, considerations of weight bear little influence over say length of trains used to transport. That is different for wet bulk goods, such as various oils transported across the port railway area. With their relatively high density, the capacity management side has to pay attention to not overburdening the used infrastructures in terms of their carrying capacity.

Bundling can be defined as the consolidation (or bringing together) of the flows of goods in time as well as in space (Fazi, 2014). In the bundling of freight, goods are combined to achieve economies of scale and scope as well as other advantages like improvement of transport quality, increased (service) network economies or a reduction in total area utilisation. Apart from economic reasons, changes to bundling can occur as result of policy, legal or technology pushes.

Pricing the process by which an organisation decides how much to charge customers for transport services. Pricing forms part of the domain of proactive strategies that influence demand by changing demand patterns using price/monetary incentives, often referred to as revenue management (Tavasszy & De Jong, 2013). Active pricing management helps in reducing the wide demand fluctuations and smoothing the demand over time. This makes it easier to plan service capacity to fulfil the demands at the right time. In the port railway stakeholder environment, many of the institutional relations are mediated using contracts-of-use that e.g. give the right to use specific railway infrastructures to rail operators from railway managers or concern the transport service among freight forwarders, rail operators and terminal operators. This leaves room for the application of pricing mechanism from the revenue management domain such as the use of booking systems, customer segmentation, time differential pricing and even sales promotions (Tavasszy & De Jong, 2013).

These factors that make up freight transport demand characteristics, is displayed in Figure 5 below.

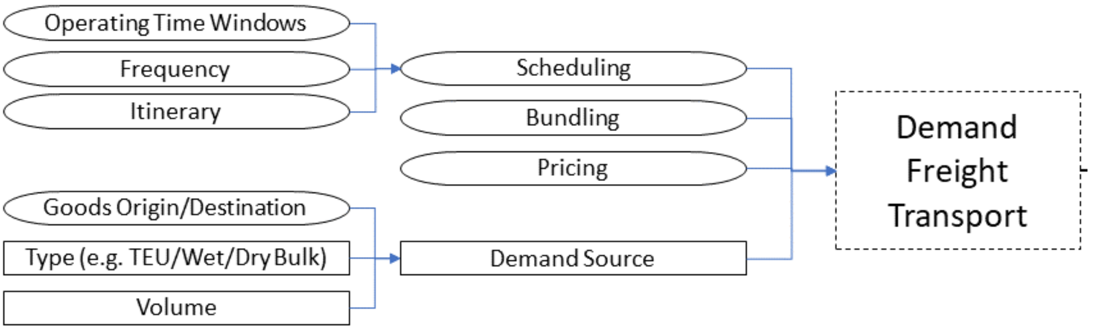


Figure 5 Schematic representation of factors making up freight transport demand.

2.2.3 Port Railway Sub-systems

The port railway system is comprised of terminals, branch line freight trains, yards, main line freight trains, main line. Demand for freight transport in the port railway area extends its influence by pulling at the two 'edges' of the port railway area. In one direction the demand for goods pulls freight from overseas towards the hinterland, and in the other direction the hinterland pushes goods towards the seaside. All in all, goods transported over the port railway area come across terminals (2.2.4 Terminals), traverse by Branch Line Freight Trains (2.2.5 Branch Line Freight Trains) to (Shunting) Yards (2.2.6 Shunting Yards). Where they are shunting to become a Main Line Freight Train (2.2.7 Main Line Freight Trains) to move across the Main Line (2.2.8 Main Line). All are pictured in Figure 6.

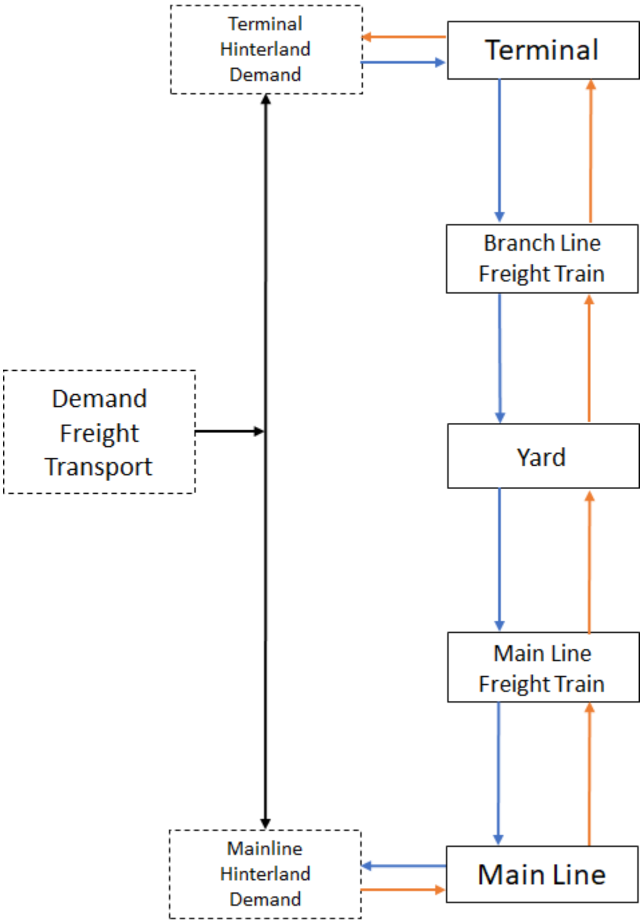


Figure 6 High-level overview of supply-side subsystems on the port railway area.

2.2.4 Terminals

Terminals in the port railway take on a number of tasks such as the organisation of collection and distribution of goods in the region, transloading between modalities, such as truck, barge, and rail depending on the type of terminal, storage, and administration. Terminals can be subdivided into product, service, and geographic-orientation (Wiegmans, et al., 1999). The type of good handled by a terminal can be used for the product-oriented classification of terminals. dry bulk, liquid bulk, wagon loads and containers. By using a service-oriented classification approach, the terminals are distinguished as terminals that focus on the handling of shuttle trains, mixed trains or charter trains (Wiegmans, et al., 1999). In this classification shuttle train terminals focus on the transhipment of high-volume container transport being located in large harbours. The handling of intermodal transport units is focus area of mixed terminals, while dry and wet bulk goods are the concern of charter terminals. In the perspective of terminals' geographic orientation, terminals can be classified according to the specific region or hinterland terminals cater to. Terminals operate under economies of scope and scale, and therefore tweak the two main determinants for capacity, operating hours (i.e. the availability), and transhipment capacity per hour (Visser et al., 2007). According to Saanen & Rijsenbrij (2011), the design of terminals which cater to rail modalities are comprised of railway track, with bundles of track compiled in separate shunting and handling areas, as well as turnaround facilities such as a whye or turnaround table for turning rolling stock. Furthermore, terminals have areas dedicated to handling goods from the complementary modality, storage areas for goods. As well as, equipment used for handling (in the form of reach stackers or cranes) and storing activities. Lastly, offices and terminal staff facilities. Further automation of handling systems for use in trucks, trains, barge also presents an avenue for increased handling capacity (Visser et al., 2007).

2.2.5 Branch Line Freight Trains

Branch Line Freight Trains are the trains connecting the terminal to yards. In the Netherlands, a branch line is the track and switches to which several railway connections are connected to provide access to a business park on the main railway (ProRail, 2019). These branch lines can differ from the main port railway line in that they are: beyond central control, non-electrified, and intersect (manually-operated) road crossings (Appendix B Interviews). However, in the framework they are considered extensions to the main line since some terminals' access is through the main line, and due to capacity considerations and legislative change branch lines are increasingly similar to main lines in their operation. There are several branch lines to the companies and terminals attached to the shunting yard. Trains in their type, speed, and length characteristics predominantly determined and constraint by the specific composition of locomotives, wagons (Jensen *et al.,* 2017). Hernández *et al.* (2011) specify that the amount and type of wagons as well as their length, volume and weight capacity are primary indicators of train capacity. Milenkovic & Bojović (2020) posit that the utilisation of the theoretical capacity is key in determining realised capacity of freight trains.

2.2.6 Shunting Yards

Shunting Yards known as shunting yards, classification or marshalling yards, are major railway system features as nodes in rail freight transport networks (Appendix B Interviews). The main functionality concerns incoming trains which are decomposed, and the railcars are then composed into the desired outgoing train composition (Marinov et al., 2014). With this method, wagons may be sent across the network such that some mixture of origin - destination can be supported without a large amount of individual one-to-one linkages being made. They are distinguished by the disassembly and reassembly of train procedures using a track and switch system. The freight itself is not moved from train to train, but the wagon carrying the freight can be assigned to another as opposed to yards or terminals of other kinds. The freight filled wagons are carried to the shunting site by incoming locomotives, which then travel from left to right across the siding, at point which point they are taken by outbound locomotives. In general, the yard complex can be subdivided into three major zones, all of which involves a series of parallel sidings: the receiving zone in which inbound trains enter, the sorting area where wagons are reconfigured, and the departure area at which arranged sets of wagons wait before they are pulled out of the yard. In order for trains to go from the one subsystem to another, not only should locomotives be changed from electric to diesel powered or vice versa. Also, several activities have to be executed according to ProRail procedures, which includes braking tests, wagon tests, stickering for dangerous cargo, checking wagon lists (Appendix B, interview 21/02).

2.2.7 Main Line Freight Trains

Main line freight trains are composed similarly to branch line trains in terms of the characteristics present, yet their difference lays in the filling in of those characteristics. The most prominent difference being in the method of locomotion, their length and the ability to bundle wagons from different origins and destinations in unit cargo compositions (Hillestad et al., 2013). Main line freight trains can make use of the train traffic control control and electrification facilities, and quality of physical infrastructure on the main line, therefore in terms of their length, weight, composition and speed (Ghijsen *et al*., 2007). Main line freight trains are typically longer, and therefore heavier. The length is achieved by combining the the loads of wagons from different terminals onto one hinterland outgoing train (Ghijsen *et al*., 2007).

2.2.8 Main Line

The port main railway line is the central set of railway tracks that connects the different subsystems in the port railway area. It connects the various shunting yards present in the system with a bus type network topology. At its end the main line branches out towards the various hinterland origins and destination beyond the port railway area. The main line’s capacity is determined by the protection system, the number of parallel tracks in a section, and the presence of obstacles (ProRail, 2019). The number of parallel tracks gives rise to the possibility of facilitating to and fro directionality of trains, while multiple tracks, or sidings in the same direction allows for overtaking (*Shih et al.*, 2014). The protection system in the main line, like on the branch lines determines the ability to handle trains through size of block section, and therefore the number of blocks (Van Oort, 2015; Appendix B, interview 17/03). Advanced protection systems such as ERMTS provide improved capability for monitoring of train’s block presence and movement speeds, and combines this information to dynamically control permissible block traversal speeds. The obstacles can constrain the number and/or composition of trains traversing the port main line by: the presence, and placement of customs procedures, such as load scanning facilities or the intersections at level crossings, either other railroad tracks, with roads or inland leading waterways.

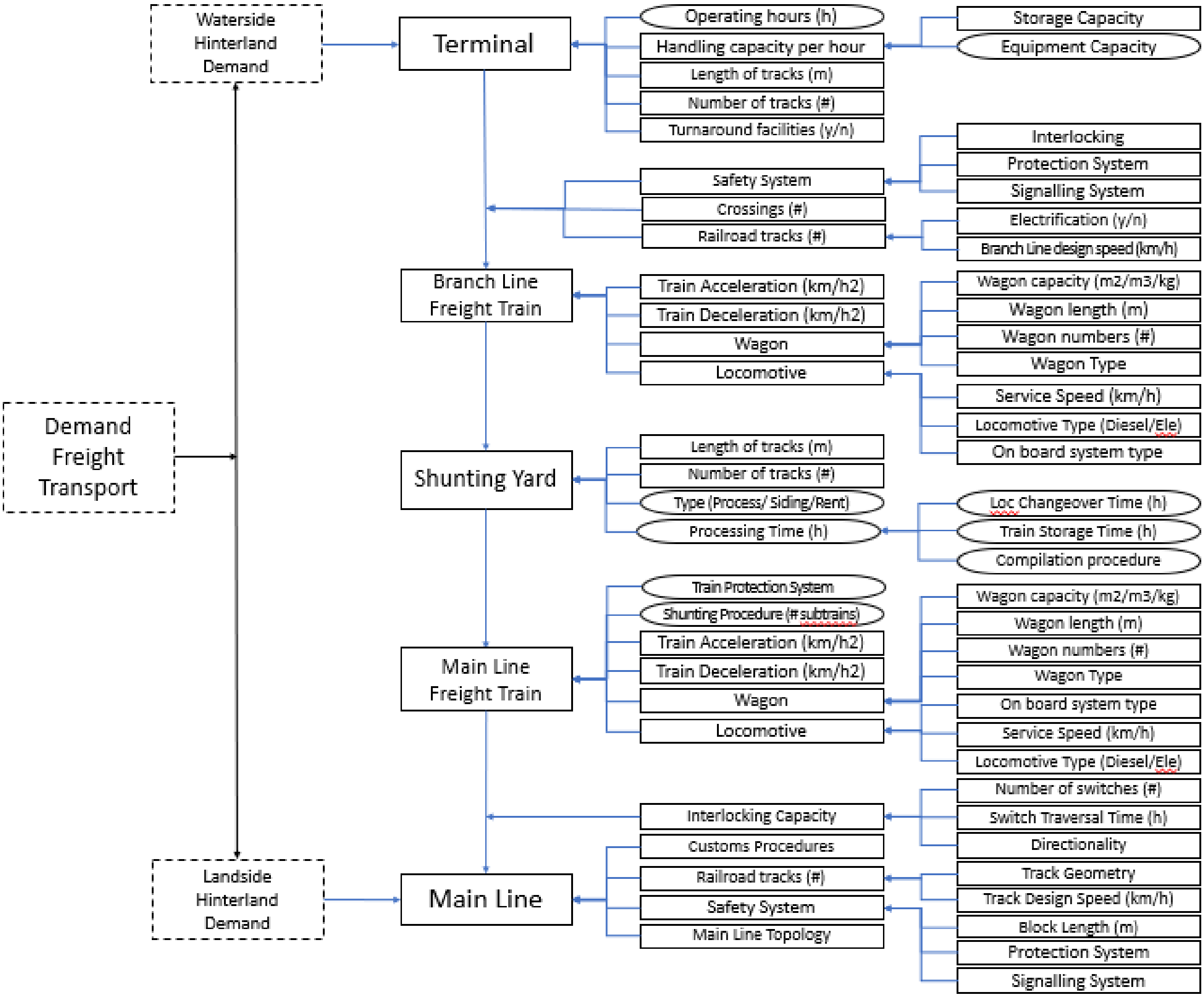


Figure 7 Framework for capacity management in port railway areas.

2.2.9 Conclusion

The framework contains a general set of the variables and their conceptual relations, and invites theorizing causal relationships towards measurement capacity performance. Railway freight capacity managers and scholars can use the framework to build capacity management theories, i.e. hypothesized causal relations between elements of the port railway system. Any port railway area can be thought a specific configuration of the variables. Capacity interventions are specific changes to the existing configuration.

All in all, the framework does not allow for direct conclusions regarding the effect of an intervention on capacity performance, however it: a) shows where in the physical infrastructure complex interactions can emerge, b) set-up the rationale for simulation study design, c) structures and inspires exploratory research and experimentation into how sensitive performance of the railway system is to (sets of) variables. It is necessary to have capacity study processes in place that systematically evaluate the effect of (changes in) the configuration of the variables in the framework. Therefore, the capacity process needs to be defined such that the frameworks variables are reasoned through systematically.

2.3 Decision-support Tooling for Railway Capacity Planning

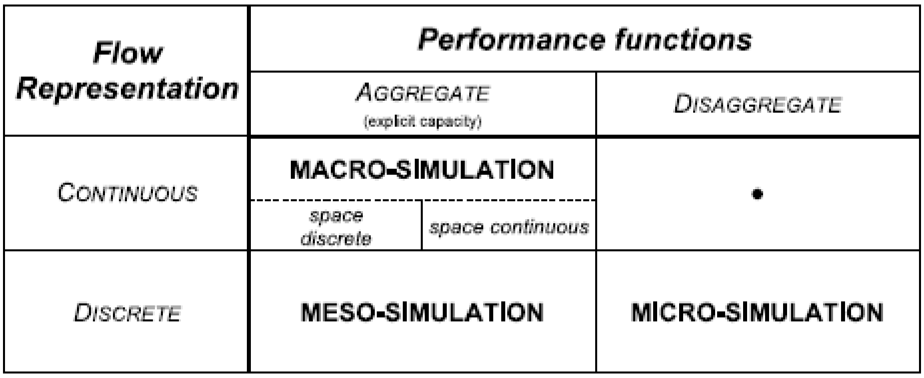
Decision-support models are used to quantify expected performance of (changes to) the railway system by approximating by the dynamics on the railway infrastructure and rolling stock. The decision-support tooling used in railway freight capacity studies is primarily comprised of: a) analytical operation research models, and b) simulation models.

2.3.1 Analytical Models

Milenkovic & Bojović (2020) identify analytical models such as realisation-based analytical models (e.g. Vromans, 2005), growth factor analytical models (e.g. Visser & Van Binsbergen, 2001), queueing models (Huisman *et al*., 2002), and Max-Plus Algebra (Kroon, 2001). Realisation-based analytical models and subsequent growth factor modelling are generally used to investigate specific locations for bottlenecks in privately conducted studies by railway infrastructure management organisations (Vromans, 2005). Tax (2010) argues that these rudimentary analytical models suffer from the same disadvantages as more advanced analytical models, such as queueing models or Max-Plus Algebra, while performing worse due to lack of incorporation of dynamics, and stochasticity.

2.3.2 Simulation Models

There are different types of simulation methods available for analysis the performance of transport infrastructures such as railway systems. Cascetta (2009), provides the following taxonomy of simulation-based studies given in Figure *8*. The axis along which differentiation occurs is flow representation and performance functions. Flow representation denotes the treatment of the network linkages, time, and mode of transport, i.e. trains, which can either be continuous in analogy of fluids. Or, discrete as implies space, time and mode of transport at the level of the individual train, or even more specific as distinctive sets of locomotives and wagons over increments of time and parts of the network. The performance functions describe how the performance of simulation objects is derived, namely aggregated through law type formulae that derive speed from object characteristics or stochasticity or disaggregated that go deeper and base performance on driver vehicle interaction with specific behaviours for each individual driver and train concerning e.g. acceleration, crossing approach, path preference.



<table>
<tr><th rowspan="2">Flow Representation</th><th colspan="3">Performance functions</th></tr>
<tr><th colspan="2">AGGREGATE
(explicit capacity)</th><th>DISAGGREGATE</th></tr>
<tr><td rowspan="2">CONTINUOUS</td><td colspan="2">MACRO-SIMULATION</td><td rowspan="2">•</td></tr>
<tr><td>space discrete</td><td>space continuous</td></tr>
<tr><td>DISCRETE</td><td colspan="2">MESO-SIMULATION</td><td>MICRO-SIMULATION</td></tr>
</table>

Figure 8 *Overview of simulation models for transport analysis and planning Cascetta (2009).*

2.3.3 Comparison of Analytical and Simulation Models

Current railway modelling literature gives an overview of some of the advantages and disadvantages of simulation models versus analytical models as decision-support tools for railway system capacity, which is presented in Table 3. The advantages, and disadvantages of both types of models are presented vis-à-vis and are based on the models described in sections 2.3.1 and 2.3.2.

Advantages	Disadvantages
● Simulation can, in contrast to most analytical models, simulate an entire network system, while combining both micro and macro level (Cascetta, 2009). Whereas analytical models are made for one level, have to be linked if multi-level analysis is demanded leading to validity concerns (Kroon, 2001). ● Simulation and analytical models offer the possibility to look into the future, or to test different scenarios. On the basis of realization dates, only extensions of the past can be tested (Tax, 2010). ● Simulations can be designed to provide very detailed output regarding a broad scope of metrics, while the output of analytical models is often limited or aimed at single indicators, especially when the analytical model performs an optimisation (Robinson, 2005). ● Simulation models have the ability to work at virtually any level of detail. Analytical models by design less inflexible and provide insufficient detail for specific questions, necessitating reworking the model (Hansen & Pachl, 2014). Adding more details increases user's trust in the model, but also increases the dependence on good input data (Tax, 2010). ● Simulations can incorporate a broader range of options for stochasticity and dynamics than analytical models can, e.g. through the inclusion of disturbance data and dynamics (Vromans, 2005).	● Simulation does not give direct information about how an optimal timetable or infrastructure configuration should look, or how the existing timetables and configurations can be improved (Hansen & Pachl, 2014). Interpretations can be used to come up with ideas for improvements can be made and they can be tested reasonably easily by carrying out of a new simulation. ● Incorporation of stochasticity and feedback dynamics entails makes that simulation models only produce estimates of system performance, and thus require statistical evaluation. Due to the natural link with timetable planning models, analytical models can be prescriptive of system performance (Robinson, 2005). ● The increased level of detail in simulation models also prolongs the simulation time, whereas analytical models can have faster computational times (Robinson, 2005; Tax, 2010).

Table 3 Comparative review of railway simulation models versus analytical models.

2.3.4 Conclusion

In conclusion, simulation tools support capacity management processes better through their flexibility of use across purposes, ability to function at multiple levels (i.e. macro, meso, micro), as well as the broadness and detail of measurement output. This flexibility is not found in analytical models. Yet, given that finding optimal configurations of railway capacity infrastructure is not part of simulation models computation, capacity managers have to be supported in their aim to improve infrastructure by processes designed for systematically applying simulations to arrive at capacity insights.

2.4 Railway Capacity Management Process Organisation

An introduction to the capacity management is given in section 2.4.1. The technical scope is discussed in section 2.4.2. The time scope of each level is outlined in section 2.4.3. Characterisations of uncertainty for scenario building are discussed in section 2.4.4. The incorporation of certain aspects, such as interventions in scenarios is presented in section 2.4.5.

2.4.1 Introduction to Capacity Management Processes

The creation of overviews of capacity management decision making processes has a tradition in disciplines such as supply chain, operations, and production management. In these disciplines, capacity management decision-making processes are referred to as planning or planning and control, where in some instances the object of planning specified by using phrases as materials planning, supply chain planning or resource planning and control. Previously developed taxonomies, frameworks, and hierarchies outlining capacity management decision making in specific are known as: Hierarchical Planning Process, Materials Resource Planning.

Across capacity management decision-making efforts in the different disciplines, a central trade-off is identified between the desire to create an integral plan while maintaining the ability to truly optimise capacity performance (Fleischmann & Meyr, 2003; Hax & Meal, 1975).

- Integrality Principle: The ideal of integral planning on railway transport system level. The process of planning should take into account time and place dynamics of the railway system, from terminals to the hinterland as a whole and consider the effects of their interdepencies, e.g. possible network cascading.
- Optimality Principle: The ideal of truly optimising of capacity decisions. The process of planning must work with concise, unambiguous definitions of the optimisation objectives, performance criteria and constraints as well as the use of exact or heuristic optimisation methods, i.e. algorithms.

This central trade-off is hierarchically decomposed in a common three-level characterisation of management decision levels, first introduced by Anthony (1965). These levels are known as strategic, tactical and operational or long, mid and short term respectively. Decision-making at these levels entails firstly determining the scope of decision-making, and secondly the scenario(s)-based characterisation of the context of decision-making (Schoemaker, 1995). Scoping entails deciding upon the which aspects of the technical system are considered in capacity management decision-making and over which time frame these aspects are considered (Schoemaker, 1995). Scenario development implies characterising both the uncertain and certain aspects regarding the technical scope over the time frame (Schoemaker, 1995).

In Table 4, an overview is given of the specified levels along with distinctive characteristics attributed in the literature to each level, regarding the scope of study (technical and temporal), and the scenario composition for studies (regarding uncertainty and interventions). The contents of the table is discussed in subsequent sections.

Decision-Making Level	**System Scope**	**Time scope**	**Uncertainty Scenario**	**Intervention Scenario**
Strategic	System-level	Long: lifetime of physical infrastructure (~20 yrs)	High: ambiguous uncertainty of economic and technological trends.	Structural: interventions into design of the system
Tactical	Sub-systems	Medium: project initialisation span (~10 yrs)	Medium: variable uncertainty of e.g. peaks in demand or process times.	Functional: intervention within a given design of system
Operational	Components	Short: (now to 5yrs)	Low: epistemic uncertainty in e.g. train arrival times	Incidental: intervention on a component.

Table 4 Discussion of decision-making levels in capacity management.

2.4.2 Technical Scope of Capacity Management

On the strategic level of capacity management, decisions are made whose consequences have a long lasting effect on the operation of the railway, and typically involve decisions on the railway system's overall performance goals and objectives, as well as the types and service levels of resources available (Marinov & Viergas, 2011). These decisions in essence determine the physical structure of a railway system and should directly therefore reflect a shared future logistic vision set out by transport policymakers, suppliers and customers (Fleischmann & Meyr, 2003).

The tactical level is about effectively and efficiently employing the existing infrastructure set out by the long-term strategic management decisions. Tactical capacity management deals with decision making and planning on the medium term. The development of train schedules which are prepared based on emerging demand patterns over time is important for the demand and supply matching on this level. Typically, system performance measurement, capacity studies and congestion analysis are prepared and executed at this level (Caris *et al*., 2008).

Capacity management on the operational level puts the given guidelines into practice, while adhering to constraints posed by higher laying decision levels. Operational capacity management occurs on the shortest term and focuses on monitoring delivery of service, readjusting plans if necessary and thus controlling the realised performance (Fleischmann & Meyr, 2003). Specifically, operational management prepares detailed instructions for immediate execution prepared as well as the operational control through e.g. traffic allocation and control (Marinov & Viergas, 2011). Operational management is thus dedicated to fulfilling railfreight transportation services and the day-to-day implementation of train schedules.

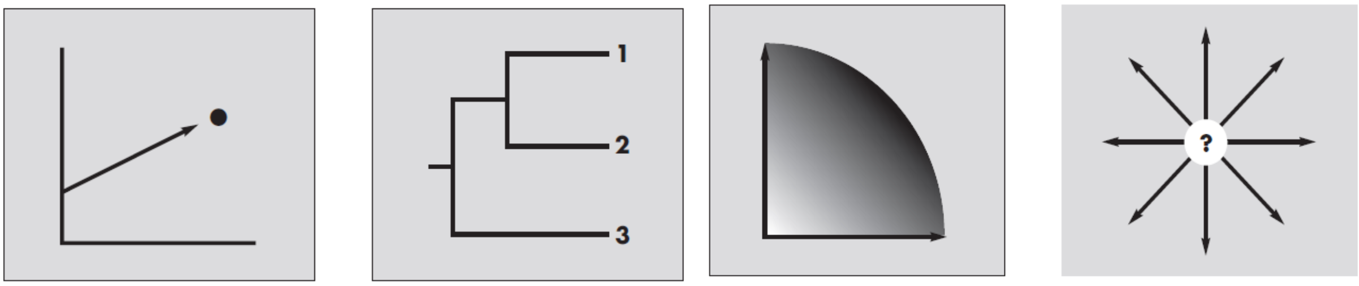
2.4.3 Time Scope of Capacity Management

Time scopes in capacity management are denoted as the farthest point in time for the planning efforts setting the endpoint of an assumptions made. (Arreco, 2015). The Port of Rotterdam Planning time horizons are delimited to long, mid and short-term time scopes. strategies. The long-term perspective, 2030 to 2065 is used for the so-called Masterplans and Port Vision documents. The strategic plans are focussed on the medium term, 2020 to 2030. While, the short term is referred to as project planning for 5-year time scopes. These time scopes are congruent to those found in the railway world, likely as a result of the similar longevity of infrastructure works. As is the case at the UK's Network Rail, owner and infrastructure manager for large parts of the UK In their role as custodian of the rail network capacity, they have developed the Long Term Planning Process (LTPP) for the development, maintenance and management of the British railway system (Network Rail, 2017).

2.4.4 Scenario Development for Uncertainty

Walker et al. (2003) identifies two types of uncertainty which affect socio-technical systems in general that apply to capacity management of freight railroad transport also, namely: epistemic uncertainty and variability uncertainty. The first type, epistemic uncertainty can be described as the limited nature of our knowledge that can be alleviated or cleared up by activities such as measuring, analysing, or researching. The second type, variability uncertainty, can be described as the innate and uncertain variability related to the social, environmental, technological and economic evolution of a socio-technical system. Technological developments, their (surprising) span applications and contexts, and resulting externalities i.e. side effects. Economic trends product, process and business model developments that have effects reaching beyond the financial statements of companies. In the context of rail freight transport especially the demand side is affected by these developments, such as origin destination relations and their allocated volumes. The behavioural dynamics of a social nature, particularly capabilities related to individuals and behavioural aspects. Behavioural aspects include human behaviour at the micro-scale or societal behaviour at the macro-scale. These reflect in the railway system for example through the behaviour of train drivers in accelerating and decelerating, which carries through effects into the macro level.

Courtney et al. (1997) discerns four levels for characterising uncertainty, which are represented graphically in the figure. In level 1 types of uncertainty, the future is presented as fairly clear, meaning that one can predict and aim for an optimal plan. Although some level of residual uncertainty is still present, it is sufficiently small to pin point in the direction of a particular strategy. Level 2, alternate futures, describes the case where the future may be one out of a few alternate futures. The analysis of discrete scenario’s leads only to a specification of uncertainty for which long term probabilistic projections are made.



A Clear-Enough Future **Alternate Futures** **A Range of Futures** **True Ambiguity**

Figure 9 Graphic explanation of uncertainty levels (left to right: 1 to 4; (Courtney et al., 1997)).

In the process of capacity management therefore strategies emerge such as preparing for uncertainty through deep research or by waiting, postponing decision-making till the uncertainty becomes clearer. It is not always feasible to delay action till a point of time at which there is potentially more certainty. The degree of uncertainty defines the course most fitting for intended interventions. Uncertainty at levels 1 and 2 where the alternative scenario probabilities are observed is particularly unusual. Uncertainty level 3 typically needs a robust static approach along a continuum of possible scenarios in which possible futures are defined. Scenarios investigate the influence of different complexities on one another. First, the evaluation of policy alternatives (strategies) in every situation can be performed. Under all these conditions the approach selected ought to be robust. There is a risk that during the scenario preparation not every scenario (or important factors in those scenarios) were taken into account. Hence, dynamic strategies should be preferred that can be adjusted in transient contexts. Level 4 uncertainty cannot solely rely on methods that attempt to forecast as they will yield unsufficing interventions. Instead the most fitting procedure would be to devise interventions that are adapting to unfolding uncertain events, such as those occurring in VUCA environments.

2.4.5 Scenario Development for Interventions

Interventions in railway infrastructure are the possible adjustment or expansion alternatives, which are generated and evaluated using an appropriate capacity evaluation model to suggest an optimal network capacity plan (Lai, 2010). Generic capacity efficiency frameworks that specify transport services interrelations are for example found in the cascade model proposed by Van Binsbergen & Visser (2001).

Marinov et al. (2014) use the long, mid and short-term hierarchical taxonomy to specify possible interventions capacity intervention in railway yards. Their long term perspectives encompasses railway strategy choices regarding the designing, technical drawing, and building of network infrastructures, the positioning of facilities used in the operation of railway transport services, prioritising maintenance of rail infrastructure system, as well as the process of acquiring and merging of system-wide railway activities, and assets.

At a strategic or macro level of transport, high level observations can be made regarding the level of capacity in the transport system. Boysen et al. (2012) classify large alterations to the network system including the positioning and building of new shunting yards, renewal, removal and improvement of existing shunting yards. This entails decisions regarding the type and magnitude of shunting mechanisms, e.g. humps. Additionally, the strategic level encompasses what railway routes ought to be serviced at what shunting yards, and the subsequent consequences for shunting yard design and connections. Particularly, amount and length of sidings, as well as directionality of switching arrangements. Whether high-cost investment activities regarding facilities at yards should be undertaken such as the development of interlocking systems.

The tactical level is preoccupied mainly with decisions on the investments on medium-cost equipment for example big maintenance projects or shunting locomotives. But also, the establishment of service facilities (e.g. operating structures, repair shops, and the like.), as well as closure or reconstruction on a single carriageway. Small scale innovations and improvements that affect the assertions, such as changes to the time brackets, process times, and variability incorporated in a) freight train schedule generation, b) the definition of routes for freight including their intensity and duration, c) timetables, d) pathway routing of loaded freight wagons, e) railway train traffic control procedures at low levels, f) blocking procedures alternatively noted as the clustering of train cars into partitions that continue transportation jointly across various parts of the railway system.

The operational level features methods for allocating block windows efficiently and effectively, such as those described in reviews by. The review by Milenkovic & Bojović (2020) presents and describes train car operations such as rail freight wagon inventory management, the distribution of empty rail freight wagons, freight wagon pooling concept, and the combined allocation of empty and loaded freight wagons. On other areas of the operational level day by day management activities are mentioned such as loc allocation and crew scheduling, as well as timetable adjustments and dispatching.

A generalisation of the possible capacity interventions along the previously specified time axis is presented as Table 5.

Decision-Making Level	Interventions in physical structures	Interventions in operating strategies
Strategic	Structural: Expansions, major adjustments.	Structural: Systemic changes to e.g. generic traffic management across the network, (re)design of network
Tactical	Functional: adjustment to the use within ‘given’ infrastructural design.	Functional: interventions to specific works in the system and their interrelations.
Operational	None or incidental component replacement.	Incidental: Allocation Mechanisms (booking), Control Measures (splits) and Component Interventions

Table 5 Overview of generic interventions corresponding to distinct levels of capacity management.

2.5 Interorganisational Coordination in Freight Railway Capacity Management

In this chapter, we discuss governance structure found in railway capacity management, and how it is influenced primarily by bottom-up coordination between organisations (section 2.5.1 Governance of Freight Railway Capacity Management). Dependencies in coordination processes are described (section 2.5.2 Coordination Process Design). Thereafter we expand upon design rules, principles and mechanisms that academic literature puts forward for designing effective interorganisational coordination in the context of logistics (section 2.5.3 Coordination Process Mechanisms

2.5.1 Governance of Freight Railway Capacity Management

Managing capacity of railway freight occurs in a governance design, which we define in line with Bevir (2012) to be a specific institutional organisation of decision-making rights, which are distributed over stakeholders involved in creating, maintaining, and making use of capacity. The constitutionality of the organisation of decision-making rights here refers to the a) formal regulatory nature given in by laws, or contractual arrangements and b) informal regulatory nature, derived from culture, or gentleman's agreements (Koppenjan en Groenewegen, 2005). The goal of institutional design of governance is to get stakeholders to make decisions regarding capacity that will in the end improve the performance of the infrastructure, meaning decisions that guarantee safety, reliability, and affordability of freight railway transport in the future. Research in the governance domain is therefore primarily aimed at the way interaction of stakeholders is conditioned under the influence of governance design and what performance it yields (Veeneman, 2019). An in-depth understanding of how the organisation of decision-making influences performance of the infrastructure can therefore be used to suggest governance designs that are aimed at improving performance (Hirschhorn et al., 2019).

Governance literature informed by the field of institutional economics describe different hierarchical layers that influence infrastructural capacity decision-making as shown in Figure 10. Finger and Künneke (2011), in line with Williamson (1998), identify three layers of institutional environment: embeddedness, governance and coordination. Embeddedness is the institutional environment that deals with high level informal institutions (norms and values) and formal institutions (constitutional, and treaty law, rules and procedures). The railway freight capacity management is in this case embedded in regulation specifying ProRail as the relevant infrastructure manager for physical railway elements as well as guaranteeing infrastructural access to freight railway operators (Van der Horst & Van der Lugt, 2014). The governance layer is primarily the domain of responsibilities referring infrastructures' design specifics. In this layer, the technical design principles and market governance arrangements are related. Responsibilities are divided within the technical and institutional context concerning: a) tasks of monitoring and controlling operations of technical nature and b) rights pertaining to market transactions (and public service obligations) of ownership and decision-making (Künneke, 2013). The coordination layer refers to the interaction between the different individual parties, specifically the techno-operational coordination as well as economic transactions involved in realizing a specific related goods or services (Künneke, 2013). This implies that transactions do not involve mere physical exchanges of goods on the market, but exchange of rights and duties, as well as the execution of control tasks is also included. Transactions are not free of charge; some examples of costs associated with transacting are search costs for finding the right partners and products, the cost of time necessary to negotiate exchanges (Coase, 1937). An example can be found when information is exchanged among railway parties in order to dynamically formulate a real time block planning.

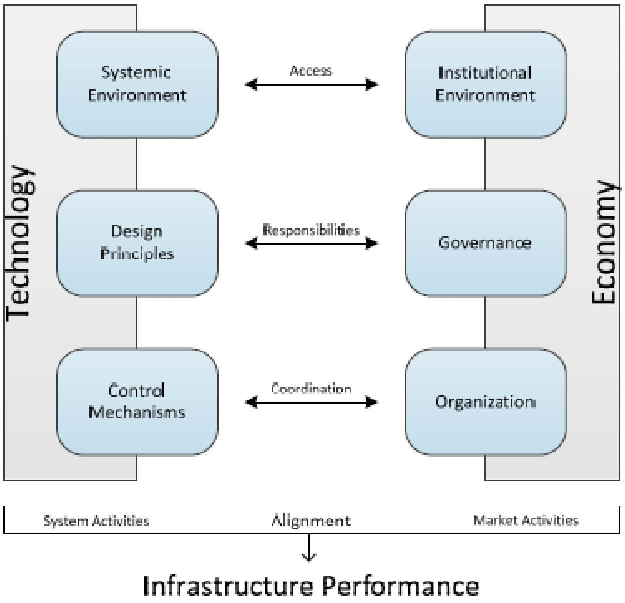


Figure 10 Alignment perspective of technical and economic design from: (Scholten & Künneke, 2016).

Powell (2003) describes the three ways in which the three prespecified layers can be structured institutionally in order to minimise transaction costs incurred in coordination, namely through markets, hierarchies and networks. This view is embedded in transaction cost economics, where Coase (1937, 1960) and Williamson (1975) made contributions to describe that aligned governance structures are most efficient, meaning that in the long run total transaction costs are lower than in other governance structures. In market-based governance, competitiveness drives the decision-making process as parties can freely make choices among alternatives for access, governance, and transactions. In hierarchical structures this freedom of choice is more rigid, with a controlling party having the authority to decide independently, or even on behalf of other involved actors. Networks feature no clear power relations, yet do not offer the flexibility of market choice. Instead involved stakeholders have the maneuvering room to negotiate joint solutions. Networks structures, as a hybrid, provide the opportunity to arrive at optimal and holistic governance designs that are in accordance with stakeholders standards' goals, albeit being vulnerable for information asymmetries and strategic behaviour of actors in the network (Veeneman, 2019). It can be concluded that in networked governance, in the absence of clear direction giving top-down institutional environment, that governance structure is emergent from the coordination of organisations regarding control mechanisms.

Capacity management decision-making with the Port of Rotterdam and Prorail can be seen as a form of network governance. Finger *et al.* (2005) place capacity management as a critical technical function governing specific technical infrastructural elements. Their research thus suggests that the technical function of capacity management should be matched with an institutional governance structure. This structure can best be typified as a network, not merely because of the physically networked (meaning interconnected, and interoperable) nature of railway infrastructure in the port, but also because of the absence of clear hierarchical, or market functioning (De Lange & Chouly, 2004). The railway infrastructure governance is thus mentioned in the same vein as other networked infrastructure sectors, such as electricity networks (Jonker, 2010) and water supply networks (Garcia et al., 2007).

Interorganisational infrastructure capacity management necessitates coordination activities as coordination problems arise given the interdependencies among stakeholders. The port railway infrastructure's capacity related activities are interorganisational in nature, as stakeholders conduct capacity studies and make decisions in capacity management jointly. The arising interdependencies can take the form through information requests, cost- and benefit distribution or exchanges of decision rights used in the management of capacity. They therefore take physical appearance on the framework's coordination layer, which is commonly seen in interorganisational logistic decision-making (Babeliowsky, 1997; Van Der Horst & Van Der Lugt, 2014). The definition of coordination places capacity management for rail freight additionally in the domain of process-managerial research which takes a network perspective on interorganisational interaction, dependency and decision-making, as well as in the earlier described institutional economics domain (Klijn, 2005; Teisman et al., 2009). In this process they are linked to other stakeholders through their mutual interdependencies.

2.5.2 Coordination Process Design

Coordination theory posits that "coordination can be defined as managing dependencies among activities" (Malone and Crowston 1994; De Bruijn & Heuvelhof, 2018). Therefore, a characterisation can be made of different kinds of dependencies and the coordination processes that govern them. The benefit of placement within process-managerial coordination theory literature is two-fold in that we can: 1) justifiably take a process-view towards coordination in capacity management, and 2) draw on mechanisms and design principles put forward by coordination theory.

Both Crowston (1991) and Zlotkin (1995) present an outline of three foundational varieties of dependencies, which is discussed in this section, namely: 1) flow, 2) sharing, and 3) fit dependencies. The origin of each of these three varieties lays in the existence of activities that relate to particular resource. A 'flow' type dependency occurs when precursor activity produces a resource that is required to perform a subsequent activity. The flow dependency is perhaps the most common dependencies and implies that the product in question must be available at the right time, in the right place and according to the right specifications. When multiple activities require the use of the same resource, the dependency is referred to as a 'shared' dependency. Possible occurrences include times at which a single person, or machine is required for the execution of multiple activities. The sharing dependencies is a critical part in process management as it typically involves allocating the shared resources. Lastly, when multiple activities in jointly and in parallel produce a single resource this is referred to as a 'fit' dependency. An example would be in the technical design of a railroad shunting yard where several engineers work on the design of specific components that have to be aligned in order to fit in the final assembly of the shunting yard.

