Allocating Rail Capacity through Socioeconomic and Environmental Criteria

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Preface

With great pleasure, I present my thesis on capacity allocation according to socioeconomic and environmental criteria. I wrote this thesis for my graduation from the MSc in Transport, Infrastructure & Logistics program at the TU Delft. In addition, this thesis was written as part of an internship at ProRail, specifically the Department of Capacity Management.

Following the MSc in Transport, Infrastructure & Logistics was a satisfying and fun experience. I was surprised by the additional knowledge on the transport domain that I could gain through all the courses, and I learned about several tools and skills that I can apply during my future career. Still, I experienced the MSc as challenging, given the high workload of all the courses and projects and the difficulty level of some courses. In particular, the pre-master program was demanding, representing eight courses I had to complete between my BSc and MSc. Most of these courses were mathematical, requiring a high time investment to pass the exams. However, I am still grateful for completing everything during the past three years, considering what studying at TU Delft has brought me.

In this thesis, I developed a method that applies socioeconomic and environmental criteria defined in European regulation on train services. I am proud of the method I developed: it provides decent output, works in favour of the research questions, and is supported by several colleagues within ProRail. Developing this method and writing my thesis was sometimes challenging, given the recent introduction of the regulation in July 2023. Hardly any relevant scientific documentation and exemplary frameworks were available to me, which meant that a significant amount of ideas and solutions for a method had to come from myself. This kept me motivated throughout writing this thesis, and I hope my effort led to a higher quality of the thesis.

In this preface, I would like to thank ProRail and several individuals who contributed in writing this thesis. First, I thank ProRail for accepting my application for another internship at their organisation. I already completed an internship at ProRail in 2021, and I felt honoured that I got a chance to do it once more. I loved cooperating with my colleagues at ProRail, and I had a great time working at the 'Inkpot'. In particular, I would like to thank Rik van Haaren and Renske Breevoort for their supervision during my internship. Both supervisors regularly checked in with me on my progress and personal developments. Specifically, I am thankful for Rik's acceptance of my application in October last year and for Renske's efforts to introduce me to all relevant colleagues from within and outside of ProRail.

I also would like to thank my three supervisors from the TU Delft. Firstly, I would like to thank Rob Goverde for being the chair of my graduation committee. He was happy to answer my concerns whenever I had practical or organisational questions. I appreciated how he gave me the feeling that I could always ask him for support. I am also grateful for Jan Anne Annema's support. Despite his busy agenda, he was able to join the other two supervisors and provide feedback on how to structure and motivate my research. Finally, I appreciated the support of Didier van de Velde, who often provided me with valuable knowledge on rail transport governance and continuously asked me critical questions that enhanced the quality of my thesis.

Lastly, I thank my family and friends during the past months. During my internship at ProRail, I had less time to spend with friends and family than usual, but they always understood me. In particular, I want to thank my parents, Karin and André, for their support during the MSc. They motivated and supported me in numerous ways during the pre-master and the MSc, especially when challenging moments occurred. I will forever be grateful for their love and the opportunities they crafted for me.

I aim to inspire others with my research and hope the reader can enjoy my thesis.

Utrecht, 8 July 2024
David Vlot

Summary

In July 2023, the European Commission (EC) proposed a European regulation for capacity use on the European railway network (hereafter: 'the regulation'). In the railway sector, Infrastructure Managers (IMs) allocate capacity to railway undertakings (RUs) based on national guidelines or rules. This proposed regulation includes a new approach to such capacity allocation by assessing the socioeconomic value of capacity requests according to socioeconomic and environmental criteria (SEE criteria). The methods that use the SEE criteria included in the regulation will replace the current methods on capacity resolution per country in 2030 (European Commission, 2023). Therefore, infrastructure managers (IMs) want to get insight into the potential impact of the SEE criteria on capacity allocation and whether this will affect the optimal use of the infrastructure. Developing a method that evaluates capacity requests based on these SEE criteria from the regulation is necessary since such a method has yet to be available, given the recent introduction of the regulation. This thesis has the following main research question:

- Main research question: What is the indicative impact of a method on SEE criteria on capacity allocation and railway network utilisation in the Netherlands?

Approach

This thesis creates a method for assessing capacity requests' socioeconomic value. This method is crafted using best practices across Europe and scientific literature. The method calculates the socioeconomic value of capacity requests according to the SEE criteria in the regulation, leading to a prioritisation of these capacity requests.

The application of the method took place through a case study of railway lines and associated capacity conflicts. The prioritisation of capacity requests indicates what results emerge from the method. The extent to which this result is indicative of future capacity allocation outcomes follows from the review of strategic guidance enclosed in the regulation and additional considerations. The considerations emerge through a sensitivity analysis, expert consultation, and ethical assessments.

In conjunction with the posed considerations, the method's outcome in the case study gives insight into future capacity allocation outcomes and procedures.

State of the Art

The regulation includes five SEE criteria, which ensure a non-discriminatory approach for capacity allocation when negotiation between RUs does not provide a solution. Article 8 of the regulation provides five SEE criteria according to the following formulation:

1. Operating cost for operators of rail transport services and the resulting impact on prices for customers of rail transport services;
2. Time-related cost for customers of rail transport services;
3. Connectivity and accessibility for people and regions served by the rail transport services;
4. Emissions of greenhouse gases, local air pollutants, noise and other external cost of rail transport services and by their likely alternatives;
5. Safety and public health implications of rail transport services and their likely alternatives (European Commission, 2023).

Neither the current approach for capacity allocation in the Netherlands through the 'Algemene Maatregel van Bestuur' (AMvB) nor the Timetable Redesign for Smart Capacity Management project related to the regulation provides suitable frameworks for applying SEE criteria. Only in Norway and Sweden do the IMs use methods that allocate capacity through a socioeconomic evaluation of capacity requests.

Swedish IM Trafikverket shifts the train paths from the capacity requests in the time-distance diagram to find different solutions for capacity conflict. In the end, the socioeconomic value of each emerging plan (timetable) is calculated and used to choose the socioeconomically preferred conflict resolution (RISE & VTI, 2024). Norwegian IM Bane NOR calculates the loss of utility when a specific capacity request does not receive access. Ultimately, the capacity request with the highest possible total utility

loss receives capacity access, ensuring that the total utility loss to society is as low as possible (Bane NOR, 2023).

Finally, the Norwegian method is deemed more applicable as a 'blueprint' for a method to the European SEE criteria compared to the Swedish method. This finding holds because the Norwegian approach evaluates a broader range of rail transport effects compared to the Swedish approach and, therefore, has a higher chance of aligning with European SEE criteria in a better way.

Method

The method developed in this thesis calculates the utility loss across the regulation's five SEE criteria. The following effects across the criteria can occur when a capacity request cannot receive capacity access:

- SEE criterion 1 – operating costs: The RU has to cover its fixed costs with fewer operating train services. A decrease in the number of running trains creates a price increase to customers. The additional money all customers spend on train travel is a loss in utility.
- SEE criterion 2 – time-related costs: goods or passengers must receive transport through alternative train connections. These trains could have a longer travel time or require transfers between multiple trains. Such travel and transfer time can emerge by finding the connection of train services with the shortest possible travel time that provides an alternative to passengers or goods impacted by the rejection of the capacity request. The increase in total time spent on travel across all passengers or goods represents the utility loss on this criterion.
- SEE criterion 3 – connectivity and accessibility: the frequency of the total train service decreases following the rejection of a capacity request. This development happens because, when the capacity request did receive capacity access, the passenger or shipper could have more train services to choose from compared to the scenario when the capacity request did not receive capacity access. Such frequency decrease leads to a longer time window before each next train departs. The additional time spent waiting for the next train to arrive represents the utility loss on this criterion.
- SEE criterion 4 and 5 – external costs, safety and public health: Given the interdependencies between these two SEE criteria, these SEE criteria receive a simultaneous evaluation. When a train service receives no capacity access, train travel becomes less attractive to customers. This development leads to a shift in some passengers from the train to other modes of transport. The increase in external effects caused by these modal shifts is a loss in utility.

Expressing the outcome per SEE criterion happens through the utility unit, representing the total satisfaction of consuming a good or service (Kirkbride-Smith, 2014). Calculating the total utility loss per capacity request is possible by summing up the utility losses corresponding to each of the abovementioned SEE criteria. The request with the highest total utility loss receives capacity access. Besides the input data on the capacity request that the RU should provide, the method uses several assumptions and parameters as part of its calculation.

Case Study Results

Applying the developed method to the case study follows next, which entails conflicting capacity requests on the Deventer—Bad Bentheim railway line. There are two capacity conflicts on the railway line. Within each conflict, capacity requests from Public Service Obligation (PSO) and open-access train services compete for capacity.

The method's prioritisation differs for both conflicts compared to what one would expect according to the Dutch AMvB. The method favours for the case study open-access train services, whereas the AMvB favours PSO train services. These differences stem from the notion that the method does not distinguish PSO train services from open-access train services. In contrast, the AMvB generally prioritises PSO train services over open-access train services.

In addition, train services prioritised according to the method also show how RUs can behave when they want a higher chance of receiving capacity access: they can use trains with a higher capacity, stop at more stations, cover longer routes, and run outside peak hours.

Strategic Guidance

According to the regulation, member states may provide their IM with strategic guidance on allocating capacity across capacity requests. For the Netherlands, the strategic guidance could include the following four aspects:

- General objectives of the national rail policy. The contour note of the 'Toekomstbeeld Openbaar Vervoer 2040' (TBOV) defines these general objectives.
- An outlook on the development of rail infrastructure. The development of rail infrastructure in the Netherlands takes place through the 'Programma Hoogfrequent Spoor' (PHS), TBOV, and the Trans-European Transport Network (TEN-T) regulation.
- General requirements and guidelines regarding the use of rail infrastructure capacity. The line network plan from TBOV covers this aspect.
- An outlook on the planned development of rail services operated under public service obligations. The national and regional PSOs from governing bodies awarded to the RUs show the future ambitions for Dutch rail transport (European Commission, 2023).

After evaluating a capacity request with the four abovementioned aspects, one can see whether or not a train service from this capacity request aligns with the strategic guidance. For the case study of railway lines, the selection of the best-performing train services according to strategic guidance aligns with the prioritisation order according to the method on SEE criteria. Therefore, this shows that, in this case, open-access trains fit the Dutch transport policy objectives better than PSO trains. Still, the definitive impact of strategic guidance on capacity allocation depends on whether it prevails over the SEE criteria in cases where there is a disagreement between the two systems on the outcome.

Considerations

The meaning and validity of the case study results emerge through sensitivity analysis, expert review, and ethical deliberations. The sensitivity analysis and the interviews with experts highlight the possible effects of the included parameters on the outcome of the method. Therefore, proving the non-discriminatory nature of the method through calibration is vital. Such calibration ensures the method can apply to various cases and distribute capacity fairly.

The method's strengths are its transparency, traceability, and ease of understanding. In addition, the method can induce the societal-driven behaviour of RUs. These strengths can occur by challenging them to create capacity requests with high socioeconomic value and by making it more attractive to negotiate conflict resolutions with one another. Ultimately, the final capacity allocation could lead to a train product with a higher socioeconomic value to the customer.

Justice theories reveal the method's ethical impacts (Pereira, Schwanen, & Banister, 2017). The method prioritises train services that bring the highest societal benefits to the greatest groups of individuals. There is a risk that the method, therefore, could give less priority to the benefits that could apply to train services used by minorities, like regional train services.

Conclusions

Two types of impacts on capacity allocation can emerge: impact on the capacity allocation processes and the capacity allocation outcomes.

Considering the impact of using SEE criteria on capacity allocation processes, RUs will behave more beneficially to society. This behaviour occurs when RUs aim to increase the socioeconomic value of their capacity request. Given that the outcome the method produces is unknown beforehand to the RUs, the method can cause RUs to find more solutions to capacity conflicts during the negotiation phases of the capacity allocation processes. More solutions found in negotiation can lead to a higher acceptance of capacity requests.

Considering the impact of using SEE criteria on capacity allocation outcomes, the method prioritises open-access train services more than the AMvB currently used in the Netherlands. This finding is valid for the case study of railway lines and the method designed in this thesis. Following ethical concerns, the method should improve its ability to support the regional accessibility function of rail public transport.

This result on capacity allocation outcome is indicative, given that the method 'objectifies' the characteristics of train services. The method uses assumptions and parameters to calculate utility losses, and these two aspects of the method influence its sensitivity. Calibrating the method through multiple runs on multiple cases of capacity allocation can tackle the concerns but can lead to new outcomes.

Discussion

This thesis is one of the first contributions to scientific research on socioeconomic capacity allocation, following the limited availability of scientific sources and best practices. Therefore, the method in this thesis is one of the first proposals for such capacity allocation. The method finds its strength in applying Random Utility Theory (RUT) and using Norwegian IM Bane NOR approaches and scientific literature. Scientific researchers are encouraged to expand this thesis' method or use methods with different fundamentals, like the approach used by Swedish IM Trafikverket. Such new methods can help solve the concerns raised on the method developed in this thesis.

The result of applying the method on the case study railway line indicates, in extreme cases, that a new organisation of rail passenger transportation in the Netherlands could emerge, with more competition on the tracks and fewer steering opportunities for the Ministry of Infrastructure and Water Management. Besides the chosen method, assumptions, and parameters, the extent to which such developments occur depends on the possible impact of strategic guidance and the coordinating role the Ministry could adopt. Still, preparing legislation and policies that ensure the service of particular train stations when such development occurs could be helpful.

The following recommendations apply to the method:

- Make the method capable of slightly modifying the capacity requests to allow more capacity requests to receive access.
- Replace some of the assumptions in the method with additional input variables or parameters. In addition, a correction on inflation to all parameters should occur by considering one base year for all data. These amendments can all increase the quality of the method.
- Include minimal frequencies per train segment in the method following the discussed ethical considerations.

Samenvatting

In Juli 2023 publiceerde de Europese Commissie een voorstel voor een verordening omtrent het gebruik van spoorweginfrastructuurcapaciteit in de gemeenschappelijke Europese spoorwegruimte (hierna: 'de verordening'). In de spoorsector kennen spoorbeheerders capaciteit toe aan vervoerders op basis van richtlijnen en wetgeving. De voorgestelde verordening bevat een aanpak om capaciteit te verdelen langs sociaaleconomische en milieu-gerelateerde criteria (afgekort in het Engels naar 'SEE criteria'). De huidige methodes die in elke lidstaat capaciteit verdelen worden in 2030 vervangen door methodes die gebruikmaken van de SEE criteria uit de verordening (Europese Commissie, 2023). Om deze reden willen spoorbeheerders inzage krijgen in de potentiële impact van SEE criteria op capaciteitsverdeling en de benutting van de infrastructuur. Het ontwikkelen van een methode die capaciteitsaanvragen evalueert langs de SEE criteria uit de verordening is hierbij voorwaardelijk. Dit komt doordat zo'n methode ten gevolge van de recente introductie van de voorgestelde verordening nog niet beschikbaar is. Deze scriptie heeft de volgende hoofdvraag:

- ⊃ Hoofdvraag: Wat is de indicatieve impact van een op SEE criteria gebaseerde methode op capaciteitsverdeling en netwerkbenutting?

Aanpak

Deze scriptie creëert een methode die de sociaaleconomische waarde van capaciteitsaanvragen beoordeelt. Deze methode wordt vormgegeven op basis van praktijkvoorbeelden uit Europa en wetenschappelijke literatuur. De methode berekent de sociaaleconomische waarde van een capaciteitsaanvraag op basis van de SEE criteria uit de verordening, wat leidt tot een prioritering van deze aanvragen.

De methode is toegepast op een case study spoorlijn die capaciteitsconflicten kent. De prioritering van capaciteitsaanvragen uit de case study geeft een indicatie van de uitkomsten die kunnen volgen op basis van de methode die ontwikkeld is. De mate waarin deze uitkomst de daadwerkelijke toekomstige verdeling van capaciteit zal zijn hangt af van de strategische richtsnoeren zoals geformuleerd in de verordening en een aanvullende beschouwing. De beschouwing vindt plaats aan de hand van een gevoeligheidsanalyse, de consultatie van experts en ethische afwegingen.

De uitkomst voor de case study op basis van de methode in samenhang met de beschouwing geeft inzicht in de voorziene uitkomsten en processen van capaciteitsverdeling.

De stand van zaken

De verordening bevat vijf SEE criteria, welke een niet-discriminerende verdeling van capaciteit mogelijk moet maken indien een onderhandeling tussen vervoerders en de spoorbeheerder niet tot een uitkomst leidt. Artikel 8 van de verordening biedt de volgende omschrijvingen van de vijf criteria:

1. Exploitatiekosten voor exploitanten van spoorvervoersdiensten en de daaruit voortvloeiende gevolgen voor de prijzen voor klanten van spoorvervoersdiensten;
2. Tijdsgerelateerde kosten voor klanten van spoorvervoersdiensten;
3. Connectiviteit en toegankelijkheid voor mensen en regio's die door de spoorvervoersdiensten worden bediend;
4. Broeikasgasemissies, lokale luchtverontreiniging, lawaai en andere externe kosten van spoorvervoersdiensten en de aannemelijke alternatieven daarvoor;
5. Gevolgen voor de veiligheid van de spoorvervoersdiensten en voor de volksgezondheid, en de aannemelijke alternatieven daarvoor (Europese Commissie, 2023).

Noch de huidige verdeling van capaciteit in Nederland op basis van de 'Algemene Maatregel van Bestuur' (AMvB), noch Timetable Redesign (TTR) gerelateerd aan de verordening zijn geschikt als kader voor de toepassing van SEE criteria. Alleen in Noorwegen en Zweden gebruiken de spoorbeheerders methodes die capaciteitsverdeling op basis van een sociaaleconomische evaluatie van capaciteitsaanvragen mogelijk maakt.

De Zweedse spoorbeheerder Trafikverket verplaatst de treinpaden in het tijd-wegdiagram om oplossingen voor capaciteitsconflicten te vinden. Uiteindelijk wordt de sociaaleconomische waarde van elk gevonden plan (dienstregeling) berekend en gebruikt om de sociaaleconomische meest gewenste conflictoplossing te vinden (RISE & VTI, 2024). De Noorse spoorbeheerder Bane NOR berekent het utiliteitsverlies als een bepaalde capaciteitsaanvraag niet gehonoreerd wordt. Uiteindelijk ontvangt de capaciteitsaanvraag met het hoogst mogelijke utiliteitsverlies capaciteit, waardoor wordt gegarandeerd dat het totale utiliteitsverlies voor de maatschappij zo laag mogelijk is (Bane NOR, 2023).

Alles overwegend is de Noorse methode ten opzichte van de Zweedse methode het meest geschikt als 'blauwdruk' voor een methode die de SEE criteria toepast. Deze vaststelling is geldig aangezien de Noorse aanpak een breder palet aan spoor-gerelateerde effecten evalueert vergeleken met de Zweedse aanpak en daarmee beter overeenkomt met de voor Europa geformuleerde SEE criteria.

Methode

De in deze scriptie ontwikkelde methode berekent het utiliteitsverlies langs de vijf SEE criteria uit de verordening. De volgende effecten treden op als een bepaalde capaciteitsaanvraag geen capaciteit toegekend krijgt:

- SEE criterium 1 – exploitatiekosten: De vervoerder moet zijn vaste kosten dekken langs minder operationele treindiensten. Een afname in het aantal rijdende treinen creëert een prijsstijging voor klanten. De extra uitgaven door klanten aan treinvervoer is daarmee een utiliteitsverlies.
- SEE criterium 2 – tijd gerelateerde kosten: Goederen of passagiers moeten getransporteerd worden door middel van alternatieve treinverbindingen. Deze treinen kunnen een langere reistijd of overstappen tussen meerdere treinen teweegbrengen. Zulke reis- en overstaptijd kan bepaald worden door de verbinding aan treinen te vinden die een zo kort mogelijke reistijd kent voor passagiers en goederen die geraakt worden door de niet gehonoreerde capaciteitsaanvraag. De totale toename in gespendeerde tijd aan het reizen per trein langs alle passagiers en goederen vertegenwoordigt het utiliteitsverlies met betrekking tot dit criterium.
- SEE criterium 3 – connectiviteit en toegankelijkheid: De frequentie van de totale treindienst neemt af indien de capaciteitsaanvraag geen capaciteit toegekend krijgt. Deze ontwikkeling komt voor omdat wanneer capaciteitsaanvragen wel gehonoreerd worden, de passagier of verlader uit meer treindiensten kan kiezen vergeleken met een scenario waarin de capaciteitsaanvraag niet gehonoreerd wordt. Zo'n afname in frequentie leidt tot een langer tijdvenster voordat de volgende trein zal vertrekken voor de klant. De extra tijd die de klant spendeert aan het wachten op het vertrek van de volgende trein vertegenwoordigt het utiliteitsverlies met betrekking tot dit criterium.
- SEE criteria 4 en 5 – externe kosten, veiligheid en publieke gezondheid: Gegeven de afhankelijkheden tussen deze twee SEE criteria worden deze criteria tegelijkertijd onderzocht. Wanneer een treindienst geen capaciteit toegekend krijgt wordt het reizen per trein minder aantrekkelijk voor klanten. Deze ontwikkeling leidt tot een 'modal shift', waarbij sommige klanten de trein inruilen voor alternatieve modaliteiten. De toename van externe effecten veroorzaakt door deze alternatieve modaliteiten is een utiliteitsverlies.

De uitkomst per SEE criterium wordt uitgedrukt door middel van de eenheid utiliteit, welke de algehele tevredenheid van de consumptie van een bepaald product of bepaalde dienst vertegenwoordigt (Kirkbride-Smith, 2014). Het berekenen van het utiliteitsverlies per capaciteitsaanvraag is mogelijk door het sommeren van alle utiliteitsverliezen die optreden langs de bovengenoemde SEE criteria. De capaciteitsaanvraag met het hoogste totale utiliteitsverlies krijgt capaciteit toegekend. Naast de inputdata die de vervoerder ten behoeve van zijn capaciteitsaanvraag dient aan te leveren, gebruikt de methode een aantal aannames en parameters om de berekeningen te kunnen uitvoeren.

Case study resultaten

De ontworpen methode wordt toegepast op een case study, welke capaciteitsconflicten op de spoorlijn Deventer – Bad Bentheim behelst. Er treden twee capaciteitsconflicten op langs deze spoorlijn. Binnen elk conflict concurreren capaciteitsaanvragen van concessievervoerders en vervoerders opererend in open toegang met elkaar.

De prioritering van conflicterende capaciteitsaanvragen door de methode wijkt af van wat men zou verwachten op basis van de Nederlandse AMvB. De methode kent voor de case study prioriteit toe aan de treindiensten in open toegang, terwijl de AMvB prioriteit toekent aan concessietreinen. Deze verschillen komen voor op basis van het gegeven dat de methode geen onderscheid maakt tussen treindiensten uit een concessie en treindiensten in open toegang. Dit geldt niet voor de AMvB, welke in het algemeen concessietreinen boven treindiensten in open toegang rangschikt.

Verder geeft deze prioritering van treindiensten op basis van de methode aan hoe vervoerders zich kunnen gedragen indien ze hun kansen op het verkrijgen van capaciteit willen vergroten. Vervoerders kunnen treinen met een hogere capaciteit inzetten, op meer stations halteren, langere routes bedienen en buiten de spitsuren blijven doorrijden.

Strategische richtsnoeren

Volgens de verordening kunnen lidstaten hun spoorbeheerders voorzien van strategische richtsnoeren bij het verdelen van capaciteit. In het geval van Nederland kunnen de strategische richtsnoeren op de volgende aspecten betrekking hebben:

1. Algemene doelstellingen van het nationaal spoorwegbeleid: De contourennota van het 'Toekomstbeeld Openbaar Vervoer 2040' (TBOV) definieert deze algemene doelstellingen.
2. De verwachte ontwikkelingen van de spoorweginfrastructuur: De ontwikkeling van de spoorweginfrastructuur in Nederland vindt plaats op basis van het 'Programma Hoogfrequent Spoor' (PHS), het TBOV en de verordening omtrent de Trans-Europese Transportnetwerken (TEN-T).
3. Algemene eisen en richtsnoeren met betrekking tot de benutting van spoorweginfrastructuurcapaciteit: De netwerkkaarten uit het TBOV vervullen dit aspect.
4. De vooruitzichten met betrekking tot de geplande ontwikkelingen van spoordiensten die in het kader van openbaredienstverplichtingen worden geëxploiteerd: De nationale en regionale concessies die overheidsorganen aanbesteden aan vervoerders geven inzicht in de toekomstige ambities voor het Nederlandse spoorweggebonden vervoer (Europese Commissie, 2023).

Na het evalueren van een capaciteitsaanvraag op basis van de vier bovengenoemde aspecten kan men zien in hoeverre een treinserie overeenkomt met de strategische richtsnoeren. Voor de spoorlijn uit de case study zijn de capaciteitsaanvragen die voorkeur genieten op basis van de strategische richtsnoeren ook de capaciteitsaanvragen die voorkeur genieten op basis van de methode omtrent SEE criteria. Dit laat zien dat, in dit geval, treindiensten in open toegang beter aansluiten op doelen van Nederlands transportbeleid dan concessietreinen. Desondanks geldt dat de definitieve impact van de strategische richtsnoeren op capaciteitsverdeling afhangt van in hoeverre de strategische richtsnoeren prevalleren over de SEE criteria in het geval dat beide systemen het niet meer elkaar eens zijn over de uitkomst van capaciteitsverdeling.

Beschouwing

Een beschouwing van de betekenis en geldigheid van de case study resultaten volgt op basis van een gevoeligheidsanalyse, beoordelingen van experts en ethische beraadslagingen. De gevoeligheidsanalyse en interviews met experts benadrukken het mogelijke effect van parameters op de uitkomsten van de methode. Om die reden is het van belang om een kalibratie van de methode uit te voeren en aan te tonen dat deze niet-discriminerend is. Zo'n kalibratie zorgt ervoor dat de methode toegepast kan worden op meerdere casussen en capaciteit eerlijk kan verdelen.

De kracht van de methode zit in zijn transparantie, traceerbaarheid en begrijpelijkheid. Bovendien kan de methode vervoerders aansporen om maatschappelijk gewenst gedrag te vertonen. Dit laatste kan inhouden dat vervoerders capaciteitsaanvragen met een grote sociaaleconomische waarde indienen, of dat vervoerders meer capaciteitsconflicten in onderhandeling willen oplossen. Ten langen leste zou de uiteindelijke capaciteitsverdeling kunnen leiden tot een beter treinproduct voor de klant.

Rechtvaardigheidstheorieën kunnen de impact van de methode op het gebied van ethiek weergeven (Pereira, Schwanen, & Banister, 2017). De methode kent prioriteit toe aan treindiensten die de grootste maatschappelijke baten kunnen leveren voor de grootste groep aan individuen. Er is echter een risico dat de methode hierdoor minder prioriteit toekent aan voordelen die van toepassing zouden kunnen zijn op treindiensten gebruikt door minderheden, zoals de regionale treindiensten.

Conclusies

Twee vormen van impact op capaciteitsverdeling kunnen voorkomen, namelijk op processen en uitkomsten van capaciteitsverdelingen.

Aangaande de impact van het gebruik van SEE criteria op processen van capaciteitsverdeling geldt dat vervoerders meer maatschappelijk voordelig gedrag zullen vertonen. Dit gedrag komt voor zodra vervoerders het doel hebben om de sociaaleconomische waarde van hun capaciteitsaanvraag te vergroten. Aangezien de uitkomst van de methode onbekend zal zijn voor de vervoerders voordat deze toegepast wordt, kan de methode vervoerders ertoe verleiden om meer capaciteitsconflicten in onderhandeling met elkaar en met de spoorbeheerder op te lossen. Dit kan tot gevolg hebben dat meer capaciteitsaanvragen geaccepteerd zullen worden.

Aangaande de impact van het gebruik van SEE criteria op de uitkomst van capaciteitsverdeling geldt dat de methode meer prioriteit toekent aan treindiensten in open toegang ten opzichte van de momenteel in Nederland gebruikte AMvB. Deze uitkomst is geldig voor de spoorlijn uit de case study en de methode ontwikkeld binnen deze scriptie. In reactie op de ethische overwegingen zal de methode beter in staat moeten worden gebracht om de regionale functie van spoorweggebonden openbaar vervoer te ondersteunen.

Deze uitkomst van capaciteitsverdeling is indicatief, aangezien de methode de karakteristieken van treindiensten objectief maakt. De methode gebruikt aannames en parameters om utiliteitsverliezen te berekenen, en deze twee aspecten beïnvloeden de gevoeligheid van de methode. Het kalibreren van de methode door deze meermaals te 'runnen' op meerdere casussen van capaciteitsverdeling kan de geuite zorgen aanpakken en tegelijkertijd tot nieuwe uitkomsten leiden.

Discussie

Deze scriptie vertegenwoordigt één van de eerste bijdragen aan wetenschappelijk onderzoek omtrent sociaaleconomische verdeling van capaciteit, aangezien er beperkt wetenschappelijke literatuur en referentieprojecten beschikbaar zijn. Om die reden is de methode in deze scriptie één van de eerste voorstellen om zulke vormen van capaciteitsverdeling uit te voeren. De methode vindt zijn kracht in zijn toepassing van de 'Random Utility Theory' (RUT) en de benutting van ervaringen uit Noorwegen en kennis uit wetenschappelijke literatuur. Wetenschappelijke onderzoekers worden aangemoedigd om de methode uit deze scriptie uit te breiden of methoden te gebruiken met andere basisbeginselen, zoals het geval is voor de methode gebruikt door de Zweedse spoorbeheerder Trafikverket. Zulke nieuwe methodes kunnen mogelijk kritieken op de methode ontwikkeld binnen deze scriptie beantwoorden.

De uitkomst van de toepassing van de methode op de spoorlijn uit de case study laat zien dat in het uiterste geval een nieuwe marktordening op het Nederlandse spoor kan ontstaan. Hierbij kan meer concurrentie op het spoor en een beperktere mogelijkheid tot sturing vanuit het Ministerie van Infrastructuur en Waterstaat optreden. Naast de methode, aannames en parameters hangt de mate waarin dit zal voorkomen af van de mogelijke impact van strategische richtsnoeren en de coördinerende rol van het ministerie. Desalniettemin is het voorbereiden van beleid en wetgeving nuttig om ervoor te zorgen dat bepaalde treinstations bediend blijven mochten de hier beschreven ontwikkelingen zich voordoen.

De volgende aanbevelingen zijn van toepassing op de methode:

- Maak de methode geschikt om capaciteitsaanvragen beperkt aan te passen zodat meer capaciteitsaanvragen gehonoreerd kunnen worden.
- Vervang enkele van de aannames in de methode door extra input variabelen en parameters. Verder wordt een inflatiecorrectie aangeraden die voor alle parameters een zelfde basisjaar toekent. De som van deze aanpassingen zal de kwaliteit van de methode verbeteren.
- Overweeg het gebruik van minimale frequenties per trein segment in de methode als reactie op de ethische beschouwing in deze scriptie.

Content

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List of Abbreviations

ACM	Authority for Consumers and Markets
Aml	(The railway station of) Almelo
AMvB	'Algemene Maatregel van Bestuur' (General Administrative Measure)
Bh	(The railway station of) Bad Bentheim
CNA	Capacity Needs Announcements
Dv	(The railway station of) Deventer
EC	European Commission
EEA	European Economic Area
ENIM	European Network of Infrastructure Managers
ERFA	Rail Freight Association
ERTMS	European Rail Traffic Management System
EU	European Union
FR	Freight trains
FTE	Forum Train Europe
GHG	Greenhouse gas
Hgl	(The railway station of) Hengelo
HVO	Hydrotreated Vegetable Oil
HST	High-speed train for passenger
I&W	Ministry of Infrastructure and Water Management
IC	Intercity or long-distance trains for passengers
IM	Infrastructure manager
IMA	'Integrale Mobiliteitsanalyse' (Integral Mobility Analysis)
LOS	Level Of Service
NST	Standard goods classification for transport statistics
PAH	Polycyclic Aromatic Hydrocarbons
PHS	'Programma Hoogfrequent Spoor' (Program High-frequency Rail)
PSO	Public Service Obligation
RE	Regional trains for passengers
RISE	Research Institute of Sweden
RNE	RailNetEurope
RU	Railway undertaking
RUT	Random Utility Theory
SCBA	Social-cost-benefit analysis
SEE criteria	Socioeconomic and environmental criteria
TBOV	'Toekomstbeeld Openbaar Vervoer 2040' (Future Vision for Public Transport 2040)
TEN-T	Trans-European Transport Network
TCR	Temporary Capacity Restrictions
TTR	Timetable Redesign
VoT	Value of Time
VoTTS	Value of Travel Time Savings
VTI	Swedish National Road and Transport Research Institute
WLO	'Welvaart en Leefomgeving' (Prosperity and Living Environment)

1 Introduction

This thesis discusses the impact of socioeconomic and environmental criteria (SEE criteria) on rail capacity allocation and railway network utilisation. Through the motivation and scope of the research, a definition of the problem emerges. Solving the formulated problem takes place utilising research questions and research methods.