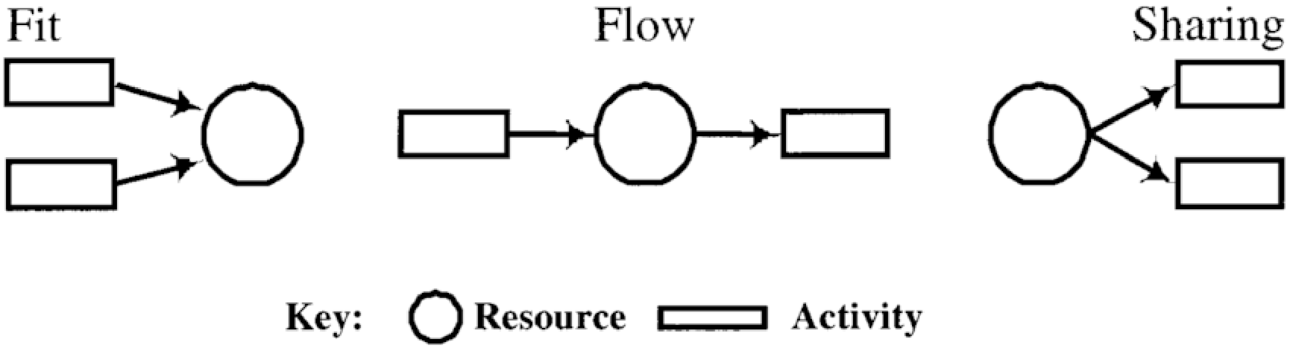


Figure 11 Types of process dependencies from Crowston (1991) and Zlotkin (1995).

The quality of coordination process can expressed through the maturity of its development. Although there are at least over thirty different process maturity models on the market, Capability Maturity Model (CMMI) is frequently used in academia, US defence contracting, and industry (Basili et al., 2002; Siemens, 2013). Empirical research shows that working towards higher process maturity levels can assist in producing high quality outcomes, reducing cost and time, and increasing productivity within various industries and sectors, such as software engineering (Butler, 1995), aerospace engineering (Yamamura, 1999) and engineering project management (Cooke-Davies & Arzymanow, 2003). Figure 3 outlines the maturity levels involved in CMMI, each higher step focuses on greater repeatability, structure, and continuous improvement concerns incorporation.

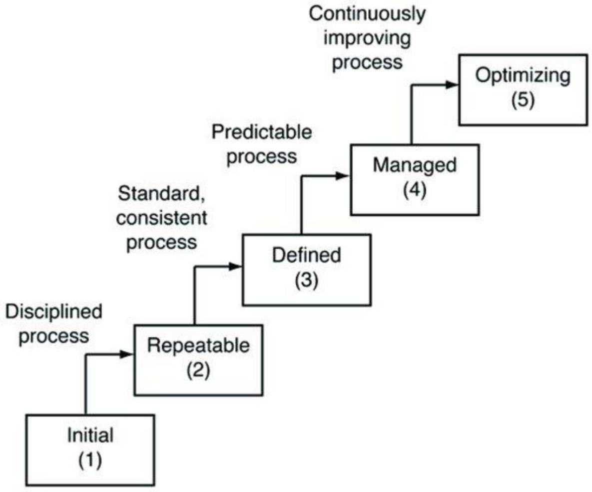


Figure 12 Capability Maturity (Model from Paulk et al., 1993).

2.5.3 Coordination Process Mechanisms

As, the value of taking the process perspective to coordination (including dependencies and mechanisms) lays in the opportunity to tap into academic literature outlining beneficial matches dependencies and mechanisms (Malone et al., 2003). The mechanisms described in the following section can help structure processes to become less centred around (the problems of) dependencies, and instead focus again on gaining progress, a desired degree of transparency, traceability, and substantive quality in decision-making (De Bruin & Ten Heuvelhof, 2010). The coordination processes that are described above have constant and variable characteristics associated with them. Constant meaning there is a base of fruitful mechanisms which are found across different processes and variable meaning that a single dependency can be managed through a host of diverse mechanisms (Malone et al., 2003). The combination of identifying dependencies and coordination mechanisms offers an opportunity for improving coordination processes.

Early work on coordination by March & Simon (1958), on the basis of which subsequent authors have distilled three coordination principles through which coordination of interdependent decision-making processes can be improved, namely a) coordination by standardisation, b) coordination by plan, c) coordination by mutual adjustment (Thompson, 1967). Coordination by standardisation denotes the bounding the scope of activities that can be undertaken by an organisation through rules, or fixed procedures. Stable and repetitive situations to be coordinated can be steered through the preconceived and consistent sets of rules (Galbraith, 2014). Coordination by plan is characterised by increased room variation in procedures or rules than the coordination by standardisation, it therefore denotes the creation of plans among mutually dependent organisations. Plans figure to loosely steer execution in dynamic situations, while e.g. confronted with updated requirements (Mintzberg, 1979). Coordination by mutual adjustment (Thompson, 1967) or coordination by feedback (March & Simon, 1958) is suitable for fit dependencies. When faced with volatile, uncertain, complex, ambiguous (vuca) situations coordination by mutual adjustment is a suggested mechanism (Galbraith, 2014). There is considerably more transfer of information during these coordination processes, which then also involves more communication and decision-making (Thompson, 1967).

Star (1989) addresses the importance of boundary objects for coordinating expert collaboration, which enable cooperation without complete mental models of either's work, working together successfully while using "different units of analysis, methods of aggregating data, and different abstractions of data" and lastly collaborate in spite of having different objectives, time windows, and stakeholder fields.

Gosain et al. (2004) describe coordination mechanisms aimed specifically at interorganisational, technology supported coordination in a logistics context, where they recommend: a) advanced structuring & b) dynamic adjustment. Advanced structuring denotes the idea of structuring information exchange and dependent processes *ex ante* with room to manoeuvre, alike coordination by plan. Orton & Weick (1990) referred to these situations as being "loosely coupled", where "coupled" denotes the dependent structuring of process, while "loosly" denotes that the degree of dependence may decrease in case of unexpected changes, or more broadly put when uncertainty resolves.

Gosain et al. (2004) built on this work by proposing three aspects to advanced structuring which built onto the coupling and looseness concepts, namely standardisation of process and content interfaces, modular interconnected processes, and structured data connectivity. This reflects the structuring and use of especially decision-support model as a boundary object. Standardisation of process and content interfaces refers to the standardisation of specific sub-processes crossing organisational boundaries (interfaces), the specifications of data formats and shared data bases. Modular interconnected processes are complex processes disaggregated into sub-processes (tasks), which can be independently executed by the collaborating organisations to achieve clearly specified coupled outputs (i.e. transforming flow to fit dependencies). Structured data connectivity is about having the ability to share structured transaction data and content between collaborating organisations in a digital format.

The dynamic adjustment, alike coordination by mutual adjustment, denotes to the rapid adjustment of inter-organisational processes in response to changes in complex collaboration situations. Complex collaboration situations are characterised by VUCA, volatile, uncertain, complex and ambiguous. Gosain et al. (2004) expand by incorporating IT learning processes explicitly. This leads them to propose three aspects to the mechanism, namely 1) the breadth of information shared with collaborators, 2) the quality of information shared with collaborators and 3) deep coordination-related knowledge. In order to react rapidly to (surprising) changes in the environment, a breadth of interorganisationally shared information of high quality is needed to base effective reactions on. Deep coordination-related knowledge denotes the shared mental model, deep knowledge of others' information base, experience, organisational workings, processes, and functions (Gosain et al., 2004).

2.6 Knowledge Gap

The literature review presents a synthesis of principles for the design of technical capacity management processes and the coordination of interdependencies in decision-making processes. The literature review finds that principles derived for technical capacity management processes principles are mature, in that they have been applied and validated in a wide range of capacity management settings (Vogel et al., 2016; Fleischmann & Meyr, 2003). However, the literature review also finds that the principle-based approaches are relatively new in application to the problem space of (semi) public interorganisational networked processes using decision-support models as found in Port of Rotterdam and ProRail cooperation. The research problem posed intersects the topic of network governance of infrastructure, decision-support model mediated public governance processes and application of coordination principles to network decision-making processes.

- Networked governance of infrastructure planning is faced with more coordination challenges than other governance forms, given the novelty to design processes to govern network coordination free from market mechanisms or the workings of hierarchy (Roehring *et al.,* 2019; Klijn & Koppenjan, 2016). Roehring *et al.* (2019) conclude that more research is necessary aimed specifically at identifying causes of coordination challenges that make the decision-making processes in interorganisational networked coordination fundamentally different than the issues common in dyadic market or hierarchical organisational relationships. This finding is acknowledged to be important for the specific port infrastructure governance environment by De Langen *et al.* (2018).

- The role and effects of decision-support model use in public organisations' interorganisational coordination processes is not described sufficiently by case study research, especially considering the inability to generally extend case study-based findings from the private domain (Jonathan & Ruslin, 2018). As problems arise due to accountability, and the amount and variety of systems used (Jonathan & Ruslin, 2018). Because, public organizations are becoming increasingly dependent on joint decision-support models, therefore more interorganizational governance research for this environment is needed (Helin, 2019).

- The use of principles to design better performing coordination processes is a well-established practice, however in the review by Trang *et al.* (2013) not a single article focused exclusively on coordination mechanisms in the case of decision model-supported networked coordination. Even though existing decision-support model governance research already reveals the importance of coordination mechanisms that bridge the divide between social and technical aspects (Trang *et al.*, 2013). Specifically, in the transportation domain, Pan *et al.* (2019) signal that the design of cooperative transport services has knowledge gaps relating to (non-market) network-based cooperation, and the role decision-support tooling in these collaborations.

An open knowledge gap in the academic literature thus presents itself in the question of how to use coordination principles to design the networked process alignment of (semi) public organisations in capacity management. The research presents an opportunity to present and execute a design approach for a capacity management coordination process that applies technical and interorganisational coordination principles in the public network domain.

2.7 Synthesis of Principles for Coordination in Capacity Management

The goal of institutional design of governance is to get stakeholders to make decisions regarding capacity that will in the end improve the performance of the infrastructure, meaning decisions that guarantee safety, reliability, and affordability of freight railway transport in the future. An in-depth understanding of how the organisation of decision-making influences performance of the infrastructure can therefore be used to suggest governance designs that are aimed at improving performance.

Capacity management decision-making with the Port of Rotterdam and Prorail is a form of network governance, because of the physically networked nature of railway infrastructure in the port, but also because of the absence of hierarchical, or market functioning. The port railway infrastructure's capacity related activities are interorganisational in nature, as stakeholders conduct capacity studies and make decisions in capacity management jointly. Interorganisational infrastructure capacity management necessitates coordination activities in as coordination problems arise given the interdependencies among network stakeholders.

The networked coordination characterisation justifies a process-view towards coordination in capacity management and allows drawing on mechanisms and design principles put forward by coordination theory. Insights from coordination process design and coordination mechanism that are beneficial to the improvement the performance of coordination processes provide valuable input for our intervention in the Port of Rotterdam and ProRail capacity study process problems.

Synthesising the insights gotten from academic literature yields a list of principles that designers of cooperative process can leverage in order to secure aligned performance of the process. This synthesis is presented in Table 6 underneath.

Theme	**Principle**	**Section & Sources**	**Implication for the process design**
Integrality Coordination in Capacity Management	Should explicitly address interdependencies in time and place dynamics of subsystems Should consider uncertainty caused by stochasticity and feedback loops in the interdependencies. Should consider uncertainty or at least allows forecast errors. Should be based on rolling planning horizons Should incorporate an ‘upward’ flow of information’ and ‘downward’ flow of constraints Should be supported by advanced decision support tooling.	Section 2.2.1 Section 2.2.2 Section 2.2.3 (Fleischmann & Meyr, 2003) (Schneeweiss, 1995) (Hax & Meal, 1975) (Vogel *et al.*, 2016) (Cascetta, 2009) (Kroon, 2001)	The integrality principles introduces multi-level, multi-scope perspectives as part of the design, which require capacity planners to address effects of local interventions on a global system level, and vice versa. The principles dictate that the design must be supported by simulation tools able to cope with complexity.
Optimality Coordination in Capacity Managment	Should specify objective function(s) Should hierarchically decompose decision-making Should make use of systematic problem decomposition. Should increase the level of detail regarding subsystems at lower system aggregation levels Should incorporate decreasing length of planning horizon Should increase level of detail increases regarding time periods, e.g. years to months Should make use of continuous improvement strategies	Section 2.2.1 Section 2.3 (Fleischmann & Meyr, 2003) (Vogel *et al.*, 2016) (Schneeweiss, 1995)	Optimality principles introduces hierarchy into the division of capacity planning tasks: the strategic system level, and the tactical subsystem level, increasingly constraining: physical, temporal scope, level of detail. Introduces rigor in the capacity study methods for problem analysis: structured root-cause and bottleneck analysis, and assessment of interventions: computation, experiments, heuristic process design.
Coordination of Dependencies in Processes: Maturity	Should be specified according to CMMI	Section 2.4.2 (Paulk et al., 1993)	The requirements list of the design should incorporate CMMI-derived requirements that purport performance of the process in quality of outcomes, effectiveness, and time-efficiency of process steps.
Coordination of Dependencies in Processes: Mechanisms	coordination by standardisation coordination by plan coordination by mutual adjustment standardisation of process and content interfaces modular interconnected processes structured data connectivity the breadth of information shared with collaborators the quality of information shared with collaborators deep coordination-related knowledge	Section 2.4.3 (Thompson, 1967) (Gosain et al., 2004) (Star, 1989) (Gosain et al., 2004)	Following these principles may help in overcoming disagreement arising from dependencies in the capacity study process. It implies finding challenging fit, flow, and sharing type coordination processes, and suggests to improve by applying the specified principle-based intervention of either advanced structuring or dynamic adjustment to create loosely coupled processes through boundary objects.

Table 6 List of principles for coordination in capacity management from the literature.

3.Main Research Question

In chapter 3, presents the main research questions in section 3.1 Research Questions, and concludes with section 3.2 Conclusion to Chapter 3.

3.1 Research Questions

Aligned rail freight capacity definitions are necessary for matching supply and demand for transport services, such that simulations of railway use can be made. By simulating future rail transport growth scenarios into these simulation models, it is possible to identify prominent bottlenecks in the infrastructure. Leading to the main Research Question (RQ), which is further decomposed in sub questions (SQs):

RQ: *How to improve the alignment of collaborating organisations on quantitative metrics for railway freight capacity in the Port of Rotterdam with the use of meso-level simulation models?*

To further clarify the terminology used in the research question, improved alignment constitutes an improved process overview for capacity study wherein inputs, methods and outputs are shared, by design, among collaborating organisations. The collaborating organisations are the Port of Rotterdam and ProRail in networked cooperation among the capacity managers belonging to both organisations. Quantitative metrics for railway freight capacity are the quantitative proxies for the measurement of capacity construct. Freight capacity in the port context denotes source, path, and destination for freight transport and transhipment. Meso-level decision support models include the role and use of decision support systems (e.g. simulations like RailGenie).

SQ1: *Around which principles should technical railway systems capacity management be organised?*

Principles for designing technical capacity management processes need to be distilled from the literature. Based on these principles the process design can be constructed that bases it claim to alignment improvement to the incorporation of tried and tested principles. The question is directed specifically to find answer regarding the alignment of coordination challenges in engineering projects, which is for example addressed in hierarchical planning and control literature. These principles cannot be copied without careful consideration of the specific railway transport capacity topics, delineating what capacity in railway systems is. Through compiling the list of principles, it is possible to identify how capacity should be managed according to the academic state of the art.

SQ2: *How to design the alignment of inter-organisational capacity management activities?*

Besides technical coordination, the Port of Rotterdam and ProRail are also in need of a process-managerial coordination principles, which aim specifically at the networked collaboration between the both parties. An understanding needs to be formed regarding what dependencies these organisations face. Furthermore, principles need to be derived from research showing how successful cases of process managerial coordination in transport planning processes deal with coordination challenges.

SQ3: *How are current capacity management processes at the different stakeholders defined and aligned?*

A clear understanding of the current capacity can show exactly what challenges the collaborating organisations face in their (joint) capacity management processes. These challenges can serve as focal point to direct design attention at for overcoming alignment issues. The design principles serve as a guidance for improving alignment but can only be successfully incorporated when effectively matched with stakeholder challenges.

SQ4: *What requirements are set for simulation-guided collaboration in capacity management?*

The capacity management processes under scope are dynamic in that inputs, methods, and outputs can differ with each specific case. Measuring the performance of dynamic processes using quantitative metrics is hard to do validly, time intensive and possibly subjective. However, by specifying requirements an evaluation can be made of the design's adherence to stakeholder ex ante expectations of the proposed design.

SQ5: *What does the improved collaborative capacity management process look like?*

An improved process design is proposed after synthesising principles and challenges within the requirements specified. The improved capacity management process should denote what inputs, methods and outputs are desired tied to the specific activities in question.

SQ6: *How do the collaborating organisations evaluate the proposed capacity management process?*

To judge the potential of the process design for the client organisations, an evaluation needs to be undertaken from which feedback and improvement directions are gotten. The evaluation should not only cover potential useability, but also compare with the current process, besides exposing limitations. Given that members participating in this research do not regularly (re)design capacity management processes and earlier mentioned caveats, part of the question will revolve around how to evaluate in the first place.

3.2 Conclusion to Chapter 3

In establishing how to improve the alignment of collaborating organisations, answers are sought to research questions. These questions ask for the identification of general principles for use in the design of capacity planning, the specific coordination challenges faced by the collaborating organisations, and the formulation and evaluation of a process design. In the following chapter, the identified sub questions matched with the steps in the research methodology.

4. Research Methodology

In this chapter, first section 4.1 outlines the research approach chosen to answer the research questions. Second, section 4.2 provides the rationale for the design problem choice from the perspective of the research method. Third, the specific research steps and combinations with sub questions are detailed in section 4.3 Design Scientific Approach.

4.1 Overarching Research Approach

The main research question calls for an improvement design to be made in terms of the collaboration on railway freight capacities in the Port of Rotterdam area. The design is of a socio-technical system as it consists of a) social elements: stakeholder with differing interests, and levels of decision-making power, and b) technical elements: concerning the capacity of railway infrastructure and the method of determining those capacity levels. The design of socio-technical artefacts is commonly executed by using systems engineering approaches such as those presented by Faulconbridge & Ryan (2018) and Cross & Roy (1989). These approaches describe the design process of artefact which are guided by analysis of the environment and using academic knowledge.

However, this research effort does not only comprise a design effort of a socio-technical artefact in a complex environment, but also aims to contribute to resolving open academic knowledge gaps. Specifically, at those collaborative tensions in the collaborative railway freight capacity planning processes in the Port of Rotterdam stakeholder network. That in turn touches upon open knowledge gaps regarding alignment of collaboration in public networks guided by decision-support models, specifically simulation models. It is in this light that an overarching approach is sought, which are aimed at parallel design and research efforts.

The Design Science Methodology is such an overarching method that works towards concrete artifact design as well as guides complementary research activity (Peffers *et al.*, 2007). Furthermore, Design Science, has a firmly rooted position in technology mediated interorganisational coordination research community as asserted by Hevner *et al.* (2004). The research aim directs to what Peffers *et al.* (2007) refer to as an objective-centred solution as in this research, where the need for aligned capacity planning process is recognised, and the research contributes societally and scientifically by the development of instantiated artefact, and its conceptual design approach (Gregor & Hevner, 2013).

The Design Science Methodology breaks up the artefacts design process into 5 discernible steps: 1. Identify Problem & Motivate, 2. Define Objectives, 3. Design & Develop, 4. Demonstrate & Evaluate, and 5 Communicate. Through each of these steps potential linkages for research are given through a matching with the specified research questions. An overview of the (sub)questions and the methods to answering them are given in the section 4.3 Design Scientific Approach.

4.2 Research Scope of the Design Problem

The design science method allows for a structured approach for this scoping towards specific instances of design problems (Peffers *et al.*, 2007). Design problems are comprised of a specific problem context and stakeholder goals, which call for improvement through the design of an artefact (Wieringa, 2014). This methodological scoping towards a specific design problem (i.e. the case studied) is desirable, because the research questions intuitively invite a broad and lengthy research effort that is potentially detrimental to the quality of the work, the time bounds, and ambition levels set for the project. The design problem was first introduced in section

1.2 Problem Statement, where the rationale for the design problems choice from the societal perspective is given.

The design problem and research problem are mutually attuned to ensure that the design problem's context and stakeholder interactions are congruent with the knowledge gap and research questions posed. To this end, a rationale for the design problem choice must also be given from the scientific perspective (Wieringa, 2014). The rationale for the design problem choice is based on the congruence of the context and stakeholders with the research problem posed, and the specific revelatory nature of the design problem case. First, the context and stakeholders in the Port of Rotterdam's railway capacity planning comply with the specific interorganisational characteristics regarding networked capacity planning collaboration using decision-support models as posed in section 2.6 Knowledge Gap. Second, the case of Port of Rotterdam and ProRail collaboration presents a unique case that is of scientific value due to its revelatory nature (Yin, 2017). The revelatory nature lays in the normally inaccessible nature of the collaborative planning effort, due to confidential nature of the capacity planning process.

To further scope the design problem choice, first, the organisations within primary scope are taken to be the Port of Rotterdam and Prorail, with the role of Macomi and the Ministry of Infrastructure and Waterways secondarily discussed where relevant.

Second, we study the current collaborating process in the specific context of the shunting yard Shunting yard as main case while building on the documentation of other cases for support where relevant, which include the shunting yard (ProRail, 2019), Caland Bridge (Min. I&M, 2015) and other (Macomi, 2020) capacity studies as cases, and refer to geographically, or temporally different cases only where relevant. Although the resulting improved collaborative process design should be generalisable to other cases. The studied improvement strategies are not an exhaustive list of possibilities, rather a prioritised overview, with the most promising strategies pursued further. The aim of this research is to study how improve the alignment of collaborating organisations in their capacity management effort using quantitative analytical tools, not to solve physical capacity problems.

4.3 Design Scientific Approach

This section deal with the Design Scientific Approach used in this research, which is detailed in paragraphs: 4.3.1 Identify Problem & Motivate, 4.3.2 Define Objectives, 4.3.3 Design & Develop, 4.3.4 Demonstrate & Evaluate, and 4.3.5 Communication.

4.3.1 Identify Problem & Motivate

How are current capacity planning processes at the different stakeholders defined and aligned?

To answer this question, first an overview must be made of the current internal capacity measurements that support the capacity planning processes. This overview includes the specific infrastructural elements that are taken into account while defining capacity on specific railway parts. As well as the scope of capacity measurements in terms of the time windows (e.g. whether in minutes, or hours), and unit sizes (length of track, or areal size) employed. The organisations are reliant on each other for the supply of (infrastructural) specifications, forecasts and other types of information at various stages during their planning processes. A mapping of these linkages will prove illustrative for the as is situation of aligned capacity planning in the Port of Rotterdam.

The method to map out such an overview the process diagram is constructed using concepts from the Business Process Modelling and Notation (BPMN), such as swim lanes, activities and decisions. BPMN provides standardised concepts to use in creating overview of information and activities, as present in the collaborative capacity planning process, however full use of the method is not necessary as not a software executable process is envisioned. BPMN bears great similarity to other (process) modelling languages, such as value stream mapping, but is found to have greater readability and understandability (Vega-Márquez, 2019).

4.3.2 Define Objectives

Around which principles should technical railway systems capacity management be organised?

For the design to be successful in aligning organisations, the academic state of the art in technical capacity management principles for coordination in engineering projects should be discussed. By means of literature review, four relevant outputs are produced: capacity management KPI's, a technical capacity framework, overview of decision-support model types and design principles derived from planning and control literature. The technical capacity framework serves to increase understanding of the configuration of capacity-relevant railway subsystems. The principles propose the objectives the designed process should adhere to or strive to achieve. The output can guide the design process towards improved planning activities between the stakeholders involved, using their simulation tools.

How to design the alignment of inter-organisational capacity planning activities?

The questions ask for the academic state of the art in inter-organisational capacity planning methods. By means of literature review, outputs such as methodologies, design principles or success & failure factors are generated. These outputs propose the objectives the designed process should adhere to or strive to achieve. The output can guide the design process towards improved planning activities between the stakeholders involved, using their simulation tools. Critical here is the observation that the process design is not greenfields, but the eventual process design is based on existing ties, tools and technicalities, which the literature review output should accommodate. These general principles must therefore necessarily be transformed to address the design problem later.

4.3.3 Design & Develop

What requirements are set for simulation-guided collaboration in capacity planning?

Aside from the academic perspective on design objectives, the stakeholder-experts also have views on what constitutes good planning process performance. As the specification of requirements is a process of constraining the design space, it is part of the design and develop step (Wieringa, 2014). Stakeholder interviews serve to identify measurable indicators for the performance of the process.

What does the improved collaborative capacity management process look like?
The design of this new improved planning process entails the timing, content and extent of the interlinkages between stakeholders' planning processes. The functioning of the new planning process can be tested a case study surrounding the Port's and ProRail's use of the decision-support tooling. From the emerging desired planning process, it is likely that the simulation tool used for decision support has to be augmented. Therefore, a list of improvements of simulation software is a logical side product at this stage. Output from the newly designed planning activities is likely to depend on the forecasts, and assumptions stemming from the stakeholders involved, especially regarding expected size and source and destination of cargo flows, and as well as used transport routes. Therefore, an assessment of the sensitivity towards the used scenarios is in order.

The production of a process diagram serves as the method of producing the improved process overview.

4.3.4 Demonstrate & Evaluate

How do the cooperating organisations evaluate the proposed capacity management process?
The research concludes with a validation of the improvement intervention, based on a specific area on the Port of Rotterdam's railway area, where the authority, ProRail are jointly working on a capacity definition. To this end, it should be argued how the new planning process performs in terms of the set-out performance indicators. The case study will help with the evaluation, as it poses a cause for Prorail and the Port of Rotterdam to meet and try-out the improved collaborative planning process. The improved design can be tested through a simulation of a capacity study process wherein the participants rate their satisfaction with the experience. The methodology used here is in line with TU Delft evaluations of gamified logistics workshops.

4.3.5 Communication

The communication step encompasses the sharing of the research' findings in this case through the writing of a thesis report. The communication is mostly in line with the sequence of descriptions given in previous sections. However, the presentation of the thesis also diverts from the nominal sequence for the execution of the design science methodological steps, as the setting of objectives is discussed before the identification and motivation of the problem. This presentation is preferred because of three reasons.

First, the literature-derived principles are gotten from the capacity planning and control domain, where the principles have been extensively validated in order to serve as general guidelines for capacity planning processes, see section 2.7 Synthesis of Principles for Coordination in Capacity Management. Therefore, they can be discussed and understood in separation of the case study specific problem situation discussed later in chapter 5. In this way the principles are kept in the literature review chapter that they are compiled from, as suggested in the Design Science Research Publication Schema proposed by Gregor & Hevner (2013).

Second, the reordered sequence pertains to the presentation of the research only. In the design of the process, the nominal sequence of using specific problem context and subsequently mapping the principles is adhered to and presented as such. This is presented in Table 11 in chapter 6.

Third, earlier works describing principle-based design method for addressing challenges perceived by stakeholders, present their work in a similar structure for the reasons mentioned above. Examples include Peffers et al. (2003), and Zuiderwijk et al. (2014) in whose work the principles are placed before the elaboration of case study specific challenges within the literature review section.

Figure 13 Structure of the thesis outlining the methodological steps in context with the chapters they are presented in, and the sub questions answered.

5. Current State System Description

In the first chapter of this report is discussed how freight railway systems are clogging under the strain of ever-growing volumes of freight, which highlights the importance of well-functioning capacity management. processes. Then, the perception that current capacity planning processes at the Port of Rotterdam are problematic is shortly discussed. This chapter follows by motivating why and how this capacity planning process is perceived as problematic.

To this end, section Organisational Descriptions starts by giving introductions of the organisations that are part of the capacity management processes. Section 5.2 Organisational Interrelations describes (the institutional nature of) their interrelations. Section 5.3 delves into the details of the capacity management processes at ProRail. Section 5.4 Port of Rotterdam Capacity Study Process 5.3 delves into the details of the capacity management processes at the Port of Rotterdam. Section 5.5 Comparative Analysis of Inputs, Methods and Outputs takes a comparative stance and discusses what main challenges emerge from current ways of working. The difference in capacity study processes show some of the dilemmatic trade-offs present in capacity studies between the data used, methods employed, and output indicators consulted.

5.1 Organisational Descriptions

Participating directly in the capacity study process of rail infrastructure in the area of the Port of Rotterdam, are the Port of Rotterdam Authority, ProRail, The Ministry of Infrastructure and Waterways, and Macomi.

According to their website (Port of Rotterdam, 2011): “The Port of Rotterdam is the authority that is, under their charters, responsible for: a) the development, construction, management and operation of the port and industrial area in Rotterdam, and b) the promotion of the safe, effective and efficient handling of shipping in the port of Rotterdam and the offshore approaches to the port. Their key revenue streams consist of rental income and port dues. The Port of Rotterdam Authority lets port sites to companies, primarily to storage and transhipment companies and to the chemical and petrochemical industries, including energy producers. The Port of Rotterdam imposes port dues on ships that make use of the port. The Port of Rotterdam invests in public infrastructure, such as roads in the port area, in customer-specific infrastructure, such as quay walls and jetties, and in the development of new port sites. In order to handle shipping as effectively as possible, Port of Rotterdam invests in a traffic management system, patrol vessels and emergency control. “

ProRail is the infrastructure supplier responsible for the Dutch rail network infrastructure. The responsibility being for the construction, maintenance, management and safeguarding of infrastructure used in the Dutch railway sector. As an independent party, they allocate slots on tracks, regulate and accommodate train traffic and build and improve (shunting) yards and tracks. Lastly, ProRail maintains track, switches, signs and crossings. ProRail aims to supply a safe, reliable, and sustainable rail network.

Macomi is the supporting advanced analytics and software development company that builds and services the tooling used to simulate the rail freight in the Port of Rotterdam for both the Port of Rotterdam and Prorail. It takes the role of intermediary in the capacity study process when it takes on a consulting project from either party.

Furthermore, the capacity study process features secondary organisations as well, including the terminal operators at the Port, and rail operators. Although they participate in the usage of capacity, and their insights inform various stages of the capacity study process, they are not an active shaping part of any of the capacity management processes.

Concluding, the observation that responsibility for construction, maintenance and management lays with ProRail is particularly noteworthy with regards to the infrastructure present at the Port of Rotterdam, because that area is the complete domain of the authority, while only constituting part of the domain of ProRail. This disparity in perspectives on physical scope leads to inevitable tension in the decision-making surrounding capacity. Consequently, the Port Authority can be expected push for the interests of stakeholder in the Port Industrial Complex, while ProRail has to encompass a larger field of stakeholder forces in the Dutch polder.

5.2 Organisational Interrelations

In their work towards joint capacity studies in the port railway area ProRail and the Port of Rotterdam currently relate to each other within both contractual formal and cooperative informal relations.

Recent overviews of formal contractual organisational interrelations are given in both the Port of Rotterdam's Collaboration Agenda, and the institutional overview of coordination in port hinterland transport chains by Van Der Horst & De Langen (2008).

These obligations have been put into an overview by Port of Rotterdam in their Collaboration Agenda (Port of Rotterdam, 2019b). These are closely related to the port's ownership structure and regulatory environment. Where ownership of the port is comprised of the municipality of Rotterdam (70%) and the Dutch national government (30%). Prominent capacity-related regulation includes: Environment and Planning Act, National Port Policy, Programme Approach Nitrogen (PAS) (Port of Rotterdam, 2019b).

Van der Horst & Langen (2008) and in extension Van der Horst & Van der Lugt (2014) expand on organisational interrelations and interdependencies and the resulting coordination problems in the Port of Rotterdam's supply chains. In that, both papers take a flow of goods or mode of transport-based perspective to coordination, specifying the how regarding volume, timing and placement of (container) goods from entrance to the port to egress towards the hinterland. Owing to e.g. the unequal distribution of coordination-related costs and benefits, a lack of means or intention to invest of organisations, strategic competition-related considerations, the absence of a dominant firm, risk-averse behaviour and a focus of firms in hinterland chains towards the short-term. Although their search of news articles and expert interviews regarding coordination problems aimed primarily at identifying mechanisms for resolving private company's coordination problems. Regarding public or public-private coordination problems they stress the need for beginning collective action, which can take a public form of governance, such as the establishment of a government body (i.e. port authority), a form of public–private cooperation, or more sector and industry specific: a (branch) association, or jointly developed/used IT-system (Van der Horst & Langen, 2008).

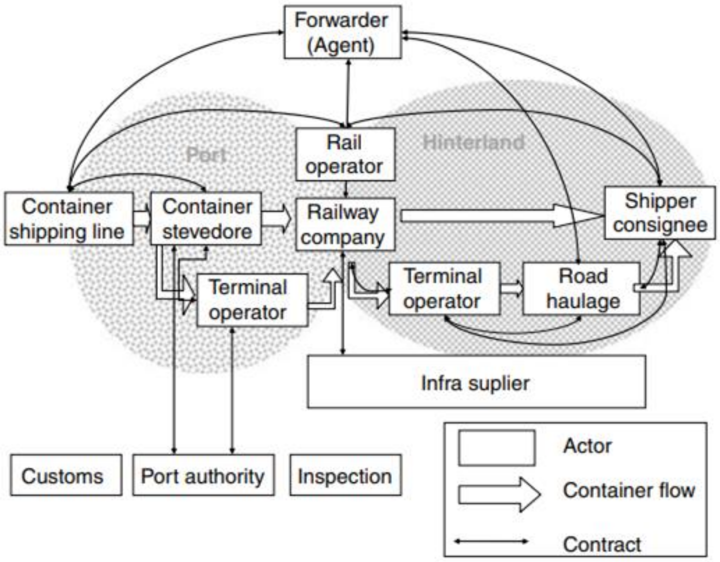


Figure 14 Institutional ties in the port railway area (Van der Horst & Langen, 2008).

The Port of Rotterdam and Prorail cooperation does not feature in either of these overviews of formal institutional ties. That is unexpected given the the Port's ownership of railway infrastructure and ProRail's contractual agreement to manage it. As well as their previously touched upon joint use of IT systems, data sources and their shared responsibility for high performance effective and efficient freight railway transport options. The interviews conducted with experts (Appendix B Interviews 19/02) showed that informal relational agreement does exist between both organisations, in the form of a cooperation agreement. This cooperation agreement specifies the intention of both organisations to work together in order to maximise their performance on the shared railway capacity supply responsibility. The relation is thus not based on institutional artefacts per se, but very much given in by relational aspects such as having a shared vision regarding the development and trends of railway freight demand, mutual performance goals, trust for mutually beneficial cooperation. The cooperation resolves some of the coordination tension that existed before especially regarding the availability of (competition sensitive) data, which support the capacity study process by allowing higher resolution or greater detail in scrutinising specific infrastructures in parts of the port railway system.

5.3 ProRail Capacity Study Process

Maintaining and adjusting capacity of railway is part of the core capabilities of infrastructure supplier ProRail. As a result, over the years ProRail's capacity study process has become an established, tried, and tested way for ProRails capacity group to study bottleneck occurrences in the port freight railway system. Within the organisation, the capacity management department is positioned as tactical planning group in between operational rail traffic management and the strategic investment group. The case studies a shunting yard and shunting yard used as basis to compile this section, see (ProRail, 2019;2020).

In the following section, the capacity study process is described in more detail. The aim of the process description is to comprehensively reflect the process using two different perspectives, namely sequentially, and input-output. The sequentially of process steps follows from the process diagram as shown in the Appendix F Current State Functional Process Diagrams.

The process diagram in the style of BPMN serves to give an overview of the sequential flow of activities, data and messages across the stakeholders included in the diagram. Process diagrams are colloquially referred to as 'spaghetti diagrams', which reflects the tangle of flows present in these diagrams. Although insiders to the process are able to follow the diagram, it might prove more difficult to untangle the inputs, outputs and methods employed in the process. The exposition below aims at reflecting the input-output structure rather than the sequence. It describes in detail how data inputs are transformed through quantitative methods in order to arrive at the output. Additionally, it allows for a more in-depth discussion of how and why different inputs, methods and outputs come to be and are interrelated, even though they might feature in distinct up or downstream parts of the process.

Redacted

Figure 15 Overview of shunting yard, lines and terminals within the shunting yard scope, (ProRail, 2020).

5.3.1 Input Assumptions

Input for the capacity studies is given in by realised traffic data from internal ProRail systems and the economic forecasts supplied by the Dutch economic planning bureaus. Starting point of analysis is a list of realised discrete railyard events (i.e. entries and exits of the yard) as its source data. This data is acquired to an internal railway traffic monitoring database for those tracks and parts of the yard that are electric and guarded. The occupancy of each track per event is accounted for in the data. The capacity studies are forward looking in nature to anticipate growing demand placed on the infrastructure at points in the future based on forecasts. ProRail aligns with the freight forecasts made by the Dutch economic planning bureaus. From these forecasts growth forecasts emerge following formula: $\frac{Forecasted\ number\ of\ trains}{Currently\ realised\ number\ of\ trains} = Growth\ Factor$. The added number of trains is assigned to the tracks using an inhouse method of Prorail, to end up with a list of discrete movement events for the future case scenario.

The Ministry of Infrastructure and Waterworks produces nation-wide freight transport forecasts, which includes rail, road, inland waterway and maritime transport since the beginning of 2017. The starting point of these forecasts are the reference scenarios created in the exploratory Wellbeing and Environment, or *Welvaart & Leefomgeving* (WLO) study 2030-2050 by the planning agencies (CPB and PBL) and are extended using the BasGoed aggregate freight transport model. The WLO 2030-

2050 study includes and elaborates on two reference scenarios one of which is 'low' while another is 'high', which are carried through into the BPGV, the Basic Goods Transport Forecast or *Basis Prognose GoederenVervoer* (BPGV). The source of variation between both reference scenarios can be found in the variable uncertainties on the macro and micro economic level. The macro uncertainty refers to changes in world economic growth, international trade, Dutch ports' competitive position, climate policy and transport policy. The micro level takes account of more specific developments in the Port area, such modal shift agreements for container transport to and from the Maasvlakte area, the breakdown by energy carriers, the closure and opening of various coal-fired power stations, as well as the opening of new terminals. These volume forecasts are transformed to reflect the number, and types of trains, the transformed BPGV forecasts are compiled by ProRail for use in the capacity study process.

The forecast shows that total freight transport will grow in both reference scenarios, and specifically those flows that are of interest to the port. As a result of international economic developments and ongoing globalisation, international transport flows (supply, transport and transit) will grow the most. Domestic transport grows less rapidly and even shrinks slightly in the low scenario. Rail freight transport has the strongest growth rate of all modes. In the high scenario, this is reinforced by a possible CO2 tax on inland navigation. Many of the forecasts made in recent years have been revised downwards each time. In mid-2019 the WLO2 (2015) scenario is assumed. This forms the basis for drawing up the Basic Goods Transport Forecast (BPGV) over target years.

ProRail has further refined this prognosis by taking into account local developments (*Lokale Ontwikkelingen*), the so-called BPGV2018_low_LO, and BPGV2018_High_LO, which forecast cargo weight transported (million tonnes).

These forecasts are added to the realisation data in the subsequent capacity study method aiming to gain insights in the effects of future infrastructure use. The ratio of the number of trains in the realisation data and the forecasted number of trains is used as the growth factor in the subsequent capacity study method.

5.3.2 Method and Decision-Support Model Use

As decision support model of choice, an Excel-based tool is used to find the minimum number of tracks required in a rail yard, without overburdening the available hourly capacity for more than 16 times per month. This tool uses the list of realised discrete railyard events (i.e. entries and exits of the yard) as its primary source data. By means of two distinct methods with diverging assumption regarding the behaviour of so called ‘passersby’. Passersby use or occupy the shunting yard for the purpose of overtaking, decelerating as to prevent waiting later

In essence, both methods assume that in practice one track is/will be kept free from locomotive movements and shunting movements (the so-called 'through drivers'). The difference lies in the conviction whether (method 1) or not (method 2) all through-traffic shunting movements are included in the original occupancy time report. Method 2 therefore tries to filter out all through-trafficker movements in advance.

Method 1:

1. Identify the number of overcrowded hours based on all occupancy times (including passersby).
2. Determine the number of tracks required by means of linear regression.
3. Remove one ‘dedicated’ pass-through track.
4. Multiply by growth factor (prognosis / realization).
5. Add back one pass-through track.

Method 2:

1. Identify the number of overburdened hours on the basis of a minimum occupancy time (with the aim of filtering out passerby’s). In this case, occupancy times >0.2 hours are included.
2. Using linear regression to determine the number of tracks required.
3. Multiply by growth factor (prognosis / realisation).
4. Add one 'transit track'.

Method 1 assumes that the vast majority of passersby go over the electrified, monitored track, which means that all their occupancies are logged and are included in the generated occupation times data report. Method 2 however assumes that many of the traffic passing through over one or more of the non-electrified tracks, which are not logged and therefore not included in the occupation times data reports. Simply put, method 1 assumes that the occupation times report is complete, while method 2 does not assume that the occupation times report is complete. Therefore, method 2 chooses to filter out all logged 'through traffic' in advance and to correct for this at the end of the calculation by adding one through traffic track. Method 1 is convinced that all relevant movements are included, so that before multiplication by the growth factor, a correction has to be applied by removing one continuous track, which is added at the end of the calculation. Summarizing, both methods have their advantages and disadvantages which are given in an overview in Table 7.

	Method 1	Method 2
Advantages	There is no need to make an assumption about the definition of a passerby.	From the onset passersby trains do not inflate the number of trains counted.
Disadvantages	Relevant train movements might be missed due to exclusion in the data set.	Necessitates an assumption for the maximum occupation duration by a passerby. For example, are all occupancy times shorter than 0.1, 0.2 or 0.3 hours? This assumption has a relatively large influence on the results compared to other assumptions.