1.1 Motivation

In July 2023, the European Commission (EC) proposed a European regulation for capacity use on the European railway network (hereafter: 'the regulation'). According to the European Commission (2023), the regulation aims to harmonise the allocation of capacity on the European rail network across all European Union (EU) member states and thus enhance rail transport within the union. The main goal of the regulation is 'to lay down a framework allowing rail infrastructure capacity and traffic to be managed more efficiently, thereby improving the quality of services and accommodating more traffic on the railway network'. The regulation includes several innovations, including the use of socioeconomic and environmental (SEE) criteria to be applied by the infrastructure manager (IM) during the annual allocation process for conflict-solving between different train type segments (long and short-distance passenger rail transport and freight rail transport) and between different capacity requests by competing railway undertakings (RUs) within these segments.

Several EU member states currently have their prioritisation methods for capacity allocation. When the use of a railway line is congested, and negotiations between RUs and IM do not lead to a solution, these methods allow for a decision on which request from a RU receives the capacity to access. This principle means that the prioritised rail transport service receives capacity access and that other rail transport services receive capacity access within the remaining capacity or not at all if no capacity is left. In a situation of complete scarcity, the IM starts a capacity enhancement plan that assesses how the available capacity on the concerned railway line can increase to aid the issues. Afterwards, the IM conducts a conflict-resolving procedure, deciding which conflicting requests receive capacity access.

The national priority rules per country will be replaced in 2030 by the SEE criteria from the regulation. Therefore, IMs want to get insight into the potential impact of the SEE criteria on capacity per train type segment and whether this will affect the optimal use of the infrastructure. One of the IMs is ProRail in the Netherlands, which manages one of Europe's most dense railway networks according to Bešinović (2020). Given the recent introduction of the regulation, the status of the regulation as a 'proposal', and the current lack of a method that operationalises the European SEE criteria, giving direction on the development of this new approach to allocating capacity is still possible. Therefore, ProRail also wants to know which method leads to which utilisation of the railway network.

1.2 Scope

The scope considers the aspects of SEE criteria and capacity allocation that are part of the research and the railway line that is part of the case study.

1.2.1 Capacity Allocation

The regulation considers a range of topics related to the infrastructure capacity of the European railway network. These topics include, for example, stakeholder consultation and framework agreements. Therefore, this research's scope is the regulation articles that assess scheduling and capacity allocation.

Considering the SEE criteria, only the criteria described in the regulation are part of the research. Other descriptions of SEE criteria defined outside of the regulation or by IMs are thus not assessed. However, other applications of SEE criteria are part of the literature review to find which method is most suitable for allocating capacity based on the SEE criteria from the regulation.

1.2.2 Case Study

The case study of the research represents an assessment of the railway line between Deventer and the Dutch/German border near Bad Bentheim. This railway line has a length of around 72 kilometres and processes both domestic, national and international passenger trains and freight trains. Figure 1-1 contains a map of the railway line.

Figure 1-1: The railway line running from Deventer via Almelo and Hengelo to the Dutch/German border near Bad Bentheim (OpenRailwayMap, 2024).

The operation of railway lines is conflicted with several challenges. The most significant challenge involves the number of requests from RUs to run trains in open access that apply to these railway lines. Several of these requests are international train services between destinations in the Netherlands and Germany, which align with the ambitions of the involved national and regional governments (van Kuijeren, 2024). The capacity requests are 'in competition' with one another for the usage of a limited amount of train paths on the line, or these requests compete with train paths currently used by trains running based on a PSO. The number of train paths does not allow for easy extension due to the high number of sections of the infrastructure network that limit the capacity.

There is the remark that several train services use only specific parts of the entire railway line between Deventer and Bad Bentheim. The train services that connect two stations or more on the railway line are thus also included in the case study. This notion implies, for example, that the regional train service between Zwolle and Enschede is included in the case study since it serves five railway line stations between Wierden and Hengelo. In contrast, the regional train service between Hardenberg and Almelo is excluded from the case study since it only serves the Almelo station on the railway line.

1.3 Problem Definition

A review of the regulation shows that network effects can emerge after implementing SEE criteria for capacity allocation. Since SEE criteria are within Europa only applied by the IMs of Sweden and Norway, according to Stojadinović, Bošković, & Bugarinović (2019), for most countries in the EU, introducing a method on SEE criteria primarily for capacity allocation implies a replacement of current national capacity allocation methods. Changes to capacity allocations can lead to different capacity accepted requests between competing capacity requests since other aspects are part of the evaluation. Since capacity requests differ, for example, in running times and stopping patterns, and there is high interaction between trains running on densely used railway networks like in the Netherlands, network effects can emerge after implementing SEE criteria. Using a specific method employing SEE criteria can thus significantly define the attributes of these network effects.

Another driving force behind these network effects is that using SEE criteria can also affect the behaviour of RUs concerning the capacity request they deliver to the IM. Given the introduction of the four Railway Packages on European legislation for the railway sector and its' induced competitive pressure between RUs, these train operators are eager to claim capacity when the availability of capacity is scarce. If RUs alter their capacity requests to increase their chances of receiving capacity access, additional effects on the railway system occur.

Considering the previous findings, the following problem statement emerges:

- ⊃ Problem statement: The impact of the proposed European approach for capacity allocation through a method on SEE criteria is unknown in terms of the effects on the railway network and the capacity requests.

Creating a method based on SEE criteria can aid in solving the problem statement since this method provides a capacity allocation outcome that indicates these possible impacts. Applying the method to the case study leads to a specific utilisation of the railway infrastructure. The utilisation outcome indicates what behaviour RUs might show during the capacity allocation. In addition, the utilisation outcome gives insight into the desirability of the developed method and possible recommendations for further improvement. Since the application of the method only includes one case study, the results could merely indicate this desirability and the recommendations.

Considering the previous finding, the following research objective emerges:

- Research objective: To create a method that defines the socioeconomic and environmental value of a capacity request through European criteria and show the possible effects of these criteria on network utilisation and capacity allocation procedures.

1.4 Research Questions

Several research questions structure the research and aid in resolving the problem statement and research objective. These research questions entail a division into the main research question and sub-questions. Based on the problem statement and research objective, the following main research question applies:

- Main research question: What is the indicative impact of a method on SEE criteria on capacity allocation and railway network utilisation in the Netherlands?

The main research question allows a distinction into the following sub-questions:

- Sub-question 1: Which methods for applying SEE criteria are currently available, and to what extent do these methods align with the criteria defined in the regulation?
- Sub-question 2: How does the method for capacity allocation calculate the socioeconomic value of capacity requests across the SEE criteria in the regulation?
- Sub-question 3: What result on capacity allocation emerges when one applies the method on the case study railway line Deventer – Bad Bentheim?
- Sub-question 4: How do the results from the method for the case study relate to strategic guidance?
- Sub-question 5: How indicative are the results, considering the sensitivity and applicability of the method?

The first sub-question helps define what knowledge gap the method should tackle. The chapter first assesses the regulation and the closely related Timetable Redesign. A literature review takes place to find currently available methods related to SEE criteria. Based on the findings, the knowledge gap is defined, which defines to what extent current methods that apply SEE criteria are compatible with the regulation.

The second sub-question revolves around a method that can calculate the socioeconomic value of a capacity request. This question answers the knowledge gap from sub-question 1 by creating a method compatible with the SEE criteria defined in the regulation.

The method evaluates the Deventer – Bad Bentheim case study railway line for the third sub-question. By comparing the prioritization of the conflicting capacity request according to the current Dutch allocation method with the prioritization according to the method from sub-question 2, the impact of the method on capacity allocation and network utilisation becomes apparent.

A vital article in the regulation that influences capacity allocation besides the SEE criteria is Article 11 on strategic guidance. A qualitative assessment of strategic guidance applicable to the case study railway line gives insight into the relation between the method and strategic guidance. This assessment takes place for the fourth sub-question.

The final sub-question allows for a general assessment of the method. It discusses the strength of the results and the desirability of using the method for capacity allocation.

1.5 Research Methods

Several research methods apply to provide answers to the sub-questions. The research methods that relate to these sub-questions are visible in Table 1-1.

Table 1-1: The sub-questions and their relative research methods.

Sub-question	Research method
Sub-question 1: Which methods for applying SEE criteria are currently available, and to what extent do these methods align with the criteria defined in the regulation?	Desk research
Sub-question 2: How does the method for capacity allocation calculate the socioeconomic value of capacity requests across the SEE criteria in the regulation?	Desk research
Sub-question 3: What result on capacity allocation emerges when one applies the method on the case study railway line Deventer – Bad Bentheim?	Desk research and case study assessment
Sub-question 4: How do the results from the method for the case study relate to strategic guidance?	Desk research and case study assessment
Sub-question 5: How indicative are the results, considering the sensitivity and applicability of the method?	Desk research and interviewing

The research methods have the following descriptions:

- Desk research: A review of an extensive body of literature is part of the desk research. This review includes scientific journal articles, reports, policies, and knowledge and data available to ProRail.
- Case study assessment: The case study allows testing the designed method on real-life capacity conflicts. The case study railway line thus turns a theoretical method into practice and shows the effects of the method.
- Interviewing: For this research method, several rail experts respond to multiple questions about the topics from this thesis. Their answers to the questions provide information that can help answer the sub-questions. The interviews in this thesis have an evaluating nature, and the interviewing method will support the other two research methods in this thesis.

1.6 Outline

First, chapter 2 provides the literature review portion of this thesis. The chapter assesses what is and needs to be known about capacity allocation according to SEE criteria, creating a knowledge gap. Chapter 3 creates the method that uses the SEE criteria from the regulation, which partly emerges through modification of the methods reviewed in Chapter 2. Chapters 2 and 3 thereby answer sub-questions 1 and 2, respectively.

Chapters 4 and 5 assess the case study railway Deventer – Bad Bentheim. In Chapter 4, the case study is evaluated by the method, and in Chapter 5, by the strategic guidance. Both chapters, therefore, show the impact of the regulation on capacity allocation. Chapters 4 and 5 thereby answer sub-questions 3 and 4, respectively.

Chapter 6 consists of a sensitivity analysis of the results, an evaluation of the method through interviews, and a review of ethical theories to answer sub-question 5.

The research ends with the conclusion and discussion sections of chapter 7, which answers the main research question. This thesis further contains the reference list and the appendices.

2 State of the Art

This chapter entails the literature review on applying SEE criteria to capacity allocation and on methods that calculate the socioeconomic value of train services. The literature review includes an introduction to rail capacity, the proposed regulation from the European Commission (EC) and the Smart Capacity Management project of Timetable Redesign (TTR). It also includes an evaluation of possible capacity allocation methods through socioeconomic evaluation of train services. The extent to which there is correspondence between these methods and the described SEE criteria in the regulation indicates the knowledge gap that the method of this thesis has to fill. This chapter thereby answers sub-question 1:

- Sub-question 1: Which methods for applying SEE criteria are currently available, and to what extent do these methods align with the criteria defined in the regulation?

2.1 Scarcity in Capacity Access Allocation

A timetable for railway systems is needed to make the railway network operation possible. According to Liebchen (2006), the lines and routes on which the transport of passengers and goods takes place define the input to the timetable. The timetable allows for predictable train travel to be made possible for end-users like customers by defining the departure and arrival times on these train lines. Within a timetable, the position of a train on the network and the time the train occupies this position is vital to the planning process. According to TNO (2024), a train path is 'the infrastructure capacity needed to run a train between two places over a given time-period'. A train series is a grouping of such train paths planned trough a common pattern in time (one train path every one, two or other multiple per hour), according to ProRail (2024). In addition, each train series has a train series number.

Generally, there is a 'limit' to the number of train paths that can fit into the timetable. Besinovic and Goverde (2018) define practical capacity as 'the maximum number of train paths that can run on the infrastructure within a certain period given the traffic pattern, operational characteristics or timetable structure'. The practical capacity is thus dependent on the capacity balance, which shows the distribution of capacity across the number of trains and the stability of the timetable, including the available buffer times, traffic heterogeneity and the average speed of the trains. Figure 2-1 contains an example of a capacity balance with train heterogeneous traffic consisting of multiple train segment types. Here, a 'train segment' is a category of trains with similar characteristics concerning transported commodities, stopping patterns, running times, and route length.

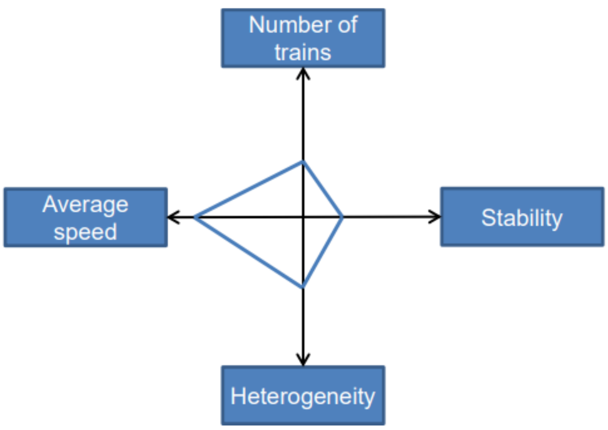

Figure 2-1: The capacity balance for mixed traffic operation (Goverde, 2023).

When reaching the maximum capacity of a line and no more train paths can be added to the timetable, the railway line is 'congested'. This finding means that fulfilling all requests from railway undertakings (RUs) is impossible and that the infrastructure manager has to distribute this capacity scarcity across all RUs, where not all RUs receive the capacity access they wish. Here, the 'access' stands for the access to use a railway network excerpt during a given time window, according to Perennes (2014).

2.2 Proposal for a European Regulation on Capacity Use

In July 2023, the EC proposed regulation nr. 443 on using railway infrastructure capacity in the single European railway area (hereafter: 'the regulation'). According to the EC (2023), their regulation aims to harmonise the allocation of capacity on the European rail network across all European Union (EU) member states and thus enhance rail transport within the union. The main goal of the regulation is 'to lay down a framework allowing rail infrastructure capacity and traffic to be managed more efficiently, thereby improving the quality of services and accommodating more traffic on the railway network'. The proposal includes several innovations, as described in several regulation articles. The articles most relevant to the scope, as discussed in Section 1.2, are part of this review. Some of these articles stem from allocation methods currently used by several European IMs. The appendix in Section 9.1 provides a conspectus of these allocation methods. The appendix in Section 9.2 provides a timeline showing the most vital changes to the railway sector following the proposed regulation.

2.2.1 Article 8 - Socioeconomic and Environmental Criteria

A significant innovation in the regulation is using socioeconomic and environmental criteria (SEE criteria) applied during the annual allocation process for conflict solving between train type segments and between train path requests by competing RUs within these segments. Article 8 discusses these SEE criteria and regulates scarce infrastructure capacity management (European Commission, 2023).

According to Article 8, when there is scarce infrastructure capacity, IMs shall first try to resolve conflicts through consultation with the involved RUs. This procedure is similar to the negotiation allocation method used by several European countries. The appendix in Section 9.1.2 contains a general discussion of this method.

If resolving conflicting capacity requests is impossible through consultation with RUs, the IM should allocate the scarce infrastructure capacity non-discriminately using the SEE criteria. Article 8 provides five SEE criteria according to the following formulation:

1. Operating cost for operators of rail transport services and the resulting impact on prices for customers of rail transport services;
2. Time-related cost for customers of rail transport services;
3. Connectivity and accessibility for people and regions served by the rail transport services;
4. Emissions of greenhouse gases, local air pollutants, noise and other external cost of rail transport services and by their likely alternatives;
5. Safety and public health implications of rail transport services and their likely alternatives (EC, 2023).

The proposed regulation suggests that the methods applied to assess the conflicting proposals along these SEE criteria are going to be developed by the European Network of Infrastructure Managers (ENIM). ENIM will be the successor of the Platform of Rail Infrastructure Managers in Europe (PRIME) (ProRail, 2023). ENIM will represent a network of rail infrastructure managers in Europe. ENIM aims to strive for a uniform European railway network and to enhance the roll-out of the innovative European Rail Traffic Management System (ERTMS) on the rail infrastructure in Europe (European Commission, 2024).

When allocating scarce infrastructure capacity, the IMs should consider the strategic guidance their associated EU member state provides (European Commission, 2023). Section 2.5.2 discusses strategic guidance in detail in section 2.5.2.

2.2.2 Article 11 – Strategic Guidance

As discussed in section 2.5.1, the Ministries of Transport from EU member states can provide the IMs with strategic guidance on allocating capacity along congested infrastructure. The Ministry of Infrastructure and Water Management (I&W) will provide strategic guidance within the Netherlands. The Ministry can receive input to this strategic guidance from other parties involved in creating rail transport policies, like the IM, RUs and other governing bodies. The strategic guidance could include the following elements as formulated in the regulation article 11.3:

- General objectives of the national rail policy.
- An outlook on the development of rail infrastructure.
- General requirements and guidelines regarding the use of rail infrastructure capacity.
- An outlook on the planned development of rail services operated under public service obligations' (EC, 2023).

The regulation mentions that member states shall cooperate to ensure consistency between the strategic guidance provided by different member states.

2.2.3 Articles 16 to 18 – Correspondence with TTR

As indicated in the introduction of this chapter, the new regulation proposed by the EC is, to some extent, related to the Timetable Redesign for Smart Capacity Management project (TTR). Articles 16 to 18 of the proposed regulation relate specifically to the three phases of TTR, where Article 16, Article 17, and Article 18 each are titled 'Capacity Strategy', 'capacity model' and 'capacity supply', respectively. When assessing the train segment types and making comparisons between the involved train segment types during the advanced planning phase of TTR, the SEE criteria described in Article 8 of the regulation need consideration (EC, 2023).

2.2.4 Article 32 – Congested Infrastructure

As stated in Article 32, the IM allocates capacity first to the requests in line with the pre-planned train paths defined during the capacity supply phase described in Article 18. Capacity requests that do not correspond with these pre-planned train paths and cannot fit into the timetable on congested railway lines can thus be accepted or rejected by the IM.

2.2.5 Article 37 – Auctions

According to Article 37, in cases where there is a conflict between capacity requests between rail services with similar characteristics and performances along the SEE criteria, the IM may allocate capacity by using an auctioning method. This procedure is similar to the auction allocation method used by several European IMs. The appendix in Section 9.1.5 discusses this method in general.

2.3 Timetable Redesign

According to Montero, Finger, & Gortazar (2023), the regulation is mainly inspired by the Timetable Redesign for Smart Capacity Management project (TTR). TTR was created thanks to a cooperation between RailNetEurope (RNE), Forum Train Europe (FTE) and the European Rail Freight Association (ERFA). The design process evaluated input from experts from both IMs and RUs. TTR updates capacity allocation processes to present-day requirements concerning flexibility, (cost)efficiency, and (cost-)effectiveness (RailNetEurope, 2021). According to Brandt, Visser, and Westgeest (2022), TTR aims to come to a harmonised timetable on a European level and create a uniform procedure for requesting and allocating capacity. Applying TTR in the Netherlands will take place for the first time for the timetable year 2025. TTR consists of several stages, visualised in Figure 2-2.

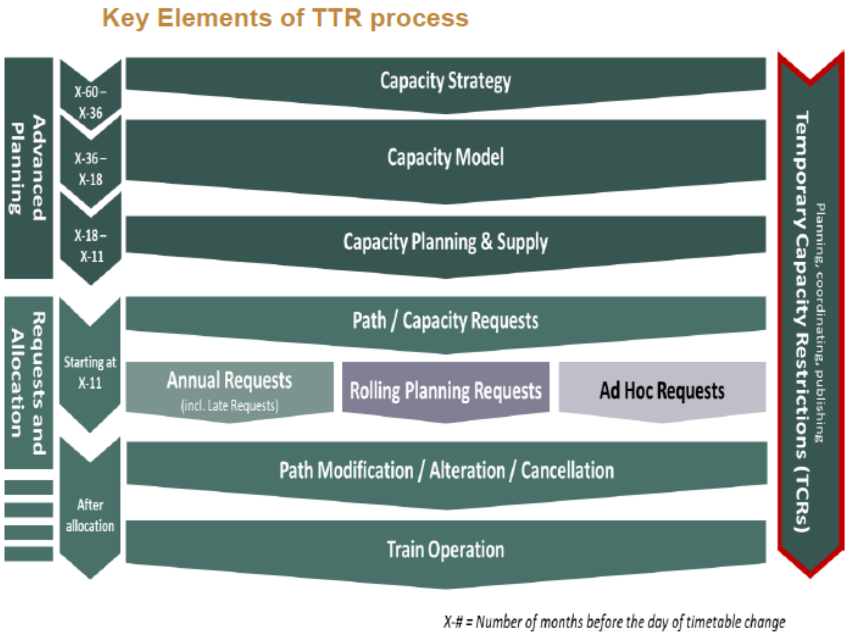

Figure 2-2: The main stages of TTR (RailNetEurope, 2021).

The following holds about the various stages within the advanced planning phase of TTR:

- Capacity Strategy: Within the Capacity Strategy, the IMs inform the RUs on the main principles used during the planning of capacity as well as to inform on future infrastructure developments.

Within this phase, governmental bodies have a participating role. This role entails the requests by regional and national governments for product steps in the timetable, which are additional or changed train services compared to previous timetables.

- Capacity model: Within the capacity model stage, the IMs discuss and communicate with the RUs the expected train volumes per train segment. Also, the share of capacity used for temporary capacity restrictions (TCRs) needed when executing construction work, for example, is planned in this stage. The RUs provide capacity requests and ambitioned product steps through Capacity Need Announcements (CNAs). Within this phase, RUs are consulted on several issues to be solved by the IM, such as handling the TCRs and CNAs.
- Capacity supply: Within the capacity supply phase, the IMs provide the timetable to the RUs, which contains all train paths with associated train segments and the TCRs for the complete timetable year. These timetables are created based on the capacity model phase, including consultation and cooperation with RUs (RailNetEurope, 2021).

The following holds about the various stages within the request and allocation phase of TTR, which are not related to specific train segment types:

- Path/capacity request: A RU applies a formal request to use a given path or capacity from the capacity supply:
  - Annual request: A request from an RU to use the pre-planned train paths or capacity during a particular timetable year, where the traffic volume is more or less at a fixed level and applies to the entire timetable year.
  - Rolling planning requests: requests from RUs to use the pre-planned train paths or capacity that are not necessarily applicable to a particular timetable year and where announcing its request takes place during the timetable year. These requests must be announced between 120 and 30 days before the start of the operation. Processing these requests takes place according to the principle of first-come-first-served.
  - Ad hoc request: requests from RUs announced at terse notice or requests from RUs that cannot fit within the pre-planned paths indicated in the capacity supply phase. Processing these requests takes place utilising the principle of first-come-first-served.
- Path modification / Alteration / Cancellation: The RU can request a (partial) modification and/or cancellation of allocated train paths. The IM can also alter initially allocated paths if deemed not usable anymore. The IM aims to minimise the instances where all of this happens.
- Train operation: The trains run along the infrastructure from the IM according to the timetable accepted by the RU. (RailNetEurope, 2021).

In general, TTR thoroughly aligns with the regulation. This alignment applies not only through the phases of TTR that correspond with the phases of capacity management defined in Articles 16 to 18 in the regulation. This conclusion stands because both TTR and the regulation align in the goal to harmonise timetabling and come to uniform capacity distribution procedures across Europe. TTR does not provide the frameworks to apply SEE criteria, meaning that findings of these practices must take place outside of TTR. Therefore, TTR cannot provide a fundament for a method on SEE criteria.

2.4 Current Practice in the Netherlands

One of the countries that participated in the TTR smart capacity management project is the Netherlands. Currently, the allocation of capacity in the Netherlands takes place based on an 'Algemene Maatregel van Bestuur' (AMvB) (general administrative measure), which is, according to the Dutch senate (2024), a decree by the Dutch government which supplements legal rules. The concerned AMvB is entitled 'Besluit capaciteitsverdeling hoofdspoorweginfrastructuur' (Decree Capacity Distribution Main Rail Infrastructure) and contains the articles that define the rules that need to be applied when conflict resolution needs to take place on congested infrastructure, as described at Overheid.nl (2024). The AMvB operationalises through the Dutch IM ProRail Network Statement (ProRail, 2023).

When there is a conflict between capacity requests in the Netherlands, article 7 of the AMvB states that the IM first can agree with the involved RU through a levy. If the levy does not lead to a solution or cannot be applied, the IM will declare the involved infrastructure as 'overloaded' (congested). After this declaration, a capacity enhancement plan starts, and the IM assesses how the available capacity on the concerned railway line could increase. This process must take place within six months, and solutions could include alterations to the timetable and/or expansion of the infrastructure (ProRail, 2023).

When declaring the infrastructure congested, priority rules mentioned in Article 10 of the AMvB will determine which capacity request receives priority. These priority rules consider the service type of the associated train movement. The AMvB defines the following train service types:

- Public Service Obligation (PSO): train services provided at the request of and through a contract with a governmental body. In the Netherlands, these PSOs must comply with the 'Wet Personenvervoer 2000' (Law Passenger Transport 2000).
- International train service: a train service connecting destinations between the Netherlands and neighbouring countries.
- National train service: a train service connecting destinations only within the Netherlands.
- High-speed passenger transport: a train service that uses the high-speed infrastructure in the Netherlands with a minimal speed of 250 km/h.
- Urban ('stadsgewestelijk') regional public transport: regional trains serving stations on railway lines with 'urban' stations as identified on map 1 of the AMvB. Most railway lines with 'urban' stations generally represent the railway lines within and from/to the Randstad area in the Netherlands.
- Rural ('streekgewestelijk') regional trains: Regional trains serve most of the stations on railway lines with 'rural' stations as identified on map 1 of the AMvB. Most railway lines with 'rural' stations exist outside the railway lines within and from/to the Randstad area in the Netherlands.
- Standard freight transport: transport of freight by train utilising standardised train paths, of which the speed, length and acceleration characteristics apply through the Dutch network statement (Eerste Kamer der Staten-Generaal, 2024).

According to the tenth article of the AMvB, the following priority order is applicable, starting with the train type with the highest priority and ending with the train type with the lowest priority:

1. International public transport and international high-speed passenger transport operated based on a PSO.
2. Urban regional public transport operated based on a PSO.
3. National public transport (public transport that is not high-speed or urban/rural regional transport) based on a PSO.
4. International public transport, excluding night trains.
5. National high-speed passenger transport based on a PSO.
6. International high-speed passenger transport.
7. Rural, regional public transport operated based on a PSO.
8. Urban regional public transport.
9. National public transport.
10. National high-speed passenger transport.
11. Rural, regional public transport.
12. Standard freight transport.
13. Other passenger transport.
14. Trains without a transport function (Eerste Kamer der Staten-Generaal, 2024).

Article 8 of the AMvB defines the minimal capacity allocated to certain train types. For international and/or high-speed services, a minimal frequency of train services per hour or day applies to the high-speed line between Schiphol and Antwerp and international train routes. Furthermore, a minimum frequency per train on national and international routes applies to freight trains. For the remaining public transport types, a minimal frequency of two train paths per hour applies between major stations (as defined in the appendix of the AMvB) and a minimal frequency of 1 or 2 train paths per hour between the other train stations, depending on the time of the day.

Next, Article 11 of the AMvB states that if there is a conflict between capacity requests and the same public transport train service type, the IM should prioritise decreasing the train passengers' travel time as much as possible, considering the number of train passengers involved. For the remaining train service types unrelated to public transport, Article 10a defines that the capacity request involving the train with the lowest noise disturbance receives capacity access.

Considering the appendix in Section 9.1, the current capacity allocation procedure, as described in the AMvB, corresponds the most to the concept of the administrative procedure since evaluating capacity requests takes place according to a standardised procedure. However, in the Netherlands, most capacity requests are merely assessed utilising priority rules based on the associated train service type rather than the characteristics of these trains described through criteria. Priority criteria such as travel time and noise disturbance are considered only within the same train service type. This finding implies that the current Dutch capacity allocation procedures hardly provide frameworks for applying SEE criteria. This conclusion means that finding these methods must take place outside of the Netherlands.

Finally, what becomes apparent when looking at the order of the Dutch priority rules is that, in general, train services operated based on a PSO receive priority above train services not operated based on a PSO. This finding holds since in Article 10, only between positions 4 to 7 non-PSO trains are favoured over PSO trains. In addition, the AMvB does not provide a fundament on which forming a method on SEE criteria is possible, since the AMvB merely assesses the service type and contract type of a train service, not its socioeconomic value.

2.5 Literature on Socioeconomic and Environmental Criteria

Since TTR and the Dutch AMvB do not provide the necessary frameworks to apply SEE criteria and to provide an answer to sub-question 1, this section should evaluate what is known and is unknown about applying SEE criteria within literature and experience outside of the Netherlands. This section does this by assessing the literature on SEE criteria through the following sources:

- Scientific literature.
- The application of SEE criteria by the IMs in Norway and Sweden.
    - Specifically, the Swedish and Norwegian IM were selected given that according to Figure 9-1 in the appendix in Section 9.1 provided by Stojadinović, Bošković, & Bugarinović (2019), SEE criteria are only applied in Norway and Sweden.
- A feasibility study executed by the Research Institute of Sweden (RISE) and the Swedish National Road and Transport Research Institute (VTI)

2.5.1 SEE criteria within the Scientific Literature

Montero et al. (2023) concluded that the experiences with socioeconomic criteria used in Sweden align with the goals of the proposed regulation by the EC. At the same time, the experiences with SEE criteria in other countries besides Sweden are significantly limited. Given these circumstances and the fact that the regulation originates from the near past, the amount of scientific literature available on SEE criteria is limited.

2.5.2 Method by Bane NOR in Norway

The Norwegian IM Bane NOR used SEE criteria to resolve conflicting capacity requests between multiple passenger and/or freight trains. The IM evaluates competing capacity requests using a modelling tool developed by Oslo Economics. The model assumes that when two capacity requests, which are called option A and option B, compete with one another, only one of the options can receive capacity access. The model calculates the utility loss for not operating option A when selecting option B and vice versa. The alternative with the highest possible utility loss is chosen based on the model output. This decision ensures that the highest possible amount of utility loss that could occur to society is averted. (Bane NOR, 2023).

The model calculates the utility of the following aspects of the capacity requests:

- Loss of utility resulting from time shift: When a capacity request does not receive capacity access, the method estimates how many minutes later the next train departs that can transport the involved passengers or goods. The method calculates the utility loss associated with this time shift by multiplying the Value of Travel Time Savings (VoTTS) by the minutes until the next train departure.
- Loss of utility resulting from the modal shift: When a capacity request does not receive capacity access, the method estimates how many passengers and/or goods will alternatively receive transport through other modalities as the effect of the time shift from the initially planned train. The method calculates this through the rule of half. This rule assumes that passengers or goods who switched due to increased travel time receive half of the associated utility loss.
- Loss of utility resulting from negative externalities: A train running along a railway line impacts the environment and public health due to external effects. These external effects are described as 'negative externalities'. Other modalities besides the train can have different volumes of associated externalities. Thus, the method assesses whether the modal shift calculated at the previous bullet point implies an increase in negative externalities and the associated utility loss.

- Profit loss resulting from operating costs (empty train operation): As input to the valuation model, the user has to define, in case the capacity request is not granted with capacity access, whether the train would run empty without transporting passengers or goods or not run at all. In case when the train runs empty, the utility involved with not running the train at all will be calculated (Oslo Economics, 2022).

2.5.3 Method by Trafikverket in Sweden

SEE criteria are used by Swedish IM Trafikverket as priority criteria for capacity dispute resolution. The SEE criteria often apply as a last resort after the infrastructure has been declared congested and consultation with RUs has not provided a solution. The SEE criteria are, therefore, not applied during the TTR advance planning process, which contradicts the suggestion in the proposed regulation by the EC (RISE & VTI, 2024).