Table 7 Outlining the advantages and disadvantages of both methods.

A disadvantage of method 1 is that it is assumed that all relevant occupation times are included, while it is quite possible that relevant movements are missing, because these have gone through the NCBG tracks of which no occupancies are recorded. The advantage of method 2 is precisely that there are fewer worries about missed passersby, because the starting point is to filter them out in advance and correct them at the end.

Overall, the method employed is strong in its trusted usage due to full inhouse development, fully documented assumption base and successful use in previous cases. However, it exhibits the following limitations:

- No micro-level modelling or performance indicators therefore no exact bottleneck pinpointing in infrastructure.
- Limited or even no testing of intervention alternatives due to reliance on extrapolation or macro-level assumption adjustments.
- Each analytical model must be tailor-made for different scopes, and infrastructure configurations.
- The analytical models are specifically built to return a single performance indicator, therefore provide limited perspective on capacity usage.
- No modelling of variability in subsystems regarding process times, driving times and waiting times as a result, therefore neglecting effects of exponential relation waiting time and occupation.
- No modelling of variability between subsystems regarding infrastructure interdependencies, therefore interactions e.g. terminal <-> shunting yard, on occupations and (secondary) delays is not taken into consideration.

5.3.3 Performance Indicator Description

The output ProRail derives from their method is a maximum capacity overburdening measure for measuring the acceptable capacity usage on rail yards, such as those in the shunting yard area. The operationalised definition of the capacity is the occupancy hours of the tracks in the yard. Building upon this operationalised definition of capacity is the notion that capacity is overburdened when all tracks in the yard are occupied for more than 80% of the time in the timespan of an hour. The threshold for capacity expanding intervention is when capacity is overburdened for more than 16 hours in the span of a month. The derivation for the 16 is based on the idea that yards intrinsically have enough physical slack and traffic control measures available to be able to counter overburdened hours within the working day. While anymore would lead to disruptions of operations on the yard that can no longer be countered through the measure, which risks further propagation of capacity problems. If overburdened capacity occurs more often than the 16 hours a month, the chance increases that two overburdened hours occur within the same day leading to disturbances that cannot be recuperated within the same day.

In case of an identified capacity bottleneck, potential directions for solutions are explored in conjunction with the experts from Port of Rotterdam, and technical consultants. In a set of meetings, the exposed problems are discussed, and are matched with possible solutions through brainstorming and evaluation of alternative technical drawings. After a set of solutions is identified the process is carried over to the investment decision-group at ProRail.

5.4 Port of Rotterdam Capacity Study Process

As noted earlier in this chapter, the Port of Rotterdam Authority has a singular role in the railway systems capacity management process. On one hand, it is ensuring the smooth sailing of port stakeholders' activities falls directly within its mandate and its contribution in terms of data and qualitative insights are critical. On the other hand, the responsibility pertaining to the railway systems functioning as well as all of the corresponding institutional and legal ties with railway companies, and constructors lay ultimately with ProRail. From this position, there is a clear role for the Port Authority to actively participate in the process given their interests and resources. Albeit, more as a passenger than a driver. Born out of the wish for the capacity study process to be conducted in a more integral and dynamic fashion integral with respect to the vast network of subsystems present in the port railway area (Interview Port of Rotterdam, 19/02), and dynamic in terms of interlinkages that make structures communicating vessels (Interview Port of Rotterdam, 21/02). The subsequent development of RailGenie in partnership with Macomi was driven by this desire for a next generation tool to analyse and predict capacity usage of freight traffic in the port railway system.

In continuance of this chapter we describe the capacity management process from the perspective of the Port of Rotterdam Authority, which is summarised in the figure below. In the same vein as in the part on ProRail's current capacity management process, we do not discuss the process in complete order of sequentially, but rather in the input, method, output structure as this reflects better how the process is structured. Here, too, is it important to show how different forms of input, methods and output are interrelated and what the rationale is for including, transforming or excluding information for use in the process.

5.4.1 Input Assumptions

Input for the capacity planning process is supplied to the Network Planning and Capacity (NPC) group in the Environmental Management department by the port planning group (PPD) in the Port Development department. PDD explores possible effects and desirability of economic developments on the port in terms of shipping traffic, road traffic and rail traffic, land availability and the accommodated mix of industrial activity. An Annual Masterplan Cycle Port Planning is compiled by the department based on information gathered from external sources such as economic forecasts provided by the ministry and augmented with the information collected by the area managers. The planning is adjusted in case new relevant insights emerge over time. The timing of various cyclical planning documents is described as short, medium, and long term. With the short term denoting the 5 year project planning. Medium term denoting the 10 year strategic planning horizon. Port Visions and Masterplans are part of the long term planning process that follow an approximate 30 year period.

Stakeholder consultation processes form integral part of the planning detailing activities and implementation of policies. These are dynamic processes among the Port of Rotterdam, their shareholders and client companies, as well as peripheral societal stakeholders detailed in appendix A. Aim of these consulting processes is the come to actionable decision making that give go or no-go signals to policy implementation. The Port of Rotterdam thus tries to pro-actively seek out stakeholders' requests, especially when confronted with the demand of possible clientele. Demands that might not be directly unifiable or even have adverse effect regarding the overall value-added process at the Port of Rotterdam. It is the responsibility of the Port of Rotterdam synthesise or even limit in the name of the broader (mutual) interest in operating and developing in the long term. The precise formulation of this broad mutual interest, e.g. in the financial economic terms of societal cost-benefit analysis is therefore imperative for the port authorities societal licence to operate.

5.4.2 Method and Decision-Support Model Use

The aim of capacity planning is currently defined as the process of determining whether capacity problems will arise in the future given the realised infrastructure.

In this process the Port of Rotterdam formally participates in ProRail capacity study processes, but also executes studies independently. To this end, the Port uses a decision support tool called RailGenie. RailGenie is a discrete event simulation tool that helps identify effects of current and future volumes in terms of cargo, trains and locations on a network of interest. RailGenie allows to test different scenarios, altering infrastructure, routing and control, train characteristic or their processes.

Aim of the study is to establish the impact of independent variables on the operational metrics. That impact can be approximated by independently modifying variables to reflect the economic and technical trends and developments previously described. When in the simulation study, multiple variables are adjusted simultaneously, it becomes impossible to trace back variables' individual contribution.

An example from the Port of Rotterdam is the shunting yard area capacity study that endeavours to find if the prospected increase volume of good demanded to be transported poses problems for the current infrastructure. Intention is to isolate the effect of developments occurring at the a shunting yard. In this instance only the goods volumes to and from the a shunting yard are set the target year while the rest of the ports handled goods volumes are kept stable, equal to base case 2017. Here a disagreement with ProRail lays regarding tool use as ProRail capacity expert argue that scenarios should reflect all train volume (Appendix B Interviews). In order to reflect the interaction effects with trains to and from other parts of the port, the choice was made to incorporate non- a shunting yard volumes as opposed to leaving out those volumes (and thus trains). This interaction is desirable because trains traversing the branch line crossover into port's main train line.

For any comparative running of the simulation, it is important to keep the contours of that run stable. Therefore, when transforming goods volumes into a schedule for trains using RailGenie, it is important that the dates of demand occurrence coincide. When done correctly the runs accurately reflect the hourly, and daily distributions of in a way that makes them comparable. Aside from this, in the simulation the period and number of warm-up days the same. Next the choice of the simulated period is made for one week in October and with separate locomotives. October is chosen as it is the month that has peak demand. As a rule of thumb, in the prechecks, it is managed that there are no bottlenecks in the running of the base year as again these might obscure effects sizing. Although, it depends on how to deal with this in a case by case basis. For a shunting yard simulation, there is no problem if there are bottlenecks at the elsewhere.

Advantages present themselves in that meso-level simulation model use enables the ability to incorporate appropriate problem & solution dynamics. It models variability and thus exponential behaviour of occupation and delay. It models infrastructure interdependency and therefore the effects of delay propagation through the railway network.

Limitations manifest in that there is no standard method and indicators to support bottleneck localisation in infrastructure. There is also no standard method for the specification of interventions regarding how to conceive and configure, and sensitivity test alternatives. The method and process do not enable to escalate process hierarchically where appropriate to come to decision-making regarding modelling assumptions and interpretation of results (Interview Port of Rotterdam, 21/02).

5.4.3 Performance Indicator Description

The previously described process leads to the establishment of *grosso modo* three major types of output: evolution of waiting times, delay and turnaround times.

Firstly, the amount and progression of train waiting time in the model is an important indicator for bottleneck detection. Two factors come into play: namely the development of waiting times during the run time of the model and the additional time required to clear the backlogged trains. RailGenie calculates and plots both in their evolution of waiting times window. The evolution of waiting times graphs based on various differing process times produce characteristic views on the matter, see Figure 16.

At a processing time of 2 hours some peaks emerge, but are quickly cleared in the simulation model. The total throughput time for all scheduled trains is roughly equal to the chosen run time period of the experiment. This output pattern is not a sign of a bottleneck. At 3.2 hours of processing time firstly some peaks emerge that clear quickly, then an insurmountable peak in delay occurs that the model is not able to recover with the runtime period of the simulation experiment. A typical example where it is difficult to say whether the area under scope is a bottleneck in practise. At 5.1 hours of processing time, a peak emerges only days after warming-up the simulation. This peak does not at all recover with the runtime period, backlogs of trains build up and the delay does not recover. It takes an additional two weeks in simulation experiment to process the remaining trains in the model. This example is a definitive bottleneck.

Figure 16 Graphs depicting progression of total delays of trains with various processing times (2;3.2;5.1 hrs resp.).

At the Port of Rotterdam this inability of the rail system to recuperate is in case of an identified capacity bottleneck, potential directions for solutions are explored in conjunction with the experts from Port of Rotterdam, and technical consultants. There is a challenge to align with and trigger subsequent processes due to lacking expression or indicator of urgency for capacity intervention (Interview Port of Rotterdam, 21/02). In a set of meetings, the exposed problems are discussed, and are matched with possible solutions through brainstorming and evaluation of alternative technical drawings. After a set of solutions is identified the process is carried over to the investment decision-group at ProRail.

5.5 Comparative Analysis of Inputs, Methods and Outputs

The difference in capacity study processes expose some of the dilemmatic trade-offs present in capacity studies between the data used, methods employed, and output indicators consulted. These dilemmatic trade-offs in the current design of the capacity study process are taken as main challenges that the designed process artefact is meant to tackle.

Although the current planning method ultimately lead to concrete, and implementable capacity interventions, there is still a way to go in the transition towards long-term planning with a focus on value added. In this transition, challenges emerge as a consequence of currently perceived short-term operational goal orientation. Flexibility and adaptability of planning and implementation towards anticipated trends can be difficult especially in the multi-stakeholder environment. An example of this is the difficulty of aligning the evolution strategies of client companies with port planning ideals. Additionally, the incorporation of third-party interests belonging to the neighbouring public, organisations in civil society and governmental organisations proves difficult particularly when related to motives of ecological, and social nature. The coordination disagreements about inputs, methods and outcomes is found difficult particularly because of loss of position, information asymmetry, and assumed special interest in collaborating parties. These three perceptions strengthen the idea that opportunist strategic behaviour may be to blame for the disagreements. The loss of position is felt through the fact that the Port of Rotterdam wants to move to RailGenie as simulation model, but ProRail prefers the tacit knowledge embedded in their experts regarding their models proven through use, regardless of known disadvantages. The information asymmetry, manifest in different forms between two parties. Special interest is suspected as ProRail considers Port of Rotterdam predictions to be to positive, stemming from their observation that WLO scenarios are decreased in magnitude as years approach, while the Port of Rotterdam's stay at their high. The Port of Rotterdam has an information advantage here, because rather than ambition, it has detailed knowledge trends and changes in the port railway area. These coordination challenges warrant presentation in detailed form.

When we directly compare the differences in capacity study execution and enrich that view using the interviews of participants, we can distil a set of challenges that impede the current performance of the capacity study process in Table 8 below.

#	Challenge	Explanation	Source
1	The problem behaves dynamically in that uncertainty exists regarding a) the volumes that the infrastructure should be capable of dealing with, and b) where the bottleneck element or sub-system is.	The ability of the railway system's infrastructure to fulfil in the demand for freight transport is interpreted differently as perspectives on physical scope, timeline, and level of detail change. It is difficult to pinpoint where the cause of malperformance lays, due to feedback loops, and stochasticity. Subsequent capacity management process design is helped by explicitation of variables at work, and structured root cause analysis methods for locating the bottleneck.	ProRail, 2019; ProRail, 2020; Appendix B Interviews 18/02; Appendix B Interviews 19/02; 5.4.2 Method and Decision-Support Model Use.
2	The effects of interventions as proposed solutions are dynamic, uncertain, volatile: a lack of reasoning regarding structure versus dynamics in the design and use of the railway network.	Capacity management processes are hindered by this challenge by a) the fact that effectiveness of interventions can only be speculated on beforehand, and experimentation can give conclusiveness, b) the requirement of using advanced tools, such as simulation tools that can replicate the effects of stochasticity, and deterministic feedback loops present in the railway system.	5.4.1 Input Assumptions; 5.4.2 Method and Decision-Support Model Use.
3	Disagreement regarding the volume forecasts used	Disagreement about forecasts of volumes arises from: a) the fact that they are uncertain, and sensitive to changes in the assumption used to create them; b) Port of Rotterdam, and ProRail prefer forecasts created by themselves aligned with subsequent stakeholders in capacity information; c) the potential strategic useability of forecasts in the interest of the own organisation.	ProRail, 2019; 2020; Appendix B Interviews 18/02, Appendix B Interviews 19/02
4	Disagreement regarding the configuration of volume forecasts in the modelling process.	Process times of trains at shunting yards and volumes at adjacent terminals are primary levers that influence delay and occupancy rates for trains and infrastructure. Adding the forecasted volumes to all subsystems in the simulation model at unchanged process time assumptions tends to overburden the system. Overburdening that is not relevant to the intended scope of study can be solved through the reducing process times or reduction of volumes for out of scope sub systems. can solve, but disagreement exist on which to choose.	ProRail, 2020; 5.4.1 Input Assumptions; 5.4.2 Method and Decision-Support Model Use
5	Disagreement regarding the interpretation of study's operational metric outcomes	Operational metrics bear no natural interpretation that informs go or no-go decision making. In both capacity study methods, the view that unrecoverable delays as a result of overburdened sub systems constitute a capacity problem in need of an intervention. Yet, other metrics that inform the value of interventions are helpful to evaluate operational capacity performance or to relay succeeding organisational processes.	ProRail, 2019; 2020 Appendix B Interviews 18/02; 19/02
6	Lack of opportunity for hierarchical escalation in decision-making, which slows the process	To have capacity studies produce actionable results, decisions must be made to select assumptions or interpretations that need resolvement. This resolvement trancents the possibilities given in the (standardisation) agreements between both parties. At these times, it is highly desirable that a clear 'chain of command' is visible, as the capacity studies success falls or stands with the ability to execute and follow-up actionably.	Appendix B, interview 19/02
7	Experienced difficulty in follow-up in subsequent capacity decision-making processes	Operational metrics, whether in Excel-based or simulation tooling only yields unambiguous results in 'extreme' cases, while in others inconclusiveness remains, forcing some capacity studies to call for further study instead of action towards increased monitoring, or capacity interventions.	ProRail 2019; Appendix B, interview 19/02

Table 8 Overview of challenges identified, their rationale and source

6.Design of the Capacity Study Process

In this chapter design of a capacity study process is elaborated upon. First, requirements are formulation on the basis of client interviews, and findings from the literature review in section 6.1 Requirements Formulation. In section 6.2 Proposed Capacity Management Process Design the proposed capacity study process is presented. Section 6.8 Conclusion of summarising the main points made in this chapter.

6.1 Requirements Formulation

The requirements and their sources to the process design are presented in the classification functional and nonfunctional. According to Wieringa (2014) a functional requirement can be defined as the constraint posed on the wanted functionality of designed artifact. The functionality of a designed artefact is defined as the end of the artefact's interaction with its environment that is (part of) the service delivered to the client. Nonfunctional requirements are by definition addressed to the properties a designed artefact which is not directly and specifically related to its functionality. This distinction is made in the formulation of functional and nonfunctional requirements posed to the process design, the results of which are presented in Table 9 and Table 10.

Functional Requirements

Requirement Formulation	Source
1 The process must result in capacity planning decisions 1.1 Must produce metrics necessary for go/no-go investment decisions 1.2 Must conclude in a ranking of urgency 1.3 Must lead to conclusions that are fully traceable in that decision-making becomes systemic 1.4 Must facilitate root cause analysis of capacity problems in support of capacity planning 1.5 Must facilitate economic analysis in support of capacity planning	Sections: 2.3.1, 2.3.6, 2.5; Appendix B: interview 18/02, 19/02, 13/05.
2 Must give insight in the urgency or time window within which capacity interventions 2.1 Must result in the ranking subsystems in terms of urgency of capacity problems 2.2 Must result in subsequent ranking of subsystems in terms of timing of capacity intervention	Appendix B, interview 13/05.
3 Must involve Port of Rotterdam Network Planning, ProRail Capacity Management, and ProRail Railway Traffic Control	CMMI; Appendix A
4 Must rely on realistically accessible data and tools 4.1 Must rely on accessible data sources for information within Port of Rotterdam and ProRail: Sherloc, Nemo, Railway Logs 4.2 Must incorporate compliance to forecasts from Ministry of Infrastructure 4.3 Must rely on advanced decision-support tool-use	Section 2.3.6; Appendix B, interview 18/02, 17/03.

Table 9 List of functional requirements

Nonfunctional Requirements

Requirement Formulation	Source
1. Must provide a description of the process 1.1 Must create overview of activities 1.2 Must provide sequence to the activities in the process 1.2 Must define organisational responsibilities over specific activities 1.3 Must describe the resources (data, functional roles, tools) needed to perform the process 1.4 Must map dependencies among the activities, work products, and services of the proces 1.5 Must specify specific objectives for the execution of the process and its results in terms of quality, cycle time, use of resources 1.6 Must specify incorporate management review activities for the process and the work products	Appendix B, interview 31/03, CMMI
2. Must support the process of process improvement 2.1 Must support the use of process optimisation techniques 2.2 Must help in identify and address process risks (sources of delay, strong disagreement) 2.2 Must help in reducing uncertainties 2.3 Must incorporate explicit activities aimed at monitoring and controlling the process 2.4 Must incorporate evaluation activities at the end of the process	Appendix B, interview 19/02, CMMI
3 Must support secondary, but related activities 3.1 Must support the training needed for performing and supporting the process	CMMI

Table 10 List of nonfunctional requirements.

6.2 Proposed Capacity Management Process Design

This section describes the process of design through the description and rationale of design choices made. First, the design process is introduced in section 6.2.1 Description of the High-Level Design Choices. Second, the separate macro-processes are described in section 6.2.2 Macro-process division choice. The preference for simulation tools for decision-support is expanded upon in section 6.2.3 Decision-support model choice. Fourth, the scope, and use of indicators for measuring capacity performance is described in section 6.2.4 KPI Choice.

6.2.1 Description of the High-Level Design Choices

A conceptual process design for capacity planning must address not only activities and their sequence, but also describe interfaces with the three elements of capacity management, namely technical understanding of the system, decision-support tooling, and capacity performance indicators (as discussed in chapter 2).

Informing the design choices are three previously identified design objectives, namely a list of capacity coordination principles, an overview of challenges to be addressed in the process, and requirements set for the process. Section 2.7 Synthesis of Principles for Coordination in Capacity Management presents principles deemed conducive for coordination in designing capacity management processes. Additionally, our study of current capacity management processes yielded a list of challenges emerging from coordination attempts in prevailing processes, presented in section 5.5 Comparative Analysis of Inputs, Methods and Outputs. The list of requirements is previously outlined in section 6.1 Requirements Formulation.

Subsequent discussions with the Port of Rotterdam and ProRail yield that the principles could be used to design a process which overcomes most of the challenges experienced. Therefore, a matching is made of challenges and resolving principles, which is presented in Table 11. The table presents a rationale for the matching and points towards initial implications for design. The specific implications for design are reflected upon in the high-level design choices, and in reflection on the incorporation of principles in the macro-processes. Although not all challenges are potentially fully covered using existing principles, sufficient direction of making choices in the design options presented aided by the constraint posed on the design by the requirement list in section 6.1 Requirements Formulation. The inspiration for the design choices came from a list of design options drawn up as a morphological chart. The options were used to facilitate discussions with stakeholders. The morphological chart is included in Appendix C Design Options.

The preferred alternative addresses explicitly the challenges faced and incorporates the previously identified principles. The design is derived in an iterative process that to make choices among design options within the limits posed by the requirements list. The preferred alternative process design is more detailed than the mere filling in of the design options. The additional depth is gotten in a process that includes scrutiny of the capacity framework presented earlier, discussion with stakeholders and supervisors and learning by doing. The depth is thus integral part of the commonplace iterative design process as specified and followed in design science methodology.

Challenge	**Principle**	**Rationale**
The problem behaves dynamically in that uncertainty exists regarding a) the volumes that the infrastructure should be capable of dealing with, and b) where the bottleneck element or sub-system is.	Should explicitly address interdependencies in time and place dynamics of subsystems	Pinpointing problems in emergent exploratory fashion is difficult in the face of highly connected systems. The capacity study processes becomes more effective when system level overview studies are undertaken that explore the interdependencies.
	Should be based on rolling planning horizons	In alignment with the forecast and plannings processess already present at the Port of Rotterdam and ProRail, the capacity study, at least at strategic level, should seek to be in line with the rolling progression
	Should consider uncertainty caused by stochasticity and feedback loops in the interdependencies	Without explicit addressal the role of variability, stochasticity in the railway system dynamcis, the process leaves room for subjective judgement about its effects on capacity performance and thus disagreement, while the process and decision-support tool should quantitatively underpin reasoning.
	Should consider uncertainty or at least allows forecast errors.	As forecasts are inherently uncertain, it is therefore wise not to base the entire capacity study process on forecasts alone. Rather, additional techniques such as backcasting should play a part in capacity
	Should be supported by advanced decision support tooling	Analytical options will not sufficiently capture the complexity of railway system dynamics. This neccessitates the use of simulation models, particularly of meso-level simulation as it can take the previously mentioned macro and micro perspectives.
The effects of interventions as proposed solutions are dynamic, uncertain, volatile: a lack of reasoning regarding structure versus dynamics in the design and use of the railway network.	Should make use of systematic problem decomposition	System level overview in scanning where potentially problematic areas are, then zoom in to arrive at a smaller physical and temporal scope as well as an increased level of detail.
	Should increase the level of detail regarding subsystems at lower system aggregation levels.	At strategic level review, a narrow range of broad metrics should suffice to seperate potentially problematic trains and subsystems from those in the clear. However, in root-cause analysis, a more detailed view is needed regarding stakeholder, mode, and infrastructure specific metrics.
	Should incorporporated decreasing length of planning horizon	A smaller range or the exploration of specific capacity problems identified in strategic reviews. This helps reduce uncertainty of assumptions, ease of execution.
	Should increase level of detail increases regarding time periods, e.g. years to months.	In the tradeoff between simulated period and runtime duration, a decreasing length of planning horizon (simulated period) can allow for more detailed metrics to be measured. Therefore, the choice to simulate only the busiest month of the year should suffice.
	Should make use of continuous improvement strategies	Simulation models can adress the effects of intervention due to their adaptability compared to analytical models. Yet, simulation models alone do not yield optimal (interventions to) configurations of infrastructure systems. Therefore, the process design should incorporate iterative through comperative
Disagreement regarding the volume forecasts used	Coordination by mutual adjustment	Before using advanced simulation tools, forecasted volumes were the main parameter for adjusting capacity study outcomes. Now, with a simulation model as boundary object, and a broader information base the significance of forecasts decreases in the mutual adjustment dicussions surrounding model use. However, divergent paths will happen as their are internal reasons at both parties why they insist on
Disagreement regarding the configuration of volume forecasts in the modelling process.	Partially Adressed in mutual adjustment: standardisation of process and content interfaces, modular interconnected processes, structured data connectivity	Volumes and process times are 'sharing' type resources. The difference in the effects of volume pruning versus process time shortening on performance is still unknown. A study into the effects of both options should be carried out, based upon mutually agreed design. A standardisation decision can be reached which reduces the dependency as it allows independent execution.
Disagreement regarding the interpretation of study's operational metric outcomes	Should specify objective function(s) in mutual adjustment	Disagreements around the outcomes cannot be solved unless goals are formulated for those outcomes, i.e. define what needs to be achieved, e.g. low throughput times, or punctuality.
	Modular interconnected processes	The method involved in setting-up, running of the simulation, as well as distilling outcomes is modular process in that both parties can execute it seperately. Therefore both parties gain control and understanding of the simulation at work. This strengthens the position of the simulation model as a boundary object, which delivers independent accurate and thus relatviely undisputed outcomes.
	Standardisation of process and content interfaces,	The operational metrics that have to be considered are standardised per capacity macro-process, and based upon recommendations by independent academics. Stakeholder specific operational metrics are additionally introduced in this broader spectrum of operational outcomes.
	Structured data connectivity	As the quantitative work happens within the simulation model, parties share a joint boundary interface.
Lack of opportunity for hierarchical escalation in decision-making, which slows the process	Should hierarchically decompose decision-making	Given problems with operational metrics like ambiguity, uncertainty, and strategic use, capacity managers cannot always be expected to come to joint decisions. This necessitates options for escalating decision-making to higher decision making levels.
	Should incorporate an 'upward' flow of information' and 'downward' flow of constraints	However, information passed up must be suited to the information needs at those levels. In return, the passed down contraint, can ease further decision-making through standardisation.
Experienced difficulty in follow-up in subsequent capacity decision-making processes	Increasing breadth of information shared with collaborators	Subsequent decision-making processes rely on metrics beyond the operational domain such as financial economic interpretations of operational metrics. The capacity process should incorporate these metrics, because it improves flow to subsequent processess, provides broader information base upon which decision can be made to be of better quality, and allows for the explicit incorporation of secondary stakeholders' interests.
	The quality of information shared with collaborators	Higher resolutions give greater insight into the exact location, and time of capacity problem occurence. This can help in influencing, negotiating, steering the decision-making of successive processes.
	Deep coordination-related knowledge	Deep coordination-related knowledge denotes the shared mental model i.e. knowledge of others' information base, organisational workings, and processes. A thorough understanding of these circumstances is conducive for coordination.

Table 11: Mapping of challenges and resolving principles and their rationales.

6.2.2 Macro-process division choice

In the context of hierarchically oriented capacity management processes, distinct capacity study activities are required at different moments for different goals in support of decision-making. Consequently, the design capacity study is divided in four parts: Strategic Overview, Tactical Bottleneck Analysis, Tactical Intervention Effect Analysis, and Financial-economic analysis.

- The strategic overview process serves to monitor and benchmark the complete rail system in the Port Industrial Area in the face of economic and technical long-term trends. This cyclical monitoring activity with rolling horizon identifies potential problems in the port railway system by taking a global i.e. system-level perspective across shunting yards and terminals. As a process of high-level monitoring of interdependencies, it stands apart from other macro-processes. The process relays subsequent down scoping into more tactical level capacity processes.

- The bottleneck analysis aim is twofold, namely, to identify and locate bottlenecks, as well as determining establishing the level of urgency associated with fixing the bottleneck. This takes a local perspective to railway area sub-systems (specific yards, branch lines, train instances). By overloading the subsystem with trains, potential problematic physical infrastructures and operating strategies are identified. The macro-process is distinct from other macro-processes as it uses artificial scenarios for the detection of bottlenecks and thus does not reflect actual or forecasted performance of the infrastructure.

- The intervention effect study is designed to gauge the effectivity & efficiency of possible interventions or solution directions. The method employed in studying effects of interventions is a search that uses experiments to test falsifiable hypotheses on cause and effect relations in the infrastructure, that are borne out of the capacity framework. This process is distinct through its reliance on expert knowledge for the formulation of interventions, (statistical) interpretation of effects, and

- The financial economic analysis aims to provide the information base for identifying (the most) fruitful opportunities for improving infrastructure through the determination of financial-economic metrics reflecting the limited financial capacity to invest, and communicating the results of capacity studies to colleagues and higher-ups (Table 11). In this process results from intervention effect study are transformed to annual economic performance metrics which are part of the standard Dutch cost-benefit procedure, namely value of travel time and value of reliability. The financial economic analysis broadens the information base by introducing economic, non-operational indicators to the analysis.

Each macro-process is described in four parts, namely through its goal setting, method of simulation configuration, compilation and interpretation of performance indicators and its incorporation of design principles. The goal setting reflects the why or the purpose of each macro-process. The method of simulation configuration reflects how the process must be executed. The performance indicators describe what the outcomes of each process are. In this way, each macro-process touches upon all four aspects of capacity management, the process, the decision-support tooling, performance indicators, and technical understanding involved in working with the previous three.

6.2.3 Decision-support model choice

Although current capacity processes make use of both an analytical model, and simulation model, the proposed design works only with simulation models. This as a result of the demands posed by the process on the decision-support tooling capabilities. This design choice is made for three reasons, namely because of principle-informed capability needs, challenges partly attributable to the use of analytical models, and the subsequent insurmountable limitations to analytical methods. The process is associated with the use of the RailGenie simulation tool, although other meso-level simulation tools with similar capabilities can also execute the process design. It must be stressed that the process is leading and therefore adjustments to the simulation tool are suggested where capability gaps are identified, not the other way around.

The list of principles (Table 6), and the rationale for matching by the principles (Table 11) indicate that capacity management processes should explicitly address: 1) interdependencies in time and place dynamics of subsystems, 2) uncertainty caused by stochasticity and feedback loops in the interdependencies, and 3) increase the level of detail regarding subsystems at lower system aggregation levels. The limitations to realisation analytical models make that subsystems can only be studied in isolation, neglecting the interdependencies. More advanced analytical models that take into account interdependencies require basic hourly patterns as input, which in the case of the Port of Rotterdam are unreliable owing to stochasticity in arrivals and process times (Table 3). Analytical models that do not require these patterns, lack the integrated ability for multi-level study and broadness of performance indicators presented (Table 3).

Challenges that are partly attributable to current model use include uncertainty about the problems' dynamic behaviours, lack of depth in determining the effects of interventions, and the current focus on a single performance indicator (Table 11). Problems' dynamic behaviours are addressed better by simulation models which incorporate occupancy and delay relations across subsystems supporting bottleneck identification. The effects of interventions as proposed solutions are dynamic, uncertain, volatile and therefore difficult to approximate using analytical tools, or the tools must be specifically made for the purpose. Simulation models are more flexible in that regard and can fulfil multiple purposes by design. Simulation models are fit for resolving disagreement regarding the interpretation of study's operational metric outcomes, because of the broad array of multi-level indicators calculated.

The RailGenie meso-level simulation tool is made in joint development with ProRail and Port of Rotterdam to fulfil these purposes and therefore presents itself as best decision-support tool alternative. Currently, the tool does not perfectly support the process design, therefore adjustments are suggested where necessary for the execution of the process. The tool was previously introduced in section 5.4.2 Method and Decision-Support Model Use.

6.2.4 KPI Choice

A key element of capacity management is the determination of capacity performance using indicators. Each macro-process makes tailor-made use of specific indicators in terms of their category, scope, approximation by quantitative metrics, and dimensioning. These sets constitute an unweighted objective function for the measurement of capacity performance (Table 11). The indicators, and the quantitative metrics used to express them are derived from the academic and professional railway literature, and stakeholder interviews. The performance indicators used in the process follow the infrastructure and rolling stock distinction made in section 2.1 Rail Freight Infrastructure Asset Capacity Performance. They are operationalised in Appendix E Performance Indicator Definitions.

- Scale is the magnitude of volumes and trains transported over the railway systemKnowledge of the scale of the demand for capacity adds context to the other capacity performance metrics and allows for comparison across subsystems (2.2.2 Demand Patterns; Versteegt, 2004)
- Feasibility denotes the achievability of handling freight transport volumes as expressed in the realised capacity occupation rate which results from train dynamics in the railway system. Feasibility reflect the degree in which infrastructure is able process the scale of demand (Goverde & Hansen, 2013). When the scale of demand becomes too high, occupation rates increase, and are thus the feasibility of the subsystem's handling of additional freight is reduced.
- Stability is the ability of the infrastructure to contain the primary delays accrued by trains while they're waiting for reserved and occupied (moving) block sections and sidings. Stability is the contrast to the feasibility, in that feasibility of occupation rates at adjacent subsystems are a cause for the loss of stability in a subsystem (Goverde & Hansen, 2013). In the language of queueing models, it reflects the waiting time (Delorme et al., 2008; Kroon, 2001).
- Robustness of the infrastructure is determined through its ability to withstand external influences, especially increases in traffic volume. This is expressed by means of its tipping point volume, the amount of trains before delays accrued can no longer recuperate. The robustness of infrastructure informs capacity managers of the capacity performance as a function of external developments, and therefore contrasts with the feasibility and stability metric which are internally oriented (Kroon, 2001; Goverde & Hansen, 2013).
- Urgency is the expected time period before intervention is inevitable into the infrastructure. This is based off the bottleneck analysis' signalling of a tipping point. To arrive at a prioritisation of problems to be solved and intervention to be executed, the urgency of problems in the subsystem needs to be established (Appendix B Interviews, interview 13/05).
- Economic performance of infrastructure is determined by the economic consequences of emerging trends, bottlenecks, and interventions on the railway system's rolling stock performance. Economic performance is a standard indicator for later stages of capacity planning (Appendix B Interviews, interview 13/05)
- Travel time is the time a train needs to fulfil its itinerary in the railway system (ProRail, 2011). Turnaround times are the gross measure of train's travel time, process time and delay time in the port railway area (Macomi, 2020). Together, with punctuality and process times, capacity managers have a complete picture of the size and ratios in train's operational time.
- Punctuality is the size of delay experienced in a train's turnaround time. Punctuality reflects the delay that affects a train, and when analysed for different types of trains gives an indication of problematic areas through the rolling stock perspective (Goverde & Hansen, 2013).

6.4 Strategic Overview

6.4.1 Goal of the Strategic Overview Macro-Process

Strategic overview process serves to monitor the systems general ability handle transport demand in the face of economic and technical long-term trends. This capacity study activity therefore serves to align capacity management with the strategic planning processes, benchmarking and monitoring performance. Corresponding to the strategic viewpoint is the scoping, which encompasses the complete rail system in the Port Industrial Area. In this cyclical process, analyses are renewed at established intervals that correspond to the progression in economic forecasts and technological development. As such, the strategic overview capacity study must be revamped whenever the stakeholders Port of Rotterdam or ProRail decide upon updated forecasts impacting e.g. demand-side changes in for example amount and composition of freight volumes, and the resulting number of trains or other effects on capacity elements presented in the capacity framework. Additionally, major technical changes should be considered in these capacity studies. An example would be studying the effects of the implementation of hybrid diesel electric locomotives as main mode of propulsion for freight trains or the implementation of a next generation train control and rail traffic management systems. The strategic overview is thus cyclical in that it returns after fixed periods of time in the maximum case every 10 years coinciding with the delivery of a new WLO by the PBL, and CBS among others, but likely shorter given short planning cycles at the port and irregular coincidence of technology lifecycles (see 5.3.1 Input Assumptions, and 5.4.1 Input Assumptions).

6.4.2 Method of Simulation Configuration

The method of simulation configuration consists of 4 broad decisions: namely the scoping decision, the scenario setting, assumption setting and sensitivity analysis.

First step in the capacity study planning process is the decision to scope the capacity planning effort to suit the aim to benchmark the system. In principle, whenever new demand forecasts, or technology trends emerge a new capacity study process should be started to benchmark the performance of the entire railway system. However, if a lack of reliable data manifests on which to base simulation assumptions, then the scope of study should be kept at the subsystem level for which reliable data is available as otherwise it would invalidate comparisons made. For scoping the time window, the busiest month in term of volume distribution (in % of total annual volume) makes for the desired month of choice, because peak capacity utilisation is more likely to expose problematic capacity elements.

Second, scenario setting is done by detailing which assumptions related to change over time are made about the railway system (as outlined in section 2.4.4 Scenario Development for Uncertainty). The configuration method consists of comparing the result of general operational metrics between a base year scenario and (a) target year scenario(s). The current state scenario consists of data inputs and assumptions based on operating technologies closely resembling or even calibrated to correspond to the current state of the railway system. Data must therefore be collected regarding process times, and the number train movements from Port and ProRail sources respectively and determined through a process of mutual adjustment first, then over time become standardized. The target year however uses forecasted input data and assumptions based on a year in the future that corresponds or aligns closely with the update in question.

Third, beyond those assumptions related to change over time, assumptions must be made to setting realistic simulation model behaviour. To arrive at sound capacity determination, a choice must be made for elements and their configuration in each scenario. This consist of two parts: first congruency check with the capacity framework, ‘translation’ for simulation model incorporation. The capacity framework presented provides an extensive overview of the elements influencing capacity on a system-wide and subsystem level (2.2 Technical Framework for Port Rail Capacity Management). Thus, the case and the simulation must be checked for congruency on these elements. While the translation for model specific incorporation is given in Table 31, and is based on previous workshops. The context of this method is mapped in detail in the micro-process design in Appendix G Proposed Micro-Process Design. This micro-process design highlights the work done before being able to run a simulation in terms of discussion activities for mutual adjustment and data gathering activities.

Fourth, sensitivity analysis is then decided in the simulation study to account in part for uncertainty and non-verifiability of assumptions made. Both the number and range of possible assumptions are too large for realistically testing all factor sensitivities within the time of capacity study projects. Factorial experiment designs enable the most efficient use of computational power and sensitivity testing (Montgomery, 2017). However, given that those participating in the process do not necessarily have the statistical background required for the meticulous planning and (statistical) interpretation of experiments with factorial design. Therefore, one-factor-at-a-time sensitivity analyses can serve a purpose as accessible, albeit inefficient statistical sensitivity analysis (Robinson, 2005).

6.4.3 Strategic Overview Capacity Performance Indicators

The output from a strategic overview are formulated in operational terms in the way they are derived from RailGenie and summarised in Table 12. The subsystems need to be compared based on their operational performance divided in through infrastructure systems versus the mode of transport. And, on the earlier described railway performance indicators stability, feasibility, travel times and punctuality. These are operationalised through delays, turnaround times, and occupancy rates per cluster, as well as mode of rolling stock-based performance indicators such as turnaround time per train instance. Although given the high-level nature of strategic overview, the value of insight gotten from the specified performance indicators is primarily in being able to prioritise subsequent analyses.

The method for measuring the outputs for infrastructure subsystems is as follows. First, as both base case realisation volumes and forecasted volumes are important and controversial inputs in the capacity study, both need to be displayed in full detail. Showing progression of a unified expression in tonnage and container volumes (TEU) at least. This gives a sense of the scale of volume increase in the scenario period. The number of trains in the railway system and number of train arrivals per subsystem need to be presented again for understanding the scale of trains in the system.

Then, mean and standard deviation of occupation rates and delays accrued per subsystem need to be compiled such that a ranking can be made sorting the down from the most occupied subsystem. Mean and standard deviation need to be retrieved, because the mean otherwise hides possible extreme values. Given that RailGenie returns replications of occupation rates and delays accrued per subsystem, a sample standard deviation should be taken. The mean accrued delay (in minutes) primarily occurs when the train is not cleared for movement by the safety system in place. The mean and standard deviation of turnaround time train types, give a comparison of train travel times on the railway area, depending on the number of stops made. Lastly, punctuality classes need to be distinguished. The punctuality classes are percentage of trains falling within a certain class of punctuality. For ProRail, these classes are generally classified according to delay time experienced by percentage of trains with a) 0 min. delay, b) under 3 min. delay, c) above 3 min. delay. In general, mutually exclusive, collectively exhaustive categories are the only constraint from the perspective of statistical testing.

The realised train numbers across scenarios is again an indicator of scale to that helps putting the average values of especially delays into perspectives. While a mean of 12 minutes of delay per train does not come across as much, but when contrasted with 500 trains per month that becomes 100 total hours of delay in that month. Mean turnaround time per train type (e.g. container, wet or dry bulk) again gives scale to the time-related metrics. Ranking train instances on delays gives insight into how which train ranking on mean delay per train type and besides presenting the standard deviation of turnaround times per train group and instance serve to give insight into the variation of delays and throughput times. The punctuality classes provide a more intuitive perspective on the delays experienced by trains in an aggregated overview. Without setting goals for the percentage on time trains and a definition for on time, these types of analysis are difficult to operationalise and act on.

The conclusion of the Strategic Overview process is either subsystem specific follow-up in case of a detected problem or underperformance at a subsystem or termination of the process. The simulation control serves to check whether the simulation has run successfully in that all expected trains are realised and that this realisation has not been for excessive delaying at the model-in point. This can occur when an overburdened infeasible run is attempted. It is resolved through a downscaling of volume or process time at the overburdened area.

The last output of Strategic Overview Analysis should be consensus on problematic subsystems and train instances that can be relayed to Bottleneck Analysis, as is signified in the micro-process design (Appendix G Proposed Micro-Process Design).

Strategic Overview	Indicator	Quantitative Metric	Per	In Unit
Infrastructure metrics	Scale	Amount of volume	System wide	Million Tons/TEU
	Scale	Number of trains	System wide	Integer
	Scale	Number of train arrivals	Subsystem	Integer
	Feasibility	Mean occupation rate	Subsystem	Percentage
	Feasibility	Standard deviation occupation rate	Subsystem	Percentage
	Stability	Mean accrued delay	Train at subsystem	Minutes
	Stability	Standard deviation accrued delay	Train at subsystem	Minutes
	Stability	Sum of accrued delay	Subsystem	Hours
Rolling Stock metrics	Travel time	Mean turnaround time	Train types	Hours
	Travel time	Standard deviation of turnaround time	Train types	Hours
	Punctuality	Mean delay	Train types	Minutes
	Punctuality	Standard deviation of delay	Train types	Minutes
	Punctuality	Fraction of total trains in punctuality class	System wide	Percentage
Simulation Control		Mean waiting time at model in	Individual train	Hours
		Realised numbers of trains	System wide	Integer
Comparison	Base case vs Forecast Scenario(s)			

Table 12 Overview of output for use in Strategic Overview.