The method of SEE criteria in Sweden currently has the following key features:

- It is the plan (timetable) with a socioeconomic value, the sum of all individual trains' socioeconomic value.
- For the socioeconomic value, only time and duration are valued. Thus, other aspects of train transport, as mentioned in the proposed EC regulation, such as accessibility, pollution, health, and safety, are not evaluated.
- Each train belongs to a specific' priority category'. Each category is associated with certain train types, rolling stock characteristics and relevant restrictions. Figure 2-3 encloses an excerpt of the table from the Swedish network statement that entails all priority categories and their characteristics (RISE & VTI, 2024).

Priority category		**Iden-tifi-ca-tion**	**Identification conditions**				Type of traffic, description	Example
			Num-ber	Time sensitive share	Regi-onal share	Traffic concept: ***Rapid****	**Note:** The text in these two columns are aimed to give an estimation of the signification for each category	
Name	Code	**key**	of passengers			transport		
Stor-pendel[1]	**SP**	*SP1*	≥ 700	≥ 75 %	≥ 75%	-	High share of time sensitive regional passengers, maximum load factor	Stockholm commuter train, peak periods
Regio-Pendel *Regional commuter*	**RP**	*RP1*	≥ 300	≥ 75 %	≥ 75 %	-	High share of time-sensitive regional passengers, very high load factor	Big cities commuter train, peak periods
		RP2	≥ 300	≥ 75 %	≥ 75 %	-	High share of time-sensitive regional passengers, very high load factor	Very heavy regional relations, peak periods
Regio-max *Regional max*	**RX**	*RX1*	≥ 200	≥ 75 %	≥ 75 %	-	High share of time-sensitive regional passengers, high load factor	Heavy regional relations
		RX2	≥ 75	≥ 75 %	-	Must	High share of time-sensitive passengers, medium high load factor + Rapid transport	Regional express traffic, peak and mid-peak periods
Regio-standard *Regional standard*	**RS**	*RS1*	≥ 75	≥ 75 %	≥ 75 %	-	High share of time-sensitive regional passengers, medium high load factor	Medium-principal regi-onal trains, peak periods
		RS2	≥ 25	≥ 25 %	-	Must	Frequent regional traffic, medium-high share of time-sensitive regional pass low load factor. Rapid transport	Regional express traffic, off-peak periods

Figure 2-3: An excerpt of the criteria used in the Swedish network statement for allocating trains to priority categories (Trafikverket, 2024).

The timetables designed to resolve the capacity conflicts emerge in a time-distance diagram. The method allocates a cost parameter to the train based on the priority category allocated to the train. The total value of a train appears by multiplying the performance in the time-distance diagram on four aspects with the corresponding cost parameters. By summing these outcomes across all trains, a total value for the plan can be found (RISE & VTI, 2024). Figure 2-4 and Figure 2-5 give insight into the described calculation steps.

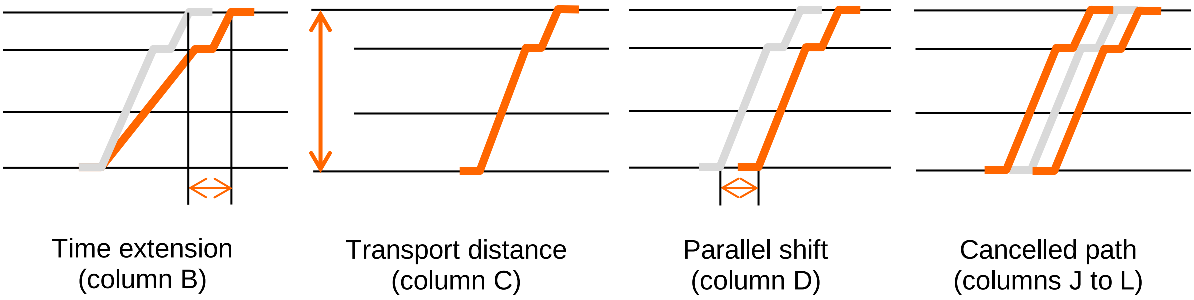

Figure 2-4: The aspects of the timetable that are assessed as part of the SEE criteria (RISE & VTI, 2024).

Priority category	Cost parameters for the following effects calculated per train				Parameters for exclusion of train path		
	Transport time	Transport distance	Displaced path time	Excluded train path	Benefit limit for train path	Corr. factor basic time	Running time template
Code	SEK/min	SEK/km	SEK/min	SEK/km	%	%	Code
A	**B**	**C**	**D**	**I**	**J**	**K**	**L**
GS	297	69	183	-	15	2	GB201211
GT	259	69	155	-	25	2	GR401410
GN	174	74	90	-	35	2	GR401409
GR	226	68	130	-	35	2	GB200710
GF	94	66	31	-	45	2	GR401410
GO	70	50	23	-	50	2	60 km/h
SP	1297	80	911	-	15	20	PX600616

Effect cost (calculation item)	**Description of calculation** (**bold** letter, see below)
Trains cost for transport distance	= Transport distance {km} x **C** {SEK/km}
Trains transport time cost	= Total transport time {min} x **B** {SEK/min}
Displaced path time cost	= Displaced path time {min} x **D** {SEK/min}
Cost for "Excluded train path"	= (Transport time {exclusion} x **B**) + (Transport distance x **C**) Where Transport time {exclusion} = Basic running time {direct}* x (100+**K**) x (100+**J**)
Cost for "freight train without time limit"	= Cost for "Excluded train path"
Cost for an association's duration	= Duration {min} x **L** {SEK/min}
Cost for a broken association	= **M** {SEK/association}
Total cost	= Summary of all calculation items above for all detailed plan days:

Figure 2-5: The calculation input for the total cost of the train plan (RISE & VTI, 2024).

The so-called 'associations' are also applied to calculate the total costs per plan. An association is a relationship between a pair of trains, which could be a connection between passengers between two trains at a station, a connection between freight cars, turnaround manoeuvres of locomotives, and other possible connections. The interruption of such associations within a plan leads to a penalty in additional costs (RISE & VTI, 2024).

By evaluating all the plans on their summed value, comparing them with one another is possible. These plans are composed through the most optimal combination of train paths. The plan with the lowest total cost thus represents the plan that solves the conflict best and that should, therefore, be put into the timetable (RISE & VTI, 2024).

2.5.4 Research on Swedish Criteria

In response to the proposed regulation of the EC, a feasibility study executed by the Research Institute of Sweden (RISE) and the Swedish National Road and Transport Research Institute (VTI) started in October 2023. The study aims to investigate whether the application of SEE criteria in Sweden, as discussed in Section 2.5.3, can be expanded to the TTR planning process and a pan-European level (RailNetEurope, 2023).

The foreseen presentation date of the final report lies within the final quarter of 2024. In March 2024, the first results of the study appeared in an intermediate report:

- According to RISE and VTI (2024), the currently evaluated aspects of train paths that are considered when using the Swedish SEE criteria are the distance and running time of the train paths and the shifts of the train paths in a time-distance diagram to make solutions to conflicts possible. However, the Swedish SEE criteria do not evaluate partly cancellations of trains and the removal of commercial stops along train paths. Thus, RISE and VTI conclude that the Swedish application of SEE criteria is helpful for adjustments that optimize timetable adjustments. However, the application of SEE criteria in Sweden could be enhanced, and further investigation is needed.
- When rolling out SEE criteria on a pan-European scale, similar data is needed for each EU member state to which the SEE criteria can be applied. RISE and VTI propose using unit values that show the volume of transport per train kilometre per country on an aggregate level for

passenger and freight transport. Two reports by IRG-Rail (2023) and JASPERS (2017) provide examples of such unit values.

2.6 Conclusion

This chapter evaluated the following sub-question:

- ⊃ Sub-question 1: Which methods for applying SEE criteria are currently available, and to what extent do these methods align with the criteria defined in the regulation?

The criteria that a method of socioeconomic evaluation must consider originate from the regulation nr. 443 from the European Commission on the usage of infrastructure capacity. This method must define which requests from RUs receive capacity when capacity is scarce. The regulation states that ENIM must develop a method that still needs to occur. Therefore, there currently are opportunities within the railway sector to design and evaluate different methods and their outcomes before selecting the most desirable method.

TTR and the Dutch capacity allocation procedure through the AMvB do not provide a fundament for such a method. Out of the remaining experiences, only the Norwegian and Swedish IMs use methods that evaluate capacity requests on their socioeconomic merits. The scientific literature and research on the topic is hard to come by, given the rare international occurrences of socioeconomic evaluation of capacity requests by IMs and the recent introduction of the regulation.

The Swedish method evaluates the socioeconomic value of the entire plan by summing up the socioeconomic value of all involved trains. For the socioeconomic value, only time and duration are relevant. Therefore, the Swedish approach aligns only with the SEE criterion that describes 'Time-related cost for rail transport services' customers. The other four SEE criteria from the regulation are thus less associated with the Swedish method.

The Norwegian method calculates the utility loss per train if the RU does not receive capacity access. The capacity request with the highest possible utility loss receives capacity access, thereby keeping the loss that occurred through the rejected requests as low as possible. This utility loss is calculated through time shifts, modal shifts, negative externalities and profit loss resulting from operating costs. These aspects roughly correspond to the five defined SEE criteria in the regulation.

Compared to the Swedish method, the Norwegian approach builds on a broader spectrum of effects of train operation compared to the Swedish approach. Therefore, the socioeconomic valuation method of Bane NOR is a more suitable 'blueprint' for a method that can assess the SEE criteria provided by the proposed regulation. Still, the Norwegian method in its current form cannot represent a method suitable to the SEE criteria from the regulation. This judgment holds because there remains a difference between the criteria the Norwegian method assesses and the criteria the regulation considers. In addition, the method applied by ENIM has to suit all countries in the single European railway area, whilst the Norwegian approach is designed solely for the Norwegian railway network. Therefore, the following knowledge gap holds:

- ⊃ A method that utilises European-defined criteria and can apply to the entire single European railway area has yet to emerge.

The notion that there is hardly any scientific literature available on the topic and that a new method on SEE criteria has to emerge indicates that this thesis provides one of the first contributions to the scientific literature on socioeconomic evaluation of capacity requests. Therefore, this thesis takes the initiative to conduct academic research on such evaluation of capacity requests.

3 Method

This chapter will present and discuss the proposed method that fills the knowledge gap found in Chapter 2. It will describe the structure of the method and the individual calculation aspects that are a part of it. The following sub-question answers this third chapter:

- Sub-question 2: How does the method for capacity allocation calculate the socioeconomic value of capacity requests across the SEE criteria in the regulation?

3.1 Conceptual Structure

The methods aims to assess multiple capacity requests that are incompatible with one another in terms of their socio-economic value. This valuation must follow the five socio-economic criteria that the proposed regulation provides.

The application of the SEE criteria decides whether one of the conflicting requests from RUs should or should not receive capacity access. The method calculates the 'loss' to society for not giving capacity access by considering all the consequences of such a decision. The method thus assesses the socio-economic loss of not running a train associated with the capacity request. The request with the highest possible utility loss receives capacity access, thereby keeping the socioeconomic loss that occurred through the rejected requests as low as possible. The term 'utility' is derived from the Random Utility Theory (RUT), as Liebe, Cranenburgh, and Chorus (2023) discussed. Chorus (2022) states that the econometrician Daniel McFadden received the 2000 Nobel Prize for his development of the RUT. Kirkbride-Smith (2014) poses that utility is 'an economic term referring to the total satisfaction received from consuming a good or service'. Since the method calculates the loss in utility, the utility value in the method indicates the amount of dissatisfaction of rejecting a capacity request.

The total utility loss decomposes into a utility loss for each of the five SEE criteria. A collection of different calculation methods calculates the utility loss per SEE criterion. The calculation of this utility loss per criterion takes place in correspondence with the definitions of the criteria formulated in the regulation, as discussed in Section 2.2.1.

3.2 Effects of not Granting Capacity Access

The decision not to give capacity access to a particular request has many consequences. Of all these consequences, the method assesses the effects associated with the descriptions of the five SEE criteria in the regulation. This technique ensures that the method evaluates the socioeconomic merits of capacity requests considering the regulation. The example of the socioeconomic evaluation of capacity requests in Norway, as discussed in Section 2.5.2, is revisited to find these effects. Based on the associated sources, finding the effects takes place through the following approach:

1. The approach to finding the effects first evaluates if and how the effects across the SEE criteria are evaluated through the Norwegian IM Bane NOR method. Here, valuable concepts or calculation procedures from the method that align with the five SEE criteria descriptions from the regulation can emerge.
2. If the examples from the Norwegian IM do not provide relevant concepts or procedures to evaluate effects across the five SEE criteria descriptions in the regulation, scientific literature can provide new insights on how evaluating these effects is possible. Thus, this step represents a 'safety net' in this approach.

3.2.1 The Effect of SEE Criterion 1: Operating Costs

The first SEE criterion was described in the regulation as follows: '*operating cost for operators of rail transport services and the resulting impact on prices for customers of rail transport services*'.

To assess operational costs, the Norwegian method asks the RU whether it wants to run its rolling stock empty (i.e. without transport of passengers or goods) to the final stop on the route when their capacity request got a rejection, ensuring that the train service can still take place in the opposite direction. If the answer to this question is 'yes', the method calculates the costs associated with an empty train service run, knowing that revenue from transporting passengers or goods cannot cover these costs. If the answer is 'no', the method will not calculate any utility loss on operational costs. In such a scenario, the method thus assumes that the RU is free from making any operational costs associated with this train service (Bane NOR, 2023).

The Norwegian approach is deemed less appropriate for a method applicable to all railway networks in the single European railway area. This conclusion holds because the capacity to allow a train service to run in just one of two directions could be scarce on highly utilised rail infrastructure. In addition, integrated timetables that use consistent arrival and departure intervals (used in, for example, Switzerland (Rail2000) and Germany (Deutschlandtakt)) conflict with train services operating in one direction, assuming strict symmetry of the timetable at significant nodes in the Railway Network (Van de Velde, 2023). Figure 3-1 provides an example of an integrated timetable at a transfer station.

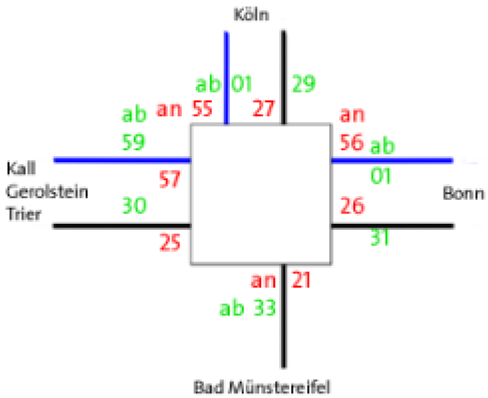

Figure 3-1: An integrated timetable at a train transfer station with train services running in both directions per line, and departures and arrivals at around :00 and :30 in the hour (Van de Velde, 2023).

As mentioned at the beginning of this subsection, the definition of the SEE criterion of operating costs in the regulation mentions, besides the operational cost itself, the effect on prices to customers resulting from operation costs. Scientific literature provides insight into the possible effects on prices. Vuuren (2002) states that when the RU receives less capacity, it needs to cover its fixed costs across fewer operating trains. For example, these fixed costs could include (the purchase of) rolling stock, costs that cannot be covered when a train is not in service. This financial challenge could increase the price to the customer when the RU covers the difference between costs and gains via ticket selling. At the same time, according to Eisenkopf & Burgdorf (2022), the price to customers can increase since fewer passengers use the train when there is no capacity access. This increase is because passengers could face an increase in travel time, transfer time, and/or waiting time, which could lead to passengers choosing alternative transport modes instead of the train. This switch between transport modes is called a modal shift. The RUs thus need to cover their costs across fewer passengers, which could lead to a price increase if the RUs want to cover the difference between costs and gains via ticket selling. Thus, a deteriorated product of train travel to passengers due to the lack of capacity access leads to a less competitive train ticket price. Therefore, the conclusion is that the increase in price across all passengers is a utility loss since customers cannot spend this additional expenditure on train transport in other sectors of society.

Since the exemplary method from Norway does not provide an appropriate solution for the method on SEE criteria of this thesis, the findings from scientific literature provide the best input to assess the effect across SEE criterion 1 on operating costs. Therefore, following the findings from this literature, the method will focus on the price increase for rail transport customers. By doing this, insight into how a capacity request performs on the criterion of operational costs emerges..

3.2.2 Distinction between SEE Criteria 2 and 3

The second SEE criterion was described in the regulation as follows: 'time-related cost for customers of rail transport services'. Furthermore, the third SEE criterion was described in the regulation as follows: 'connectivity and accessibility for people and regions served by the rail transport services'.

Following the research of Barradale & Cornet (2018), there is overlap between the second and third SEE criteria in the regulation. This finding holds because, according to the authors, connectivity considers, alongside travel time, the discomfort related to access/egress times, waiting times and transfer time. Connectivity, mentioned for the third SEE criterion, is thus closely related to time, mentioned for the second SEE criterion. Thus, a distribution of aspects of time across the two SEE criteria, 2 and 3, is required to prevent double counting in the method. The following distinction of aspects of time across the criteria is reasoned:

- The aspect of waiting time is allocated to SEE criterion 3 on 'connectivity and accessibility'. According to Chen et al. (2019), accessibility in rail transport relates to the ease of reaching destinations. A higher waiting time before the next train serves a station indicates a less accessible location with a poorer connection between the residency and the railway network. Therefore, the utility loss on waiting time is the best indicator of the effect of rejecting a capacity request considering the third SEE criterion on 'connectivity and accessibility'.
- After allocating waiting time to SEE criterion 3, two of the three remaining aspects of time, travel time and transfer time, are allocated to SEE criterion 2 on 'time-related costs'. Since these two aspects of time are part of the calculation for SEE criterion 3, allocating these two aspects of time to SEE criterion 2 can take place without the risk of double counting.
- The third aspect of time, access/egress time, is excluded from both SEE criteria. The socioeconomic contribution of this aspect of time could be questionable since, according to Givoni and Rietveld (2007), the quality of the access/egress facilities and the train station are more critical when defining the attractiveness of rail travel.

To conclude, the method of SEE criteria in this thesis should evaluate travel and transfer time for SEE criterion 2 and waiting time for SEE criterion 3.

3.2.3 The Effect of SEE Criterion 2: Time-Related Costs

The only time-related aspect evaluated in the Norwegian method is 'hidden waiting time'. This hidden waiting time is the additional time that passengers or goods have to spend 'waiting' for the departure of the alternative train when their preferred train service got cancelled. This waiting time is equal to the difference in time between the departure time of the 'preferred' cancelled train service and the departure time of the next train service (Bane NOR, 2023). Since, according to Section 3.2.2, waiting time is allocated to SEE criterion 3, this consideration of hidden waiting time from the Norwegian method cannot apply to evaluate the effect across SEE criterion 2. Still, transporting passengers and goods through an alternative (connection of) trains remains valid since the alternative train connection can have a longer travel time and consist of multiple transfers between trains, compared to the train service from the rejected capacity request. Therefore, the method used in SEE criteria in this thesis should consider the travel time increase when the preferred train service is cancelled, and transport of passengers or goods must occur through an alternative train connection. Here, the travel time consists of the running time between stations, the dwelling time at stations, and the transfer time between trains.

Scientific literature discusses the difference in the valuation of travel time and transfer time by passengers. The transfer time is experienced by passengers three times as long as the actual travel time by train, according to Bertolini (1999). The time needed to transfer between multiple trains on an alternative train connection is thus an additional loss in utility.

To conclude, the method in this thesis has to evaluate the time difference between passengers and goods between the time spent travelling with the train service from the rejected capacity request and the time spent travelling with an alternative train connection. Here, the utility loss following additional transfer time must be three times as large as the actual additional travel time. By doing this, insight into how a capacity request performs on the criterion of time-related costs emerges.

3.2.4 The Effect of SEE Criterion 3: Connectivity and Accessibility

As mentioned in Section 3.2.3, the Norwegian method evaluates the 'hidden waiting time'. This hidden waiting time corresponds to the difference between the departure time of the 'preferred' cancelled train service and the departure time of the next train service (Bane NOR, 2023). This difference in time depends on the frequency of the total of trains serving a station. The higher the total frequency, the lower the waiting time for the next departure of a train.

To conclude, the method in this thesis has to evaluate the utility loss associated with an increase in waiting time, considering that the frequency of the total train service decreases when cancelling the train service from the capacity request. By doing this, it provides insight into how a capacity request performs on the criterion of connectivity and accessibility.

3.2.5 Cohesion between SEE Criteria 4 and 5

The fourth SEE criterion was described in the regulation as follows: 'emissions of greenhouse gases, local air pollutants, noise and other external cost of rail transport services and by their likely alternatives'. Furthermore, the fifth SEE criterion was described in the regulation as follows: 'safety and public health implications of rail transport services and their likely alternatives'.

The effects of not granting capacity access have effects on both environmental impacts and safety and health factors. However, the effects across both SEE criteria are interdependent in some ways. For example, air pollution does not only affect the environment since the exhaust emission particles affect someone's health, according to Maibach et al. (2008). Another example, according to the authors, concerns noise related to train movements since the noise from trains not only harms the serenity of areas but can also cause health damage to humans. Therefore, because of these interdependencies, the effects of the two SEE criteria can best be researched simultaneously within the method.

3.2.6 The Effect of SEE Criteria 4 and 5: External Costs, Safety and Public Health

The Norwegian approach relates external effects to the number of trains running on the network. A not granted capacity access implies fewer trains run on a railway line. Fewer running trains implies less occurrence of these externalities. However, customers might shift to other transport modes when fewer trains are available. When this happens, more cars, buses, aeroplanes and other modalities run between locations, causing more externalities in their way. This knowledge means that fewer external effects caused by fewer running trains must be balanced out by more external effects caused by more running non-train vehicles (Bane NOR, 2023).

To conclude, the method used in the SEE criteria in this thesis should calculate the utility loss associated with the increase or decrease of external effects following the modal shift of passengers or goods. By doing this, insight into how a capacity request performs on the criteria of external costs, safety, and public health emerges.

3.2.7 Overview of the Effects

To summarize the findings in this section, Table 3-1 provides an overview of the five SEE criteria from the regulation and the effects across these criteria upon which the method must calculate its utility loss.

Table 3-1: An overview of the five SEE criteria from the regulation and their associated effects.

Criterion from the regulation	Effect of not granting capacity access
SEE criterion 1: operating costs	Increase in prices to customers
SEE criterion 2: time-related costs	Increase in travel and transfer time
SEE criterion 3: connectivity and accessibility	Additional waiting time following a frequency decrease
SEE criteria 4 and 5: external costs, safety, and public health	External effects following a modal shift

3.3 Eligible Capacity Requests

To find possible train services that the method can assess, this section gathers information from current timetables and possible timetables for the future. The following data sources, therefore, need to be assessed to find all information:

- The current timetable for the year 2024.
- Future product steps for the national PSO.
- Future product steps for the regional PSO.
- Freight train volumes.
- Open access requests at the Authority for Consumers and Markets (ACM).

3.3.1 Current Timetable

A consideration of the currently running timetable is functional to assess what is currently running on the case study railway line. Based on this timetable, the number of train services per train segment can be distinguished. Using additional information on which operator runs the train service and which rolling stock is used is of added value. Based on this current timetable, the 'business-as-usual' train services can be defined.

3.3.2 Future Product Steps – National PSO

The so-called 'product steps' can be defined for future expansions of the current timetable. A 'product step' can be defined as expanding the current timetable by adding new train services. For example, when the number of intercity trains per hour running between Breda and Eindhoven Centraal is expanded from two to four trains per hour, adding a third and fourth train per hour between the two cities represents a 'product step'. The PSO contract awarded by I&W to the train operator indicates the national product steps (I&W, 2023). Also, policymakers' reports and documents can aid in finding future product steps.

3.3.3 Future Product Steps – Regional PSO

Also, defining product steps for trains run according to a PSO granted by a province is achievable. The PSO contracts awarded by the provinces describe the possible product steps. Also, assessing reports and documents by policymakers to find future product steps is possible.

3.3.4 Freight Train Developments

The 'Integrale Mobiliteitsanalyse' (Integral Mobility Analysis), often abbreviated as IMA, can be assessed to find the volumes of freight trains running in the future. This document gives the number of freight trains per day that run on Dutch railways for a few socio-economic scenarios, the so-called 'Welvaart en Leefomgeving (WLO) scenarios'. These scenarios differ on the level of economic growth in the country. When considering the scenario with the highest economic development (the WLO high 2040 scenario), the maximum freight trains expected to run on certain railway lines can be derived (ProRail, 2021). The number of trains per day can be easily translated to the number of train paths per hour, knowing that one train path per hour for freight trains allows for 24 freight trains per day per direction. In addition, major construction work projects can also be evaluated to see whether the number of train paths on the impacted railway line is lower than usual and whether the number of train paths on diverted routes needs to be increased compared to regular operation.

3.3.5 Requests for Open-Access Trains

Besides passenger trains running according to a PSO, passenger trains running in Open Access can be found on the railway network. These train services are initiatives by the RU and do not exist following a PSO contract and a tendering process (Perennes, 2017). To find which trains will run in open access soon, assessing the announcements made by RUs that are compulsory towards the ACM is useful. ACM will make these announcements public once they are received. (ACM, 2024). Distinguishing all the train series needed to run these open-access trains is done by collecting all requests and associated information from RUs to the ACM.

3.4 Assumptions

This section includes several assumptions used to scope the problem and make the utility loss calculation per SEE criterion feasible. This section presents the list of assumptions and justifies these assumptions.

3.4.1 Conflict Assessment

The method assesses the capacity requests that are involved in a conflict with one another. These conflicts can be of different magnitudes. A request can conflict with another request across the entire route of the capacity request or a small section.

One could decide only to assess the sections of the entire routes of the capacity requests that are part of the conflict. However, when doing this, the impact of not granting capacity access to the other sections of the route will be neglected. The proportions of these neglected sections can differ based on the involved train segments. For example, one could expect that the train segment 'Intercity or long-distance trains for passengers' has a longer route than the segment 'Regional trains for passengers', meaning that the aforementioned train segment might have a disadvantage compared to the second mentioned train segment when assessing only sections of train routes. Another risk is that arbitrarily distinguishing between assessed and not-assessed route sections could have a significant impact on the output of the method.

For the method, two or more capacity requests to conflict with one another are sufficient regardless of to what extent these capacity requests conflict. This decision ensures an equal playing field for all involved capacity request in the conflict.

3.4.2 Timetabling

The following assumptions concern the characteristics of the timetable:

- It is assumed that the timetable is symmetrical. This assumption means that the running and stopping times on the train route are the same in both directions. Striving for the timetable to be symmetric is desired, with the most significant advantage being that it allows for identical changeover waiting times for both travel directions, according to Liebchen (2004). Assuming the symmetry of the timetable, it is sufficient to only provide input into the model for just one of the two directions of the train service. The argument is that, given the symmetry assumption, calculating for both directions would only lead to a doubling of utility losses. Evaluating the train services in just one direction would thus ease the workload when filling in the method.
- The train segments, as denoted in the TTR Capacity Strategy, are used to define the train segments in the method. This assumption ensures that the method is consistent with the developments on TTR.
- When assessing the capacity requests of RU, it is deemed acceptable to shift the proposed timetable by the RU to a period in time where the capacity request aligns with the line plan enclosed in the TTR Capacity Strategy. Doing this makes it more apparent for which train series in the TTR Capacity Strategy competition between RUs for capacity access is taking place. This assumption allows for a more straightforward assessment of the capacity conflict. Again, this also ensures compatibility between TTR and the method.
- Some train services have a different timetable between peak and off-peak hours. For example, some train series have a higher frequency or a longer route during peak hours compared to off-peak hours. Separate calculations for both peak and off-peak timetables are allowed in the method. The outcomes from both calculations receive a weight according to the portion of a natural day defined as peak hours and the portion defined as off-peak hours.

3.4.3 Train and Railway Undertaking Characteristics

The following assumptions can concern the characteristics of trains:

- To assess the impact of increased operating costs on prices to customers, the assumption entails that the increased costs to the RUs due to having less capacity access are covered entirely by increasing the price to customers. Assuming this assures that the method assesses the maximum possible societal impacts.
- It is assumed that trains transport passengers or freight, i.e., not both commodities simultaneously. This assumption aligns with the segmentation described in the TTR Capacity Strategy, where a train can be placed in the segment 'Freight trains' or one of the three segments reserved for passenger trains.
- The method will not assess the length of the train. This assumption considers that for passenger trains, the length of the train can vary across the day depending on the time. For example, an RU might opt to couple more train units to one another during peak hours. In addition, the length of the planned train might differ from the running train's length due to train malfunctions or ad-hoc adjustments to the rolling stock planning. For freight trains, a homogenization of the length of the trains aligns with expectations. The cause of this expectation is an obligation imposed by the European Commission to adjust rail infrastructure to accommodate freight trains with a length of 740 meters as part of the European Green Deal (ProRail, 2024).

3.4.4 Data

The following assumptions concern the characteristics of trains:

- In the method, data applicable to railway lines within the Netherlands is applied only. This assumption is because data on commodity numbers for international train services are more complex to come by and since it allows for the usage of data provided by Dutch IM ProRail. This assumption also implies that only (portions of) train series within the Netherlands require an evaluation. International train series are, therefore, allowed to be 'cut off' at the border between the Netherlands and Belgium or Germany.
- For train services in Open Access, RUs might not have data ready on the number of passengers or goods to be transported by their train services. If this data is unavailable, a solution is to use

data from similar train services running under a PSO. Since the volume of the transported passengers or goods might be vastly different for the train running under a PSO, the numbers get multiplied by a ratio based on the capacity of the train from the train service and the capacity of the train running under a PSO.

- For the data on the number of passengers or goods transported, there is the assumption that all commodities are distributed uniformly across the hour. This assumption makes the development of the method more feasible. It also creates an equal playing field between trains since not all train segment types are equally prone to differences in travel demand between peak and non-peak hours.

3.5 Input to the Model

To gain insight into the magnitude of the effects caused by not granting capacity access to a request, a collection of information on factors both related and not related to train service is required. Two different types of data are required:

- Train service data: data about the characteristics of the train service, where these characteristics define the magnitude of the effects caused by not granting capacity access.
- Parameter values: data not related to the characteristics of the train service.

The appendix in Section 9.3 gives a complete look through all sets of indices, input variables and parameters.

3.5.1 Train Service Data

The data on the train service represents two different types of data input. This data input consists of multiple pieces of knowledge about the train service:

- Short information on the train service: Characteristics of train services that a short answer or a single number can represent:
  - Train segment type $k \in K$: This segment type can be any of the four types that are present in the TTR Capacity Strategy, with $k = \{\text{'}High\ speed\ train\ for\ passengers\text{'}, \text{'}Intercity\ or\ long\ distance\ trains\ for\ passengers\text{'}, \text{'}Regional\ trains\ for\ passengers\text{'}, \text{'}Freight\ trains\text{'}\}$. This input is needed since the parameter values depend on the segment type.
  - Traction energy supply system $l \in L$: Electricity and diesel are the two possible energy supply types: $k = \{Electric, Diesel\}$. Some trains in the province of Fryslân use Hydrotreated Vegetable Oil (HVO) and the possibility of operating trains on hydrogen in the Netherlands in the near future is being researched (Arriva, 2024). Trains running on either of these two energy types can be considered as 'electric' trains in the model since HVO, hydrogen, and electric-powered trains allow for a decrease in greenhouse gas (GHG) emissions compared to diesel-powered trains (Kapetanović, 2023). This input is needed since the parameter values depend on the traction energy supply system.
  - Train frequency per hour fh and train frequency per day fd: the number of trains that run utilizing the train service per hour of the timetable and the number of trains that run during the entire day. For higher frequencies, better connectivity and accessibility and more operation costs and external effects could occur.
- Matrix information on the train service: Characteristics of train services associated with specific relations of two stations or commercial stops on the train service. When providing data for all possible combinations of stations or commercial stops, matrices of this data emerge. The following information is part of the discussion for each possible combination of two train stations:
  - Travel time t_{ij}: the travel time consisting of running and dwelling time needed between the two stations i and j or commercial stops, with $i = \{station\ 1, station\ 2, \dots, station\ n\}$ and $j = \{station\ 1, station\ 2, \dots, station\ n\}$. With a higher travel time, more time-related costs can emerge.
  - Travel time alternative connection ta_{ij}: Transport of passengers or freight can travel through an alternative train connection when the train service does not run. The fastest travel time consisting of running, dwelling and transfer time for each combination according to an alternative train connection is determined. This determination can take place by considering all possible alternative train connections in the timetable and selecting the train connection with the shortest path (considering travel time) in the

timetable. Depending on the alternative connection, an increased travel time for passengers could lead to higher time-related costs.