The interpretation of the operational outcomes and thus problematic locations and train groups is not constraint by predetermined specific cut off points by design, but can develop to be standardised as time progresses. The decision to follow up with bottleneck analysis at specific sub subsystems is like in the current case thus driven by expert judgement on whether a specific follow up is warranted. This is for three reasons, namely that this decision has not been marked as a challenge or found to be controversial, that errors due to brazen decision-making are unlikely, and at this stage there is no cost to doing specific studies other than time invested. Given that the decision if and how to follow up was not found to be controversial, we assume that in the new design this will not be the case either. Error-making due to brazen or overconfidence in the infrastructure's capacity is unlikely given: first, the Port of Rotterdam has an interest in assertive studying of capacity, and second the lack of pressure from constraining working time schedules. The cost of doing too many tactical studies is negligible given that there is value in knowing where there is slack capacity available.

6.4.4 Incorporation of Design Principles in the Strategic Overview

The strategic overview therefore encompasses by design many of the principles set out to counter the challenges previously experienced as presented in Table 11. Integrality principles are addressed through the high-level approach that hierarchically feeds into more detailed processes, explicitly incorporates (forecast) uncertainty in the rolling planning horizons, and uses divisions in KPI's to address railway system interdepencies. The way strategic overview studies relay into more detailed study types reflects the systematic problem decomposition and increase in systematic and temporal detail. The micro-process design foresees in explicit coordination moments where mutual adjustment should be reached for subsequent modelling parameter and set up choices for simulation.

6.5 Bottleneck Analysis

6.5.1 Goal of the Bottleneck Analysis Macro-Process

The goal of bottleneck analysis is twofold, namely, to identify and locate bottlenecks, as well as determining establishing the level of urgency associated with fixing the bottleneck. This type of analysis focuses on finding ‘weak’ spots in the infrastructures at a sub-system level. Weak implying that throughput performance on the local subsystem or element level is constraining to the throughput performance at higher levels of aggregation. In classic linear systems, such as manufacturing lines these bottlenecks or constraints are found in the for example the machines that while being fully utilised determine the overall systems output. However, in the more complex interactions of subsystems in the port railway system, determining the weakest link is not merely a question of throughput times or volumes at a specific point, but rather in its context of other linked subsystems.

Bottleneck finding is therefore a more exploratory activity, where those studying capacity rely on subtle interpretation of metrics to find where the system is constrained. The establishment of causality is somewhat obscure in that questions cannot be answered directly through specific KPI’s, but rely on interpretation by eye and experience. These questions include e.g. where the pile does up start in a transport system featuring feedback loops, like the terminal-branch line to shunting yard subsystems.

6.5.2 Method of Simulation Configuration

The method of simulation configuration consists of 4 broad decisions: namely the scoping decision, the scenario setting, assumption setting and sensitivity analysis.

Scoping the bottleneck simulation is done from the insights of the strategic overview. The strategic overview identifies which subsystems in the railway system perform worse compared to alike subsystems in the benchmark. The bottleneck analysis scopes down to these subsystems or group of adjacent subsystems for the identification of the malperformance’ root cause. In case the subsystem is a terminal or shunting yard then the scope should include the shunting yard along with paired terminals. If part of the mainline is perceived to be problematic the scope reflects that part of the main line and the freight train instances that cross it.

The scenario for the bottleneck analysis is set by using the railway freight capacity framework, as one can systematically experiment with each of the elements that influence capacity at the system level. Two notable ‘levers’, elements that are found useful in this regard are volumes and process times, which bear resemblance to work-in-progress and throughput rate in Industrial Engineering literature, e.g. The Goal (Goldratt & Cox, 2016). Tipping points can be found through generating artificial variants in either one of both in simulation experiments (as demonstrated in 5.4.2 Method and Decision-Support Model Use). These tipping points are in essence the volume of freight or the longevity of process times at which the delay or pile up generated at a specific point in the system starts to propagate, cascade, through the rail network without recuperating. In the example of a shunting yard, this implies that delays generated at a shunting yard, because trains have to wait before being allowed to proceed over the branch line to the terminal destination, at one point in time accrue to the extent that they block incoming trains from the main line. At that point, the terminal, shunting yard system is at risk of deadlocking or being at least close to deadlocking, being unable to further move. Given that the shunting yard has connections to other terminals and the mainline, this does not happen within valid simulation runs.

The bottleneck analysis can be executed by setting assumptions for the backcast scenarios and the logistical parameters reflecting future infrastructure configuration. First, backcast assumptions need to be constructed. When the bottleneck study scope focusses on subsystems, e.g. shunting yard main line connection, then the volumes of the corresponding terminal subsystems need to be multiplied with the backcast factors. The number and magnitude of back factors and corresponding simulation scenarios can vary from case to case, therefore need to be established by trial and error. For more interpretation of results, it is helpful to conduct one more simulation run after the tipping point has been found with a backcast factor that is larger than the last stable back cast factor and smaller than the backcast factor over the tipping point. Second, for the bottleneck analysis to be most effective it is best to have the infrastructure configuration as determined in the simulation model reflect the already intended changes to the infrastructure. As such the bottleneck analysis aligns with the future case as specified in the strategic overview.

The bottleneck study is a type of sensitivity analysis conducted over increasing levels of train volumes. As insights gotten are of an exploratory nature, and specifically found levels are not used for direct decision-making, therefore no further sensitivity analysis has to be done.

6.5.3 Bottleneck Analysis Capacity Performance Indicators

There are two operational metric views to indicate an apparent tipping point, namely an infrastructure-based view and train-based view. These views reflect to an extend the interaction of the demand and supply side elements of the capacity framework. Using the output generated operational metrics from RailGenie these tipping points can be found for both views. The infrastructure-based view is about average and peak occupancy rates per cluster. While the train-based view is centred around turnaround times and delays per train instance or train types. These and more performance indicators have been summarised and presented in table Table 13. According to previous use cases, process time, volume, or routes can be tweaked to expose these cascading effects. In extension of the The Goal analysis, cumulative flow diagrams can help keep track in work in process at consecutive process steps and their lead times, which concerns the number trains wanting to traverse the railways system, the location and turnaround time respectively. Shortly put the method entails comparing general operational metrics between base year volumes and artificially created process times, volumes or routes.

Subsystem occupation rates can be checked for feasibility of the backcast scenario, if the mean occupancy rates of subsystem tracks indicate that full occupancy i.e. 100% is realised at these volumes than the sum process times for each train is larger than the operating time window in that location. This gives a first indication of whether a tipping point has been reached. A condensed version is given as the mean occupation rate over backcasts per subsystem, which allows for evaluation to be done through one graph.

Stability is expressed as follows. A graph plotting the evolution of sum of train delays of (adjacent) subsystems per hour should be compiled, as this shows the sum delay effects of secondary propagating delays in one view. On the x-axis, the time period of the simulation should be plotted in hours, and on the y-axis the sum of delays accrued per train in that hour window. An example of such a graph has been displayed in Figure 16. This graph can be used to approximate stability of railway systems. Stability as from the graph it can be derived how long it takes for the delayed trains to be processed. The difference between the incoming train delay in vs outgoing train delay is a common passenger railway transport stability indicator. For each individual train the difference of delay is measured while going into the subsystem as compared to going out of the subsystem. Which means if trains are delayed entering a subsystem, say a shunting yard, can make up for that delay by e.g. being processed quicker, then their outgoing delay is smaller. N.B. this metric is not supported in RailGenie.

A graph showing the evolution of cluster occupation rate and average train delay times development as a function of backcast factors can be used to approximate robustness of railway systems. The Gantt-chart check is designed as a follow-up check in case values out of the ordinary are retrieved. In that case the Gantt-chart shows for each track at the location of unexpected results, to the detail of quarters of hours the process a specific train is engaged in. This way prominent secondary delays can be identified, which would warrant closer inspection in subsequent stages. Stability in bottleneck analysis is commonly expressed through a cumulative flow diagram (Goldratt & Cox, 2016), which displays the number of trains at each stage of their itinerary. For an “Ideal” train type, this would be from model in to shunting yard to terminal to shunting yard to model out.

Robustness is expressed by the last handleable magnitude of volume (in multiples of a base case) for the subsystem, before the tipping point. This type of visualisation stems from Scrum/Agile methods to see where bottlenecks are located. They are interpreted through the emergence of blobs, that signal the throughput rate at a predecessing stage to the current stage is higher than the throughput rate from the current stage to the next. N.B. this is also not supported by RailGenie.

Bottleneck Analysis	**Indicator**	**Quantitative Metric**	**Per**	**In Unit**
Infrastructure metrics	Scale	Amount of volume	Backcast factor	Million Tons
	Scale	Number of trains	Backcast factor	Integer
	Scale	Number of train arrivals	Subsystem	Integer
	Feasibility	Mean occupation rate	Subsystem	Percentage
	Feasibility	Mean occupation rate over backcasts	Subsystem	Percentage
	Stability	Mean delay accrued per train over backcasts	Subsystem	Minutes
	Stability	Mean delay per train movement	Subsystem	Minutes
	Stability	Gantt-chart inspection for secondary delays	Location	Yes/No
	Stability	Cumulative flow diagram: Number of trains at each stage of itenary	Time period	Integer
	Robustness	Tipping point	Subsystem	Integer
	Robustness	Sum of delay	Train per Time period	Minutes
	Urgency	Expected time till demand reaches tipping point	Subsystem	Years
Rolling Stock metrics	Travel time	Mean turnaround time over backcasts	Train instances	Hours
	Travel time	Cumulative flow diagram: Number of trains at each stage of itinerary	Time period	Integer
Simulation Control		Mean waiting time at model in	Individual train	Hours
		Realised numbers of trains	System wide	Integer
Comparison	Base case vs Backcast factors			

Table 13 Overview of output for use in Bottleneck Analysis

6.5.5 Incorporation of Design Principles in the Bottleneck Analysis

The bottleneck type studies ensure adherence to the following principles. The bottleneck analysis employs the distinct advantage of advanced meso-simulation models to test the limits of the railway system at all subsystems in the port railway area, while flexibility to scope down to specific subsystems or even tracks. In search of optimality, the principles that most prominently are incorporated in the bottleneck analysis are those urging for systematic problem decomposition and root cause analysis as part of capacity management. Also, the bottleneck analysis focuses on a more precise level of detail regarding subsystems at lower system aggregation levels. In coordination, this way of working leads to a more standardised procedure for establishing problem definitions in the face of uncertain and dynamic problem behaviours. The process for bottleneck analysis is essentially standardised and the execution thus is a modular interconnected process.

In conclusion, the bottleneck study is a true backcasting process, as opposed to the other types of capacity studies outlined here, which are more forecast-oriented. The overall outcome of this type of study is an understanding of location and limits of the railway infrastructure’s ‘weak spots’ as well as a developed indication of urgency for its improvement. In follow-up studies these results are taken as starting point for further analysis. In the intervention effect study, the location of the bottleneck is as well as the most urgent detrimental operational metric is used to formulate possible intervention, whereas the urgency indication is combined with the outcomes of financial analysis.

6.6 Intervention Effect Analysis

6.6.1 Goal of Intervention Effect Analysis

The goal of intervention effect study's is to gauge the effectivity & efficiency of possible interventions or solution directions. Here, the capacity planners use the knowledge of locality and severity of the found bottleneck in combination with the capacity framework to devise solution to capacity problems. Those solutions aim at alleviating or mitigating the negative effect such as detriments to delays, turnaround times, turnaround time reliability or any of the other applicable operational metrics from RailGenie.

The number of possible interventions combinations in the railway system, as well as the uncertainty of effects can be assumed sufficiently large to warrant necessity for effect size estimation. The variety in types interventions, such as shunting yard extension, train length adjustments, is relatively small and are encompassed largely in the capacity framework. Yet, the solution space still fairly large and complex, due to a) combinations, b) uncertainty of effects, and c) feedback mechanisms. The number of possible interventions rapidly becomes large by considering possible combinations. The magnitude of effects of interventions are uncertain, especially when interventions are thought up in combinations. Not only, because the interventions are not dreamt up in a vacuum, but also because have interfaces at other subsystems as well in the scope of the railway system leading to (non-obvious) feedback loops in the infrastructure's use of capacity.

6.6.2 Method of Simulation Configuration

The scoping of an intervention analysis is done after having either having identified the problem to solve in the bottleneck analysis, or approximated the effects of a technological trend in the strategic overview. The scope

The scenario setting of an intervention effect study reflects in natural language the specific changes anticipated to the railway system's infrastructural configuration as a result of an intervention. A helpful tool for ensuring the most relevant changes are taken into account is by checking for each of the subsystems and components in the capacity framework what change is expected.

Assumptions for the intervention effect study are set by employing the capacity framework, and the 'translation' table, using the same method for the future scenario as specified in the strategic overview. The capacity framework offers a way in which capacity planners can determine suitable interventions that satisfy the direct effects intended. It is a tool useful to systematically reason through the variables and their dependencies existing in freight railway networks in port areas. It provides a platform on which theories can be developed regarding the dynamics of interventions infrastructural subsystems on the broader whole of the network. For example, when the introduction of 740m trains is studied at the strategic level, it can be generally reasoned that regarding the mode of transport speed, acceleration and braking are affected, whereas in the level of infrastructure possibly the length of sidings at shunting yards and terminals are affected. Possibly, because in the specific case, there might be possibilities for longer trains to be drawn out on the branch lines or over a set of switches at a shunting yard. Capacity planners here rely in first instance on experience and knowledge of a) (freight) railway engineering, and b) the specific freight railway system. For homogenous freight railway systems, such as the one located at the Port Industrial Complex, a library may be compiled of frequently deliberated interventions as well as empirically validated (in)direct effects to be used for the evaluation of possible interventions.

The method employed in studying effects of interventions is therefore a search that uses experiments to test falsifiable hypotheses on cause and effect relations in the infrastructure, that are borne out of the capacity framework. After expressing for intervention alternatives: their potential configuration necessities and hypothesised capacity performance effects variations of these alternatives are formulated. Not only are various alternatives tested, also feasible variations of single alternatives are tested for their sensitivity to e.g. diminishing returns. How to specify those variants is left to capacity managers in this process. Even, when preferred alternative configurations are selected, the bottleneck analysis can be repeated to even compare robustness changes.

6.6.3 Intervention Effect Study Performance Indicators

Following this method, the intervention study yields metrics that signify the sign and magnitude of intervention on the operational metrics studied, see Table 14. These metrics demonstrate the operational effectiveness of alternative interventions in an experimental comparative way. Some of these metrics are subsequently relayed to the subsequent investment-oriented analysis for translation into monetary values. The metrics have been explained in other sections, except for the distinction between clusters, train instances and train types. Train instances is the characterisation of a train by the type of good it carries, e.g. container or bulk. Train groups denote a train's itinerary, whether they are visiting one or more terminal.

Statistical testing needs to be done to check whether the effects of intervention are not statistical anomalies (as was determined in section 2.3.2 Simulation Models). In analysis with simulation tools, factorial experiment design combined with ANOVA is the preferred method for statistical evaluation (Montgomery, 2007; Law *et al.*, 2000). The simulation runs specified in the should be replicated to achieve the desired statistical power, a heuristic determining the required amount of runs in terminating simulations is by applying Welch's method (Robinson, 2005). In this method, output of replications is plotted as a moving average, which expands with each replication. When the moving average stabilises, the desired number of runs is achieved. This method can also be used to determine the warm-up period (Robinson, 2005).

Intervention Effect Study	**Indicator**	**Quantitative Metric**	**Per**	**In Unit**
Infrastructure metrics	Scale	Amount of volume	Subsystem	Million Tons
	Scale	Number of trains	Subsystem	Integer
	Scale	Number of train arrivals	Cluster	Integer
	Feasibility	Mean occupation rate	Cluster	Percentage
	Feasibility	Standard deviation occupation rate	Cluster	Percentage
	Stability	Mean accrued delay	Train at cluster	Minutes
	Stability	Standard deviation accrued delay	Train at cluster	Minutes
	Stability	Sum of accrued delay	Location	Hours
	Robustness	Sum of delay	Train per Time period	Minutes
Rolling Stock metrics	Travel time	Mean turnaround time	Train instances	Hours
	Travel time	Standard deviation of turnaround time	Train instances	Hours
	Travel time	Mean turnaround time	Train group	Hours
	Travel time	Standard deviation of turnaround time	Train group	Hours
	Punctuality	Mean delay	Train instances	Minutes
	Punctuality	Sum of annual delay	Train instances	Hours
	Punctuality	Standard deviation of delay	Train instances	Minutes
Simulation Control		Mean waiting time at model in	Individual train	Hours
		Realised numbers of trains	System wide	Integer
Comparison	Base Case vs Forecast Scenarios vs Adjusted Scenarios (Intervention alternatives and their variants)			

Table 14 Overview of output for use in Intervention Effect Study.

6.6.4 Incorporation of Design Principles in the Intervention Effect Study

The intervention effect study incorporates the thorough testing dimension relevant in capacity management, as such it is borne out of the challenges pertaining the disagreement regarding the magnitude and configuration of volume forecasts used, the interpretation of study's operational metric outcomes and experienced difficulty in follow-up in subsequent capacity decision-making processes. These challenges are addressed as volumetric disagreement calls for organisations to mutually adjust, apart from the possibility use the modular process for the execution of the intervention effect study. The use of the shared simulation model in the intervention effect study crystallises the standardisation of process and content interfaces, and structured data connectivity in its software interface. The broad set of operational performance indicators work towards increasing quality and breadth of information shared with collaborators, as well as open deep coordination-related knowledge that remained tacit in the institutional memory of the capacity managers in the current process.

6.7 Financial economic Analysis

6.7.1 Goal of Financial Economic Analysis

In financial economic analysis, the goal is threefold: communication to external stakeholders, stimulate actionable decision-making, and to identify (the most) fruitful opportunities for improving infrastructure through the determination of financial-economic metrics. In transport planning and decision-making, a connection between the operational nature of tactical capacity planning and the financial- economic nature of CBA, is natural, because they offer a way to sound decision-making in the gray areas of operation. Whereas operational indicators particularly lend themselves to decision-making in determining if a subsystem definitely is or is not a bottleneck, they fail to give the decisive answer in more gray areas (for rationale and in-depth discussion, see section 5.3.3 Performance Indicator Description). As such, the investment study primarily addresses the challenges of actionability, communication with stakeholders (e.g. higher up and in subsequent processes). By further broadening the set of performance indicators work towards, it increases the quality and breadth of information shared with collaborators.

6.7.2 Method of Simulation Configuration

The financial economic analysis directly follows the intervention analysis in its scoping, scenario setting and sensitivity testing. That is because of reasons of comparability and efficiency. The setting of assumptions, however, has to be adjusted.

By selecting the same scope, scenarios, sensitivity analyses as the intervention effect analysis, the financial economic analysis fulfils its purpose to first broaden the information base for capacity decision-making regarding interventions, second to apply prioritisation to the interventions, and to aid communication of results to stakeholders. When comparability is maintained, the results of a financial economic analysis can be directly compared with the operational results, thus extending the information base. A preliminary estimate of the costs of an intervention can be used to decide upon the cost-efficiency of interventions tested. The comparability allows for a translation of operational results to economic results which are interpretable for a wider group of stakeholders.

The efficiency of working with the intervention scenario scope allows for the output of simulation runs to be reused, and to align with current CBA practices. The subsystem scope taken in the intervention effect analysis aligns the scoping with the practice of Dutch CBA’s, which are also scoped around tested interventions (Min. I&M, 2015).

For the execution of this analysis the assumption setting base set out in the intervention analysis has to be supplemented with factors for the translation of operational results into economic results. These factors are expanded upon in the following section.

6.7.3 Financial Economic Performance Indicators

Dutch railway investments typically convert the following operational metrics to cost or benefits in preparation of CBA of investments, namely train delay hours, train throughput reliability, and loss of demand for rail freight transport (Appendix B Interviews, Mail 20/04). Train delay hours are the hours of delay a train accrues because of (over)burdened capacity, the economic value of which is determined by the value of time concept. Train travel time reliability is an exponent of the punctuality metric discussed earlier; it measures the standard deviation from the mean throughput time. Current values are presented in Table 15, and sourced from Significance *et al.* (2013).

	Value of Time	Value of Reliability
Container	1531,2	174
Bulk	2088	452,4

Table 15 Hourly Values of time and Reliability in Euros adjusted for inflation (2020).

Values of time are comprised of two parts, transport services-related and goods-related components. The transport-services related share is made up primarily by costs associated with the provision of transport services. If the transport time decreased, vehicles and staff would be released for other transports, so there would be vehicle and labour cost savings. Additionally, there is a share made up of goods-related costs, which comprise: value reductions of perishables, the cost of capital employed (interest) pertaining to the goods transported, cost of disruptions of manufacturing processes as a result of stock-outs of critical components, and lost business as a result of long lead times.

The value of reliability denotes the measure of certainty associated with turnaround times; in other words, it is the variability around the mean turnaround time. When assessing the value of increase turnaround time reliability in freight transport, the following factors are taken into account a) expenses incurred due to suboptimal use of transport material, personnel, b) inefficiencies incurred regarding inventory management, manufacturing and distribution systems, and c) the notion that reliable turnaround times are an important requirement for just-in-time organisation of transport processes.

In Table 16, the outputs in use for this macro-process have been compiled. The total yearly delay per train instance best compiled by outputting a list of individual trains and their instances under scope, meaning container, and bulk trains with their delay (Significance *et al.*, 2013). From that list compute the mean delay and standard deviation of delay. The sum of delay in hours in the time period of the scenario scope is multiplied with values of time of corresponding train instances. The standard deviation of delay per train instance is multiplied with the value of reliability. This strategy is preferred when an intervention or change occurs at a higher system's level.

Another strategy for arriving at values of time and reliability is to focus on sum of delay accrued at the problematic subsystem(s) in scope and comparing across scenarios (Min. I&M, 2015). This strategy is effective, when the intervention or change takes place at a local level, such as the Caland Bridge example. Here the effect of value of reliability is often negligible (Appendix B Interviews, Mail 20/04).

As noted in the micro-process design Appendix G Proposed Micro-Process Design the process can end here, if problems are not deemed grave enough, or interventions not effective enough.

Additionally, to come closer to the CBA method one can include the mean delay per train to approximate the resulting demand loss, as freight forwarders can be expected to change modes in case of unreliable turnaround times (Appendix B Interviews, Mail 20/04). The calculation of which is done using external tools, such as the Ecorys Port Competition Model (Min. I&M, 2015; Appendix B Interviews, Mail 20/04). Additionally, the gains of capacity improvements only materialise over time as locked-in transport services providers adapt to profit fully from gains. Lastly, transport capacity improvements in a CBA only take into account the domestic gain therefore, international leakage is corrected for, meaning that gains will only count 50%, as was the case in the Caland bridge CBA (Min. I&M, 2015).

The method for computing at economic loss or gain of a scenario is therefore as follows:

1. Compile total yearly delay per train instance from RailGenie;
2. Compute standard deviation from average delay;
3. Transform delay to economic loss using value of time;
4. Transform standard deviation to economic loss using value of reliability;
5. Optionally use delay to compute demand loss;
6. Optionally correct for trade-off ratios over time;
7. Optionally correct for international leakage of value.

Financial Analysis	**Indicator**	**Quantitative Metric**	**Per**	**In Unit**
	Operational	Realised train numbers	Location	Integer
	Operational	Mean turnaround time	Train instance	Hours
	Operational	Sum of throughput time increases	Train instance	Hours
	Operational	Std Dev. throughput time increases	Train instance	Hours
	Operational	Sum of Delay Accrued	Subsystem	Hours
	Financial	Value of Time	Train instance	Euro
	Financial	Value of Reliability	Train instance	Euro
	Financial	Sum of Value of Time Lost	Train instance	Euro
	Financial	Sum of Value of Reliabilty Lost per Train Instance	Train instance	Euro
	Financial	Loss of demand	Subystem	Euro
	Financial	Estimated cost of intervention	Intervention Alternative	Euro
Comparison	Base Case vs Forecast Scenarios vs Selected Scenarios (Intervention Alternatives)			

Table 16 Overview of output for use in Financial Economic Analysis.

6.7.4 Incorporation of Design Principles

The incorporation of financial economic metrics is by no means introduced as a substitute for either operational metrics or autonomous decision-making by experts. Instead, this investment-oriented analysis incorporates principles that help overcome challenges faced in current capacity planning activities. It aims to be a supplement that firstly invites a more intuitive interpretation to laity (or hierarchy) and secondly helps inform actionability regarding capacity intervention decisions.

First, the addition of economic performance indicators helps increase the breadth of information shared based on information needs coming from deep coordination related knowledge. The intuitive interpretation rests with the general familiarity that professionals have with performance in monetary value, through regular use of the concept elsewhere. This helps overcome the challenges of following up capacity planning processes and supports effective escalation in the hierarchy.

Second, it supports actionability of capacity planning processes, through its alignment with subsequent processes and its incorporation in the capacity multi-objective function. The inclusion of economic performance indicators works towards the use of performance indicators that feature in the cost-benefit analysis following operational capacity planning therefore improving the link towards investment decision processes and increasing the actionability of capacity planning activities. Additionally, it allows for more homogeneous comparison between alternative variations, which may have differing impacts on various operational performance indicators at different subsystems and unifying those in a financial perspective. The actionability is derived from the fact that cost of infrastructure improvement is rather large, yet comparable across subsystems, therefore the price provides for a basis of comparison.

6.8 Conclusion of Chapter 6

A process design for port railway capacity planning is proposed which overcomes the identified challenges through a) the active guidance of capacity management and coordination principles, b) technical capacity coordination principles, c) sets of performance indicators and quantitative metrics, and d) a shared technical understanding through the capacity framework. By simulating future rail transport growth scenarios in a simulation model, it is possible to identify the current and expected state of the infrastructure usage, prominent bottlenecks in the infrastructure, evaluate intervention effectiveness and their cost-efficiency. These goals are captured in a design consisting of four macro-processes: strategic overview, bottleneck analysis, intervention effect analysis, and financial economic analysis. Strategic overview process serves to monitor the systems general ability handle transport demand in the face of economic and technical long-term trends. The goal of bottleneck analysis is twofold, namely, to identify and locate bottlenecks, as well as determining establishing the level of urgency associated with fixing the bottleneck. The goal of intervention effect study's is to gauge the effectivity & efficiency of possible interventions or solution directions. Investment-oriented analysis focuses on economic capacity expressed in financial metrics.

7. Capacity Study Process Proof of Concept Demonstration

The demonstration of the design is embodied by a proof of concept, a demonstration run of the most important elements of the capacity planning process is executed together stakeholders Port of Rotterdam, ProRail, and Macomi.

Planning is discussed in 7.1 Proof of Concept Workshop Organisation. Scope is discussed in section 7.2 Proof of Concept Scope. Subsequent sections detail the macro-process execution: 7.3 Strategic Overview, 7.4 Bottleneck Analysis, 7.5 Intervention Effect Analysis, and 7.6 Financial Economic Analysis. A reflection on validity is given in section 7.7 Proof of Concept Construct Validity . Learning is presented in 7.8 Summary of Lessons Learned. Section 7.9 Conclusion of Chapter 7 concludes.

7.1 Proof of Concept Workshop Organisation

The execution of the designed process as proof of concept serves three purposes: first for the participation-based elicitation of evaluative feedback from clients on the design, second for establishing the proof of concept's construct validity, and third for drawing lessons about the design through researcher reflection. Active participation is deemed conducive for the quality of evaluation received in the demonstration and evaluation phase (Hevner, 2004). Construct validity when referring to a proof of concept is the measure of the correctness of composition of the proof of concept (Wieringa, 2014). It is important to legitimise inferences made from the operationalisation of the conceptual process design (Yin, 2017).

The workshop is setup in three parts, where assumption discussion and validation of the simulation results are sequentially discussed. This separation is made to allow for time in between the setting of assumptions and validation of results of each macro-process step, while condensing maximally to ensure participants can recall discussions previous meetings in memory. Scoping decisions, assumptions made, and results presented are recorded and communicated to the participants through a slidedeck presentation presented through Microsoft Teams. An overview of the slides presented is included in Confidential Appendix J Slide Deck Presented in Evaluatory Meetings.

	Agenda	**Attending**
Workshop 1	Subsystem Scope Temporal Scope 2018 scenario setting Bottleneck setting	Railway and Shipping Traffic Expert, Port of Rotterdam Freight Railway Capacity Expert, ProRail Principal Consultant, Macomi
Workshop 2	2018 assumption and result validation Bottleneck assumption and result validation 2040 scenario setting 2040 intervention scenario setting	Railway and Shipping Traffic Expert, Port of Rotterdam Freight Railway Capacity Expert, ProRail
Workshop 3	2040 assumption and result validation 2040 intervention validation Evaluation of the simulation process	Railway and Shipping Traffic Expert, Port of Rotterdam Freight Railway Capacity Expert, ProRail Principal Consultant, Macomi

Table 17 Overview of the workshop organisation.

7.2 Proof of Concept Scope

The proof of concept capacity process is scoped down compared to the prescribed process design in order to focus research effort on salient aspects of the proposed design and to maintain construct validity. The scoping down allows to cover the full length of the process, while sacrificing some depth. This sacrifice is necessary to maintain construct validity, as data and simulation model restrictions prevent execution as designed. The following sections are 7.2.1 Subsystem Scope and 7.2.2 Temporal Scope.

7.2.1 Subsystem Scope

The physical scoping of the proof of concept in terms of the subsystems under study is limited relative to the proposed design, as at the time of research, the input datasets used are insufficient for simultaneous simulation of the entire port railway system and do not lead to realistic outcomes. Therefore, a shunting yard and the terminals it serves are exclusively studied, the subsystems are listed in Table 18, and their configuration is shown in Figure 17. Although divergent from the proposed design, this is acceptable for the proof of concept as it aligns with the Port of Rotterdam and ProRail case as presented in chapter 5. Furthermore a shunting yard was marked as main case in the chapter 4, as it is the both the most current case of capacity planning and most representative for the current state of the interorganisational capacity planning process. Therefore, the choice for the shunting yard scope ensures that comparability and thus internal validity is maintained throughout the research approach (Yin, 2017).

Subsystem	**Characterisation**
Shunting Yard	Shunting, and stabling yard
Terminal	*Redacted*
Terminal	*Redacted*
Terminal	*Redacted*

Table 18 Overview of subsystems in proof of concept scope.

Redacted

Figure 17 Redacted Technical Drawing of Subsystems and their Connections in 2018 (ProRail, 2020).

7.2.2 Temporal Scope

For the simulation experiments, the temporal scope of simulation is set at a single month, because of the simulation model currently becomes unstable for run times of a year. The month chosen is October as it is the busiest month and any capacity problems, if present, are thus more likely to arise there. This scope was previously used to study the shunting yards and terminals (Macomi, 2020). Clients agreed to use this time scope in the first workshop. The choice for the month of October affects the interpretation of indicators by presenting the subsystems at their busiest level. This is considered in the interpretation of performance indicators.

7.3 Strategic Overview

This section outlines the representation of the strategic overview in the proof of concept. The paragraphs are structured in line with the sequence of the proposed design in sections: 7.3.1 Scoping, 7.3.2 Scenario Setting, 7.3.3 Assumption Setting, 7.3.4 Assumption Testing & Sensitivity Analysis, and 7.3.5 Performance Indicators. Lastly, conclusions are drawn in section 7.3.6 Conclusion.

7.3.1 Scoping

The scope of the strategic overview is brought in line with that of the overarching proof of concept to avoid invalid simulation results. It is thus limited in terms of physical and time scope compared to the proposed design. In the proof of concept, only the terminal subsystems directly connected with the shunting yard are considered. Consequently, the complete railway system benchmark is not executed, and only the month of October is studied. In terms of interpretation of results, the lack of a benchmark makes interpretation through comparison of subsystems' performance more difficult.

7.3.2 Scenario Setting

Two scenarios are set in the strategic overview, one scenario of the year 2018 as a base case scenario and one of the year 2040 as a future case scenario. Using these scenarios, it is possible to estimate the effects of demand trends for railway freight transport on the capacity performance over time. 2018 is chosen as it is the most recent year for which realisation volumes and infrastructural map configuration were available. 2040 is chosen as it is the furthest reliable forecast year for both Port of Rotterdam and ProRail.

The critical uncertain, and non-verifiable assumptions made in the scenarios relate to the train volumes, process times and infrastructural map used. The volumes of block trains, unit cargo and port shuttle are critical due to the simulation models' sensitivity to (train) volumes, and uncertain with respect to their 2040 forecasts. Block train volumes in the 2018 case are taken from realisation data previously compiled by the Port of Rotterdam and ProRail. For the 2040 case, the forecasts of the Port of Rotterdam are used, because ProRail was unable to compile the dataset containing ProRail forecasts, due to inability to operate the tool. Unit cargo volumes are excluded from the scenarios as the data set composed previously by Port of Rotterdam and ProRail were compiled wrongly, as it generated too many unit cargo trains. Port shuttle volumes are excluded from the 2018 case to maintain comparability to the ProRail capacity study (ProRail, 2020). The infrastructural map is critical, because of changes made to the configuration of the terminal. Lastly, critical and uncertain are the trains destined for terminal, which are cut into two due to the limited length of tracks present there. This compilation procedure is a special case for the port railway area, and thus not modelled in RailGenie. Assumptions will have to be made to operationalise this procedure in the model.

Scenario Elements	2018	2040
Block Train Volumes	Realisation data over the year 2018	Forecast of the Port of Rotterdam: Green Unlimited including customer developments.
Unit Cargo Train Volumes	Not included, as irregularities were detected in the dataset	Not included, as irregularities were detected in the dataset
Port Shuttle Train Volumes	Not included to allow for comparability with the ProRail capacity study.	Not included,
Shunting Yard Process Times	Estimate of process time based on partial realisation data from Sherlock tool in line with ProRail capacity study (ProRail, 2020).	Estimate of process time based on partial realisation data from Sherlock tool in line with ProRail capacity study (ProRail, 2020).
Terminal Process Times	Estimate of process time based on partial realisation data in line with Port of Rotterdam capacity study (Macomi, 2020).	Estimate of process time based on partial realisation data in line with Port of Rotterdam capacity study (Macomi, 2020).
Infrastructural Map	Map reflects 2018 infrastructure.	Map reflects 2040 situation
Branch Line Speed	*Redacted*	*Redacted*

Table 19 Comparison of critical, non-verifiable scenario assumptions between base and future case.

7.3.3 Assumption Setting

By setting assumptions for modelling, the scenarios are translated into two configurations of the simulation model. The assumptions are set using expert opinion in the workshops, the capacity framework, and the tool for operationalising the framework into the simulation model presented in .Appendix D Simulation Model Assumptions Operationalisation. These assumptions are carried over and supplemented where necessary in subsequent macro-process steps. For a full overview of assumptions made, including those deemed non-critical or verified, see Confidential Appendix H Proof of Concept .

Three differences in assumptions are presented Table 20 Base case 2018 assumptions.Table 21 Future case 2040 assumptions. The block train volumes, infrastructural map are different in both scenarios. Shunting yard process times and terminal process times at out of scope subsystems have been set at 2 hours for each activity to prevent overburdening. The other estimates are as mentioned set to reflect previous approximations.

Scenario Elements	2018 Assumptions
Block Train Volumes	Volumes according to realisation figures.
Unit Cargo Train Volumes	*Redacted*
Port Shuttle Train Volumes	*Redacted*
Shunting Yard Process Times	Shunting yard processes, both incoming and outgoing are set to (ProRail, 2020). Rest of the port's shunting yards is at reduced levels.
Terminal Process Times	Container terminal loading and unloading are drawn from (Macomi, 2020). Wet bulk loading and unloading time is set at (Macomi, 2020).
Infrastructural Map	The XML-map of 2018 is used (Macomi, 2020).
Branch Line Speed	Speed limit on the branch line set (Prorail, 2011).

Table 20 Base case 2018 assumptions.

Scenario Elements	2040 Assumptions
Block Train Volumes	Full 2040 forecast of the Port of Rotterdam: Green Unlimited including customer developments.
Unit Cargo Train Volumes	*Redacted*
Port Shuttle Train Volumes	*Redacted*
Shunting Yard Process Times	Shunting yard processes, both incoming and outgoing are set to (ProRail, 2020).
Terminal Process Times	Container terminal loading and unloading are drawn from (Macomi, 2020). Wet bulk loading and unloading time is set at without distribution (Macomi, 2020).
Infrastructural Map	The XML-map of 2018 is used (Macomi, 2020).
Branch Line Speed	Speed limit on the branch line set.

Table 21 Future case 2040 assumptions.

7.3.4 Assumption Testing & Sensitivity Analysis

Assumption testing and sensitivity analyses serve to finalise the experimental design for the scenarios by showing the effects of the scenarios set to the assumptions made. In the strategic overview, a one-factor-at-a-time approach is used to the performance indicator's sensitivity to the scenarios set and the sensitivity evaluation, because the between scenario changes occur coincidentally, and it allows for comparison with the factorial sensitivity design in the intervention effect analysis.

The questions whether to include a) unit cargo, and b) port shuttle are subjected to sensitivity testing, as well as the question of how to model the separate travel of train halves over the branch line to . The composition of the sensitivity analyses is given in Table 22. These sensitivity analyses are fully presented in 15.4 Confidential Appendix I Assumption and Sensitivity Testing.

	Variable	Current incorporation	Change to
1	Unit Cargo	No	Yes
2	Port Shuttle	No	Yes
3	Branch Line Train Separation Modelling	Branch line speed reduction	Shunting yard process time increase

Table 22 Overview of sensitivity analyses conducted for strategic overview.

In conclusion of the sensitivity analyses, the exclusion of unit cargo and port shuttle volumes is only a minor underestimation of arrivals rates, with no significant effect on occupation rates and delay accrual at subsystems. The separate train movements are modelled as a speed reduction of the branch line and not as a process time increase, as the speed reduction has a significant effect on performance, while the process time increase assumption is deemed too uncertain (in reflection to the real situation) to incorporate, aside from that it has only a negligible effect.

The testing of sensitivity to both types of process time changes is left for the intervention analysis, because the realisation process times align with previous studies for the base case and are deemed more uncertain for the future case, given the likelihood of (continuous) process improvements in the future.

7.3.5 Performance Indicators

The strategic overview presents quantitative metrics regarding scale, feasibility, stability, robustness travel time, and punctuality. In the proof of concept, a selection from the total list of quantitative metrics (Table 12) is taken. For scale, the number of trains arrivals are selected. For feasibility, the mean and standard of occupation rates per subsystem are considered. Stability is demonstrated by the delays accrued per subsystem. The rolling stocks' travel time is measured through its turnaround time. Punctuality is not explicitly addressed here as the results agree with the delay accrued and turnaround time indicators.

[redacted]

Figure 18 Mean turnaround time per train instance, Standard Deviation (SD) across replications in the error bars (5 replications of 31 days). (Redacted)

[redacted]

Figure 19 Mean occupation rate per subsystem, SD across replications in the error bars (5 replications of 31 days). (Redacted).

[redacted]

Figure 20 Sum of delay accrued per subsystem, SD across replications in the error bars (5 replications of 31 days). (Redacted).

From Figure 18, Figure 19, and Figure 20, three rival theories emerge in workshop 2 for explaining the problematic delay accrued at a shunting yard and , as caused by a subsystem that is used too intensively:

- High occupation rates at the shunting yard leading to delay at terminal;
- High occupation rates at the terminal leading to delay at the shunting yard;
- High occupation rates at the branch line connecting both leading to delays at both.

From the three theories, the high occupation rate of the branch line arises as the most promising, due to a process of elimination of the other theories and congruency with the earlier conducted study, see ProRail (2020). The other rival theories have downsides to their explanatory power.

If occupation rates at the shunting yard were problematic (Figure 19), then delays at the other terminals would be expected too (Figure 20), likewise increases in turnaround time would be seen in other trains (Figure 18). This is not the case.

High occupation rates at terminal (Figure 19) do not explain delays at itself (Figure 20). Terminal ’s occupation rates relative to the occupation rates at terminal are not considered to be significantly higher (Figure 19).

The high occupation rate of the branch line between terminal and the shunting yard does account for delays accrued at both subsystems, and therefore is flagged as the most likely theory for explaining delay accrual.

7.3.6 Conclusion

The strategic overview suggests that the branch line between terminal and the shunting yard is the most likely bottleneck. Subsequent analysis therefore takes this theory for further scoping. At this stage, no KPI’s for branch line occupation have been selected, but there will be in upcoming analysis.

7.4 Bottleneck Analysis

This section outlines the representation of the strategic overview in the proof of concept. The paragraphs are structured in line with the sequence of the proposed design in sections: 7.4.1 Scoping, 7.4.2 Scenario Setting, 7.4.3 Assumption Setting,7.4.4 Assumption Testing & Sensitivity Analysis, and 7.4.5 Performance Indicators. Lastly, conclusions are drawn in section 7.4.6 Conclusion.

7.4.1 Scoping

The scoping of the bottleneck analysis is done in accordance of the process design by following the interpretation of KPIs in the strategic overview. The strategic overview's results suggest a possible bottleneck at or in between a shunting yard and Terminal. To further scrutinise the system, volumes of all terminal subsystems in scope are increased in stepwise fashion to detect whether tipping point behaviour occurs in the system, as outlined in bottleneck analysis section 6.5.2 Method of Simulation Configuration.