- Transfer time tt_{ij}: For each alternative train connection, the total travel time could consist of transfer time, which passengers experience three times as long as the actual time spent transferring between trains. Therefore, the time spent transferring between trains is defined since transfer times lead to more time-related costs.
- Transported commodity c_{ij}: The train transports several passengers or goods between stations or commercial stops i and j. Utilising origin-destination data on numbers of passengers or goods could be possible here. The higher the number of passengers or goods transported, the higher the time-related and external costs could be.
- Frequency alternative train connection fa_{ij}: The number of train alternative connections per hour, excluding the frequency of the assessed train services, is defined. This information defines the connectivity and accessibility associated with a train service.
- Distances between stations s_{ij}: The distance between the two stations or commercial stops i and j. More operation costs, time-related costs, and external effects could occur over longer distances.

3.5.2 Parameters

Concerning the parameters, the following values are collected:

- For SEE criterion 1, operating costs, the relative price increase is calculated based on the relative decrease in travel demand. For SEE criterion 4, external costs, and SEE criterion 5, safety and public health, the number of passengers or goods that shift from the train to other transport modes needs to be calculated. Elasticities allow for the calculation of price increases and the magnitude of the modal shift. Thommen & Hintermann (2023) provided the value for the elasticity e of the train service, which is $-0{,}7$. (Thommen & Hintermann, 2023)
- The price factor pf_k per train segment k, which shows the price per kilometre travelled by train, is assessed to calculate the price to customers. These values were collected for passenger transport by Dielesen (2024) and freight transport by Visser (2020). All values are depicted in Table 3-2.

Table 3-2: Price factor per kilometre per passenger or tonne-kilometre (Dielesen, 2024) (Visser, 2020).

Train segment type (k)			
High-speed trains for passengers	Intercity or long-distance trains for passengers	Regional trains for passengers	Freight trains
0,14	0,14	0,14	0,02

- Wardman, Chintakayala, de Jong, & Ferrer (2012) provided a list of values of time (VOT) for passenger transport in several EU countries, including the Netherlands. Since their article is also used in the feasibility study by RISE & VTI discussed in Section 2.5.4, these VoT values are highly relevant to future European methods on socioeconomic evaluation of capacity requests. The article provides VOTs for distances $r \in R$ with boundaries of 5, 25, 100, and 250 kilometres for the travel motives h, with $h = \{commuting, business, other\}$. Each VOT represents an amount of money in euros associated with an hour spent on board a train. These VOTs can allocate a value to the travel time between two stations or commercial stops. Table 3-3 gathers all the VOTs for train travel applicable to the Netherlands.

Table 3-3: Train VOT for passenger transport in the Netherlands (euros per hour).

		Distance r between stations in kilometres			
		5 - 24	25 - 99	100 - 249	250 >
Travel motive (h)	Commuter	5,09	6,88	8,93	10,61
	Business	21,65	29,30	38,03	45,18
	Other	4,38	5,93	7,69	9,13

- To determine which passengers have which of the three travel motives $h \in H$ from Table 3-3, the ratio defined by Drost (2014) can be applicable. This author found that, on average, the division of passengers across the travel motives, as shown in Table 3-4, is applicable.

Table 3-4: The division of travel motives across train passengers (Drost, 2014)

Travel motive (h)		
Commuter	Business	Other
69%	3%	28%

- Binsuwadan, de Jong, Batley, & Wheat (2022) found the VoT for freight transport. Here, a VoT in freight transport applies to both carriers and shippers. Since RUs are only involved with providing transport and do not own the transported goods, only the value for a carrier is required. The VoT for a carrier for rail freight transport is 1,77 euros per tonne per hour (Binsuwadan et al, 2022).
- To determine which passengers or goods shift to which alternative transport mode g, a division of modal shift ms_g across transport modes g is required with $g = \{\text{transport mode } 1, \text{transport mode } 2, \dots, \text{transport mode m}\}$. Jernbanedirektoratet (2022) gathered division percentages across alternative transport modes for passenger transport. These divisions differ for passenger transport modes based on the distance s_{ij} between stations i and j, described by distance $r \in R$ with boundary values 0, 70 and 200. Table 3-5 gathers the relevant numbers.

Table 3-5: The division of train passengers across possible modal shifts from the train to three other modalities (Jernbanedirektoratet, 2022).

		Transport mode (g)		
		Car	Bus	Aeroplane
Distance r between stations in kilometres	0 - 69	80%	20%	0%
	70 - 199	90%	10%	0%
	200 >	80%	10%	10%

Similar data is found for rail freight transport by Jonkeren (2020). This data is not dependent on the distance s_{ij}. Table 3-6 shows the data.

Table 3-6: The division of goods across possible modal shifts (Jonkeren, 2020).

Transport mode (g)	
Truck	Ship
68%	32%

- To find out how many more cars, busses, aeroplanes, trucks and ships will travel due to a modal shift, each transport mode's g utilisation u_g rate must be known. This utilisation rate shows how many passengers or goods vehicles transport on average. The utilisation rates for passenger transport originate from several sources, including Tooren et al. (2024), Johnston & Harris (2019) and CBS (2024). Table 3-7 collects all utilisation rates.

Table 3-7: The average amount of passengers transported per vehicle (Tooren et al., 2024), (Johnston & Harris, 2019) (CBS, 2024).

Transport mode (g)		
Commuter	Business	Other
1,05	15,30	133,00

Utilisation rates are also collected for freight transport as well. Forkenbrock (1999) and CBS (2024) collected these rates per transport mode g. Table 3-8 shows this collection.

Table 3-8: The average amount of goods transported per vehicle in tonnes (Forkenbrock, 1999) (CBS, 2024)

Transport mode (g)	
Truck	Ship
14,80	3500,00

- To calculate the external effects of the increase or decrease in the number of trains, cars, buses, aeroplanes, trucks, and ships, the method uses external cost factors e_g per transport mode g. The factors found by Maibach et al. (2008) got a definition per transport mode. The external cost factors of transport found by Maibach et al. (2008) consider the following external effects:

- Noise pollution: costs of annoyance and health costs associated with noise emerging from moving vehicles.
- Accidents: accidents that can emerge from moving traffic.
- Air pollution: the extent to which transport emits air pollutants.
- Climate change: the extent to which transport impacts climate change in the long term and globally.
- Up- and downstream processes: indirect effects of energy production, vehicles and transport.
- Nature & landscape: habitat loss, fragmentation, and quality loss emerging from transport.
- Soil & water pollution: the extent to which transport emits Polycyclic Aromatic Hydrocarbons (PAH) and heavy metals (Maibach et al., 2008).

From the list of external effects above, according to Lindberg (2005), accidents can correspond to internal effects due to transport users' decisions, like drivers' behaviour in road transport. Therefore, there is a disclaimer that the external cost factors of transport by Maibach et al. (2008) do, to a minor extent, also consider an internal effect.

The external factors related to the train, car, and bus also depend on the train segment type k. In addition, the external factors related to the train depend on the traction supply type l. The factors represent all possible effects on the environment, safety and health. Summing up all effects are justified since external effects often contain interdependencies. Table 3-9 to Table 3-12 enclose all external cost factors.

Table 3-9: The external costs for train transport in euros per kilometre (Maibach, et al., 2008).

		Train segment type (k)			
		High-speed trains for passengers	Intercity or long-distance trains for passengers	Regional trains for passengers	Freight trains
Traction supply type (l)	Electric	0,74	0,74	0,62	1,12
	Diesel	1,67	1,67	2,08	4,37

Table 3-10: The external costs for passenger transport modes in euros per kilometre (Maibach, et al., 2008).

		Train segment type (k)		
		High-speed trains for passengers	Intercity or long-distance trains for passengers	Regional trains for passengers
Transport mode (g)	Car	0,06	0,06	0,15
	Bus	0,29	0,29	0,56

Table 3-11: The external costs for aviation in euros per trip (Maibach, et al., 2008).

Transport mode (g)
Aeroplane
16,05

Table 3-12: The external costs for freight transport modes in euros per kilometre (Maibach, et al., 2008).

Transport mode (g)	
Truck	Ship
0,29	7,94

3.6 Mathematical Model

This section explains the calculation of the utility loss per criterion and which intermediate calculation steps are required to find these utility losses. The appendix in Section 9.3 presents a complete recap of the calculation steps or formulas used.

3.6.1 The Calculation of SEE Criterion 1: Operating Costs

As discussed in Section 3.2.1, the price increase to customers shows the effect on operation costs when a capacity request from a RU does not receive capacity access. Such price increase depends on the decrease in passengers or goods transported by train. This decrease follows the number of passengers that perform a modal shift. Calculating this degree of modal shift takes place through the level of service (LOS). The LOS is dependent on the travel time, the waiting time (dependent on the frequency of the train), and the transfer time spent on all performed transfers (Hogenberg, 2024). Although the LOS does not include an assessment of operational costs, it is applicable to calculate the modal shift, which is required to find the possible utility loss on operating costs. The LOS of the timetable including the train service ($LOS_{incl,ij}$) and excluding the train service ($LOS_{excl,ij}$) can be calculated with the following formulas:

1) $$LOS_{incl,ij} = t_{ij} + \frac{60}{fa_{ij} + fh} \cdot 0{,}5$$

2) $$LOS_{excl,ij} = ta_{ij} + \frac{60}{fa_{ij}} \cdot 0{,}5 + tt_{ij} \cdot 2$$

These formulas include the following elements:

- $LOS_{incl,ij}$ = the LOS including the assessed train service for the relation of locations i and j.
- $LOS_{excl,ij}$ = the LOS excluding the assessed train service for the relation of locations i and j.
- t_{ij} = the travel time of the train service between locations i and j.
- ta_{ij} = the travel time of the alternative train connection between locations i and j.
- fh = the frequency of the train service per hour.
- fa_{ij} = the frequency of the alternative train connection per hour between locations i and j.
- tt_{ij} = the transfer time associated with the alternative train connection between locations i and j.

Formula (1) calculates the LOS ($LOS_{incl,ij}$) that applies when the capacity request receives capacity access and is thus part of the timetable. It finds the LOS by adding the travel time (t_{ij}) and the waiting time between stations i and j along the train service from the capacity request. The waiting time depends on the interval between trains, calculated by dividing 60 minutes by the frequency of the train service from the capacity request (fh) and the other trains (fa_{ij}). This deviation is multiplied by half, assuming that the arrival of passengers at the platform is distributed uniformly across time.

Formula (2) calculates the LOS ($LOS_{excl,ij}$) when the capacity request receives no capacity access and is thus not part of the timetable. Now, the travel time of the alternative train connection (ta_{ij}) is applicable. The frequency of the train service based on the capacity request (fh) is no longer applicable. In addition, transfer time (tt_{ij}) applies since the alternative train connection can consist of transfers. As discussed in Section 3.2.3, passengers experience transfer time three times as long as the actual transfer time. Given that, according to Section 3.5.1, transfer time is already part of the travel time of the alternative train connection, the transfer time is multiplied by two instead of three to prevent double counting.

Based on the outcomes for both $LOS_{incl,ij}$ and $LOS_{excl,ij}$, the following formulas can be used to calculate the decrease in the number of transported passengers or goods:

3) $$ca_{ij} = c_{ij} \cdot \left(\frac{LOS_{incl,ij}}{LOS_{excl,ij}}\right)^{e}$$

4) $$cl_{ij,train} = c_{ij} - ca_{ij}$$

These formulas include the following elements:

- $LOS_{incl,ij}$ = the LOS including the assessed train service for the relation of locations i and j.
- $LOS_{excl,ij}$ = the LOS excluding the assessed train service for the relation of locations i and j.
- e = the elasticity of train travel.
- c_{ij} = the transported commodity as a number of passengers or a freight in tonnes between locations i and j along the train service.
- ca_{ij} = the transported commodity as a number of passengers or a freight in tonnes between locations i and j along the alternative train connection.
- $cl_{ij,train}$ = the decrease in the number of passengers or goods transported per train between locations i and j.

Formula (3) calculates the number of passengers or goods that will use the train service when the train service from the capacity request does not run (ca_{ij}). Calculating this number occurs by multiplying the current number of passengers or goods transported (c_{ij}) by the ratio following the outcomes on the LOS subject to the elasticity of train travel $\left(\left(\frac{LOS_{incl,ij}}{LOS_{excl,ij}}\right)^{e}\right)$.

Formula (4) calculates the decrease in passengers ($cl_{ij,train}$) or goods using the train service.

To find the relative difference in the number of passengers or goods transported per train, the following formula can be used:

5) $$\triangle q = \frac{\sum_{i=1}^{n}\sum_{j=1}^{o} ca_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{o} c_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{o} c_{ij}} \cdot 100\%$$

This formula includes the following elements:

- c_{ij} = the transported commodity as a number of passengers or a freight in tonnes between locations i and j along the train service.
- ca_{ij} = the transported commodity as a number of passengers or a freight in tonnes between locations i and j along the alternative train connection.
- $\triangle q$ = the relative difference in the number of passengers or goods transported per train as a percentage.

Formula (5) finds the relative difference in the number of passengers by comparing the number of passengers when the capacity request is accepted (c_{ij}) or rejected (ca_{ij}).

To find the relative difference in prices to customers, the following formula can be used:

6) $$\triangle p = \frac{\triangle q}{e}$$

This formula includes the following elements:

- $\triangle q$ = the relative difference in the number of passengers or goods transported per train as a percentage.
- e = the elasticity of train travel.
- $\triangle p$ = the relative difference in price to customers per train as a percentage.

Formula (6) follows the formula on the price elasticity of demand (Thomas, 2024).

The following formula calculates the utility loss on operation costs:

7) $$V_{operation} = \triangle p \cdot pf_k \cdot \sum_{i=1}^{n}\sum_{j=1}^{o}(s_{ij} \cdot ca_{ij})$$

This formula contains the following elements:

- $V_{operation}$ = the utility loss on the operation costs of the train service per day.
- $\triangle p$ = the relative difference in price to customers per train as an percentage.
- pf_k = the price factor pf_k in euro per kilometre (for $k \neq freight\ train$) or euro per tonne-kilometre (for $k = freight\ train$) for train segment k.
- s_{ij} = the distance between locations i and j.
- ca_{ij} = the transported commodity as a number of passengers or a freight in tonnes between locations i and j along the alternative train connection.

Formula (7) calculates how much additional expenditure customers make on train travel. The expenditure emerges by multiplying the price increase ($\triangle p$) with the price factor (pf_k). The total additional expenditure across all travels occurs by multiplying this outcome with all remaining transported passengers or goods (ca_{ij}) and the associated distances (s_{ij}) between location i and j.

3.6.2 The Calculation of SEE Criterion 2: Time-Related Costs

As discussed in Section 3.2.2, not granting capacity rights influences passengers' travel and transfer time. The following formula calculates the utility loss on these time-related costs:

8) $$V_{time-cost} = \left(\sum_{i=1}^{n} \sum_{j=1}^{o} (ta_{ij} - t_{ij} + 2 \cdot tt_{ij}) \cdot c_{ij} \right) \cdot VOT_{hkr}$$

This formula contains the following elements:

- $V_{time-cost}$ = the utility loss on the time-costs of the train service per day.
- t_{ij} = the travel time of the train service between locations i and j.
- ta_{ij} = the travel time of the alternative train connection between locations i and j.
- tt_{ij} = the transfer time associated with the alternative train connection between locations i and j.
- c_{ij} = the transported commodity as a number of passengers or freight in tonnes between locations i and j along the train service.
- VOT_{hkp} = the Value of Time in euro per hour (for $k \neq freight\ train$) or euro per tonne-hour (for $k = freight\ train$), depending on the route distance of the train service r and the travel motive h.