7.4.2 Scenario Setting

The bottleneck analysis is forward looking in that it attempts to pre-empt future capacity problems by backcasting. The simulation is therefore executed using the assumptions made in preparation of the 2040 scenario. The scenario assumption relating to block train volumes is adjusted using the backcast factors. The backcast factors are gotten through progressive increases until the delay times became irrecuperable.

Scenario Elements	Bottleneck Scenarios
Block Train Volumes	Specified according to backcasts for the subsystems at a shunting yard, comprised of 2X, 3X, and 4X times the 2018 block train volumes. All other subsystem's train volumes are kept at 2018 level.

Table 23 Translation of bottleneck scenario to block train volume assumptions.

7.4.3 Assumption Setting

The block train volumes represent progressive raising of the 2018 block train volumes for the terminals located at a shunting yard. All other subsystem's train volumes are kept at 2018 level. These are displayed in Figure 21.

[redacted]

Figure 21 Number of train arrivals per subsystem across bottleneck scenarios. (Redacted).

7.4.4 Assumption Testing & Sensitivity Analysis

The bottleneck study is a type of sensitivity analysis conducted over increasing levels of train volumes. As insights gotten are of an exploratory nature, and specific levels are not used for direct decision-making, therefore no further sensitivity analysis is done in the proof of concept.

7.4.5 Performance Indicators

In workshop 2, four KPI's are identified as most promising by the stakeholders in the detection of bottlenecks out of the total set of KPI's: 1) the volume of trains multiple at the tipping point, 2) urgency, and 3) delays per train movement at subsystems in the scenario before the tipping point, and 4) mean occupation rate of the branch line across scenarios.

The sum of delays per train at the shunting yard proved irrecuperable at four times the 2018 train volumes. However, in the current infrastructure that volume will not be reached. Therefore, no urgency can be derived from the prevention of completely overburdening infrastructure.

The figures presented in workshop 3 related to delays per train movement at subsystems in the pre-tipping point scenario and the branch line occupation rate contained numerous errors, and unexplainable results. The delays per train movement table for the pre-tipping point scenario showed delays at all train movements from terminals to shunting yard and vice versa. The occupation rates were tainted due to a software bug in the registration of train dynamics, misspecification of the occupation rate metric at the branch line, and faulty assumption in the arrival rate of trains in the model. These figures have been left out of this document in the interest of brevity and understandability.

Figure 22 presents a corrected version of the mean occupation rate per branch line per scenario. Compared to other branch lines, the branch line connecting a shunting yard and terminal is occupied more.

Secondly, at the request of clients in workshop 2 an additional table containing the delays per train movement for the future case scenario was compiled. It is based on only one replication as the metrics are not currently present in the simulation model. Table 24 show that from a shunting yard delay is accrued only from two types of movement, namely towards terminal and towards the main line. Only at terminal is delay accrued when going to a shunting yard.

[redacted]

Figure 22 Mean occupation rates of branch lines across bottleneck scenarios (5 replications of 31 days). (Redacted).

Train Movement	Sum of Delay Accrued (hh:mm:ss)	Mean Delay Accrued per Train (hh:mm:ss)	Number of Delayed Train Movements	Total Number of Train Movements

[redacted]

Table 24 Overview of delays per train movement in October 2040, contextualised with the number of train movements (1 replication of 31 days). (Redacted).

7.4.6 Conclusion

The bottleneck analysis as conducted in accordance with the process design during the workshops did not yield the desired insights. Therefore, the branch line occupation analysis has been redone to account for a bug, and KPI misspecification present in the simulation tool. Furthermore, on the suggestion of the clients another analysis was done.

Both the mean occupation rates at the branch line and delay per train movement overview suggest that the bottleneck is located at the branch line between a shunting yard and Terminal.

7.5 Intervention Effect Analysis

This section outlines the representation of the strategic overview in the proof of concept. The paragraphs are structured in line with the sequence of the proposed design in sections 7.5.1 Scoping, 7.5.2 Scenario Setting, 7.5.3 Assumption Setting, 7.5.4 Assumption Testing & Sensitivity Analysis, and 7.5.5 Performance Indicators. Lastly, conclusions are drawn in section 7.5.6 Conclusion.

7.5.1 Scoping

The intervention effect analysis is scoped at specifically the bottleneck discovered in the branch line towards. To this end, the scope and subsequent simulation configuration are tailored specially to establish the intervention effects on the shunting yard, the terminal and the branch line.

7.5.2 Scenario Setting

Three intervention scenarios are developed that are tested in the analysis:

- Branch lines speed is increased by automating the level crossings. This intervention is deemed the best suited to counter the discovered branch line bottleneck. Automation would approximately lead to a doubling of the speed on the branch line (and halve the travel time).
- Terminal process time reduction, due to process improvements or handling capacity investments. This scenario is tested as processes tend to become more efficient overtime, and it is therefore advantageous to contrast the branch line speed increase. If the scenario yields considerable improvement compared to the branch line speed increase, then the rival theory regarding high occupancy rate at holds.
- Shunting yard process time reduction, due to process improvements or handling capacity investments. This is incorporated for both trend appraisal and the checking of rival theory regarding high occupancy rates for a shunting yard.

7.5.3 Assumption Setting

The simulation modelling assumptions underlying the intervention effect analysis are the same as those used in the 2040 scenario. However, new assumptions are introduced to reflect the proposed intervention of increasing the speed of the branch line by automating the operation of level crossings along the line. The proposed intervention is inspired by a previously organised solution-oriented workshop at ProRail with Port of Rotterdam and Arcadis experts present in the context of ProRail's capacity study. This is chosen as the most promising of the several solution alternatives discussed. Although at that time, attendees were unable to evaluate what the capacity performance effect would be of the interventions.

Intervention Scenarios	**Assumption**
Branch lines Speed Doubling	*Redacted*
Terminal Process Time Reduction	*Redacted*
Shunting Yard Process Time Reduction	*Redacted*

Table 25 Translation of intervention scenarios into modelling assumptions.

7.5.4 Assumption Testing & Sensitivity Analysis

For the intervention effect analysis, sensitivity is more systematically measured than in the strategic overview, as the outcomes are important for decision-making rather than the informative aspect of the strategic overview. The intervention's effect is established through a full factorial experiment design, which specifies the simulation configuration and runs found in 15.4 Confidential Appendix I Assumption and Sensitivity Testing. This in contrast to the strategic overview, where the added effort and increased difficulty of interpretation were not justified for the straight comparison of scenarios.

- For delay accrued at Terminal , Shunting Yard Process Times (B), Branch Line Speed Limit (C) and their interactions are statistically significant (Table 49) and relevant (Table 48).
    - Reducing Shunting Yard Process Times leads to a reduction in delay accrued.
    - Increasing Branch Line Speed Limit leads to a reduction in delay accrued of.
    - The interaction of AB makes that if both are reduced, delay accrued is reduced.
    - The interaction of BC makes that if both at low level, delay accrued is increased.

- For delay accrued at Shunting Yard a shunting yard, Terminal Process Times (A), and Branch Line Speed Limit (C) are statistically significant (Table 51) and relevant (Table 50).
    - Reducing Terminal Process Times leads to a reduction in delay accrued of.
    - Increasing Branch Line Speed Limit leads to a reduction in delay accrued of.
    - The interaction of AC makes that if both at low level, delay accrued is reduced with.

7.5.5 Performance Indicators

The KPI base is reduced to focus only on the delay time accrued measured at both subsystems, because delay is the primary negative effect of changing structure and use of infrastructure over time. Additionally, as a result of the bottleneck analysis, the only indicators pertaining to the shunting yard and terminal are referred to for analysis. Although the branch line occupation rate is seen as problematic cause of delay, it is left out of the set of indicators, because for testing interventions effects are more interesting.

The comparison of expected effects per intervention shows that an increase of the speed on the branch line between a shunting yard and is the more effective than process time reductions at the terminal or shunting yard. The results of the intervention analysis are displayed in Figure 23. Additional conclusion from the analysis is that occupation rates at neither of the subsystems are too problematic, given that a 25% reduction of the process times lead to little reduction of delay accrued at adjacent subsystems.

[redacted]

Figure 23 Comparison of expected delay reduction per intervention scenario, SD in error bars (24 replications across 31 days). (Redacted).

The use of factorial experiment design allows for the testing of interaction effects between the interventions. The effect of a speed increase of the branch line on shunting yard delay is greater when terminal process times are low. Both the results from effects testing and the statistical ANOVA results are found in Confidential Appendix H Proof of Concept .

7.5.6 Conclusion

The intervention effect analysis and sensitivity analysis firstly confirm that the branch line is a cause of delay at both a shunting yard and Terminal. Secondly, the branch line speed intervention is proved to be highly effective in reducing delay. As a result, the interventions are carried over to be tested for financial economic cost-effectiveness.

7.6 Financial Economic Analysis

7.6.1 Scoping

The scope of the financial economic analysis is limited to the branch line speed increase intervention. The proof of concept differs from the proposed design in terms of the time window examined. The financial economic analysis should take a yearly perspective, but takes the perspective of October in this proof of concept.

7.6.2 Scenario and Assumption Setting

The financial economic analysis supplements the intervention analysis with one assumption, as presented in Table 26.

Financial Economic Scenario	Assumption
Value of Time	Value of time is assumed at €1,531.20 at the 2020 CPI, as taken from Table 16. The value of time pertaining to container freight trains is used, as is common in exploratory CBA railway capacity studies in The Netherlands, see (Min I&M, 2015).

Table 26 Assumptions made in the financial economic analysis.

7.6.3 Assumption Testing & Sensitivity Analysis

No further quantitative sensitivity analysis was planned for the financial economic analysis as the figure was merely taken to be indicative, and the intervention effect study already discussed sensitivity. Although participants did evaluate qualitatively what the sensitivity effect of economic indicators could be when incorporating further CBA practices such as international leakage and trade-off ratios, both of which cancel each other out.

7.6.4 Performance Indicators

The interpretation of economic performance was limited to the appreciation of value of time changes to delay accrued at the adjacent subsystems a shunting yard and terminal. Disregarded were the value of reliability, trade-off effects, international leakage as at this stage merely an indication was deemed informative enough.

[redacted]

Figure 24 Economic comparison of the intervention options (24 replications across 31 days). (Redacted).

7.6.5 Conclusion

As the time for the third workshop ran out before fully covering the financial economic analysis, no decision was reached on how to interpret the outcomes. Although it was shortly mentioned that the potential benefits of automation were surprisingly high.

7.7 Proof of Concept Construct Validity

Overall, the construct validity of the proof of concept process, as means to evaluate the process design is limited, because of the limited scope of the proof of concept, the discussions regarding setup assumptions and counterintuitive results of the simulation study which were unexplainable at the time of the workshops. These issues led to a rejection of the process' simulation results by the clients, because validity of the modelling effort could not be guaranteed.

The relatively smaller scope of the proof of concept means that only a limited elements number of the design can be evaluated directly. The major elements that are most missed in this regard are: 1) the benchmarked comparison of other yards and terminals in the railway system, 2) the contrast with the ProRail forecasted volumes, and 3) the ability to show the full depth of quantitative metrics. The benchmarked comparison would allow for a contextualised comparison of performance indicators across the railway system. The comparisons in the proof of concept merely supported within scope comparisons with differing subsystems, e.g. in terms of number of sidings, and type of goods catered for. The contrast with the ProRail forecasted volumes was not included in the proof of concept. The effect of this on the evaluation remains limited as the bottleneck analysis takes over part of the volume sensitivity analysis, and previous interviews indicate that the disagreement regarding the use of different forecast volumes will not be resolved by changes to the capacity study process (Appendix B Interviews, 17/06). Full presentation and discussion of all performance indicator output was infeasible due to the time constraints posed on the workshop sessions, and the congruency of results as discussed in the next paragraph.

Some of the results of the simulation were unexpected, counterintuitive or contrary to results from earlier capacity studies. Unexpected is the result regarding branch line occupation rates under increasing train traffic. Although after the workshop, the observed effect appeared to be explained by three factors, namely software bug in the registration of train dynamics, misspecification of the occupation rate metric at the branch line, and faulty assumption in the arrival rate of trains in the model. In the workshop the result was not addressed properly and the trust in simulation outcomes diminished. Counterintuitive the result regarding unchanging occupation rate at terminal while facing an increase in the number of train arrivals. The unchanging occupation rate at terminal is explained by the change in train facilities there, which had gone unnoticed in the setting of assumptions.

Practical limitations to the research effort are detrimental to the construct validity. These limitations are present in the proof of concept execution in terms of limitations of time, detailed knowledge about the simulation model's functioning and current functional constraints of the simulation model. The effect of practical limitations arises because the previously mentioned problems occurred in tandem, and were unresolvable at the time of the workshop, otherwise their effects on validity would be smaller.

All in all, the deviation of the proof of concept process from the conceptual designed process presents a limitation to the degree to which valid evaluative conclusions can be drawn from the workshops. In the interest of the research, a compilation is made of lessons learned from the execution are summarised in the subsequent paragraph and the results of process evaluation are discussed in the subsequent chapter.

7.8 Summary of Lessons Learned

Although the reduced proof of concept construct validity limits the extent to which the designed process is evaluated, it does not diminish the value of lessons drawn from execution of the process. These lessons are reflections of the researcher on the disparity between expected interaction and the realised interaction of clients in the proof of concept. Lessons are drawn categorised according to the in those relating to the process' steps, and the assessment of performance indicators.

An abridged variant of the capacity study process is not sufficient to draw out the full potential of the design in addressing coordination challenges. During the proof of concept execution, a gap in validation iterations of assumptions and simulation results emerged leading to misunderstanding and discussion. The cyclical, iterative nature of the capacity study is thus crucial to guide discussions and decision-making in the process. Furthermore, ample time is necessary to test, crystallise and communicate choices related to scenario set up, modelling assumptions and interpretation of performance indicators.

Successful presentation of performance indicators does not rest with merely choosing appropriate metrics, but rather on presenting insightful combinations of indicators. Another important aspect is the explainability of the effects shown in comparisons. Indicator presentation is an iterative process, wherein the value of indicators and their combinations shown rest with the particular simulation outcomes and scope of study.

7.9 Conclusion of Chapter 7

The execution of a proof of concept capacity study process was undertaken in support of three research aims, namely for participation-based elicitation of evaluative feedback from clients on the design, for establishing the proof of concept's construct validity, and for drawing lessons about the design through researcher reflection. The execution of the proof of concept has limited construct validity necessitating the need for nuancing the derived evaluative findings. The execution yielded lessons concerning the conceptual process design, regarding the prerequisite complete going through the process, and the presentation of performance indicators.

8. Capacity Study Process Evaluation

The evaluation chapter present a step made to determine whether the designed artefact shows the potential to be operationally dependable in achieving stakeholders' goals, i.e. that the functions in the way it is intended to. The evaluation approach is described in section 8.1 Description of the Two-step Evaluation Approach. The formative requirements evaluation is presented in section 8.2 Evaluation of Adherence to Requirements. The summative evaluation is outlined in section 8.3 Execution of Proof of Concept Evaluation. A summary of findings is made in section 8.4 Main Evaluation Observations. Conclusions are discussed in section 8.5.

8.1 Description of the Two-step Evaluation Approach

The evaluation is conducted both formatively and summatively. The formative evaluation denotes the continual process of assessing whether the proposed process design complies with the functional requirements posed (Gregor & Hevner, 2013). The summative evaluation rather addresses the design's potential for usability and is evaluated primarily in the context of the proof of concept and secondarily in terms of non-functional requirements (Wieringa, 2014; Venable, 2006).

Regarding formative evaluation, Hevner et al. (2004) posit that in design science research of the kind undertaken in this study, the artefact can be considered complete and effective when the requirements of the problem it was meant to solve are satisfied. Pries-Heje *et al.* (2008) further note that this form of artificial ex ante evaluation form can help validate the consistency and integrity of the design search process, and remark that quality of the design search process can be a marker for design quality. As such requirements evaluations are a continuous aspect of the design process and is conducted by both insiders to the process and external experts in process management and transport domains, which is demonstrated in the interviews in the Appendix B Interviews. However, there are two important critiques pertinent in the context of specifically this research, namely that: a) the requirements list merely provides an insight into the validity of the artefact and is not an evaluation by those employing the artefact and b) the one case study can be considered limited in its single case 'N=1' rationality. Therefore, in extension of the requirements list based evaluation, a stakeholder evaluation is executed using a case study specific proof of concept simulation study.

The conducted case study functions as a proof of concept in the naturalistic summative evaluation of the previously elaborated process design, in accordance with the normative guidance on design science evaluation given by Pries-Heje *et al.* (2008). As is demonstrated that the development, implementation and execution of the process design, not only is the design feasible in sense that requirements are adhered to, but also that participating stakeholders in the designed process acknowledge it as an improvement on earlier iterations. The requirement adherence, qualitative inspection by stakeholders, comparison to current state and exploration of (unexpected) detrimental effects of design therefore all form part of this evaluation process.

8.2 Evaluation of Adherence to Requirements

The first evaluation activity encompasses checking the compliance of the design with its specified requirements. This is done using the functional requirements specified in Table 9. Only the functional requirements are checked in this fashion as non-functional requirements are signifiers of design quality and should be measured according to client perception, as occurs in proof of concept evaluation (Wieringa, 2014). Table 27 shows the mapping of macro- and micro-Processes in the design with the functional requirements, specified in section 6.1 Requirements Formulation. The naming of microprocesses derives from the microprocess diagrams found in Appendix G Proposed Micro-Process Design.

Macro Process	Micro Process	Req. #	Explanation
Strategic Overview	Decide Scope, Compile Volume Forecasts.	1.1	Strategic questions on developments of economic and technology factors enter the capacity management process through the strategic overview. In this process the trends have to be translated for configuration of the simulation model, along with possible interventions that follow in the process.
	Interpret Prescribed KPI set.	2.1	The ranking of subsystem's problems is explicit joint decision-making activity. Prioritisation is done for the urgency with which to conduct deeper analysis. The ranking decision is subsequently used in bottleneck analysis and therefore well incorporated in the overall process.
	Compile Volume Forecasts, Characterisation of Infrastructure Components.	3	The process involves these departments in gathering information that sharpen understanding of problems and inform assumption making and validating simulation outputs.
	Compile Volume Forecasts, Validate Assumptions.	4.1	Activities referring to data supply gathering, modelling assumption-making, and validation are incorporated with available data sources.
	Decide Scope.	4.2	The Strategic Overview explicitly incorporates both volume forecasts, and compiles and transforms them where necessary, because unifying to one forecast proved not negiotiable.
Bottleneck Analysis	Volume Settings, Parameter Assumption.	1.2	With backcasting weaknesses in the infrastructure become apparent. From the volume increase used in backcasting, it can be analysed what the timeframe for action (i.e. urgency) is.
	Define Bottleneck Location	1.4	Root cause analysis is done, as comparisons are made between sub-systems performance over volume increases. Using insights from queueing theory, capacity managers can then pinpoint bottlenecks.
	Compile Prescribed KPI set	2.2	A subsequent ranking of subsystems in terms of timing of capacity interventions is gotten from the combination of the urgency determination and root cause analysis, which leads to a sub system, and their time indication of 'breaking' in the broad sense of the word.
Intervention Effect Analysis	Brainstorm Interventions, Selection of Testable Interventions, Specificying Variants of Intervention Alternatives.	1.3	Traceability of decision-making is ensured here by the formal testing and experimentation with (sets of) interventions and their sensitivity. The technical capacity framework supports this process as it displays the configuration of the system, and therefore can be used to denote the intervention alternatives.
	Joint Check of Compilation	4.3	Although all the macro-processes are supported by RailGenie, the requirement is discussed here as RailGenie here presents and compares results integrally.
Investment-oriented Analysis	Joint Check of Compilation	1.1	The capacity process supports investment decisions from both the perspective of the Port of Rotterdam and ProRail given the inclusion of both stakeholders explicit kpi's regarding urgency and economic implications of both problems and solutions. Therefore, the process supplies both stakeholders in internal deliberation regarding communication with subsequent processes and higher-ups, economic capacity constraints, and cost-effectiveness of interventions. As addition to the operational metrics.
	Transformation of Operational Metrics	1.5	The financial economic metrics gained during the use of simulations is specifically attuned to the economic information need to base CBA's on, through the explicit incorporation of value of time, value of reliability and demand loss metrics.

Table 27 Mapping of Macro- and Micro-Processes in the design with the functional requirements.

8.3 Execution of Proof of Concept Evaluation

The evaluation of the process design together with the clients encompasses two main elements, namely: 1) the execution of a simulation case study on a shunting yard according to the process design, and 2) the questioning of the clients' opinion on the proposed design. The execution of the proof of concept is described earlier in chapter 7. In the following, the questioning of the interviewees is described.

The proof of concept workshop is organised to gather clients' views on the proposed design with the use of the proof of concept. In addition, in earlier stages of the research two interviews were held with earlier versions of the process design including a demonstration of a simulation study. These were conducted as trial runs for the full proof of concept to improve the process design another iteration. In both evaluation workshops, the qualitative inspection by stakeholders is central. In addition to a comparison to the current state and exploration of (unexpected) detrimental effects of design therefore all form part of this evaluation process. To be precise the proposed solution process design is evaluated using three core areas of elicitation, put forward by Venable (2006) namely:

- In reflection on the proof of concept's potential "usefulness" expressed in terms of effectiveness and efficacy in overcoming the perceived challenges (Checkland and Scholes, 1999).
- In direct comparison to current state processes at both Port of Rotterdam and ProRail.
- In reflection on potential (and perhaps obfuscated or surprising) long-run impacts, for better or worse in supporting capacity management processes.

These guiding questions help stakeholders articulate ideas on the design, which can then be distilled in an overview of evaluative sentiments. The clients, presented in Table 28, responded to the questions by identifying potential strengths and weakness of the design, in addition to potential opportunities and threats that might emerge from the use of the design. The points are condensed from interview transcripts of evaluator meetings and subsequent email exchanges, presented in Appendix B Interviews.

Interviewee	Design Confrontation
Freight Railway Traffic Expert, Port of Rotterdam	Earlier Process Design Presentation
Manager Freight Capacity Planning, ProRail	Earlier Process Design Presentation
Railway and Shipping Traffic Expert, Port of Rotterdam	Proof of Concept Participation
Freight Railway Capacity Expert, ProRail	Proof of Concept Participation

Table 28 List of Interviewees consulted for proof of concept evaluation.

8.4 Main Evaluation Observations

From the both the evaluation through requirement adherence and the evaluative interviews, main observations are distilled. The sections are divided as follows: 8.4.1 Strengths, 8.4.2 Weaknesses, 8.4.3 Threats, and 8.4.4 Opportunities.

8.4.1 Strengths

The strengths of the process design can be summarised through a division of functioning and structure of the design. The current challenges addressed through the design are furthermore coupled vis-à-vis to the identification of strengths.

In functioning, the design delivers well on measurement of system and intervention alternative performance. In the measurement of system performance, it is good that not only average system performance is measured, but also the variability of performance indicators is considered (Appendix B Interviews, mail 26/06). The incorporation of factorial design helps systematise that process. The design further makes a valuable extension to robustness type indicators compared to the ProRail studies. Additionally, the financial-economic perspective is seen as welcome extension as the broadening of the performance indicators that possibly alleviates some of the disagreement regarding the interpretation of study's operational metric outcomes (Appendix B Interviews, mail 26/06; interview 12/06). The proof of concept economic performance analysis elicited the observation that the level of detail helps in the Port of Rotterdam's ambition to reduce on general infrastructure spending and instead more precisely relate investment to specific customers (7.6 Financial Economic Analysis).

The design manages to come a step closer to the root of capacity problems, even in the current case where problems behave dynamically, with uncertainty regarding a) the volumes needed to be dealt with, and b) the location of the bottleneck. The design's functionality in systematic decomposition aides with gathering an understanding of the problem. Compared to the current practise, it allows for a more precise definition of bottleneck locations, which in turn enables designing better interventions, and better choosing of preferred interventions.

The design aides the development of intervention alternatives and alternative's sensitivity to specific configurations. The design therefore gives explicit attention to the effects of interventions in the dynamic, uncertain, volatile railway system. Adding structured reasoning to the process, through framework use, and tests of the design and use patterns of the railway network.

In terms of structure, the design slightly improves the line of reasoning capacity study modelling choices from problem to solution to execution. In the first two proof of concept workshops, the design ensured full traceability of simulation modelling assumptions, compilation of (sets of) alternatives, and alternatives' specific configuration (7.3 Strategic Overview).

The challenges of disagreements faced over inputs such as in the earlier capacity management processes are in first instance addressed by using the simulation model as negotiation, and coordination boundary object. Meaning there is a potential for lessening the disagreement regarding the magnitude and configuration of volume forecasts in the modelling process.

8.4.2 Weaknesses

The perceived weaknesses of the design pertain particularly to the challenge of gathering and analysing the input parameter data, while maintaining credible and valid simulation results.

The gathering and transforming of the input assumptions required for simulation is challenging, in so far that they precisely reflect processes as they occur in the port railway area. Questions arise like: What exactly should be measured and where? How much measurement error is embedded in the measure? What is the cost of measuring? These questions demonstrate the challenge of choosing where and what to measure in a huge technical system like the port railway system.

In turn, the calibration steps in implementing the design are considered a source of risk too. The calibration of the model and attuning it using gathered inputs, running the base case simulation and then comparing it to actual performance outcomes will prove challenging under an unsatisfactory body of data. This is important for two reasons pertaining to validation of the model on the one hand, and the reliability of predictions made on the other. The validity is important for establishing whether the simulation model produces accurate results, which reflect actual railway system performance. The reliability concern reflects the challenge to accurately predict the systems response to proposed interventions. To that end, a comparison needs to be made between the system's and simulation's sensitivity to intervention, which might prove difficult given the low amount of interventions occurring in the port railway area.

With the current working of the tool statistically informed sensitivity analysis is hard to execute. The simulation tool is not able to execute replications of the same experimental design due to a bug. The tool also does not support the derivation of standard deviations across separate simulation runs. Lastly, all statistical testing must be done using export in a separate environment, e.g. Excel.

The interpretation of KPI's is highly dependent on combinations of quantitative metrics. Although the design clusters metrics around categories of indicators, it insufficiently details how specific quantitative metrics within KPI categories should be interpreted in tandem. Furthermore, even at a location specific level detail, the indicators do not provide incontestable insight into where exactly capacity problems arise, and whether problems found are genuine root causes or rather secondary effects of problems elsewhere. Therefore, the effort-intensive, expert-dependent and subjective process of visual inspection of simulation model animations and deep exploration of quantitative metrics across their potential dimensions and scopes remains necessary.

8.4.3 Threats

Political reasoning can pose threats to the successful use of the process design through the temptation of strategic behaviour as a result of distributive effects of capacity interventions. This threat underlines the importance of verifiability of data used as an input for capacity studies. Especially in the case of (subjective) metrics that are retrieved from expert opinion or experience questions arise regarding the auditability and verification of measures. Besides the question of how to proceed with specific disagreement regarding verification issues can be threatening, albeit that is partly incorporated in the design through the hierarchical escalation possibilities.

8.4.4 Opportunities

The opportunity is signalled that working the process provides incentives and insights which help to further improve the process by identifying simulation model improvements, and data gathering opportunities. Currently, there is a broad range of data not yet systematically measured in the port railway area, but opportunities for measurement are not capitalised yet. There might be too much possibilities for data gathering, of which it is unsure what the value is. Thus, when in the process of executing simulation studies, it is discovered that specific pieces of data are of value, because of assumption-building or calibration purposes, this is indicative of a need for data gathering.

8.5 Conclusion of Chapter 8

Evaluations are undertaken to determine whether the designed artefact is potentially operationally dependable in achieving stakeholders' goals, i.e. that the functions in the way it is intended to. Formative evaluation of the design options and preferred design is undertaken in the iterative formulation of the preferred design by both insiders to the process and external experts in process management and transport domains. Summative evaluation is conducted in two ways by evaluating adherence to the stakeholder-derived requirements and through naturalistic proof of concept discussion. The proof of concept is compiled through presentation technical capacity framework, macro-process design and the distilled results from execution of a simulation study for the case of a shunting yard railway area.

The design is found to potentially address part of the experienced coordination challenges and is formulated within requirements posed by the Port of Rotterdam and ProRail. Strengths found include an appreciation of the functioning in terms of performance measurement production, root cause analysis facilitation, and formal testing of alternatives and their sensitivities. Strengths found in the structure of design include the traceability of decision-making and the central role of the 'neutral' simulation model. Weaknesses manifest primarily in the use and controversy of assumptions, and in the consequent ability to validate and calibrate the model to practise situations. That weakness presents the opportunity of directing data gathering activities based on the data pertaining to the most important assumptions and metrics.

9. Discussion

In the previous chapter the designed artefact is evaluated for its success, its usefulness to the clients of this research. This chapter takes a step back to evaluate the design science method employed to arrive at the artefact. This means that findings presented return on the originally identified knowledge gap of how to align organisations in capacity management processes, and the role of capacity management and coordination principles therein. In the context of design science, a threefold distinction is made to comprehensively discuss and reflect upon the research conducted, namely from the perspectives of the domain researcher, empirical researcher and helper (Wieringa, 2014).

The subsequent sections of this chapter therefore discuss the domain-specific academic contribution (section 9.1), the empirical validity of the findings and their limitations (section 9.2), as well as the practical contributions and limitations from the helper perspective (section 9.3). Lastly, the discussion is concluded in section 9.4 Conclusion of Chapter 9.

9.1 Discussion from the Domain Perspective: Contributions to the Interorganisational Capacity Planning Literature

The research makes a twofold contribution to the domain of interorganisational capacity planning. First, through formulation of a proposition of a conceptual design approach for the alignment of interorganisational capacity planning processes, which is discussed in section 9.1.1. Second, through the situated instantiation of the process design discussed in section 9.1.2. They are presented as contributions of this research, because of “the importance of both the contributions made in the form of viable artefacts and the contributions at more abstract levels” in reconciling the design and research problem (Gregor & Hevner, 2013).

9.1.1 Conceptual Design Approach for the Alignment of Interorganisational Capacity Planning Processes

This research presents a process design for an interorganisational capacity planning process that has the potential to improve alignment between the collaborating organisations. The principle-based design method described in this research presents a novel approach to addressing alignment problems in the domain of decision-model supported capacity planning collaboration between networked organisations (2.6 Knowledge Gap and 9.2 Scientific Relevance). The process design is formulated through a design science method, wherein specific coordination challenges are matched to literature-derived principles regarding technical and process managerial coordination of capacity planning processes. Where after, the design is evaluated against stakeholder defined requirements and through discussion of the proof of concept: an executed capacity study using the formulated design.

The design approach presents a more minor contribution towards networked infrastructural capacity planning, because it systematically studies coordination challenges in a specific case with process analysis. networked infrastructural capacity planning is faced with more coordination challenges than market-based or hierarchical governance forms, leading to misalignment with organisations’ internal objectives and their dynamic context. This research presents an overview and analysis of coordination challenges detrimental to the performance of networked coordination in current capacity study processes. The research finds coordination challenges arising from the disagreement around modelling assumptions, disparate use of decision-support models and the interpretation and communications of outcomes using performance indicators.

Another minor contribution lays in the literature review conducted in the context of the design approach provides a state-of-the-art overview of design principles derived from established technical capacity planning and interorganisational process coordination literature, which are validated for use in the application context of this research. Capacity planning processes are for their technical part anchored in the use of railway capacity management performance indicators, a framework for reasoning about the port railway system's capacity dynamics, decision-support tools, and technical coordination principles. These coordination principles stressed the the importance of maintaining and upholding two principles in capacity management process, integrality and optimality. The literature review aimed at coordination theory put forward the idea that coordination processes need to be loosely coupled, and can use decision support models as source of neutral information. Loosely coupled processes mix standardization, planning and mutual adjustment of (decision making) activities, data sharing and metric interpretation.

Limitation in the design approach is related to the non-specificity of design principles found, the degrees of freedom presented in the design search and the subsequent reliance on the specific experience of the designer, the help of stakeholders involved, and grey literature available. The design approach is therefore difficult to reproduce reliably in application to a different occurrence of a similar highly specific design problem. This was even demonstrated in the execution of the design approach in this research, as the relative inexperience of the designer necessitated frequent iterations to recover suboptimal design choices.

Second, limitation is that the general design principles do not cover the complete set of specific coordination challenges. As a result, the use of the design approach does not lead to a complete addressal of misalignment in the interorganisational coordination of capacity planning. It is not clear from the onset of the design effort which challenges will be left unaddressed by the generated process design. The expectations of those involved in the design approach must therefore be carefully managed not to create the insinuation that the process design is a panacea for interorganisational misalignment.

9.1.2 Situated Instantiation of the Process Design

The literature study also pointed out how difficult and limited the specific literature on freight railway management is regarding capacity planning, especially when compared to the passenger railway domain (e.g. Van de Velde *et al.*, 2012). The process design itself presents a contribution to the domain, although on a lower level of abstraction and knowledge maturity than the design approach (Gregor & Hevner, 2013).

The specific railway capacity planning process developed in the research draws together the shared use and understanding of railway capacity management performance indicators, a framework for reasoning about the port railway system's capacity dynamics, and decision-support tools. The capacity planning processes' addressal of each element is structured by the technical coordination principles of integrality and optimality, besides the interorganisational coordination principles of process maturity and loose coupling structure. As such the process design aims to address coordination challenges experienced by the clients.

The process enables the identification of the current and expected performance of capacity, as well as prominent bottlenecks in the infrastructure. In the process intervention effectiveness and their cost-efficiency is evaluated. These goals are captured in a design consisting of four macro-processes: strategic overview, bottleneck analysis, intervention effect analysis, and investment-oriented analysis. The macro-processes are described through their goals, method of simulation configuration, and interpretation of performance indicators.

Limitations to the process design present themselves in the lack of rigorous testing and measuring of a) the effects of the process design on alignment, b) the usability of the design for its clients. Drawing these results would necessitate a longitudinal set-up across multiple case studies (Yin, 2017). Furthermore, the design science approach must then be adjusted to reflect more of the implementation of the artefact, as is done in technical action research (Wieringa, 2014).

9.2 Discussion from the Empirical Perspective: Generalisations and Limitations

The research conducted ventured to validate the use of established principles to overcome coordination challenges in a specific new application domain using a single case study, describing the design problem. From the standpoint of empirical methodology, two challenges are identified in the acceptability and valid generalisation of research findings, namely the nature of single case mechanism research discussed in section 9.2.1 and the mode of evaluation using involved stakeholders discussed in 9.2.2.

9.2.1 Discussion on Single Case Study Methodology

Although only a single case is studied at the present, we believe that the research method underlying the case study conducted further strengthens the external validity of the principles applied, and provides a limited basis for generalising the contributions of this research.

Design science research as executed here constitutes the use of an experimental artefact to further advance the goals of stakeholder while learning about the artefact’s potential effects in situ. The artefact is exploratory, in that it is not yet transferred to the original problem situation. Therefore, the research is not an effect study of the design. Rather, research yields a design approach and subsequent process design that is validated by proof of concept through this study. There are limitations which have to be considered thoroughly in the interpretation of results, but in turn inspire direction for further research.

The case was conducted in the specific Dutch technical and institutional setting with the accordingly attuned interplay between port authority and infrastructure supplier, and railway network dynamics. In other countries, and even in other parts of The Netherlands dynamics may differ due to different technical layouts and specifications, institutional arrangements or decision-making processes. The validation effect from this study on principle-based design, therefore, does not automatically entail the transferability of principles applied here.

Yet principle-based design method and subsequent the process applied to the case study, possibly extend beyond the applicability of the two studied organisations to other organisations that cooperate in a dyadic fashion in a network (as opposed to a hierarchy or market). Although, the case was composed of publicly funded organisations set up as legal private entities, we suspect based on the reviewed literature on networks that the principles uphold in broader application domains. We note here the advanced maturity of the principles used in composing the proposed design.

Despite limitations to the external validity, conservative suggestions for possible generalisations can be made based on the thesis. These generalisations were not tested here, and thus not presented as conclusions to the research but are written up here in the belief that further research might prove fruitful in advancing new application domains. A possible new application domain can be found in private interorganisational capacity coordination processes that are linked through supply networks, yet not through direct contractual relations. Such as those relations that occur among separate suppliers in a single client's supply network looking to improve their capacity planning through the sharing of information without pricing (Pan, 2019). Another example is found in the complementary delivery of (public) transport services. An example here, is the case of a national transport provider collaborating with a local last-mile urban transport provider. If the services are complementary and the organisations do not compete, then networked collaboration would be appropriate (Powel, 2003). In the case of coordination within hierarchies or markets, command and control influenced principles or price-based principles respectively would likely be more in order.

9.2.2 Discussion on Proof of Concept Process Evaluation with Stakeholders

The method of evaluation using a proof of concept in interviewing stakeholders allows for the elicitation of feedback from stakeholders in a tangible way, however the value of this type of evaluation is heavily dependent on the proof of concept's validity as a construct (Yin, 2013; Wieringa, 2014). Section 9.1.2 Situated Instantiation of the Process Design established the limitations regarding the proof of concept's instantiation. This section discusses the contribution and limitations of stakeholder evaluation to the research.

In the onset of the research, there was a different plan for evaluating and iteratively improving the process design presented in this research. The idea was that the researcher would be physically present at the offices of the client while conducting the research and in that process have frequent contact with the stakeholders. Due to consequences related to Covid-19, that plan was adapted to the evaluative method presented currently in the research that includes *ex post* evaluation workshops and interviews. Although it helps the from an empirical perspective as accurate reporting on evaluative feedback is easier in the organised interview setting than documenting feedback arising from small daily discussions. From the helper perspective, the executed evaluation method is less desirable, because it allows for gaps between the expectations and realisations of the design, and a decreased ability to steer the design in a for stakeholder's desirable direction, e.g. including preferred additional activities.

Separating the process design from the specifics of the case study proved difficult in evaluation. Several causes can be named, namely that the research concerns a current topic with some novelty involved, besides the specificity of the proof of concept results apparently conflicting, but rather counterintuitive results drawing attention away from the process design. Another is that the stakeholders involved both specified the challenges faced and participated in the proof of concept, which is a source of potential bias. This is addressed through the evaluation's extension towards non-involved railway experts from both organisations. It can be concluded that there the brief evaluation with stakeholders, whom not regularly deal with process abstraction, yields only limited results regarding the process design. Rather, the incorporation of railway management process experts is more useful to evaluate the process design.

9.3 Discussion from the Helper Perspective: Practical Implications

In the discussion from the perspective of the helper, we discuss the narrow client and broad societal usefulness of the design and interpret it beyond the evaluation alone. We reflect upon how the design methodology and the ability of the design help overcome perceived challenges, but in the process are not panacea. A reflection is made on how the incorporation of broader set of data influences alignment, whether parts of the proposed design open up to (previously not explicitly observed) possibilities of strategic behaviour of organisations in turn causing misalignment and what how the RailGenie model facilitates alignment.

9.3.1 Discussion on the Use of Quantitative Metrics

The proposed design proposes a sets of quantitative performance indicators comprehensively reflect railway system performance. These enable capacity managers partly to overcome the challenge of precisely defining problematic areas in the face of complex railway problems and consequently develop specific solutions.

What was explicitly not researched, and thus does not form part of the design is the way in which indicators should be considered in the language of operations research' rule-based decision-making, e.g. multi-criteria decision-making. This has not been researched for the following three reasons.

First, these decisions are made in mutual adjustment processes that allow for the specificity of demand patterns and configuration of individual subsystems. The actual capacity decision-making focusses on metrics appropriate for the capacity configuration case at hand. To give a narrow example, yard with a small number of tracks will generate more delay at preceding terminals, than a yard with a large number of tracks at the same occupation rate, phenomenon known as erlang loss found in queues with blocking behaviour (Whitt, 1992).

Second, capacity planners find it hard to compare quantitative metrics given that no explicit goals have been formulated for the performance of railway capacity. There is no objective function or likewise for the quantitative metrics and while it is expressed that low occupation rates are desirable; no reference or benchmark is used to evaluate occupation rates.

Third, capacity planners find comparisons among metrics difficult to make when they are at opposite ends of the capacity tradeoffs, e.g. between demand and supply, infrastructure and mode of transport, occupation versus delay, and speed versus time. The importance of mean occupation rates of tracks at yards is bigger at smaller yards than larger yards. It is difficult to weigh the relative importance of metrics across capacity tradeoffs as they differ in units of measurement, relate to a different physical scope (e.g. a single track, or complete yard), different mathematical treatment (means, sums, variation). Therefore, the tradeoffs are considered key helpful perspective in capacity decision-making.

9.3.2 Discussion on the Addition of Financial Metrics

Instead of prescribing normatively how the performance indicators should be used to arrive at decision, we present a discussion that compares operational performance metrics with financial metrics to expose the kind of considerations that can go into evaluating the indicators. These are discussed visa vis for reasons of brevity.

The incorporation of financial economic metrics in the transport planning domain is a common feature and presents advantages compared to operational metrics. First, in that the interpretation is intuitive and natural for horizontal and vertical partners and as such present a tool for communicating about capacity performance. They are better understandable for upper management and customer facing colleagues such as the port’s business developers. Second, these metrics share a common denominator making comparisons easier. This allows for the weighing of effectiveness of interventions compared in a single unit. Unlike operational metrics, which are of various types, e.g. ordinal or categorical, and expressed in different units e.g. time, quantity or percentages. Third, they are natural to the process of capacity management precisely because investment funds themselves are scarce alike infrastructure assets. As such, efficient frontiers exist that searchable for optimal (i.e. cost-effective) bundles of interventions. Fourth, financial metrics feature clear and causal links with established standardised formulae and values. Whereas for operational values it can be difficult to pinpoint how they are derived. Five, although financial economic metrics are unlikely to convey and capture the full dimensionality of capacity performance, they are concise in reporting. They therefore can help capacity managers implement capacity evaluation systems using fewer total number of different metrics than one comprised of only operational metrics. This helps prevent measurement disintegration, the phenomenon where an overabundance of metrics becomes detrimental to the overall measurement process.

The novel inclusion of financial metrics can be a source of risk for misalignment even in the broader context, of a shared capacity framework, and simulation model, and capacity planning process. The research identified 5 disadvantages of financial metrics compared to operational metrics. First, operational data is found to be more closely aligned with strategic decisions in terms of turnaround times and punctuality. Second, while the financial statements propose, operational metrics can take a distinctly longer-term perspective especially in bottleneck analysis where the found time window for urgent action, and subsequent prioritisation inform risk management for years to come. Third, to some extend operational metrics can predict financial performance better. An intervention investment that improves customer operational satisfaction, might not lead to direct economic net benefit, but can indirectly in the long run entice (new) customers to use more train-based freight transport, as well as improve their loyalty through subsequent lock-in. Fourth, operational metrics generally show the effect of operational interventions more clearly with more detail, whereas financial transformation is generally higher-level and additionally dependent on further economic assumptions such as value of time and discount rates. Final, the financial metric does not show the status quo of the division of benefits and burdens across stakeholders in capacity management, nor does it present distributive effects caused by trends and interventions. Risk exists that the financial consequences of trends and intervention become yet another point of discussion impeding successful coordination.

9.3.3 Discussion on the role of Strategic Behaviour in (Mis)Alignment

This work takes the perspective of coordination of collaborating organisations with shared mutual interest under the assumption that no strategic competition for resources takes place as a result of opportunist behaviours. The structure of the transactions of organisations is such that it can lead to the strategic behaviour of opportunism given the fewness of competing organisations in the market, established positions, and information asymmetry.

This thesis builds on the assumption that the cooperation is without the detrimental opportunistic behaviour, as typical characteristics have not been observed, and fitting counter arrangements are in place. Two of the behavioural character typifying opportunistic behaviour in networks according to Ten Heuvelhof et al. (2009) have not been observed in this study, nor in previous studies (see Van der Horst & De Lange, 2008), namely: behaviours aimed at narrow self-interest or behaviours that are of ambiguous nature. Behaviour is strategic when it is aimed at narrow self-interest, given that the organisation is aware it may jeopardise the public interest. Strategic behaviour is ambiguous in that it can be framed in ways open to two interpretations, where in one it does not harm the public interest, and in the second it serves the organisations individual interest while harming the public interest. Both were not observed as part of the current process analysis.

Furthermore, there are counter arrangements currently in place, such as (soft) legal contractual working in the form of memoranda of understanding, independent legal and financial monitoring and control by the supervising ministry as integral part of the decision-making processes regarding infrastructure assets, and comparable technical knowledge of railway systems.

We argue that although the proposed design opens parts of capacity management discussions to strategic behaviour, the design as a whole is more robust to potential strategic behaviour. Arguably, due to the incorporation of financial metrics as part of the larger operational set of metrics overt incentives are introduced that might inspire opportunist behaviour. The organisations involved can more quickly anticipate the results of positions they take. However, as noted before these financial economic metrics are standard practice in Dutch transport infrastructure decision-making; they are not newly introduced here. And any strategic behaviour that follows from it, therefore likely to present already albeit in hidden form, which invokes an information asymmetry among the stakeholders in the port railway area.

Coordination problems dealing with information asymmetry are specifically tackled by the proposed design as multiple information related challenges have been identified and addressed through better decomposition of capacity problems, the broadening the performance measurement base, extending the testing of alternatives and their sensitivities and the use of a shared simulation model as neutral source of information. This reduces the dependence of capacity management process on tacit expert knowledge, experience and subjective judgement. Furthermore, information asymmetry in computing these quantitative metrics is addressed through the decision-support tool change proposed. Whereas earlier the analytical model was solely in use by one of the parties, now a simulation tool is used that is constructed in joint agreement. As a result, the structural factor for strategic behaviour: information asymmetry is lessened overall. This goes even beyond the Port and Prorail relation to extend to broader stakeholders, where more effective communication using financial metrics enables parties to realise mutual gain in the public interest.

9.3.4 Discussion on Decision-Support Tooling

Lastly, the proposition of using the RailGenie meso-simulation model goes beyond the use as a boundary object for addressing asymmetrical information, rather it extends to address problem and solution complex dynamics and uncertainty, and facilitates multi-level perspectives on capacity. Limitations associated with the use of the meso-level simulation model are 1) the process of establishing input parameter assumptions, 2) the approximation of railway and train dynamics, and 3) significance of outcomes.

First, the model is most sensitive to parameters that are hard for clients to measure well. Therefore, the incorporation of methods for the statistical evaluation of sensitivity is needed to conduct sensitivity well. The difficulty associated with the current (lack of) support in the tool constitutes a minor nuisance. First, because model sensitivity for hard to measure parameters is idiosyncratic to many quantitative decision-support tools, and second, because working with the model helps capacity analysts in understanding which input parameters are the most pressing to measure.

Second, in the approximation of the railway and train dynamics of a simulation model lays the core of multi-level analysis, as what goes for the general case does not always go for each specific case, even though the model itself facilitates it. For instance, regarding the shunting yard shunting yard case study, there is a train halving operation that leads to double the amount branch line trains compared to mainline trains for terminal. This special operation is due to specific matching of configuration at the terminal (i.e. short sidings), with the main line train wagons that carry its destined goods (they are too long collectively). The earlier mentioned input parameters are consciously entered by the modeller, and therefore explicitly checked, while those assumption that are model given remain hidden. RailGenie does a good job here in supplying a visualisation that allows for a functional check of the model's workings. What works also is checking explicitly the technical framework and filling in details for each subsystem and their capacity elements. Multi-level capability does not entail multi-level validity, especially regarding those assumption the model user does not set-up, but the technical framework helps to check.

Third, currently, RailGenie does not display statistical information because of which it is difficult to judge whether results are effects or statistical anomalies. This is a limitation, because statistical anomalies do occur, given that often in practice only one simulation run per setup is done, and sample sizes are occasionally not large enough, or sample-heavy tests need to be used because of assumption violation (i.e. use of non-parametric tests that account for heteroscedasticity).

9.4 Conclusion of Chapter 9

This thesis contributes to the interorganisational capacity planning domain, through the validation of a principle-based design process and the subsequent presentation of a process design artefact for improving interorganisational alignment in railway capacity planning. There are limitations to the external validity of the research only describes a single case for establishing the design problem. Nevertheless, possible generalisation is sought in the application of the design approach to other domains that feature collaborative capacity planning efforts by networked organisations using decision-support models. Limitations are also present in the execution and evaluation of the proof of concept, owing to the proof of concept's limited validity as a construct for research, and that stakeholders involved are not regularly designing capacity planning processes. The helper discussion reflects on the effects of choices regarding the process design to improve alignment. Limitations are present regarding the use of metrics, especially economic ones, as well as the decision-support tool used. The research' potential effect on strategic behaviour is found to be partly beneficial and partly detrimental. As findings have been discussed, the following concludes the research.

10. Conclusion

This chapter concludes the research by providing an answer to the main knowledge question (9.1) that has driven the research process. In this process, we subsequently revisit the sub research questions that jointly lead up to the main question. In section 9.2 the scientific relevance of this thesis is summarised. Section 9.3 presents its societal relevance. Last, further work and recommendations are stated in section 9.4.

9.1: Answer to the Main Research Question

How to improve the alignment of collaborating organisations on quantitative metrics for railway freight capacity in the Port of Rotterdam with the use of meso-level decision support models?

This research presents a design for an interorganisational capacity planning process that has the potential to improve alignment between the collaborating organisations in the Port of Rotterdam. The interorganisational capacity planning process improves alignment as it is designed to address specific coordination challenges of collaborating organisations with literature-derived principles for technical and interorganisational capacity planning. The design principles structure the process' addressal of the infrastructure's configuration, KPI's, and the decision-support model towards integrality and optimality in capacity decision-making. Process' activities are designed to be loosely coupled using a meso-level simulation tool as neutral representation of railway system's working in dynamics and performance.

The interorganisational capacity planning process design supports the benchmarking of current and expected performance of capacity, and the identification of prominent bottlenecks in the infrastructure. In the process, intervention effectiveness and cost-efficiency are evaluated. These functions are fulfilled in four distinct macro-processes: strategic overview, bottleneck analysis, intervention effect analysis, and financial economic analysis. The macro-processes are specified through a process flow design, meso-level simulation study set-up, and their use of tailored quantitative metrics.

The principle-based design method used presents a novel approach to addressing alignment problems in the domain of decision-model supported capacity planning collaboration between networked organisations.

9.1.1 *Around which principles should technical railway systems capacity planning be organised?*

Capacity planning processes are for their technical part anchored in the use of railway capacity management performance indicators, a framework for reasoning about the port railway system's capacity dynamics, decision-support tools. The technical capacity coordination principles of integrality and optimality structure capacity planning processes' addressal of each element.

Integrality demands integral planning on railway system level from terminal to the hinterland as a whole and considers the complex effects of interdepencies, e.g. possible network cascading. Optimality comprises the ideal of optimising of decisions through unambiguous definitions of performance criteria, and use of rigorous iterative improvement methods, and root cause analysis. Simulation models can support decision-making as complexity derived from stochasticity and feedback loops are captured in broad scope, multi-level quantitative performance indicators, as opposed to analytical methods.

9.1.2 *How to design the alignment of interorganisational capacity planning activities?*

In their railway capacity planning activities, the Port of Rotterdam and ProRail are networked collaborators meaning that both parties must coordinate dependencies among their activities through loose coupling in the absence of hierarchy or competition. The looseness is given by presence of structured discussion and interpretation in the process. The coupling is made primarily through the joint use of a simulation model which acts as boundary object, an uncontroversial source of data on the performance of the railway system. Lastly, as coordination takes place in process form, CMMI guidelines for the effectiveness and efficiency of process are also taken as principles.

9.1.3 *How are current capacity planning processes at the different stakeholders defined and aligned?*

The current capacity management processes at the Port of Rotterdam and ProRail are fraught with challenges that renders them misaligned, as occurs in the analysed case study at a shunting yard. Disagreement exists between the two parties on the data inputs configuration, capacity study methods and tools and railway system performance outputs and their interpretation. There are seven challenges that need to be overcome in process of designing capacity management processes which align ProRail and the Port of Rotterdam.

1. The problem behaves dynamically in that uncertainty exists regarding a) the volumes that the infrastructure should be capable of dealing with, and b) where the bottleneck element or sub-system is;
2. The effects of interventions as proposed solutions are dynamic, uncertain, volatile: a lack of reasoning regarding structure versus dynamics in the design and use of the railway network;
3. Disagreement regarding the volume forecasts used;
4. Disagreement regarding the configuration of volume forecasts in the modelling process;
5. Disagreement regarding the interpretation of study's operational metric outcomes;
6. Lack of opportunity for hierarchical escalation in decision-making, which slows the process;
7. Experienced difficulty in follow-up in subsequent capacity decision-making processes.

These challenges have been identified through flowchart-driven process analysis. The process analysis delves into micro-level capacity management processes at the Port of Rotterdam and ProRail and details how organisations proceed individually, where in their processes they meet, and to what ends.

9.1.4: *What requirements are set for simulation-guided collaboration in capacity planning?*

For the process design a list of functional and non-functional requirements has been drawn up. The functional requirements engineering was done by from an analysis including interviews with the Port of Rotterdam and ProRail, besides the current state analysis and literature review. 4 high-level functional requirements that emerged are:

1. The process must result in capacity planning decisions;
2. Must give insight in the urgency or time window within which capacity interventions;
3. Must involve Port of Rotterdam Network Planning, ProRail Capacity Management, and ProRail Railway Traffic Control;
4. Must rely on accessible, available data and tools.

These high-level requirements are further specified to the level that they control flows of activities and information in the designed process. The non-functional requirements were gotten from CMMI requirements specification, which control the general quality of the process design.

9.1.5: ***What does the improved collaborative capacity planning process look like?***

The proposed design defines four distinct macro-processes, Strategic Overview, Bottleneck Analysis, Intervention Analysis, and Financial Economic Analysis. The macro-processes are the result of matching challenges with technical and interorganisational coordination process principles, and supported by performance indicators, decision support model use, and the capacity framework.

Strategic overview process serves to monitor the systems general ability handle transport demand in the face of economic and technical long-term trends and is scoped at the level of the railway system. The process constructs a railway system-wide benchmark reflecting current and future capacity performance. Scenarios describe the current and future configuration of the infrastructure using the capacity framework. These scenarios are converted to assumptions for simulation configuration. In interpretation of the indicators comparisons across subsystems are drawn to identify malperforming ones.

The goal of bottleneck analysis is twofold, namely, to identify and locate bottlenecks, as well as determining establishing the level of urgency associated with fixing the bottleneck. The analysis is scoped towards problematic subsystems showing high occupation rates and associated delay times. Artificial train volume scenarios are constructed, which probe subsystem's robustness by progressively increasing volumes until a subsystem can no longer cope, and causes irrecuperable delay revealing the bottleneck.

The goal of intervention effect analysis is to gauge the effectivity & efficiency of possible interventions or solution directions. The analysis is scoped such that it contains the observed bottleneck and subsystems affected by it. Using the capacity framework intervention scenarios are drawn up. The intervention effect analysis uses rigorous factorial experiment design to test the intervention's effects and their sensitivity.

Financial economic analysis focuses on the use economic capacity expressed in financial metrics to communication to stakeholders, delineate cost-effectiveness, and stimulate actionable decision-making. It is designed as an addition in this regard to the operational metric-oriented processes.

9.1.6: ***How is the proposed coordinated capacity planning process evaluated?***

The process' potential for use to improve alignment is evaluated based on stakeholder-derived requirements and a proof of concept. The design is found to address part of the coordination challenges within process requirements posed by the Port of Rotterdam and ProRail. Strengths found include the functioning in terms of performance measurement production, root cause analysis facilitation, and testing of alternatives. Strengths found in the structure of design including the traceability of decision-making and the central role of the 'neutral' simulation model. Weaknesses manifest primarily in the use of assumptions, and the subsequent inability to validate and calibrate the model to the situation in practice. That weakness presents the opportunity of directing data gathering activities based on the data pertaining to the most important assumptions and metrics.

9.2 Scientific Relevance

This thesis proposes a process design artefact for improving interorganisational alignment in railway capacity planning. The conceptual design process leading to the artefact is formulated to address knowledge gaps present regarding the challenges in the networked governance of infrastructure, the design of decision-support model mediated public governance processes, and the application of coordination principles to interorganisational transport planning processes. The research describes the design of a conceptual process, wherein mature principles from the hierarchical planning and control literature are transformed and applied to the novel application domain of networked interorganisational planning processes as an exaptation design scientific contribution (Gregor & Hevner, 2013).

Networked infrastructural governance is faced with more coordination challenges than market-based or hierarchical governance forms, leading to misalignment with organisations' internal objectives and their dynamic context (Klijn & Koppenjan, 2016). Roehring *et al.* (2019) find that most interorganisational planning research focusses on markets and hierarchical settings and suggest deeper analysis of the causes of coordination challenges present in networked planning. This research presents an overview and analysis of coordination challenges detrimental to the performance of networked coordination in current capacity study processes. The research finds coordination challenges arising from the disagreement around modelling assumptions, disparate use of decision-support models and the interpretation and communications of outcomes using performance indicators.

The use of principles to design better performing coordination processes is a well-established practice, however the literature lacks findings on the potential of principle-based process design for interorganisational coordination processes facilitated by decision-support models (Trang *et al.*, 2013). Ferrel *et al.* (2019) explain that the transport planning domain mostly applies design principles for coordination processes where highly specific system elements are concerned, e.g pricing or route scheduling. Future research should thus focus on applying coordination principles to integrated interorganisational coordination processes at the overarching system level (Ferrel *et al.*, 2019; Pan *et al.*, 2019). This research' design effort firstly builds on the maturity of coordination principles derived from the planning and control literature as guides for design through their matching with observed challenges. Secondly, the design is evaluated in the novel application domain of system-level alignment in railway transport planning processes. The research therefore provides insight into the effect of transforming principles into a design for a novel application context.

All in all, the researched derives its main scientific relevance from the proposition of a conceptual design process for the improvement of alignment in interorganisational coordination in decision-model supported capacity planning. The design method structures the integration of detailed knowledge of coordination challenges in networked infrastructural governance, a transformation of mature coordination principles into a process design and evaluation of the artefact in the novel application domain.

9.3 Societal Relevance

The core design problem addressed by in the thesis is that the Port of Rotterdam and Prorail find interorganisational capacity studies are currently conducted ad hoc in lengthy processes, in which there is disagreement about inputs, methods, and outputs, which renders them misaligned. Problems and their solutions behave dynamically causing uncertainty regarding cause and effect. There is disagreement regarding magnitude and configuration of volume forecasts used, and the subsequent interpretation of study's operational metric outcomes. Lastly, the process is slowed by a lack of opportunity for hierarchical escalation in decision-making, and experienced difficulty in the follow-up in subsequent processes.

The specific railway capacity planning process developed in the research draws together the shared use and understanding of railway capacity management performance indicators, a framework on port railway system's capacity dynamics, and decision-support tools. The capacity planning processes' addressal of each element is structured by the technical coordination principles of integrality and optimality. The interorganisational coordination principles of process maturity and loose coupling structure address process' performance and place the simulation model as boundary object conducive to collaboration. As such the process design aims to address coordination challenges experienced by the clients.

In functioning, the design delivers well on measurement of system and intervention alternative performance. The KPI measurement method covered in the design provides improvement in the measurement of variability of performance indicators, and the statistical testing of effects and sensitivities. The designed use of the capacity framework aides the development of intervention alternatives and alternative's sensitivity to specific configurations. Besides making the valuable extension to robustness indicators. Additionally, the financial-economic perspective is helpful in the broadening the set of performance indicators to alleviate disagreement regarding the interpretation of study's operational metric outcomes, and in the communication to higher-ups and towards non-expert colleagues and as representation of financial capacity.

The design's functionality in systematic decomposition aides with gathering an understanding of the problem. The design presents a step towards root case analysis of capacity problems. The design traces the rationale of capacity study choices fluently from problem to solution to decision-making processes. The challenges of disagreements faced over inputs such as in the earlier capacity management processes are partially addressed through the simulation model as negotiation, and coordination boundary object.

9.4 Further Work and Recommendations

Findings and limitations resulting from this thesis invite future work. Three opportunities for future research are expanded upon, and a main recommendation is suggested.

Limitations to the generalisability of the case study's findings provides opportunities for future research. Establishing a broader case study base strengthens the external validity of the research endeavour. These efforts can be made effective when conducted in adjacent research environments. The first promising environment is found in port railway capacity processes occurring in different locations or even nations. Case studies conducted in other port areas allow for direct comparison with this research, and can be used to come to greater depth and understanding regarding antecedents of misalignment, the effects of process design, and include topics not studied here, such as the roles of trust and contracts.

A second opportunity for future research environment is present in other interorganisational networked collaboration processes found in the transport or supply network setting. For example, in the public transport capacity domain where complementary transport providers collaborate to deliver high quality transport services, as is the case in cooperation between long haul public transport and last mile transport services (Pan et al., 2019). In keeping this analogic generalisation valid, coordinating organisations should be sought such that they remain close to those studied here, in terms including but not limited to networked collaboration, scope and scale of joint capacity planning and decision-support model use.

The third opportunity for future research lays in a design science approach that cover more extensively of the later design stages of demonstration and evaluation, particularly the implementation side. In this research it was found that all efforts of executing the process design with stakeholders sharpened the design in ways that increased both the scientific value and societal value of the work. Technical action research is suited for this purpose Wieringa, 2014).

The first recommendation pertains to the scope of this research aimed primarily at intervention into capacity as a configuration of infrastructural assets under management of the Port of Rotterdam and ProRail. The demand side planning and control aspects of railway capacity present a direction in which to improve capacity processes. In this research, simple demand side capacity interventions are addressed and mentioned, but the scheduling and controlling actions of traffic controllers on the tactical and operational level have been interpreted as emergent distributions owing to the set-up of the simulation model. Given that trains follow a specific and rather predictable path on the railway system, in theory, the schedule can be optimised in minimizing delay for example by adjustments to these scheduling decisions and control rules. Modern scheduling procedures that focus on delay management can inform for example control the movements to and from terminals by rule-based procedures. Pricing mechanisms can serve in enforcing these schedules. That would present opportunities for e.g. peak shaving interventions.

The second recommendation follows from the weaknesses and threats emerging from evaluation and discussion on the data foundation for the simulation model. Both the Port of Rotterdam and ProRail concern over the use the weaknesses perceived in validated model use as integral and corner stone part of capacity decision-making. Continued work on improving the data foundation is highly recommended. On the one hand, the assumptions made to setup the simulation studies need to become sufficiently anchored through realisation data. On the other hand, the measurement of KPI's in the port railway area is key because it can help tuning the simulation model and help capacity managers to develop normative views on operational performance of the port railway capacity.

9.5 Academic Reflection

The academic reflection presents a personal reflection upon the research process and draws lessons from the experience.

First, the research process was complicated by the complexity arising from the broad stakeholder base. Complexity arose from the (conflicting) interests of parties involved, the managing of expectations regarding the research' products, and inexperience of working with large numbers of stakeholders. The, at times, conflicting interests of stakeholders, led to tensions. The point of learning is that communicating early and clearly about the inability to incorporate all expectations, interests into the work is crucial for the research process later. It is worth the time and effort to demarcate the possibilities and priorities through discussion, such that disappointment or quality concerns later can be prevented.

Second, the thesis deals with the current challenging topic of interorganisational capacity planning at a conceptual level that has not been addressed extensively in either academic or grey literature. In that regard, the level of ambition of the research scope to design and proof of concept a novel process was too high in hindsight. An example of warranted scope reduction pertains to the incorporation of financial economic perspectives, that although integral part of capacity planning, added to much complexity to the design in terms of novelty in the process, absence in the simulation tool, and introduction of possible strategic behavioural issues. Here, staying closer to the current processes would have made the research effort more manageable, and the more closely scoped content of higher quality.

Third, the research process was intense, but gratifying in terms of personal learning. In conducting this research, I learned primarily about the complexity of managing stakeholders, process managerial and technical workings of railway systems capacity, and strengthened my insights in how to employ quantitative information for decision-making.

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12. Appendix A Stakeholder Analysis

A stakeholder analysis is conducted, and a brief overview of the most important outcomes is presented below. The purpose of use lays mainly in the identification of goals and thus the interest of stakeholders involved in capacity management in the port railway area. Main insight is that stakeholders' interest in differ not much in their goals for the port railway area in general, but more nuanced in how much of their resources they intend to dedicate towards advancing these goals.

Stakeholder	Goal	Needs	Main activities	Resources
Port of Rotterdam (Havenbedrijf Rotterdam N.V.)	High utility assignment through smart applications to further enhance the customer experience for its customers. It is aimed to increase the safety and efficiency for the port throughout, with high transshipment efficiency.	High data processing power, high sensor readings input, manageable and well-arranged overview in a portal.	Provide services for the handling of freight, facilitate growth to remain leading.	Infrastructure, knowledge and expertise, financing.
ProRail	Develop and manage the public roads, waterways and waters of the Netherlands,and ensure a sustainable living environment.	Support from Ministry of infrastructure and water ways. High performing digital infrastructure funding.	Monitoring of traffic, infrastructure and foundations. Creating policy measures and facilitating the design of new infrastructures.	Legislative powers, financing, policy measures, partner companies.
Municipality of Rotterdam	Ensure financial stability through/for Port of Rotterdam, ensure accessibility of entire municipality including Port of Rotterdam, create sustainable policies.	Clear policy Cooperation among companies and citizens. Public support. High performing digital infrastructure.	Create policy measures to achieve goals. Ensure social stability and safety.	Legislative powers, financing, policy measures, partner companies.
Ministry of Infrastructure and Waterways	Liveable and accessible Netherlands with a smooth flow of traffic in a well-designed clean and safe environment.	Support from Parliament Well informed by Port of Rotterdam & ProRail as stakeholder.	Monitoring. Guaranteeing the public interest.	Policy measures, shareholder influence.
Transshipment Terminals	Maximizing profit through Efficient operations, i.e. maximum capacity utilization	Detailed information on external effects (delays etc.), detailed information on internal processes (on-offloading times), clear working schedule, on time partners Clientèle.	Transporting freight, transshipping freight from deepsea vessels to other modes of transport.	Investments. Directing activities. Port of Rotterdam road infrastructure, docks, freight handling infrastructure, shipping information, freight manifests.
Shipping companies	Maximizing profit through ease of operations, clear assignment of location and time slots, flexibility.	Clear insights in required operations, planning details and operating instructions.	Operating ships for freight transportation.	Usage of Port of Rotterdam Infrastructure, transport mode.
Rail Freight Transport Companies	Maximizing profit through ease of operations, clear assignment of location and time slots, flexibility.	Clear insights in required operations, planning details and operating instructions.	Operating trains for freight transportation.	Usage of Port of Rotterdam Infrastructure, transport mode, internet connected devices.
Customs	Enforcing Dutch and international laws regarding the import, transit and export of goods.	Clear insights in throughput of freight.	Declaring goods that enter or exit the port. Scanning for possible trade of illegal goods.	Scanning facilities, freight manifests, investigative powers

Table 29 Stakeholder description (after Remijn et al., 2019).

13. Appendix B Interviews

Over the course of the thesis, several interviews were held for the purposes of understanding the capacity management processes, port railway system dynamics and evaluation. The interviews are anonymised, and interviewees are merely identified through their employer organisation.

Interview Prorail 18/02: Freight Railway Capacity Experts (2)
Topic for discussion was the process ProRail uses for measuring the capacity usage on rail yards, such as those in the shunting yard area. The operationalised definition of the capacity is the occupancy hours of the tracks in the yard. Building upon this operationalised definition of capacity is the notion that capacity is overburdened when all tracks in the yard are occupied for more than 80% of the time in the timespan of an hour. The threshold for capacity expanding intervention is when capacity is overburdened for more than 16 hours in the span of a month.

An Excel tool is used to find the minimum amount of tracks required in a rail yard, without overburdening the available hourly capacity for more than 16 times per month. This tool uses a list of realised discrete railyard events (i.e. entries and exits of the yard) as its source data. This data is acquired to an internal railway traffic monitoring database for those tracks and parts of the yard that are electric and guarded. The occupancy of each track per event is accounted for. Which makes it possible to infer occupancy durations of tracks.

The capacity studies are forward looking in nature to anticipate growing demand placed on the infrastructure at points in the future based on forecasts. Prorail aligns with the freight forecasts made by the Dutch economic planning bureaus. From these forecasts growth forecasts emerge following formula$\frac{Forecasted\ number\ of\ trains}{Currently\ realised\ number\ of\ trains} = Growth\ Factor$**.** The added number of trains is assigned to the tracks using an inhouse method of Prorail, to end up with a list of discrete movement events for the future case scenario.

Additionally, stemlines to and from specific destinations in the vicinity of the shunting yard are analysed by looking at the daily traffic over each individual line. The traffic is based on reports done by the terminals that send freight trains over the stem lines. Capacity is here defined as the ability of the stemlines to process the traffic within time bounds set by operating hours of terminals and railway freight operators.

Interview Port of Rotterdam 19/02: Freight Railway Traffic Expert
Dynamic view on capacity management
In the past capacity studies were done in a reactive manner based on signals coming out of the operational managementof the port railway infrastructure, which was due to historical reasons, e.g. “we’ve always done it this way” and lack of tools able to cater more advanced demands. From now on out, aim is to take proactive steering approach that takes into consideration tactical/strategic concern on capacity management. This entails simulating future scenarios for railroad freight transport, so that problems can be solved using structured and repeatable processes in time.

Tooling is important in realising that desired capacity management methodology. The tooling should be able to address major capacity elements such as those addressed in the table below wherein a small comparison between Excel and simulation tools are made.

	Physical Elements	Operating Strategies
Transport Infrastructure	Statically addressable in Excel. Dynamically addressable through simulation	Logistic Parameters in both Excel and simulation tools. Important to understand the desired traffic control strategies.
Mode of Transport	Basics difficult to do in Excel, perhaps addressed in modelling assumptions made. Exhaustively possible in simulation studies, both realistic representation and variants. Even special variants can be studied, e.g. hybrid locomotives.	Not part of the Excel method. Possible but still complex e.g. behaviour of shunting vehicles. Deemed less relevant.

Decision power is important in capacity management
Conducting capacity studies sometimes leads to results that have a call to action, because they signal capacity bottlenecks, potential improvement areas or other opportunities and threats that need resolvement. Sometimes this resolvement transcends the possibilities given in the agreements signed with ProRail. At these times, it is highly desirable that a clear ‘chain of command’ is visible, as the capacity studies success falls or stands with the follow-up after it. Therefore, a organisations working together should organise escalation options within their hierarchy to be able responds adequate to capacity interventions and prevent endless researching/writing from delaying intervention.

A moment where decision power and clear process agreements are especially necessary is when deciding upon the logistic parameters, i.e. the assumption necessary for running the simulation. A good way of ensuring the traceability and reliability of estimates is through the use of expert sessions. Certainly, if parties commit to the composition of the expert panel and their judgement upfront, this can ensure higher quality of the capacity study.

Interview Port of Rotterdam 21/02: Railway Infrastructure Expert

Capacity dynamics of railway track, rail yards, stem lines and terminal tracks

When freight trains move to or from terminals they pass to types of railway tracks that differ in ability to handle different volume of trains, speeds and propulsion types. On the one hand, the main port railway lines support high volumes of trains, at speeds of ~80km/h which are electrically propelled where the central traffic control allocates and controls railway freight traffic, on the other hand stem lines and terminal lines are non-electrified, non-monitored tracks, which operate at speeds of at most 40 km/h. The difference for the existence of these different rail types is mainly given in by economic considerations, e.g. costs, and path dependency.

In order for trains to go from the one subsystem to another, not only should locomotives be changed from electric to diesel powered or vice versa. Also several activities have to executed according to ProRail procedures, which includes braking tests, wagon tests, stickering for dangerous cargo, checking wagon lists.

Problem is that in terms of capacity these networked infrastructures are communicating vessels and can become a bottleneck for each other in case one is disrupted, delayed or blocked. In rail yards one of the reasons for long occupation is because of the list of activities train operators have to conclude before being able to proceed to their destinations. On the stem lines capacity can be ‘blocked’ or reserved for an extended period of time due to time-space slots being allocated for a trains’ drive to a terminal, its handling at the terminal terrain, and its subsequent travel back to the railway yard for locomotive exchange. Both issues lead to situations where trains are (unnecessary) waiting for each other, or worse face delay and reschedulements in order to alleviate overburdened capacity at yards or stem lines. Currently (operational) traffic control and (tactical) capacity planning have difficulty to control the movement of relocating ‘empty’ locomotives across the port railway system. As each railway operator operates their own locomotives, it can happen that relocation across the port area of specific locomotive types is necessary, even though an unused locomotive is available from the competitor. This leads to redundant transport movements.

The solution space for these problems is demarcated by the options to improve operational monitoring and control of the traffic along the yards and stem lines, to enable the time space slots to decrease in size. Additionally, trains headed in the same direction could share their time space window by following each other down the stem line. Both options would open up a lot of the occupied, but unused capacity reserves in the network. Another solution direction can be found in the direction of hybrid locomotives that can take over the cargo at e.g. shunting yards such as those found upstream at Kijfhoek. This would eliminate the need for exchanges at subsequent yards in the port railway system. Another is the creation of a pool of locomotives that can be shared by the different railway operators in the port area

Interview ProRail 31/03: Freight Railway Capacity Expert

Feedback discussion based upon earlier variant of the current state analysis. The feedback touched upon three process aspects, namely exact sequentiality, data gathering and tool use. As a result, the process was adapted to include reference to the NEMO and InfraMonitor software tools, and scope decision-making activities.

Mail ProRail 20/04: Manager Freight Capacity Planning

The connection with investment management is usually via an SCBA. We look at the social costs and benefits of measures, but also at the impact of the measures on ProRail's KPIs. In the case of capacity bottlenecks, the Social Benefit is usually calculated by multiplying the reduction in the number of train delay hours by the Value of Time (for freight trains approximately € 3,000 per train hour). In addition, the Modal Shift can also contribute to social benefits.

ProRail Traffic Control often takes care of the delivery of realisation data. They are also involved in generating and evaluating (process) measures for the capacity bottlenecks found.

The VoT for goods trains is shown in table 3.7 of the report. The VoT is € 1,270 per train per hour (TR=0.46). The VoT grows from €1,270 to € 2,761 over a period of 10 years (=1,270 / 0.46). If you still correct this to price level 2020, you are around € 3,000 per train per hour. However, it is often assumed that part of these benefits will leak abroad. The SCBA Calandbrug assumes 50%.

Reliability (VoR) can also be taken into account, but experience shows that the benefits of reliability are often much lower than the benefits of travel time.

The predicted size of the modal/port shift is difficult to determine. For the MKBA Caland Bridge, Ecorys' Container Port Competition Model was used.

In one of our own calculation tools I recently came across the following calculation rule: 10% drop in demand for every 12 minutes extra travel time. However, I don't know what the source of this is.

Interview Port of Rotterdam 13/05: Railway and Shipping Traffic Expert

Urgency of interventions more important than economic feasibility from the perspective of the Port of Rotterdam. Urgency of intervention denotes the idea of ranking the sub-systems (shunting yards, terminals), where the bottleneck is such that it leads to unrecoverable delays at various sites in the Port Railway Area. The objective of capacity management should be to compile a ranked list that denotes in what sequence and when (at the latest) which sub-system is in need of capacity interventions. Example being in say 5 years, 5 years after that and a shunting yard again 5 years thereafter. (Times given being an example only in this case).

Interview Port of Rotterdam 12/06: Freight Railway Traffic Expert

In reflection on the proof of concept’s “usefulness” expressed in terms of effectiveness and efficacy in overcoming the perceived challenges.

The functioning of the prototype covers:
- Not only (average) performance, but also robustness in the face of growing demand forecasts.
- The development of alternatives and alternative's sensitivity to specific configurations.

In terms of structure the proposed design delivers well on:
- Traceability of study design, and subsequent decision-making
- Actionable by design
- Coupling with business development functions
- Using the simulation model as tool for negotiating capacity

Direct comparison to current state processes at both Port of Rotterdam and ProRail.
- Easier to interpret outcomes, thus reducing the need for 'outside' knowledge to interpret performance.
- Less error prone, because of reduced sensitivity to single parameter inputs, as it is based on a broader set.

In reflection on potential (and perhaps obfuscated or surprising) long-run impacts, for better or worse in supporting capacity management processes.
- Still heavily reliant on quality of input for quality output, while it is difficult to achieve high quality data collection.
- Calibration will prove challenging too, for the same reasons.

Mail Communications ProRail 26/06- 30/06: Manager Freight Capacity Planning

The process shows potential for usability. The high-level nature leaves questions to be answered.
- The design is broadly scoped allowing for comparisons, but how do we measure sensitivity to scoping and scenario decisions. The statistical evaluation is a nice first step towards answering this question.
- Root cause analysis is critical for the development of effective interventions. The design presents a step towards more detail yet leaves uncertainty. How can we pinpoint a bottleneck with certainty?
- The calculation of economic loss is welcome addition. But questions remain on the validity of the simulation model for this purpose’s use.

14. Appendix C Design Options

The design search process draws from the sources previously analysed as part of the academic and professional literature research and expert interviews conducted. As a consequence, of these research activities a function-means matrix can be drawn up, which includes a subset of the available options for designing capacity management processes. In its role as facilitating product for design, it helps materialise the matching of the challenges and principles in the design search process. The design options are presented in Table 30.

Functions	**Means**			
Starting Trigger	Needs-Based	Cyclical (revisit periodically)	Exploratory	
Scope determination				
Goal	Overview	Bottleneck Analysis	Effect-sizing	Go/no-go decisions
Physical Infrastructure Scope	Emergent	Global	Sub-systems isolated	Ranked on vulnerability through exploratory search
Data input				
Scope Volumes	Base year	Forecasts	Backcast	Hybrid (forecast/backcast)
Periferal Volumes	Base year	Forecasts	Backcast	Hybrid
Scope Process Times	Base year	Forecasts	Backcast	Hybrid
Periferal Process Times	Base year	Forecasts	Backcast	Hybrid
Map	Base year	Forecasts	Backcast	
Terminal Locations	Base year	Forecasts		
Process Times	Base year	Forecasts	Backcast	
Output				
Orientation	Operational Result Oriented	Financial Economic Result Oriented	Vulnerability Oriented (Tipping Point)	Sensitivity Oriented (Pareto-Rule)
Metrics	Turn Around Times Delay times Variation in delays Occupancy Rate No. of delayed trains	Costs Capital expenditure Operational expenditure Economic Benefits Value of Time Value of Reliability	Occupancy Rates (~100%) Volumes used	Target Metric Effect versus Intervention Experiment

Table 30 Overview design options used in iteratively constructing design alternatives.

15. Appendix D Simulation Model Assumptions Operationalisation

In going from the conceptual process design to the execution of a simulation study operationalisation steps must be taken. Before the simulation runs can be executed, simulation parameter assumptions need to be decided.

This can be done with a combination of the scoping decisions in the macro-process design, and a mapping of changes in the technical capacity framework per macro-process using Table 31. Where an **x** is specified that a simulation dataset has to be altered to accurately reflect the alteration of the simulated system, whereas **(x)** signifies that a check has to be conducted to ensure datasets remain valid for use. This information can be used to search the connecting table for technical capacity framework and simulation parameters, which is an extension of earlier work done, see (Diekman et al., 2017). The work was conducted in Dutch and based on a narrower application base and is thus expanded to match the framework.

		Volume adjustments for existing terminals				Changing Terminal Characteristics			Changing Yard Characteristics	Changing Train Characteristics				Change in Routing			Changing Main Line Characteristics					Adding Trains		Model Variability			New Goods Types	
		Changing forecast scenario	Changing forecast target year	Change in volume for specific demand source	Change allocation of volumes at existing terminals	Changing the distribution of train types received	Changing the process times at the terminal	New traintype received	Changing the process time of specific train instances	New locomotive type	New wagon type	Changing the number of wagons per train	Changing wagon load factor	Maintenance work blocking tracks	New choice of routing operating strategy	Cluster preference adjustment at a shunting yard	Main line addition of new track or infrastructural work	Addition of a Railterminal	Addition of a new shunting yard	Addition of a new bundle to a terminal or yard	Additional counting point of arrivals	Additional train movement without transfer of goods	As a consequence of hinterland loads	Adding stochasticity to process times at terminals and shunting yards	Peak shaving	Change of schedules	New goods type at an existing terminal	New goods type that will transported over rail
Train Volumes	Volumes	x	x	x	x													x				x	x				x	x
	Profit Center to Terminal Allocation	(x)	(x)		x													x				x	x					x
	Direction Distributions																											x
	Load Factor																											x
	Train Instance Distribution	(x)	(x)										x					x				x	x				x	x
	Train Type Distribution					x		x			x							x				x	x					x
	Monthly Distribution																								x			
	Weakly Distribution																								x			
	Daily Distribution																								x			
	Train Schedules	(x)	(x)					x			x	x						x				x	x		x	x	x	x
Trains	Locomotives									x																		
	Wagons										x																x	x
	Train Instances									x	x	x										x					x	x
	Train Types							x										x										
	Train Groups	(x)	(x)					x			x	x						x				x	x				x	x
	Location Activities							x																				
Unit Cargo	Unit Cargo Trains	(x)	(x)					(x)	(x)						(x)													
	Unit Cargo Volumes							(x)																				
Port Shuttle	Port Shuttle	(x)	(x)					(x)																				
	Daily Schedules							(x)																				
Goods	Goods Types																					x					x	x
	Terminal Goods	(x)	(x)		(x)													x				x	x				x	x
Infrastructure	Maps														(x)		x	x	x	x	x							x
	Parking Locations																	x	x									
	Route Attributes														x		(x)		(x)	(x)								
	Pathway Attributes													x			(x)			(x)								
	Routes and Pathways Editor							x						x	x		x	x	x	x								
	Cluster Preference List															x		(x)	(x)	x		x	x					x
	Branch Lines																											(x)
	Counting Points																											
	Process Times						x	x	x		x	x												x	(x)			
Simulation	Volumes to Train Algorithm	x	x	x	x	x		x		x	x	x	x					x				x	x		x	x	x	x
	Generate Train Volume Table	x	x	x	x	x		x		x	x	x	x	x	x	x	x	x	x	x		x	x		x	x	x	x
	Train Volume Table	x	x	x	x	x		x		x	x	x	x	x	x	x	x	x	x	x		x	x		x	x	x	x
	Run Simulation	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Results	KPI Results Compilation	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Table 31 Connection technical capacity framework and RailGenie simulation set-up.

16. Appendix E Performance Indicator Definitions

The performance indicators used throughout the document are fully described here. Furthermore, the indicators are also operationalised using quantitative metrics, which are defined more precisely here. To this end, first the indicators, their rationale and source are described. Second, indicators are matched with quantitative metrics to approximate them in the context of the decision-support tool.

Table 32 specifies the indicators used in the research and design process. Then the performance indicators for infrastructure performance are presented in Table 33 List of infrastructure performance indicators, their operationalisation, and definitions. After which Table 34 List of rolling stock performance indicators, their operationalisation, and definitions. Concluding with Table 35 List of financial economic performance indicators, their operationalisation, and definitions.

Indicator	**Conceptualisation**	**Rationale and Source**
Scale	Scale is the magnitude of volumes and trains transported over the railway system	Knowledge of the scale of the demand for capacity adds context to the other capacity performance metrics and allows for comparison across subsystems (2.2.2 Demand Patterns; Versteegt, 2004).
Feasibility	Feasibility denotes the achievability of handling freight transport volumes as expressed in the realised capacity occupation rate which results from train dynamics in the railway system.	Feasibility reflect the degree in which infrastructure is able process the scale of demand (Goverde & Hansen, 2013). When the scale of demand becomes too high, occupation rates increase, and are
Stability	Stability is the ability of the infrastructure to contain the primary delays accrued by trains while they're waiting for reserved and occupied (moving) block sections and sidings.	Stability is the contrast to the feasibility, in that feasibility of occupation rates at adjacent subsystems are a cause for the loss of stability in a subsystem (Goverde & Hansen, 2013). In the language of queueing models, it reflects the waiting time (Delorme *et al.*, 2008; Kroon, 2001).
Robustness	Robustness of the infrastructure is determined through its ability to withstand external influences, especially increases in traffic volume. This is expressed by means of its tipping point volume, the amount of trains before delays accrued can no longer recuperate.	The robustness of infrastructure informs capacity managers of the capacity performance as a function of external developments, and therefore contrasts with the feasibility and stability metric which are internally oriented (Kroon, 2001; Goverde & Hansen, 2013).
Urgency	Urgency is the expected time period before intervention is inevitable into the infrastructure. This is based off the bottleneck analysis' signalling of a tipping point.	To arrive at a prioritisation of problems to be solved and intervention to be executed, the urgency of problems in the subsystem needs to be established (Appendix B Interviews, interview 13/05).
Economic performance	Economic performance of infrastructure is determined by the economic consequences of emerging trends, bottlenecks, and interventions on the railway system's rolling stock performance.	Economic performance is an extension of the operational metrics suggested and provides for the input necessary in subsequent investment planning processes (Appendix B Interviews, interview 13/05).
Turnaround time	Turnaround times being the time a train needs to fulfil its itinerary in the railway system.	Turnaround times are the gross measure of train's travel time, process time and delay time in the port railway area (Macomi, 2020). Together, with punctuality and process times, capacity managers have a complete picture of the size and ratios in train's operational time.
Punctuality	Punctuality is the size of delay experienced in a train's turnaround time.	Punctuality reflects the delay that affects a train, and when analysed for different (Goverde & Hansen, 2013)

Table 32 Overview of Indicators, their conceptualisation, and rationale.

Indicator	Quantitative Metric	Unit	Definition	Rationale
Scale	Amount of freight volume	Million Tons	Realisation or forecasted volume of non-containerised goods transported by trains in the system.	As realisation volumes and forecasted volumes are important and controversial inputs both need to be displayed in full detail. Showing progression of a unified expression in tonnage and container volumes (TEU) at least. These reflect the magnitude of changes in volume over time. The number of trains in the railway system and number of train arrivals per subsystem need to be presented again for understanding the scale of trains in the system, and to reflect how freight volumes and trains are related in the model.
Scale	Amount of freight volume	TEU	Realisation or forecasted volume of containerised goods transported by trains in the system.	
Scale	Number of trains	Integer	Realisation or forecasted volume of trains per type in the system.	
Scale	Number of train arrivals	Integer	Realisation or forecasted volume of train arrivals per instance in the subsystem. In case of shunting yards, this metric is bidirectional	
Feasibility	Mean occupation rate	Percentage	Actual subsystem's sidings occupation time per hour/Available time sidings per hour	Standard method for calculating realised occupation rates (Goverde & Hansen, 2013).
Feasibility	Standard deviation of mean occupation rate	Percentage	Sample standard deviation of occupation rate across replications	RailGenie is a terminating discrete event simulation, therefore multiple replications must be done to be able to statistically test results. (Law, 2000)
Stability	Mean accrued delay	Minutes	Average of differences between time of departure and the end of processing time per train at a subsystem.	Shows the magnitude of delay accrued per subsystem weighted by the number of train arrivals
Stability	Standard deviation of mean accrued delay	Minutes	Sample standard deviation of mean delay accrued across replications	RailGenie is a terminating discrete event simulation, therefore multiple replications must be done to be able to statistically test results. (Law, 2000)
Stability	Sum of accrued delay	Hours	Sum of the differences between trains' time of departure and the end of trains' processing time	Shows the magnitude of delay accrued per subsystem as a result of feasibility constraints elsewhere.
Stability	Sum of accrued delay	Minutes	Sum of the differences between trains' time of departure and the end of trains' processing time per movement at a subsystem.	As far as the delays can be conclusively tied to specific subsystems, delay accrued represents trains' time out of processing and driving, waiting for dispatching to occupied or reserved track elsewhere. Allows for a more detailed view of the causes of delay.
Stability	Mean accrued delay	Minutes	Average of differences between time of departure and the end of processing time per movement at a subsystem.	Allows for a more detailed view of the causes of delay.
Robustness	Tipping point	Integer	Factor used to increase in-scope terminal's volumes.	Standard concept in the analysis of systems in operations management (Goldratt & Cox, 2016).
Robustness	Sum of delay	Minutes	Sum of the differences between trains' time of departure and the end of trains' processing time per hour	For use in a graph showing the development of waiting times in a subsystem over time. Used in queueing models to interpret whether a server has enough capacity to process demand (Law, 2000)
Urgency	Expected time till demand reaches tipping point	Years	Tipping point factor/average forecast growth factor	Insight into the urgency of capacity problems can help actionable decision-making (Appendix B Interviews).

Table 33 List of infrastructure performance indicators, their operationalisation, and definitions.

Indicator	Quantitative Metric	Unit	Definition	Rationale
Travel time	Mean turnaround time	Hours	Time of model exit - time of model entry for each train instance per train	Turnaround time describes the entire time a train is within the port railway area (ProRail, 2011). In RailGenie this time signals the time trains take from the Barendrecht Vork and back.
Travel time	Standard deviation of turnaround time	Hours	Sample standard deviation of turnaround time across replications	RailGenie is a terminating discrete event simulation, therefore multiple replications must be done to be able to statistically test results. (Law, 2000).
Travel time	Mean turnaround time	Hours	Time of model exit - time of model entry for each train group per train	Turnaround time describes the entire time a train is within the port railway area (ProRail, 2011). In RailGenie this time signals the time trains take from the Barendrecht Vork and back.
Travel time	Standard deviation of turnaround time	Hours	Sample standard deviation of turnaround time across replications	RailGenie is a terminating discrete event simulation, therefore multiple replications must be done to be able to statistically test results (Law, 2000).
Punctuality	Mean delay	Minutes	Average of the per train type difference between begin time of departure and the end time of processing of trains	Standard railway definition for delay as it accrued by trains in non-processing, non-driving settings (Min. I&M, 2015; ProRail, 2011).
Punctuality	Standard deviation of delay	Minutes	Sample standard deviation of mean delay across replications	RailGenie is a terminating discrete event simulation, therefore multiple replications must be done to be able to statistically test results. (Law, 2000)
Punctuality	Fraction of total trains in punctuality class	Percentage	Number of trains in a punctuality class divided by all trains	The punctuality classes are percentage of trains falling within a certain class of punctuality (ProRail, 2011). For ProRail, these classes are generally classified according to delay time experienced by percentage of trains with a) 0 min. delay, b) under 3 min. delay, c) above 3 min. delay. In RailGenie, the delay time per train output can used for this purpose. In general, mutually exclusive, collectively exhaustive categories are the only constraint from the perspective of statistical testing.

Table 34 List of rolling stock performance indicators, their operationalisation, and definitions.

Indicator	Quantitative Metric	Unit	Definition	Rationale
Financial	Value of Time	Euro	As specified in Significance et al. (2013).	Standard translation factor between delays and economic performance for Dutch Transport Infrastructure CBA's (Significance et al., 2013).
Financial	Value of Reliability	Euro	As specified in Significance et al. (2013).	Standard translation factor between delays as a factor of turnaround time and economic performance for Dutch Transport Infrastructure CBA's (Significance et al., 2013).
Financial	Sum of Value of Time Lost	Euro	Product of the value of time and Sum of the difference in mean turnaround time per train instance in scope, or Sum of delay accrued at subsystems in scope.	The first definition is preferred when an intervention or change occurs at a higher system's level (Significance et al, 2013). The second for arriving at values of time and reliability is to focus on sum of delay accrued at the problematic subsystem(s) in scope and comparing across scenarios (Min. I&M, 2015).
Financial	Sum of Value of Reliability Lost per Train Instance	Euro	Difference in the SD around the mean turnaround time between scenarios.	Standard use of the translation factor between delays as a factor of turnaround time and economic performance for Dutch Transport Infrastructure CBA's (Significance et al., 2013).
Financial	Loss of demand	Euro	Determined using e.g. Ecorys' model (Min. I&M, 2015)	Sum of expected demand loss, as freight forwarders can be expected to change modes in case of unreliable turnaround times (Appendix B Interviews, Mail 20/04).
Financial	Estimated cost of intervention	Euro	Expert judgement or analogy to previous project.	Determined in the workshops with experts in the process of capacity planning.

Table 35 List of financial economic performance indicators, their operationalisation, and definitions.

17. Appendix F Current State Functional Process Diagrams

In this appendix chapter, the current state processes are described for ProRail (13.1 ProRail Flowchart) and the Port of Rotterdam (13.2 Port of Rotterdam Flowchart) respectively. These provide a sequenced overview of activities employed towards capacity studies in both organisations including the external actors, as well as data and information systems involved. They serve in that regard to illustrate points made in chapter 5 regarding the coordination challenges experienced by both parties. A legend for interpreting the process diagrams is presented in Figure 25 Legend for the current state process diagrams.

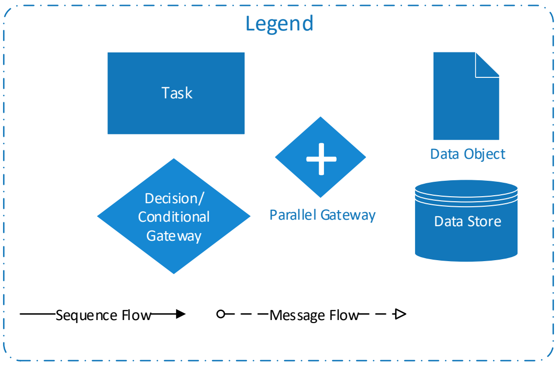

Figure 25 Legend for the current state process diagrams.

13.1 ProRail Flowchart

The flowchart detailing ProRail’s capacity study process is presented in *Figure 27*. In the flowchart, swim lanes are used to denote the various departments and organisations involved. Within these organisations and departments is outlined where the process starts, what decisions and activities follow, where information is retrieved and where the process ends.

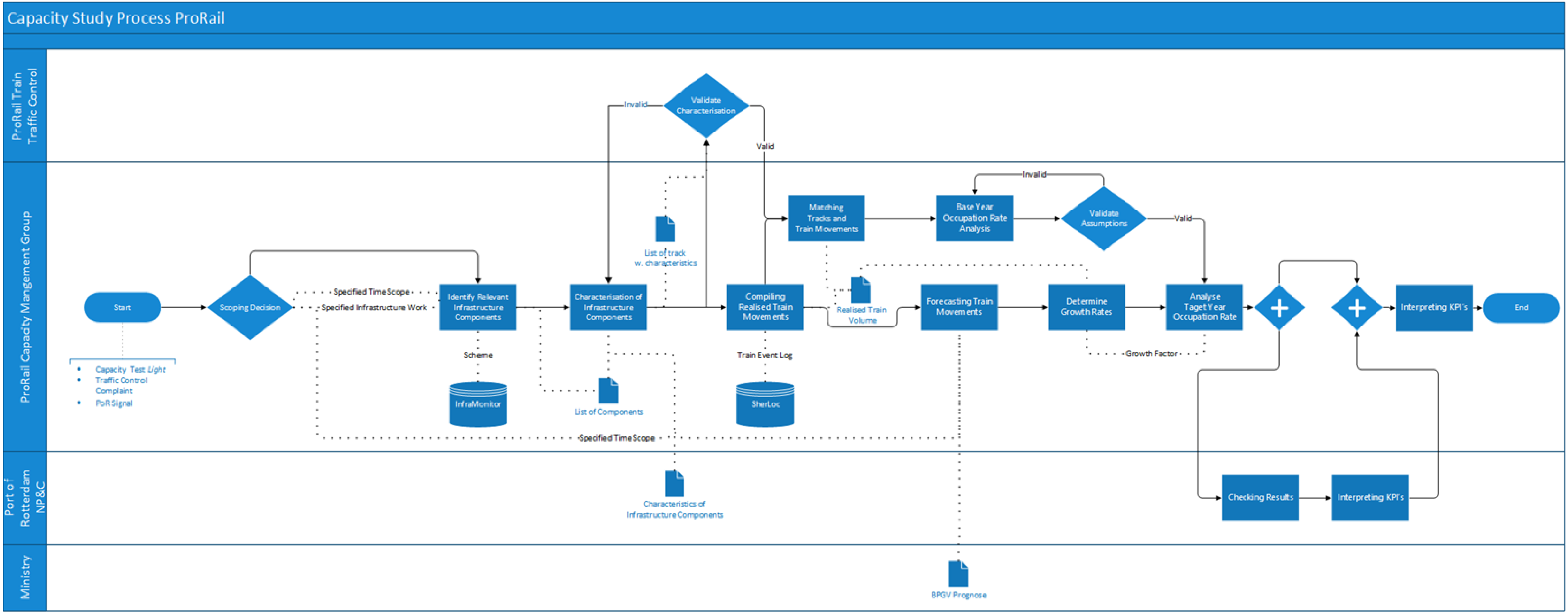

Figure 26 Flowchart outlining the sequence of activities in ProRail capacity studies.

13.2 Port of Rotterdam Flowchart

The flowchart detailing the Port of Rotterdam's capacity study process is presented in *Figure 27*. In the flowchart, swim lanes are used to denote the various departments and organisations involved. Within these organisations and departments is outlined where the process starts, what decisions and activities follow, where information is retrieved and where the process ends.

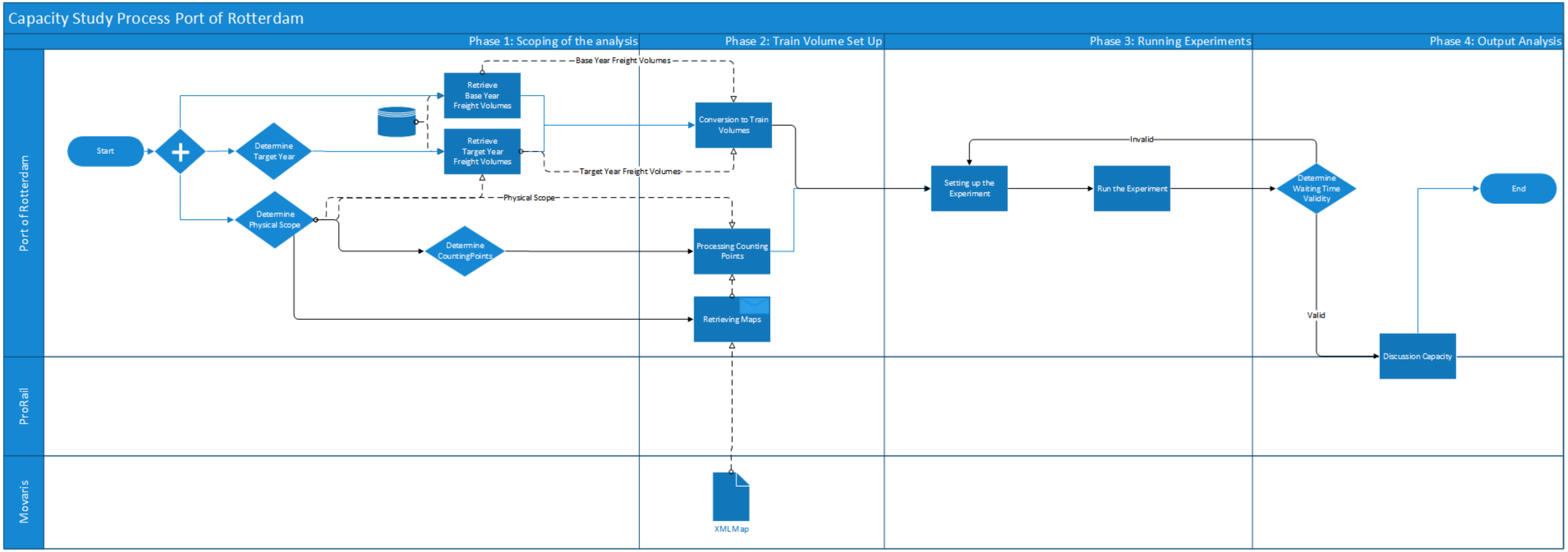

Figure 27 Flowchart outlining the sequence of activities in Port of Rotterdam capacity studies.

18. Appendix G Proposed Micro-Process Design

In this appendix the micro-process design is presented. Given the large size of the image and image quality considerations it is present on the next page in adjusted size. The flowchart detailing the designed capacity planning process is presented in Figure 29. In the flowchart, swim lanes are used to denote the various departments and organisations involved. Within these organisations and departments is outlined where the process starts, what decisions and activities follow, where information is retrieved and where the process ends. A legend for interpreting the process diagrams is presented in Figure 28, below.

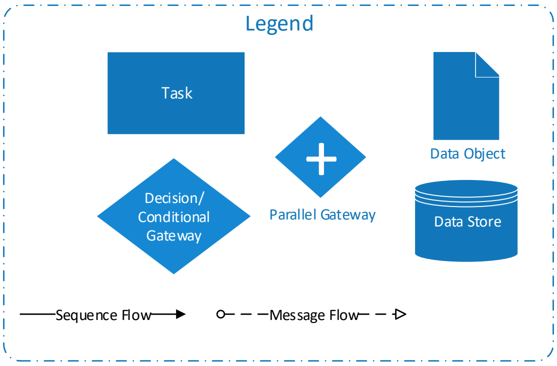

Figure 28 Legend for the proposed micro-process diagram.

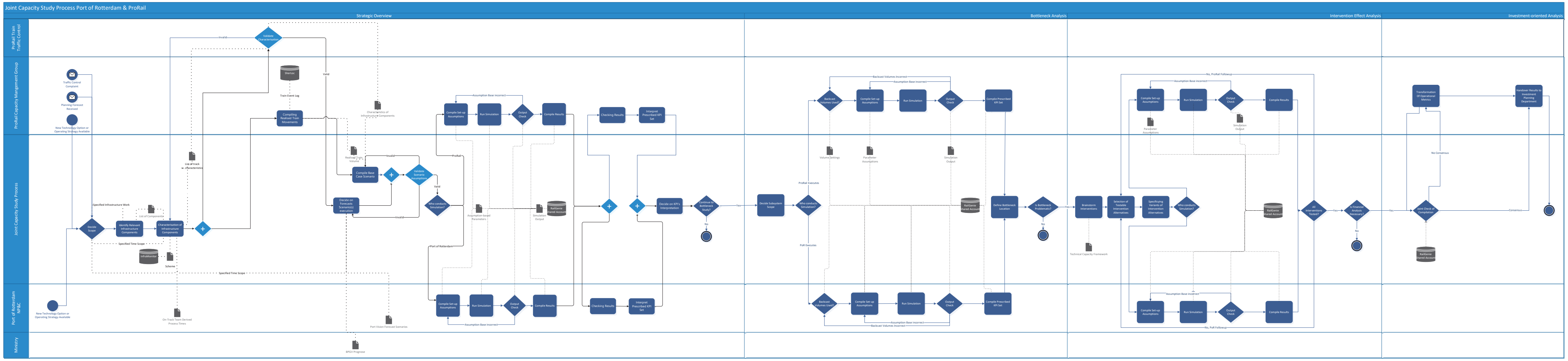

Figure 29 Flowchart outlining the sequence of activities and decisions in the proposed micro-process design for interorganisational capacity planning

19. Confidential Appendix H Proof of Concept Scenario and Assumption Development

This appendix outlines the process of scenario and assumption development in section 15.1. Thereafter specifies the scenarios used in 15.2. These scenarios are converted to assumption for use in the RailGenie simulation tool in 15.3.

15.1 Introduction to the Scenario and Assumption Developments.

The process of specifying the scenarios relies heavily on the experience and knowledge of experts regarding developments in the infrastructure's configuration. The capacity framework, and subsequent assumption operationalisation table give direction as to what topics to cover and how, see Appendix D Simulation Model Assumptions Operationalisation.

15.2 Specification of Scenarios

Firstly, the scenarios describe in natural language how the systems critical components are configured. To that end, scenarios describe the state of infrastructure components and expected changes along with the degree of uncertainty associated with this configuration of the infrastructure.

First the strategic overview scenarios are given by Table 36. Bottleneck scenarios are presented in Table 37. The intervention effect and financial economic scenarios are presented in Table 38.

	Base Case Scenario 2018	**Future Case Scenario 2040**
Block Train Volumes	*Redacted*	*Redacted*
Unit Cargo Train Volumes	*Redacted*	*Redacted*
Port Shuttle Train Volumes	*Redacted*	*Redacted*
Shunting Yard Process Times	*Redacted*	*Redacted*
Terminal Process Times	*Redacted*	*Redacted*
Infrastructural Map	*Redacted*	*Redacted*
Branch Line Speed	*Redacted*	*Redacted*

Table 36 Specification of the base case (2018) and future case (2040) scenarios.

	Bottleneck Scenario 2040
Block Train Volumes	*Redacted*
Unit Cargo Train Volumes	*Redacted*
Port Shuttle Train Volumes	*Redacted*
Shunting Yard Process Times	*Redacted*
Terminal Process Times	*Redacted*
Infrastructural Map	*Redacted*
Branch Line Speed	*Redacted*

Table 37 Specification of the bottleneck scenarios.

	Intervention Scenario 2040	Economic Scenario 2040
Block Train Volumes	*Redacted*	*Redacted*
Unit Cargo Train Volumes	*Redacted*	*Redacted*
Port Shuttle Train Volumes	*Redacted*	*Redacted*
Shunting Yard Process Times	*Redacted*	*Redacted*
Terminal Process Times	*Redacted*	*Redacted*
Infrastructural Map	*Redacted*	*Redacted*
Branch Line Speed	*Redacted*	*Redacted*

Table 38 Specification of the intervention and economic scenarios.

15.3 Assumptions

The scenarios are specified in more detail to allow for inputting into the simulation model. The assumptions presented below constitute a condensed version of the datasets used in the RailGenie simulations. These assumptions follow on the 7 scenario elements addressed in scenario development, and assign values or data deemed representative. A table is presented for each macro-process execution: Table 39 2018 scenario-specific assumptions, Table 40 2040 scenario-specific assumptions, Table 41 Bottleneck Scenario-specific assumptions, and Table 42 Intervention Scenario-specific assumptions.

15.3.1 Scenario-specific Assumptions

Number	Topic	Assumption
2018.1	Block Train Volumes	*Redacted*
2018.2	Unit Cargo Train Volumes	*Redacted*
2018.3	Port Shuttle Train Volumes	*Redacted*
2018.4	Shunting Yard Process Times	*Redacted*
2018.5	Terminal Process Times	*Redacted*
2018.6	Infrastructural Map	*Redacted*
2018.7	Branch Line Speed	*Redacted*

Table 39 2018 scenario-specific assumptions

Number	Topic	Assumption
2040.1	Block Train Volumes	*Redacted*
2040.2	Unit Cargo Train Volumes	*Redacted*
2040.3	Port Shuttle Train Volumes	*Redacted*
2040.4	Shunting Yard Process Times	*Redacted*
2040.5	Terminal Process Times	*Redacted*
2040.6	Infrastructural Map	*Redacted*
2040.7	Branch Line Speed	*Redacted*

Table 40 2040 scenario-specific assumptions

Number	Topic	Assumption
Bottleneck.1	Block Train Volumes	*Redacted*
2040.2	Unit Cargo Train Volumes	*Redacted*
2040.3	Port Shuttle Train Volumes	*Redacted*
2040.4	Shunting Yard Process Times	*Redacted*
2040.5	Terminal Process Times	*Redacted*
2040.6	Infrastructural Map	*Redacted*
2040.7	Branch Line Speed	*Redacted*

Table 41 Bottleneck Scenario-specific assumptions

Number	Topic	Assumption
2040.1	Block Train Volumes	*Redacted*
2040.2	Unit Cargo Train Volumes	*Redacted*
2040.3	Port Shuttle Train Volumes	*Redacted*
Intervention.4	Shunting Yard Process Times	*Redacted*
Intervention.5	Terminal Process Times	*Redacted*
2040.6	Infrastructural Map	*Redacted*
Intervention.7	Branch line	*Redacted*

Table 42 Intervention Scenario-specific assumptions

15.3.2 Cross-scenario Assumptions

The cross-scenario assumptions are used across all scenarios for as inputs for the simulation model, Table 43 provides an overview and a summary of these assumptions. The underlying datasets in the simulation tool RailGenie are more detailed still, but are condensed in the interest of readability. The datasets have been compiled and developed through various workshops undertaken by Macomi, Port of Rotterdam, and ProRail.

Number	Scheduling	Assumption
8	Direction Distributions	*Redacted*
9	Train Instance Distribution	*Redacted*
10	Train Type Distribution	*Redacted*
11	Monthly Distribution	*Redacted*
12	Weakly Distribution	*Redacted*
13	Daily Distribution	*Redacted*
14	Train Schedules	*Redacted*

Number	Goods	Assumption
15	Goods Types	*Redacted*
16	Terminal Goods	*Redacted*

Number	Rolling Stock	Assumption
17	Locomotives	*Redacted*
18	Wagons	*Redacted*
19	Load Factor	*Redacted*
20	Train Instances	*Redacted*
21	Train Types	*Redacted*
22	Location Activities	*Redacted*

Number	Infrastructure & Routing	Assumption
23	Separate Locomotives	*Redacted*
24	Parking Locations	*Redacted*
25	Route Attributes	*Redacted*
26	Pathway Attributes	*Redacted*
27	Cluster Preference List	*Redacted*
28	Branch Lines	*Redacted*

Table 43 List of assumptions used across scenarios.

Assumption	Topic	Explanation
29	Runtime 2018	As full year runs are currently not executable by the simulation tool in a stable fashion, a single month runtime is opted for.
30	Warmup period	First, theoretical estimate for the required warm up time of the simulation model set at 3 days, because the average train turnaround time implies that the first day’s trains exit the model by the second day. Therefore, the model is filled with trains in the third day. This is checked using Welch’ method meaning that moving averages are plotted over the warmup period until the mean stabilises (Robinson, 2005).
31	OFAT Replications	This is checked using Welch’ method (Robinson, 2005).
32	Factorial Design Replications	A 3-factor 2-level experimental design is used with 3 replications meaning a total of 24 runs is undertaken.

Table 44 Simulation experiment design assumptions used across scenarios.

15.4 Confidential Appendix I Assumption and Sensitivity Testing

15.4.1 Specification of the sensitivity analysis

Sensitivity experiments are conducted to test the effect of incorporating modelling assumptions that are: a) deemed critical by the railway capacity experts involved in the case study, or b) are non-verifiable using observed data. The final decision whether or not to test the model to parameter sensitivity is taken by the railway capacity experts, the result of which is displayed in Table 45 for the 2018 scenarios and Table 46 for the 2040 scenarios.

	Variable	Current incorporation	Change to
1	Unit Cargo	*Redacted*	*Redacted*
2	Port Shuttle	*Redacted*	*Redacted*
3	Branch Line Train Separation Modelling	*Redacted*	*Redacted*

Table 45 Experimental Design Sensitivity Analysis 2018 Scenarios.

	Variable	Current incorporation	Change to
4	Shunting Yard Process time	*Redacted*	*Redacted*
5	Terminal Process time	*Redacted*	*Redacted*

Table 46 Experimental Design Sensitivity Analysis 2040 Scenarios.

For the intervention scenario, a full factorial design was used. As the direction of effect of the variable change is known beforehand, and it was deemed likely that the process times will reduce in the future, the high scenario is the current scenario, while the low scenario represents a 25% reduction. This is detailed in Table 46 Experimental Design Sensitivity Analysis 2040 Scenarios.

15.4.2 One-Factor-At-A-Time 2018 Approach: Unit Cargo and Port Shuttle Volumes

First, volumes across unit cargo and port shuttle analyses are presented Figure 30. Second, occupation rates show only minor, statistically insignificant percent point differences, Figure 31. Third, the change in turnaround times is found to be minimal and not considered a threat to model validity Figure 32.

[redacted]

Figure 30 Number of train arrivals per subsystem in October 2018. (Redacted).

[redacted]

Figure 31 Mean occupation rate across subsystems, SD in error bars (5 replications of 31 days). (Redacted).

[redacted]

Figure 32 Mean turnaround time across train instances, SD in error bars (5 replications of 31 days). (Redacted).

15.4.3 One-Factor-At-A-Time 2018 Approach: Branch Line Modelling

The separate train movements are modelled as a speed reduction of the branch line and not as a process time increase, as the speed reduction has a significant effect on performance, while the process time increase assumption is deemed too uncertain (in reflection to the real situation) to incorporate, aside from that it has only a negligible effect. This is presented in Figure 33 & Figure 34.

[redacted]

Figure 33 Mean occupation rate in October 2018 across subsystems, SD in error bars (5 replications of 31 days). (Redacted).

[redacted]

Figure 34 Mean turnaround time in October 2018 across train instances, SD in error bars (5 replications of 31 days). (Redacted).

15.4.3 Full Factorial Design for Intervention Scenario Sensitivity Testing

For the intervention effect analysis, sensitivity is more systematically measured than in the strategic overview, as the outcomes are important for decision-making rather than the informative aspect of the strategic overview. The intervention’s effect is established through a full factorial experiment design, which specifies the simulation configuration, runs and outcomes are found in Table 47 Overview of full factorial design for 3 factors at 2 level with 3 replications.

Conclusions are as follows:

- For delay accrued at Terminal , Shunting Yard Process Times (B), Branch Line Speed Limit (C) and their interactions are statistically significant (Table 49) and relevant (Table 48).

Redacted

- For delay accrued at Shunting Yard a shunting yard, Terminal Process Times (A), and Branch Line Speed Limit (C) are statistically significant (Table 51) and relevant (Table 50).

Redacted

Run Order	Run Variant	Terminal Process Times (A)	Shunting Yard Process Times (B)	Branch Line Speed Limit (C)	Mean Delay a shunting yard	Mean Delay
1	1	0.75	0.75	2	*Redacted*	
2	1	0.75	0.75	2		
3	1	0.75	0.75	2		
4	2	1	0.75	2		
5	2	1	0.75	2		
6	2	1	0.75	2		
7	3	0.75	1	2		
8	3	0.75	1	2		
9	3	0.75	1	2		
10	4	1	1	2		
11	4	1	1	2		
12	4	1	1	2		
13	5	0.75	0.75	4		
14	5	0.75	0.75	4		
15	5	0.75	0.75	4		
16	6	1	0.75	4		
17	6	1	0.75	4		
18	6	1	0.75	4		
19	7	0.75	1	4		
20	7	0.75	1	4		
21	7	0.75	1	4		
22	8	1	1	4		
23	8	1	1	4		
24	8	1	1	4		

Table 47 Overview of full factorial design for 3 factors at 2 level with 3 replications.

[redacted]

Table 48 Overview of factors and their effects on minutes of delay accrued at terminal. (Redacted.)

[redacted]

Table 49 ANOVA output related to the delay at terminal. (Redacted).

Redacted

Table 50 Overview of factors and their effects on minutes of delay accrued at a shunting yard.

[redacted]

Table 51 ANOVA output related to the delay at a shunting yard. (Redacted).

16. Confidential Appendix J Slide Deck Presented in Evaluatory Meetings

In the following pages, a selection of the iteratively developed slidedeck is presented as was presented to the ProRail and the Port of Rotterdam at the three workshops.

17. Appendix K Summary of Capacity in Railway Systems

Summary: “What is capacity in the Rotterdam Port Railway System?”

Capacity is the ability of a port railway system to fulfil demand for freight transport. According UIC “a unique, true [measurement] definition of capacity is impossible; railway infrastructure capacity depends on the way it is utilised”. The assessment and planning of capacity utilisation comprises four elements, namely the railway system’s technical configuration, the capacity planning processes governing the configuration, indicators for the assessment of capacity performance, and decision-support tools. The technical configuration describes pattern of demand, and the railway system’s physical infrastructure and their operating strategies. Aligned capacity planning processes with clear goals, and methods to benchmark system performance, facilitate bottleneck problem identification, test of interventions and assess of capacity’s economic performance. Indicators assess the performance of capacity are comprised of sets of metrics to determine them. Performance of the (changes to) configuration and use of infrastructure is modelled with decision-support tooling.

Technical railway system configuration

The port railway system is a network wherein infrastructure and rolling stock have complex interactions. To create an understanding of interdependencies, a multi-level framework of subsystems and their elements is created. The railway system framework has three purposes, it: a) shows where in the physical infrastructure complex interactions can emerge, b) structures and inspires the formulation of interventions into the demand patterns, infrastructure and rolling stock, and c) structures the design of simulation study experiments.

The railway system consists of demand patterns originating sea-side and continental hinterland, which are catered through the capacity at infrastructure and rolling stock subsystems. The demand patterns are formed through characterisation of demand sources and volumes, the bundling of demand in logistical concepts, the scheduling and pricing strategy.

The actual transport is supplied through physical design and (controlled) operations infrastructure and rolling stock subsystems:

- Main Line: The port main railway line is the central set of railway tracks that connects the different subsystems in the port railway area.
- Shunting Yard: The main functionality concerns incoming trains which are decomposed, and the railcars are then composed into the desired outgoing train composition
- Terminals: In the port railway take on tasks such as the organisation of collection and distribution of goods in the region, and transloading between modalities.
- Branch Line Trains re the composition of trains as they run between the terminals to shunting yards.
- Main Line Trains are the composition of trains as they run between shunting yards and the hinterland.

5 Capacity perspectives to contrast for capacity assessment:

1. Objective vs realisation: The comparison of targets set with predicted capacity performance guides capacity planning towards actionable decision-making.
2. Demand vs supply: Important to compare as demand shapes how supply should match, and tension exists between demand-side (planning) and supply-side (control) efficiencies, as illustrated by e.g. peak shaving practises
3. Infrastructure subsystems vs rolling stock subsystems: performance of specific infrastructure and rolling stock using it should be compared to determine how their physical structure and operating strategies interact.
4. System level vs subsystem: the importance of capacity malperformance and infrastructural bottlenecks at e.g. a specific shunting yard can only be established relative to the performance of the complete system. What might be thought a grave occupation rate in a specific subsystem, might be good performance relative to the larger system’s benchmark.
5. Specific subsystem vs adjacent subsystem: Important to compare when establishing cause and effect for capacity (mal)performance, especially in interaction between shunting yard(s) and terminal(s).

Capacity planning processes

The capacity planning process spans four distinct types of analysis activities that differ in objectives, scope, methodology and performance indicators, namely strategic overview, bottleneck analysis, intervention effect analysis and financial analysis.

The strategic overview process serves to monitor and benchmark the complete rail system in the Port Industrial Area in the face of economic and technical long-term trends. This cyclical monitoring activity identifies potential problems in the port railway system by taking a global i.e. system-level perspective across shunting yards and terminals.

The goal of bottleneck analysis is twofold, namely, to identify and locate bottlenecks, as well as determining establishing the level of urgency associated with fixing the bottleneck. This takes a local perspective to railway area sub-systems (specific yards, branch lines, train instances). By overloading the subsystem with trains, potential problematic physical infrastructures and operating strategies are identified.

The goal of intervention effect study is to gauge the effectivity & efficiency of possible interventions or solution directions. The method employed in studying effects of interventions is a search that uses experiments to test falsifiable hypotheses on cause and effect relations in the infrastructure, that are borne out of the capacity framework.

The goal of Investment-oriented Analysis the information base for identifying (the most) fruitful opportunities for improving infrastructure through the determination of financial-economic metrics. In this process results from intervention effect study are transformed to annual economic performance metrics which are part of the standard Dutch cost-benefit procedure, namely value of travel time and value of reliability.

Performance Indicators

The effectiveness and efficiency with which capacity is utilised can be captured by indicators operationalised through quantitative metrics. The yields a list of indicators and their operationalisation through literature review and client interviews.

The capacity performance of infrastructure is determined through

- Scale is the magnitude of volumes and trains transported over the railway system.
- Feasibility denotes the achievability of handling freight transport volumes as expressed in the realised capacity occupation rate which results from train dynamics in the railway system. It is measured through the average and deviation of the occupation rate of infrastructure. While in theory 100% occupation would be exactly feasible, dynamics are such that in practice infeasibility to handle increased volumes occurs at lower rates.
- Stability is the ability of the infrastructure to contain the initial delays of trains and primary delays accrued by trains while waiting for reserved and occupied (moving) block sections and sidings.
- Robustness of the infrastructure is determined through its ability to withstand external influences, especially increases in traffic volume. This is expressed by means of its tipping point volume, the amount of trains before delays can no longer recuperate.
- Urgency is the expected time period before intervention into the infrastructure. This is based off the bottleneck

The capacity performance of rolling stock is determined through their turnaround times and punctuality.

- Turnaround times being the time a train needs to fulfil its itinerary in the railway system.
- Punctuality is the reliability of train’s turnaround times e.g. the mean delay and variation experienced by trains.
- Economic performance of investments is determined by the economic consequences of emerging trends, bottlenecks, and interventions on the railway system’s rolling stock performance. Through standardised value of time and reliability appraisal the economic effect can be determined.

Decision-support tools

The planning and control of capacity is complex as a result of the networked interdependencies of the technical railway system and stakeholders utilising it. Decision-support tools can facilitate successful capacity planning efforts through representation of railway system configuration, their capabilities to support decision-making processes, and the measuring performance indicators.

Representation of railway system configuration of both physical elements pertaining to the infrastructure and rolling stock, besides their operating strategies. Complex dynamic interaction due to networked propagation across linked infrastructures, capacity performance feedback loops, and stochasticity.

Supports process in problem identification and solution formulation. Problem identification by prioritising where performance is lagging at a system level, and by facilitating root-cause analysis at the level of components. Solution formulation allows for a wide range of interventions to be tested in multi-objective experiments. Decision-support tools enable the presentation and communication of indicators operational and financial.

18. Appendix L Scientific Article

In the appendix is presented to mandatory translation of this research' findings onto the format of a scientific paper. The paper is conceptual nature and therefore most relevant for publishing as a book chapter, such as the contribution by Fleischmann & Meyr (2003) in Handbooks in operations research and management science. Alternatively, the paper can be relevant for the journal Production Planning & Control, from which the most articles are derive that underpin the knowledge gap. These articles are conceptual literature review articles with case studies, such as Roehrich et al., (2019).

Design Principle Validation for Railway Capacity Coordination Processes

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Abstract

Overcoming the coordination challenges faced by the Port of Rotterdam and ProRail is imperative in the face of ever-growing volumes of freight in the port railway area. It requires improved alignment meaning that the internal organisation of capacity management must be made to fit the organisational objectives while simultaneously be adaptive to the changing external environment. The alignment is comprised of a systematic shared understanding of technical capacity aspects and streamlined coordination processes for navigating the technical complexity systematically. An overview of alignment challenges is presented resulting from the capacity management process analysis conducted at both organisations. The matching of challenges perceived in alignment and the principles yields a capacity management process design comprised of 4 macro-processes, a strategic overview analysis, tactical bottleneck, tactical intervention, and financial economic analysis. These macro-processes are specified through process flow design, set of tailored quantitative metrics, meso-level simulation study set-up. These are subsequently evaluated through requirements and a proof of concept simulation case study that is based on the shunting yard case. As such the research followed a design science approach, where principles and challenges are matched to yield a process design. Through execution of the case study a naturalistic validation is done of the principles compiled.

Keywords: Railway Freight, Capacity Management, Intraorganizational Coordination.

1. Introduction

In order to reach ambitious goals for climate, pollution and safety in transport, the European Union endeavoured to promote rail transport as a more sustainable substitute for road transport (EEA, 2019). The Port of Rotterdam (PoR), conscious of the changing transportation environment, has set its own goal to reach a 20% railway market share by 2033 (PoR, 2011).

Growing railway-based traffic puts existing railway infrastructure performance under stress regarding safety, reliability, and affordability (NS, 2016). Capacity utilisation rates have increased over the entirety of the Netherlands, but especially around the Rotterdam area. Nowadays, Dutch railways see the highest usage intensity per km compared to the rest of the EU (IRG-Rail, 2019). There, utilisation rates are increasing steadily towards 90% in 2040, to the effect that the network becomes more vulnerable to failure and train operations sensitive to disruptions (Min IenM, 2017).

The Port of Rotterdam and ProRail conduct capacity studies to manage demand within capacity limitations posed by the supply of infrastructure for high performance, affordable transportation. Parties desire a process of executing simulation model-supported capacity studies wherein inputs, methods and outputs are shared upfront. However, interorganisational capacity studies are currently conducted *ad hoc* in lengthy processes, in which there is disagreement about inputs, methods, and outputs to the process. They can be considered misaligned as the internal capacity management processes do not fully fit the organisational objectives, while also not being adaptive towards the dynamic railway capacity context (Henderson and Venkatraman, 1993). Lederer & Mendelow (1989) posit that the alignment is the result of coordination activities between (parts of) collaborating organisations.

Recent literature reviews point out that the research combination of networked coordination, coordination processes and coordination mechanisms relating to decision support systems is rarely studied. Roehring et al. (2019) in their general review of dyadic interorganizational governance point out that coordination issues are more in the for front in network relationships because it is challenging to design processes to govern network coordination free from market mechanisms or the workings of hierarchy. More research is therefore essential in order to gain a better understanding of the issues that make the decision-making processes in interorganisational networked coordination fundamentally different than the issues common in dyadic relationships.

A closer related literature review by Jonathan & Ruslin (2018) poses that overall research in public IT-mediated governance is lacking, especially given the inability to generally extend findings from the private domain, as issues arise due to accountability, and the amount and variety of systems used. Besides, public organizations are becoming increasingly dependent on joint decision-support tooling, so more interorganizational governance research for this environment is needed (Helin, 2019). Helin (2019) further pose that research regarding interorganisational governance using decision-support tooling research is still weakly addressed even for those few case studies undertaken in the private domain, and concludes it is an important area to study further.

The literature review of Trang et al. (2013) argues that existing IT governance research has already revealed the importance of coordination mechanisms that bridge the divide between social and technical aspects. Their literature review further pointed out that within their search not a single article focused exclusively on coordination mechanisms in the context of networks (Trang et al., 2013). An open knowledge in the academic literature presents itself in the question of how to design the process managerial alignment of organisations in capacity management therefore poses a knowledge gap for academia and the parties involved in this specific research.

An aligned rail freight capacity management process is necessary for the successful matching of demand and supply for rail freight transport services, and can be supported by simulations of the railway capacity. Leading to the main research question: *How to improve the alignment of collaborating organisations on quantitative metrics for railway freight capacity in the Port of Rotterdam with the use of meso-level simulation models?*

2. Method

The main research question calls for an improvement design to be made in terms of the collaboration on railway freight capacities in the Port of Rotterdam area. The design is of a socio-technical system as it consists of a) social elements: stakeholder with differing interests, and levels of decision-making power, and b) technical elements: concerning the capacity of railway infrastructure and the method of determining those capacity levels. The design of socio-technical artefacts is commonly executed by using systems engineering approaches such as those presented by Faulconbridge & Ryan (2018) and Cross & Roy (1989). These approaches describe the design process of artefact which are guided by analysis of the environment and academic knowledge.

However, this research effort does not only comprise a design effort of a socio-technical artefact in a complex environment, but also aims to contribute to resolving open academic knowledge gaps. Specifically, at those collaborative tensions in the multi-stakeholder railway freight capacity planning processes in the Port of Rotterdam. That in turn touch upon open knowledge gaps regarding collaboration guided by quantitative support, specifically simulation models. It is in this light that an overarching approach is sought, which are aimed at parallel design and research efforts. The Design Science Methodology is such an overarching method that works towards concrete artifact design as well as guides complementary research activity (Peffers et al., 2007). Furthermore, Design Science, has a firmly rooted position in technology mediated interorganisational coordination research community as asserted by Hevner et al. (2004).

The Design Science Methodology breaks up the artefacts design process into 6 discernible steps: 1. Identify Problem & Motivate, 2. Define Objectives, 3. Design & Develop, 4. Demonstrate & Evaluate. Through each of these steps potential linkages for research are given. An overview of the (sub)questions and the methods to answering them are given in the subsequent sections

2.1. Identify Problem & Motivate

To answer this question, first an overview must be made of the current internal capacity measurements that support the capacity planning processes. This overview includes the specific infrastructural elements that are taken into account while defining capacity on specific railway parts. As well as the scope of capacity measurements in terms of the time windows (minutes, or (quarters of) hours), and unit sizes (length of track, or areal size) employed. The organisations are reliant on each other for the supply of (infrastructural) specifications, forecasts and other types of information at various stages during their planning processes. A mapping of these linkages will prove illustrative for the as is situation of aligned capacity planning in the Port of Rotterdam.

The method to map out such an overview a modelling language known as Business Process Modelling and Notation (BPMN) is used. BPMN bears great similarity to other (process) modelling languages, such as UML and value stream mapping, but is found to have greater readability and understandability (Vega-Márquez, 2019). BPMN provides standardised concepts to use in creating overview of information and activities, as present in the collaborative capacity planning process.

2.2. Define Objectives

In order for the design to be successful in aligning organisations, the academic state of the art in technical capacity management principles for coordination in engineering projects should be discussed. By means of literature review, four relevant outputs are produced capacity management KPI's, a technical capacity framework, and design principles derived from planning and control literature. The technical capacity framework serves to increase understanding of the configuration of capacity-relevant railway subsystems. The principles propose the objectives the designed process should adhere to or strive to achieve. The output can guide the design process towards improved planning activities between the stakeholders involved, using their simulation tools.

The questions ask for the academic state of the art in inter-organisational capacity planning methods. By means of literature review, outputs such as methodologies, design principles or success & failure factors are generated. These outputs propose the objectives the designed process should adhere to or strive to achieve. The output can guide the design process towards improved planning activities between the stakeholders involved, using their simulation tools. Critical here is the observation that the process design is not greenfields, but the eventual process design is based on existing ties, tools and technicalities, which the literature review output should accommodate.

Aside from the academic perspective on design objectives, the stakeholder-experts also have views on what constitutes good planning process performance. Stakeholder interviews serve to identify measurable indicators for the performance of the process.

2.3. Design & Develop

The design of this new improved planning process entails the timing, content and extent of the interlinkages between stakeholders' planning processes. The functioning of the new planning process can be tested a case study surrounding the Port's and ProRail's use of the Railgenie simulation tools. From the emerging desired planning process, it is likely that the simulation tool used for decision support has to be augmented. Therefore, a list of improvements of simulation software is a logical side product at this stage. Output from the newly designed planning activities is likely to depend on the forecasts, and assumptions stemming from the stakeholders involved, especially regarding expected size and source and destination of cargo flows, and as well as used transport routes. Therefore, an assessment of the sensitivity towards the used scenarios is in order.

Again, a flowchart diagram serves as the method of producing the improved process overview.

2.4. Demonstrate & Evaluate

The research concludes with a validation of the improvement intervention, based on a specific area on the Port of Rotterdam's railway area, where the authority, ProRail are jointly working on a capacity definition. To this end, it should be argued how the new planning process performs in terms of the set-out performance indicators. The case study will help with the evaluation, as it poses a cause for Prorail and the Port of Rotterdam to meet and try-out the improved collaborative planning process. The improved design can be tested through a simulation of a capacity study process wherein the participants rate their satisfaction with the experience. The methodology used here is in line with TU Delft evaluations of gamified logistics workshops.

3. Principles for Coordination in Capacity Management

3.1. Technical Capacity Coordination

Across capacity management efforts in the different disciplines, a central trade-off is identified between the desire to create an integral plan while maintaining the ability to truly optimise capacity performance (Fleischmann & Meyr, 2003; Hax & Meal, 1975).

- Integrality Principle:

The ideal of integral planning on railway transport system level. The process of planning should take into account time and place dynamics of the railway system, from terminals to the hinterland as a whole and consider the effects of their interdepencies, e.g. possible network cascading.

- Optimality Principle:

The ideal of truly optimising of capacity decisions. The process of planning must work with concise, unambiguous definitions of the optimisation objectives, performance criteria and constraints as well as the use of exact or heuristic optimisation methods, i.e. algorithms.

Theme	**Principle**	**Section & Sources**	**Implication for the process design**
Integrality Coordination in Capacity Management	Should explicitly address interdependencies in time and place dynamics of subsystems Should consider uncertainty caused by stochasticity and feedback loops in the interdependencies. Should consider uncertainty or at least allows forecast errors. Should be based on rolling planning horizons Should incorporate an ‘upward’ flow of information’ and ‘downward’ flow of constraints Should be supported by advanced decision support tooling.	(Fleischmann & Meyr, 2003) (Schneeweiss, 1995) (Hax & Meal, 1975) (Vogel *et al.*, 2016) (Cascetta, 2009)	The integrality principles introduces multi-level, multi-scope perspectives as part of the design, which require capacity planners to address effects of local interventions on a global system level, and vice versa. The principles dictate that the design must be supported by simulation tools able to cope with complexity.
Optimality Coordination in Capacity Managment	Should specify objective function(s) Should hierarchically decompose decision-making Should make use of systematic problem decomposition. Should increase the level of detail regarding subsystems at lower system aggregation levels Should incorporate decreasing length of planning horizon Should increase level of detail increases regarding time periods, e.g. years to months Make use exact or heuristic optimisation methods	(Fleischmann & Meyr, 2003) (Vogel *et al.*, 2016) (Schneeweiss, 1995)	Optimality principles introduces hierarchy into the division of capacity planning tasks: the strategic system level, and the tactical subsystem level, increasingly constraining: physical, temporal scope, level of detail. Introduces rigor in the capacity study methods for problem analysis: structured root-cause and bottleneck analysis, and assessment of interventions: computation, experiments, heuristic process design.
Coordination of Dependencies in Processes: Maturity	Should be specified according to CMMI	(Paulk et al., 1993)	The requirements list of the design should incorporate CMMI-derived requirements that purport performance of the process in quality of outcomes, effectiveness, and time-efficiency of process steps.
General Coordination	coordination by standardisation coordination by plan coordination by mutual adjustment standardisation of process and content interfaces modular interconnected processes structured data connectivity the breadth of information shared with collaborators the quality of information shared with collaborators deep coordination-related knowledge	(Thompson, 1967) (Gosain et al., 2004) (Gosain et al., 2004)	Following these principles may help in overcoming disagreement arising from dependencies in the capacity study process. It implies finding challenging fit, flow, and sharing type coordination processes, and suggests to improve by applying the specified principle-based intervention of either advanced structuring or dynamic adjustment to create loosely coupled processes.

Table 1: List of principles for coordination in capacity management from the literature.

3.2. Process Coordination

Managing capacity of railway freight occurs in a governance design, a specific institutional organisation of decision-making rights, distributed over stakeholders in capacity management. The goal of institutional design of governance is to in the end improve the performance of the infrastructure, meaning decisions that guarantee safety, reliability, and affordability of freight railway transport in the future. An in-depth understanding of how the organisation of decision-making influences performance of the infrastructure can therefore be used to suggest governance designs that are aimed at improving performance.

In the coordination of activities, the Port of Rotterdam and ProRail meaning that both parties must manage dependencies among their activities in the absence of direct hierarchy or competition. This places the cooperation in process-managerial coordination theory literature such that we: 1) draw on design principles put forward by coordination theory, and 2) take a process-view towards coordination in capacity management allowing the identification of coordination challenges in current processes.

In the coordination of activities, the Port of Rotterdam and ProRail are in networked cooperation. Their cooperation is thus shaped by loosely coupled activities. Orton & Weick (1990) referred to these situations as being “loosely coupled”, where “coupled” denotes the dependent structuring of process, while “loosly” denotes that the degree of dependence may decrease in case of unexpected changes, or more broadly put when uncertainty resolves.

Coordination theory puts forward design principles conducive to alignment in interorganisational capacity planning activities. Most notably Gosain et al. (2004) proposes the concepts of advanced structuring and dynamic adjustment. Advanced structuring denotes the idea of structuring information exchange and dependent processes ex ante with room to manoeuvre, by securing standardisation of process and content interfaces, modular interconnected processes, and structured data connectivity (Gosain et al., 2004). The dynamic adjustment denotes to the rapid adjustment of inter-organisational processes in response to changes in complex collaboration situations namely 1) the breadth of information shared with collaborators, 2) the quality of information shared with collaborators and 3) deep coordination-related knowledge (Gosain et al., 2004). The coupling is made primarily through the simulation model which acts as boundary object, an uncontroversial source of data on the performance of the railway system.

Lastly, as coordination takes place in process form, CMMI guidelines for the effectiveness and efficiency of process are also taken as principles.

4. Current Challenges faced in Capacity Management Coordination

The difference in capacity study processes expose some of the dilemmatic trade-offs present in capacity studies between the data used, methods employed, and output indicators consulted. These dilemmatic trade-offs in the current design of the capacity study process are taken as main challenges that the designed process artefact is meant to tackle.

Although the current planning method ultimately lead to concrete, and implementable capacity interventions, there is still a way to go in the transition towards long-term planning with a focus on value added. In this transition, challenges emerge as a consequence of currently perceived short-term operational goal orientation. Flexibility and adaptability of planning and implementation towards anticipated trends can be difficult especially in the multi-stakeholder environment. An example of this is the difficulty of aligning the evolution strategies of client companies with port planning ideals. Additionally, the incorporation of third-party interests belonging to the neighbouring public, organisations in civil society and governmental organisations proves difficult particularly when related to motives of ecological, and social nature. The coordination disagreements about inputs, methods and outcomes is found difficult particularly because of loss of position, information asymmetry, and assumed special interest in collaborating parties. These three perceptions strengthen the idea that opportunist strategic behaviour may be to blame for the disagreements. The loss of position is felt through the fact that the Port of Rotterdam wants to move to RailGenie as simulation model, but ProRail prefers the tacit knowledge embedded in their experts regarding their models proven through use, regardless of known disadvantages. The information asymmetry, manifest in different forms between two parties. Special interest is suspected as ProRail considers Port of Rotterdam predictions to be to positive, stemming from their observation that forecast scenarios are decreased in magnitude as years approach, while the Port of Rotterdam’s stay at their high. The Port of Rotterdam has an information advantage here, because rather than ambition, it has detailed knowledge trends and changes in the port railway area. These coordination challenges warrant presentation in more detailed form.

When we directly compare the differences in capacity study execution and enrich that view using the interviews of participants, we can distill a set of challenges that impede the current performance of the capacity study process in the following list:

1. The problem behaves dynamically in that uncertainty exists regarding a) the volumes that the infrastructure should be capable of dealing with, and b) where the bottleneck element or sub-system is. The ability of the railway system’s infrastructure to fulfil in the demand for freight transport is interpreted differently as perspectives on physical scope, timeline, and level of detail change. It is difficult to pinpoint where the cause of

malperformance lays, due to feedback loops, and stochasticity. Subsequent capacity management process design is helped by explicitation of variables at work, and structured root cause analysis methods for locating the bottleneck

2. The effects of interventions as proposed solutions are dynamic, uncertain, volatile: a lack of reasoning regarding structure versus dynamics in the design and use of the railway network. Capacity management processes are hindered by this challenge by a) the fact that effectiveness of interventions can only be speculated on beforehand, and experimentation can give conclusiveness, b) the requirement of using advanced tools, such as simulation tools that can replicate the effects of stochasticity, and deterministic feedback loops present in the railway system.
3. Disagreement regarding the volume forecasts used. Disagreement about forecasts of volumes arises from: a) the fact that they are uncertain, and sensitive to changes in the assumption used to create them; b) Port of Rotterdam, and ProRail prefer forecasts created by themselves aligned with subsequent stakeholders in capacity information; c) the potential strategic useability of forecasts in the interest of the own organisation.
4. Disagreement regarding the configuration of volume forecasts in the modelling process. Process times of trains at shunting yards and volumes at adjacent terminals are primary levers that influence delay and occupancy rates for trains and infrastructure. Adding all forecasted volumes at unchanged process time assumptions tends to overburden the system, while selective process time tweaking can solve overburdening that is not relevant to the intended scope of study.
5. Disagreement regarding the interpretation of study's operational metric outcomes. Operational metrics bear no natural interpretation that informs go or no-go decision making. In both capacity study methods, the view that unrecoverable delays as a result of overburdened sub systems constitute a capacity problem in need of an intervention. Yet, other metrics that inform the value of interventions are helpful to evaluate operational capacity performance or to relay succeeding organisational processes.
6. Lack of opportunity for hierarchical escalation in decision-making, which slows the process. To have capacity studies produce actionable results, decisions must be made to select assumptions or interpretations that need resolvement. This resolvement trancents the possibilities given in the (standardisation) agreements between both parties. At these times, it is highly desirable that a clear 'chain of command' is visible, as the capacity studies success falls or stands with the ability to execute and follow-up actionably.
7. Experienced difficulty in follow-up in subsequent capacity decision-making processes. Operational metrics, whether in Excel-based or simulation tooling only yields unambiguous results in 'extreme' cases, while in others inconclusiveness remains, forcing some capacity studies to call for further study instead of action towards increased monitoring, or capacity interventions.

These observed challenges are matched with coordination principles to inform the capacity management process design

8. Proposed Capacity Coordination Design

The proposed design defines four macro-processes, each with specific goals and methods to support capacity study process. The macro-processes are the result of matching challenges with technical and coordination proces principles, and supported by performance indicators, and the capacity framework.

- Strategic Overview
- Bottleneck Analysis
- Intervention Effect Study
- Economic Capacity Analysis

Strategic overview process serves to monitor the systems general ability handle transport demand in the face of economic and technical long-term trends. This capacity study activity therefore serves to align capacity management with the strategic planning processes. Corresponding to the strategic viewpoint is the scoping, which encompasses the complete rail system in the Port Industrial Area (HIC). In this cyclical process, analyses are renewed at established intervals that correspond to the progression in economic forecasts and technological development. Cyclical monitoring activity identifying potential problems in the port railway system by taking a global i.e. system-level perspective. What is the effect of growing volumes? How will technological change such as hybrid locomotives affect operations?

When potential problematic trends and corresponding areas have been identified. Local perspective to railway area sub-systems (specific yards, branch lines, train instances). The goal of bottleneck analysis is twofold, namely, to identify and locate bottlenecks, as well as determining establishing the level of urgency associated with fixing the bottleneck. This type of analysis focuses on finding 'weak' spots in the infrastructures at a sub-system level. Weak implying that throughput performance on the local subsystem or element level is constraining to the throughput performance at higher levels of aggregation. Use of backcasting of volumes to find the breaking or tipping point in order to answer the question: what gives first? Yielding a decision whether to consider intervening.

The goal of intervention effect study's is to gauge the effectivity & efficiency of possible interventions or solution directions. The method employed in studying effects of

Challenge	Principle	Rationale And Design Implications
The problem behaves dynamically in that uncertainty exists regarding a) the volumes that the infrastructure should be capable of dealing with, and b) where the bottleneck element or sub-system is.	Should explicitly address interdependencies in time and place dynamics of subsystems	Pinpointing problems in emergent exploratory fashion is difficult in the face of highly connected systems. The capacity study processes becomes more effective when system level overview studies are undertaken that explore the interdependencies.
	Should be based on rolling planning horizons	In alignment with the forecast and plannings processess already present at the Port of Rotterdam and ProRail, the capacity study, at least at strategic level, should seek to be in line with the rolling progression of forecasts.
	Should consider uncertainty caused by stochasticity and feedback loops in the interdependencies	Without explicit addressal the role of variability, stochasticity in the railway system dynamcis, the process leaves room for subjective judgement about its effects on capacity performance and thus disagreement, while the process and decision-support tool should quantitatively
	Should consider uncertainty or at least allows forecast errors.	As forecasts are inherently uncertain, it is therefore wise not to base the entire capacity study process on forecasts alone. Rather, additional techniques such as backcasting should play a part in capacity deliberation.
	Should be supported by advanced decision support tooling	Analytical options will not sufficiently capture the complexity of railway system dynamics. This neccessitates the use of simulation models, particularly of meso-level simulation as it can take the previously mentioned macro and micro perspectives.
The effects of interventions as proposed solutions are dynamic, uncertain, volatile: a lack of reasoning regarding structure versus dynamics in the design and use of the railway network.	Should make use of systematic problem decomposition	System level overview in scanning where potentially problematic areas are, then zoom in to arrive at a smaller physical and temporal scope as well as an increased level of detail.
	Should increase the level of detail regarding subsystems at lower system aggregation levels.	At strategic level review, a narrow range of broad metrics should suffice to seperate potentially problematic trains and subsystems from those in the clear. However, in root-cause analysis, a more detailed view is needed regarding stakeholder, mode, and
	Should incorporporated decreasing length of planning horizon	A smaller range or the exploration of specific capacity problems identified in strategic reviews. This helps reduce uncertainty of assumptions, ease of execution.
	Should increase level of detail increases regarding time periods, e.g. years to months.	In the tradeoff between simulated period and runtime duration, a decreasing length of planning horizon (simulated period) can allow for more detailed metrics to be measured. Therefore, the choice to simulate only the busiest month of the year should suffice.
	Make use exact or heuristic optimisation methods	Simulation models can adress the effects of intervention due to their adaptability compared to analytical models. Yet, simulation models alone do not yield optimal (interventions to) configurations of infrastructure systems. Therefore, the process design should incorporate iterative through comperative experimentation.
Disagreement regarding the volume forecasts used	Coordination by mutual adjustment	Before using advanced simulation tools, forecasted volumes were the main parameter for adjusting capacity study outcomes.
Disagreement regarding the configuration of volume forecasts in the modelling process.	Partially Adressed in mutual adjustment: standardisation of process and content interfaces, modular interconnected processes, structured data connectivity	Volumes and process times are 'sharing' type resources. The difference in the effects of volume pruning versus process time shortening on performance is still unknown. A study into the effects of both options should be carried out, based upon mutually agreed design. A standardisation decision can be reached which reduces the dependency as it allows
Disagreement regarding the interpretation of study's operational metric outcomes	Should specify objective function(s) in mutual adjustment	Disagreements around the outcomes cannot be solved unless goals are formulated for those outcomes, i.e. define what needs to be achieved, e.g. low throughput times, or
	Modular interconnected processes	The method involved in setting-up, running of the simulation, as well as distilling outcomes is modular process in that both parties can execute it seperately. Therefore both parties gain control and understanding of the simulation at work. This strengthens the position of the simulation model as a boundary object, which delivers independent accurate and thus relatviely undisputed outcomes.
	Standardisation of process and content interfaces,	The operational metrics that have to be considered are standardised per capacity macro-process, and based upon recommendations by independent academics. Stakeholder specific operational metrics are additionally introduced in this broader spectrum of
	Structured data connectivity	As the quantitative work happens within the simulation model, parties share a joint boundary interface.
Lack of opportunity for hierarchical escalation in decision-making, which slows the process	Should hierarchically decompose decision-making	Given problems with operational metrics like ambiguity, uncertainty, and strategic use, capacity managers cannot always be expected to come to joint decisions. This necessitates options for escalating decision-making to higher decision making levels.
	Should incorporate an 'upward' flow of information' and 'downward' flow of constraints	However, information passed up must be suited to the information needs at those levels. In return, the passed down contraint, can ease further decision-making through
Experienced difficulty in follow-up in subsequent capacity decision-making processes	Increasing breadth of information shared with collaborators	Subsequent decision-making processes rely on metrics beyond the operational domain such as financial economic interpretations of operational metrics. The capacity process should incorporate these metrics, because it improves flow to subsequent processess, provides broader information base upon which decision can be made to be of better quality, and allows for the explicit incorporation of secondary stakeholders' interests.
	The quality of information shared with collaborators	Higher resolutions give greater insight into the exact location, and time of capacity problem occurence. This can help in influencing, negotiating, steering the decision-making of successive processes.
	Deep coordination-related knowledge	Deep coordination-related knowledge denotes the shared mental model i.e. knowledge of others' information base, organisational workings, and processes. A thorough understanding of these circumstances is conducive for coordination.

Table 2: Mapping of Challenges and Resolving Principles

interventions is a search that uses experiments to test falsifiable hypotheses on cause and effect relations in the infrastructure, that are borne out of the capacity framework. Not only are various alternatives tested, also variations of single alternatives are tested for their sensitivity to e.g. diminishing returns. Herein, the capacity planners use the knowledge of locality and severity of the found bottleneck in combination with the capacity framework to devise solution to capacity problems. Those solutions aim at alleviating or mitigating the negative effect such as detriments to delays, turnaround times, turnaround time reliability or any of the other applicable operational metrics from RailGenie. The number of possible interventions combinations in the railway system, as well as the uncertainty of effects can be assumed sufficiently large to warrant necessity for effect size estimation. The variety in types interventions, such as shunting yard extension, train length adjustments, is relatively small and are encompassed largely in the capacity framework. Yet, the solution space still fairly large and complex, due to a) combinations, b) uncertainty of effects, and c) feedback mechanisms. The capacity framework offers a way in which capacity planners can determine suitable interventions that satisfy the direct effects intended. It is a tool useful to systematically reason through the variables and their dependencies existing in freight railway networks in port areas.

In Investment-oriented Analysis the goal is to identify (the most) fruitful opportunities for improving infrastructure through the determination of financial-economic metrics relevant for CBA. A connection between the operational nature of tactical capacity planning and the financial-economic nature of SCBA, is natural, because they offer a way to sound decision-making in the gray areas of operation. Whereas operational indicators particularly lend themselves to decision-making in determining if a sub-system definitely is or is not a bottleneck, they fail to give the decisive answer in more gray areas.

9. Evaluation

Stakeholder workshops are organised to gather stakeholder views on the proposed design with the use of the proof of concept. In the evaluation workshops with stakeholder, the qualitative inspection by stakeholders is central. In addition to a comparison to the current state and exploration of (unexpected) detrimental effects of design therefore all form part of this evaluation process. To be precise the proposed solution process design is evaluated using three core areas of elicitation, put forward by Venable (2006) namely:

- In reflection on the proof of concept’s “usefulness” expressed in terms of effectiveness and efficacy in overcoming the perceived challenges (Checkland and Scholes, 1999).
- In direct comparison to current state processes at both Port of Rotterdam and ProRail.
- In reflection on potential (and perhaps obfuscated or surprising) long-run impacts, for better or worse in supporting capacity management processes.

9.1. Strengths

The strengths of the process design can be summarised through a division of functioning and structure of the design. The current challenges addressed through the design are furthermore coupled vis-à-vis to the identification of strengths.

In functioning, the design delivers well on measurement of system and intervention alternative performance. In the measurement of system performance, it is good that not only average system performance is measured, but also the variability of performance indicators besides making the valuable extension to robustness type indicators. Additionally, the financial-economic perspective is seen as welcome extension as the broadening of the performance indicators that alleviates disagreement regarding the interpretation of study’s operational metric outcomes

The design manages to come to the root of capacity problems, even in the current case where problems behave dynamically, with uncertainty regarding a) the volumes needed to be dealt with, and b) the location of the bottleneck. The design’s functionality in systematic decomposition aides with gathering an understanding of the problem. Compared to the current practise, it allows for a more precise definition of bottleneck locations, which in turn enables designing better interventions, and better choosing of preferred interventions.

The design aides the development of intervention alternatives and alternative's sensitivity to specific configurations. The design therefore gives explicit attention to the effects of interventions in the dynamic, uncertain, volatile railway system. Adding structured reasoning to the process, through framework use, and tests of the design and use patterns of the railway network.

In terms of structure, the design traces the rationale of capacity study choices fluently from problem to solution to execution. The design ensures full traceability of precise problem definition, compilation of (sets of) alternatives, and alternative’s specific configuration. Thereafter, the design couples actionably with subsequent processes aimed at project investment and business development, with which helps overcome the had trouble in follow-up in subsequent capacity decision-making processes. Lack of opportunity for hierarchical escalation in decision-making, which slows the process

The challenges of disagreements faced over inputs such as in the earlier capacity management processes are addressed through the simulation model as negotiation, and coordination boundary object. Meaning that ideally the disagreement regarding the magnitude and configuration of volume forecasts in the modelling process.

9.2. Weaknesses

The perceived weaknesses of the design pertain particularly to the challenge of gathering and analysing the input parameter data, while maintaining credible and valid simulation results.

The gathering and transforming of the inputs required for simulation is challenging, in so far that they precisely reflect processes as they occur in the port railway area. Questions arise like: What exactly should be measured and where? How much measurement error is embedded in the measure? What is the cost of measuring? These questions demonstrate the challenge of choosing where and what to measure in a huge technical system like the port railway system.

In turn, the calibration steps in implementing the design are considered a risky too. The calibration of the model and attuning it using gathered inputs, running the base case simulation and then comparing it to actual performance outcomes will prove challenging under an unsatisfactory body of data. This is important for two reasons pertaining to validation of the model on the one hand, and the reliability of predictions made on the other. The validity is important for establishing whether the simulation model produces accurate results, which reflect actual railway system performance. The reliability concern reflects the challenge to accurately predict the systems response to proposed interventions. To that end, a comparison needs to be made between the system’s and simulation’s sensitivity to intervention, which might prove difficult given the low amount of interventions occurring in the port railway area.

9.3. Threats

Political reasoning can pose threats to the successful use of the process design through the temptation of strategic behaviour as a result of distributive effects of capacity interventions. This threat underlines the importance of verifiability of data used as an input for capacity studies. Especially in the case of (subjective) metrics that are retrieved from expert opinion or experience questions arise regarding the auditability and verification of measures. Besides the question of how to proceed with specific disagreement regarding verification issues can be threatening, albeit that is partly incorporated in the design through the hierarchical escalation possibilities.

9.4. Opportunities

The opportunity is signalled that working the process provides incentives and insights which help further improve the process by identifying simulation model improvements, data gathering opportunities. Currently, there is a wealth of information to be gotten from the port railway area, but these opportunities are not capitalised yet. There might be too much possibilities for data gathering, of which it is unsure what the value is. Thus, when in the process of executing simulation studies, it is discovered that specific pieces of data are of value, because of assumption-building or calibration purposes, this is indicative of a need for data gathering.

10. Discussion

In the previous chapter the designed artefact is evaluated for its success, its usefulness to the clients of this research. This chapter takes a step back to evaluate the method of design employed to arrive at the artefact. This means that findings presented return on the originally identified knowledge gap of how to align organisations in capacity management processes, and the role of capacity management and coordination principles therein. In the context of design science, a threefold distinction is made to comprehensively discuss and reflect upon the research conducted, namely from the perspectives of the domain researcher, empirical researcher and helper (Wieringa, 2014).

10.1. Domain Perspective

The literature review preceding the design effort contained in this study pointed out the importance of maintaining and upholding two principles in capacity management, being integrality and optimality. Integrality being the ideal of integrally planning on railway transport system level while taking into account time and place dynamics of the railway system, from terminals to the hinterland as a whole and consider the effects of their interdepencies, e.g. possible network cascading. Whereas the optimality principle works towards the ideal of truly optimising of capacity decisions. The process of planning must work with concise, unambiguous definitions of the optimisation objectives, performance criteria and constraints as well as the use of exact or heuristic optimisation methods, i.e. algorithms. The literature review aimed at coordination theory put forward the idea that coordination processes need to be loosely coupled, and can use decision support tools as source of more or less neutral information. Loosely coupled processes mix standardization, planning and mutual adjustment of (decision making) activities, data sharing and metric interpretation.

Concluding capacity management processes such as capacity studies actionably, and conclusively proved a core challenge in this research due to the emergence of ambiguous capacity metric outcomes and absence of command and control structure in networked coordination. Out of the different indicators put forward in this research two are highlighted. The introduction of urgency as the time window for intervention making and the broadening of the capacity indicator set with economic metrics helped set a step in the desired direction. The financial economic analysis as part of capacity management forms a natural part in normative decision-making regarding whether capacity is overburdened or not, because it has a natural interpretation conducive for communicating results with colleagues, and higher-ups. Furthermore, there is limited economic capacity for railway projects.

The process that emerges from a matching of the challenges experienced and the principles identified is one that is at all stages supported by model use. The simulation is a source of great value, first through the model's working as coordinating boundary object, i.e. as source of generally accepted information about the system to overcome disagreements over assumptions and interpretations regarding inputs, dynamics, and outputs. Second, as a way to develop insight into the dynamic volatile nature of railway system capacity, in which it allows for problem definition through root cause analysis. However the risk with relying heavily on the simulation model is that it can be viewed as a perfect reflection, or even prediction of the railway system. The risk is that when the ideal cannot be measured, the measurable becomes ideal.

In the framing of the knowledge gap section 2.6, it is concluded that considerable gaps exist in how to address coordination challenges faced in the application domain of interorganisational transport coordination supported by decision-support tools. In summary, this is due to the novelty of the role of decision support tooling in coordination as boundary objects, the challenge of defining mutually agreed upon quantitative performance goals and the complexity of networked interorganisational collaboration in the context of many stakeholders. However, the literature review also finds that the maturity of principles for designing solutions stemming from coordination theory and hierarchical planning and control is rather high, due to the abundance of case studies and prevalence of articles in those directions, albeit being aimed at intraorganisational coordination and planning and control mostly. As a result, the application of these mature principles on the novel application domain, that of alignment of transport capacity coordination processes make the contribution of this thesis one of the exaptation kind, as described by Gregor & Hevner (2013).

10.2. Empirical Perspective

The research conducted ventured to validate the use of established principles to overcome coordination challenges in a specific new application domain with a single case study. From the standpoint of empirical methodology, two challenges are identified in the acceptability and valid generalisation of research findings, namely the nature of single case mechanism research and the mode of evaluation using involved stakeholders.

Although only a single case is studied at the present, we believe that the case study conducted further strengthens the validity of the principles applied. Design science research as executed here constitutes the use of an experimental artifact to further advance the goals of stakeholder while learning about the artifacts effects in situ. The artifact is exploratory, in that it is not yet transferred to the original problem situation. Therefore, the research is not an effect study of the design. Rather, that principle-based design foundation yields a design that can be validated by proof of concept through this study. Yet, there are limitations part which have to be considered thoroughly in the interpretation of results, but in turn inspire direction for further research.

The principles validated through the case study here, possibly extend beyond the applicability of the two studied organisations to other organisations that cooperate in a dyadic fashion in a network (as opposed to a hierarchy or market). Although, the case was composed of publicly funded organisations set up as legal private entities, we suspect based on the reviewed literature on networks that the principles uphold in broader application domains. We note here the advanced maturity of the principles used in composing the proposed design. A new application domain can be found in private interorganisational capacity coordination processes that are linked through supply networks, yet not through direct contractual relations. Such as those relations that occur among separate suppliers in a single client's supply network. In the case of coordination within hierarchies or markets, command and control influenced principles or price-based principles respectively would likely be more in order. These generalisations were not tested here but are written up here in the belief that further research might prove fruitful in advancing new application domains.

The method of evaluation using a proof of concept in interviewing stakeholders allows for the elicitation of feedback from stakeholders in a tangible way. In the onset of the research, there was a different plan for evaluating and iteratively improving the process design presented in this research. The idea was that the researcher would be physically present at the offices of the client while conducting the research and in that process have frequent contact with the stakeholders. Due to consequences related to Covid-19, that plan was adapted to the evaluative method presented currently in the research that includes ex post evaluation workshops and interviews. Although it helps the from an empirical perspective as accurate reporting on evaluative feedback is easier in the organised interview setting than documenting feedback arising from small daily discussions. From the helper perspective, the executed evaluation method is less desirable, because it allows for gaps between the expectations and realisations of the design, and a decreased ability to steer the design in a desirable direction, e.g. including preferred additional activities.

Separating the process design from the specifics of the case study proved difficult in evaluation. Several causes can be thought of, namely that the research concerns a current topic with some novelty involved, besides the specificity of the proof of concept results apparently conflicting, but rather counterintuitive results drawing attention away from the process design. It can be concluded that there the brief evaluation with stakeholders, whom not regularly deal with process abstraction, yields only limited results regarding the process design. Rather, the incorporation of railway management process experts would be useful to evaluate the process design.

10.3. Helper Perspective

In the discussion from the perspective of the helper, we discuss the narrow client and broad societal usefulness of the design and interpret it beyond the evaluation alone. We reflect upon how the design methodology and the ability of the design help overcome perceived challenges, but in the process are not panacea. A reflection is made on how the incorporation of broader set of data influences alignment, whether parts of the proposed design open up to (previously not explicitly observed) possibilities of strategic behaviour of organisations in turn causing misalignment and what how the RailGenie model facilitates alignment.

Instead of prescribing normatively how the performance indicators should be used to arrive at decision, we present a discussion that compares operational performance metrics with financial metrics to expose the kind of considerations that can go into evaluating the indicators. These are discussed visa vis for reasons of brevity.

The incorporation of financial economic metrics in the transport planning domain is a common feature and presents advantages compared to operational metrics. First, in that the interpretation is intuitive and natural for horizontal and vertical partners and as such present a tool for communicating about capacity performance. They are better understandable for upper management and customer facing colleagues such as the port’s business developers. Second, these metrics share a common denominator making comparisons easier. This allows for the weighing of effectiveness of interventions compared in a single unit. Unlike operational metrics, which are of various types, e.g. ordinal or categorical, and expressed in different units e.g. time, quantity or percentages. Third, they are natural to the process of capacity management precisely because investment funds themselves are scarce alike infrastructure assets. As such, efficient frontiers exist that searchable for optimal (i.e. cost-effective) bundles of interventions. Fourth, financial metrics feature clear and causal links with established standardised formulae and values. Whereas for operational values it can be difficult to pinpoint how they are derived. Five, although financial economic metrics are unlikely to convey and capture the full dimensionality of capacity performance, they are concise in reporting. They therefore can help capacity managers implement capacity evaluation systems using fewer total number of different metrics than one comprised of only operational metrics. This helps prevent measurement disintegration, the phenomenon where an overabundance of metrics becomes detrimental to the overall measurement process.

The novel inclusion of financial metrics can be a source of risk for misalignment even in the broader context, of a shared capacity framework, and simulation model, and capacity planning process. The research identified 5 disadvantages of financial metrics compared to operational metrics. First, operational data is found to be more closely aligned with strategic decisions in terms of turnaround times and punctuality. Second, while the financial statements propose, operational metrics can take a distinctly longer-term perspective especially in bottleneck analysis where the found time window for urgent action, and subsequent prioritisation inform risk management for years to come. Third, to some extend operational metrics can predict financial performance better. An intervention investment that improves customer operational satisfaction, might not lead to direct economic net benefit, but can indirectly in the long run entice (new) customers to use more train-based freight transport, as well as improve their loyalty through subsequent lock-in. Fourth, operational metrics generally show the effect of operational interventions more clearly with more detail, whereas financial transformation is generally higher-level and additionally dependent on further economic assumptions such as VoT and discount rates. Final, the financial metric does not show the status quo of the division of benefits and burdens across stakeholders in capacity management, nor does it present distributive effects caused by trends and interventions. Risk exists that the financial consequences of trends and intervention become yet another point of discussion impeding successful coordination.

This work takes the perspective of coordination of collaborating organisations with shared mutual interest under the assumption that no strategic competition for resources takes place as a result of opportunist behaviours. The structure of the transactions of organisations is such that it can lead to the strategic behaviour of opportunism given the fewness of competing organisations in the market, established positions, and information asymmetry. This thesis builds on the assumption that the cooperation is without the detrimental opportunistic behaviour, as typical characteristics have not been observed, and fitting counter arrangements are in place. Two of the behavioural character typifying opportunistic behaviour in networks according to Ten Heuvelhof (2013) have not been observed in this study, nor in previous studies (see Van der Horst & De Lange, 2008), namely: behaviours aimed at narrow self-interest or behaviours that are of ambiguous nature. Behaviour is strategic when it is aimed at narrow self-interest, given that the organisation is aware it may jeopardise the public interest. Strategic behaviour is ambiguous in that it can be framed in ways open to two interpretations, where in one it does not harm the public interest, and in the second it serves the organisations individual interest while harming the public interest. Both were not observed as part of the current process analysis. Furthermore, there are counter arrangements currently in place, such as (soft) legal contractual working in the form of memoranda of understanding, independent legal and financial monitoring and control by the supervising ministry as integral part of the decision-making processes regarding infrastructure assets, and comparable technical knowledge of railway systems.

We argue that although the proposed design opens parts of capacity management discussions to strategic behaviour, the design as a whole is more robust to potential strategic behaviour. Arguably, due to the incorporation of financial metrics as part of the larger operational set of metrics overt incentives are introduced that might inspire opportunist behaviour. The organisations involved can more quickly anticipate the results of positions they take. However, as noted before these financial economic metrics are standard practice in Dutch transport infrastructure decision-making; they are not newly introduced here. And any strategic behaviour that follows from it, therefore likely to present already albeit in hidden form, which invokes an information asymmetry among the stakeholders in the port railway area. Coordination problems dealing with information asymmetry are specifically tackled by the proposed design as multiple information related challenges have been identified and addressed through better decomposition of capacity problems, the broadening the performance measurement base, and extending the testing of alternatives and their sensitivities. This reduces the dependence of capacity management process on tacit expert knowledge, experience and subjective judgement. Furthermore, information asymmetry in computing these quantitative metrics is addressed through the decision-support tool change proposed. Whereas earlier the analytical model was solely in use by one of the parties, now a simulation tool is used that is constructed in joint agreement. As a result, the structural factor for strategic behaviour: information asymmetry is lessened overall. This goes even beyond the Port and Prorail relation to extend to broader stakeholders, where more effective communication using financial metrics enables parties to realise mutual gain in the public interest.

11. Conclusion, Limitations, Further Research

11.1. Conclusion

Overcoming the coordination challenges faced by the Port of Rotterdam and ProRail is imperative in the face of ever-growing volumes of freight in the port railway area. It requires improved alignment meaning that the internal organisation of capacity management must be made to fit the organisational objectives while simultaneously be adaptive to the changing external environment. The alignment is comprised of a systematic shared understanding of technical capacity aspects and streamlined coordination processes for navigating the technical complexity systematically. The information base on technical capacity is anchored by technical coordination principles, an overview of railway capacity management performance indicators, and a framework for reasoning about the port railway system's capacity dynamics, and discussion of decision-support models. The process coordination is anchored principles derived from process managerial coordination theory. An overview of alignment challenges is presented resulting from the capacity management process analysis conducted at both organisations. The matching of challenges perceived in alignment and the principles yields a capacity management process design comprised of four macro-processes, a strategic overview analysis, tactical bottleneck, tactical intervention, and financial economic analysis. These macro-processes are specified through process flow design, set of tailored quantitative metrics, meso-level simulation study set-up. These are subsequently evaluated through requirements and a proof of concept simulation case study that is based on the shunting yard case. As such the research followed a design science approach, where principles and challenges are matched to yield a process design. Through execution of the case study a naturalistic validation is done of the principles compiled.

11.2. Limitations

The case was conducted in the specific Dutch technical and institutional setting with the accordingly attuned interplay between port authority and infrastructure supplier, and railway network dynamics. In other countries, and even in other parts of The Netherlands dynamics may differ due to different technical layouts and specifications, institutional arrangements or decision-making processes. The validation effect from this study on principle-based design, therefore, does not automatically entail the transferability of principles applied here.

11.3. Future Research

These limitations regarding the case studies generalisability provide opportunities for future research. Firstly, through the conduction of more case studies that strengthen the validity of the research endeavour. These efforts can be made effective when conducted in adjacent research environments other national settings as problems faced here are faced elsewhere, or in different cooperation settings, such as the private supply network setting mentioned earlier. In keeping this analogic generalisation valid, coordinating organisations should be sought such that they remain close to those studied here, in terms including but not limited to hierarchical working, level of technical content to coordinate and data-intensiveness.

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