The travel time can increase since alternative connections transport passengers or goods via a train service with more intermediate stops or a longer running time. Therefore, there is a difference in travel time between the alternative connection (ta_{ij}) and the train service from the capacity request (t_{ij}). Since the alternative train connection can consist of transfers between trains and the transfer time (tt_{ij}) is experienced three times as long, according to Bertolini (1999), the transfer time also needs to be assessed. Since the transfer time (tt_{ij}) is a part of the travel time for the alternative connection (ta_{ij}), to prevent double counting, formula (8) must multiply the transfer time (tt_{ij}) by two instead of three.

To calculate the total time increase for all involved passengers or goods and the value of this time increase, formula (8) multiplies the time changes with the transported commodity (c_{ij}) and the Value of Time (VoT_{hkr}). The multiplication concerns all possible combinations of departure i and arrival j locations.

3.6.3 The Calculation of SEE Criterion 3: Connectivity and Accessibility

According to Section 3.2.2, the impact of not granting capacity access on connectivity and accessibility concerns the increased waiting time for passengers. The increase in waiting time depends on the decreased frequency of the available trains to the passenger or the shipper. The following formula calculates the utility loss on connectivity and accessibility:

9) $$V_{connectivity} = \left(\sum_{i=1}^{n} \sum_{j=1}^{o} \frac{\frac{60}{fa_{ij}} - \frac{60}{fa_{ij} + fh}}{60} \cdot 0{,}5 \cdot c_{ij} \right) \cdot VOT_{hkr}$$

This formula contains the following elements:

- $V_{connectivity}$ = the utility loss on the connectivity and accessibility associated with the train service per day.
- fh = the frequency of the train service per hour.
- fa_{ij} = the frequency of the alternative train connection per hour between locations i and j.
- c_{ij} = the transported commodity as a number of passengers or a freight in tonne hour between locations i and j along the train service.
- VOT_{hkr} = the Value of Time in euro per hour (for $k \neq freight\ train$) or euro per tonne-hour (for $k = freight\ train$), depending on the route distance of the train service r and the travel motive h.

Formula (9) is inspired by the formula Norwegian IM Bane NOR uses to calculate the 'hidden waiting time' for their socioeconomic evaluation of capacity requests (Bane NOR, 2023). To define the time interval between the trains, the time window of 60 minutes needs to be divided by the frequency. By subtracting the time interval of the frequency without the train service $\left(\frac{60}{fa_{ij}}\right)$ from the time interval of the frequency with the train service $\left(\frac{60}{fa_{ij}+fh}\right)$, the increase in waiting time emerges. All waiting times need to be calculated for all relations between locations i and j.

This increase in waiting time increases more when the frequency of the train service further decreases. Figure 3-2 gives the decay curve associated with this increase. The curve implies that the reduction in travel time when the frequency increases from one to two trains per hour, the reduction in waiting time is valued more than when the frequency increases from five to six trains per hour, for example. This principle carries on to the level where the frequency increases from zero trains per hour (i.e. the station is not served) to one train per hour. The assurance of a connection between the train stations and the train system is thus weighted heavily within the calculations for this SEE criterion.

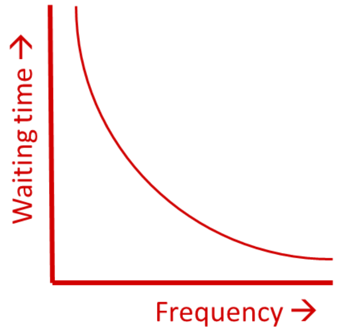

Figure 3-2: The decay curve showing the relationship between the waiting time and the frequency.

Assuming that passengers or goods are distributed uniformly at the departure location across the hour, the increase in waiting time needs to be multiplied by half. Next, formula (9) must multiply the number of transported passengers or goods (c_{ij}) to find the total waiting time increase across all transport commodities. The total needs to be divided by 60 minutes to find the increased waiting time per hour. This division allows for a multiplication with the Value of Time VoT_{hkr}, to find the costs associated with the increase in waiting time.

3.6.4 The Calculation of SEE Criteria 4 and 5: External Costs, Safety and Public Health

Section 3.4.4 discussed that when there is no capacity access, the external impact of a train service decreases since the train from the train service does not run. At the same time, there is an increase in external impact from other transport modes since passengers and goods might perform a modal shift from the train to another transport mode. To define the magnitude of the total external impact, the decrease in covered distance by the train and the increase in travelled distance by other transport modes requires an evaluation. This decrease and increase depends on the number of passengers or goods that perform a modal shift from the train to the other transport modes. The magnitude of this modal shift comes from the decrease in the number of passengers and goods transported due to the lack of capacity access for the train service. Calculating this decrease $cl_{ij,train}$ is possible by utilising the LOS. Section 3.6.1 discusses the calculation steps on the LOS.

To find which passengers or goods shift to which alternative transport mode, the following formula can be used:

10) $$cg_{ij,g\neq train} = cl_{ij,train} \cdot ms_{gr}$$

This formula contains the following elements:

- $cg_{ij,g\neq train}$ = the increase in the number of transported passengers or goods per alternative transport mode g between locations i and j.
- $cl_{ij,train}$ = the decrease in the number of passengers or goods transported per train between locations i and j.
- ms_{gr} = the percentage of passengers shifting from the train to alternative transport mode g, based on distance r.

Formula (10) calculates how many passengers or goods receive transport ($cg_{ij,g\neq train}$) via alternative transport mode g, based on the decrease in passengers or goods (that look for an alternative transport mode instead of a train) ($cl_{ij,train}$) with the percentage of passengers or goods that will select a specific alternative transport mode g (ms_{gr}).

To calculate the amount of extra distance covered by the alternative transport modes g, the following formula is applicable:

11) $$sg_{ij,g\neq train} = \frac{cg_{ij,g\neq train}}{u_g} \cdot s_{ij}$$

This formula contains the following elements:

- ⊃ $sg_{ij,g\neq train}$ = the increase in covered distance by alternative transport mode g between locations i and j.
- ⊃ $cg_{ij,g\neq train}$ = the increase in the number of transported passengers or goods per alternative transport mode g between locations i and j.
- ⊃ u_g = the utilisation rate of transport mode g.
- ⊃ s_{ij} = the distance between locations i and j.

Formula (11) calculates the distance the other transport modes will cover following the modal shift of passengers and goods from the train to other transport modes ($sg_{ij,g\neq train}$). This distance depends on the number of passengers or goods that use the alternative transport mode ($cg_{ij,g\neq train}$), the number of passengers or goods that utilise one vehicle of the transport mode on average (u_g) and the distance (s_{ij}) between the locations i and j.

The following formula calculates the utility loss on external impacts:

12) $$V_{external} = \left(\sum_{g=1}^{m}\sum_{i=1}^{n}\sum_{j=1}^{o} sg_{ij,g\neq train} \cdot ec_g\right) - MAX(s_{ij}) \cdot fd \cdot ec_g$$

This formula contains the following elements:

- ⊃ $V_{external}$ = the utility loss on the external impacts associated with the train service.
- ⊃ $sg_{ij,g\neq train}$ = the increase in covered distance by alternative transport mode g between locations i and j.
- ⊃ ec_g = the external cost factors per transport mode g.
- ⊃ $MAX(s_{ij})$ = the distance between the complete train service' starting station and the terminus station.
- ⊃ fd = the frequency of the train service per day.

Formula (12) evaluates the external impact of the additional usage of the alternative transport modes based on the outcome of the extra distance covered by these transport modes ($sg_{ij,g\neq train}$). This evaluation takes place by multiplying all distance increases with the external cost factors (ec_g) from Maibach et al. (2008) across all combinations of locations i and j and across all alternative transport modes g. This total external cost increase across all alternative transport modes gets subtracted by the external cost increase that would occur if the train service received capacity access since this external cost increase is 'prevented' when there is no capacity access ($MAX(s_{ij}) \cdot fd \cdot ec_g$). The multiplication of the route distance of the train service between the beginning and terminating station ($MAX(s_{ij})$) with the external costs of train transport (ec_g) and the frequency of the train service per day (fd) represents the subtraction.

3.6.5 The Total Utility Loss

Adding up the utility losses across all five SEE criteria creates a total utility loss associated with not running the train service. The train service with the highest total utility loss should eventually receive capacity access, considering that preventing the highest utility loss from occurring ensures that the socioeconomic burden to society is as low as possible.

To conclude, the following formula can be used:

13) $$V_{total} = V_{operation} + V_{time-cost} + V_{connectivity} + V_{external}$$

This formula contains the following elements:

- ⊃ V_{total} = the total utility loss associated with not running the train service per day.
- ⊃ $V_{operation}$ = the utility loss on the operation costs of the train service per day.
- ⊃ $V_{time-cost}$ = the utility loss on the time-costs of the train service per day.
- ⊃ $V_{connectivity}$= the utility loss on the connectivity and accessibility of the train service per day.
- ⊃ $V_{external}$ = the utility loss on the external costs of the train service per day.

3.7 Conclusion

This chapter evaluated the following sub-question:

- Sub-question 2: How does the method for capacity allocation calculate the socioeconomic value of capacity requests across the SEE criteria in the regulation?

This chapter presents a method for evaluating train service based on SEE criteria. This method is, for the most part, based on the approach currently used by Norwegian IM Bane NOR. Still, some alterations to this method based on the scientific literature apply to the method designed in this chapter to ensure that it aligns with the five SEE criteria from the regulation.

The performance across five SEE criteria determines the utility loss when a particular capacity request does not receive capacity access. These calculations make it feasible to rank the alternatives and select the train service that should receive priority when there is a capacity conflict. The method uses reasoned assumptions and parameters from the scientific literature to do these calculations.

The EC's proposed regulation emerged recently, and little information about SEE criteria is available. Therefore, this method represents the first reproducible application of SEE criteria on capacity allocation. This first application shows how the prioritisation according to the SEE criteria deviates from the prioritisation that stems from the AMvB used in the Netherlands.

Still, ENIM will develop the methods to assess conflicting capacity requests based on the SEE criteria. These methods could vastly differ from the method presented in this chapter. The research for this thesis aims at achieving the possible differences between the method from this thesis and the methods ENIM will provide to be as small as possible. This minimalization is done by striving to use a healthy mix of insights from the Norwegian approach and scientific literature in this method. This approach enhances the probability of an overlap between the method from this research and the methods ENIM will provide.

4 Case Study Results

This chapter applies the method to the case study of the railway line between Deventer and Bad Bentheim. Section 1.2.2 introduced this railway line. The results of this case study allow for an analysis of the impact of SEE criteria on capacity allocation. The following research question applies to this chapter:

- Sub-question 3: What result on capacity allocation emerges when one applies the method on the case study railway line Deventer – Bad Bentheim?

The chapter first distinguishes several train services that conflict on the railway line. The following section applies the method to these train services. The prioritisation according to the SEE criteria is compared with the prioritisation according to the AMvB. These comparisons provide the input for the conclusion of this chapter.

4.1 Train Services on the Case Study Railway Line

Section 3.3 provides the guidelines for investigating the railway line's current and future train services. There are five applicable sources for train services: the current timetable, future product steps from national and regional PSOs, freight train developments and open access requests.

4.1.1 Current Timetable

Figure 4-1 shows the timetable for 2025 on the railway line between Deventer (Dv) and Bad Bentheim (Bh) through a time-distance diagram. This diagram shows the timetable's basic hour pattern for all train services. In all time-distance diagrams, the green lines are passenger trains, and the orange lines are freight trains. The numbers in red squares correspond to the numbers of the train services mentioned in Table 4-1, which collects all the train services.

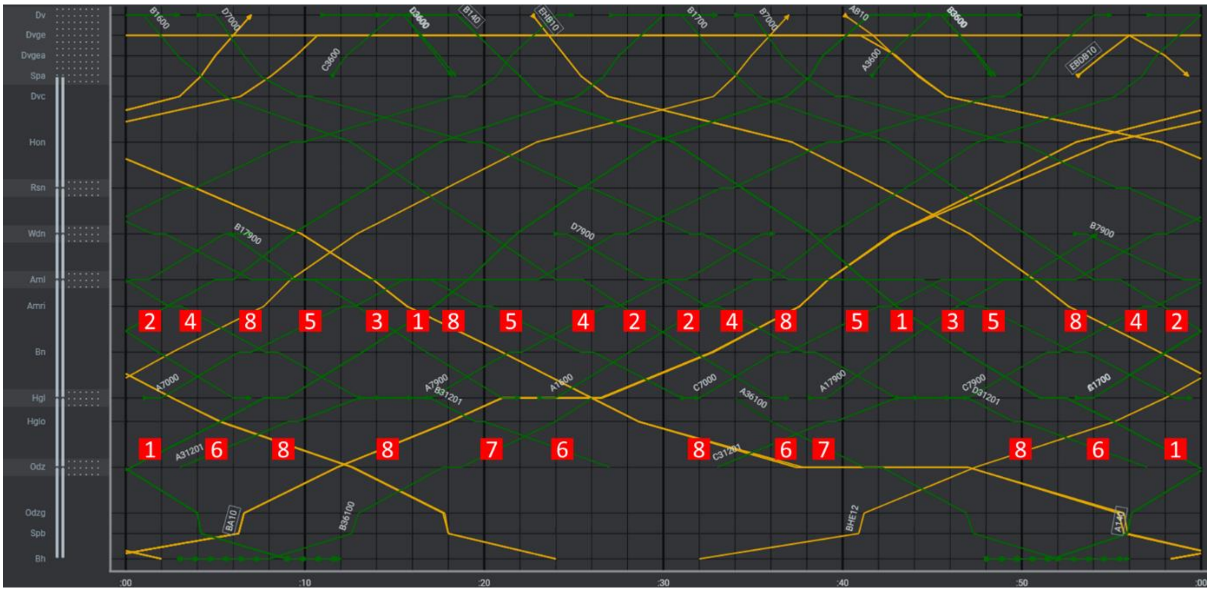

Figure 4-1: The time-distance diagram for a basic hour of the timetable of 2025 applicable to the railway line between Deventer (Dv) and Bad Bentheim (Bh). The numbers in red squares correspond to the numbers of the train services mentioned in Table 4-1 (ProRail, 2024).

For Table 4-1 and the Tables in the upcoming subsections, the following abbreviations on the Train segment types k apply:

- HST = 'High-speed train for passengers';
- IC = 'Intercity or long-distance trains for passengers';
- RE = 'Regional trains for passengers';
- FR = 'Freight trains'.

Table 4-1: All train services running under the current timetable on the case study railway line.

Train service number	Train segment type (k)	Route	Frequency per hour (fh)	Contract
1*	IC	Amsterdam C. – Berlin Obf.	0,5	Open access
2	IC	The Hague C. – Enschede	2	National PSO
3	IC	Zwolle – Enschede	1	Regional PSO
4	RE	Zwolle – Enschede	2	Regional PSO
5	RE	Apeldoorn – Almelo (– Enschede)**	2	National PSO
6	RE	Zutphen – Oldenzaal	2	Regional PSO
7	RE	Hengelo – Bielefeld Hbf.	1	Regional PSO
8	FR	(Onwards –) Deventer – Bad Bentheim (– onwards)	2	Open access

*This train service is currently a part of the national PSO. After December 2024, this train service foresees operation in open access.
**Train service 5 only runs between Almelo and Enschede during peak hours.

Currently, some night trains are operating on the case study railway line in open access. These train services include the Brussels – Amsterdam – Berlin – Prague night train. Given the low frequency of less than one train per day, these trains can be part of the ad hoc phase of TTR. Therefore, these trains are out of the scope of this research.

4.1.2 Future Product Steps – National PSO

In the PSO contract awarded by I&W, it is denoted in the future vision map that during peak hours, an additional IC service between Enschede and Deventer (and onwards) must run. This peak-hour service should run during the hours when the international IC service between Amsterdam C. and Berlin Obf. does not run (I&W, 2023). No other product steps are applicable to the case study railway line mentioned in the national PSO contract. To conclude, Table 4-2 shows additional train services for future product steps for national PSOs.

Table 4-2: All train services concerning the national PSO product steps on the case study railway line.

Train service number	Train segment type (k)	Route	Frequency per hour (fh)	Contract
9	IC	Amsterdam C. – Enschede	0,5 (during peak hours)	National PSO

4.1.3 Future Product Steps – Regional PSO

Since 2018, an IC service operates between Zwolle and Enschede (train service 3 in Table 4-1). Now that this train service is in operation, there is an ambition by the Province of Overijssel to expand the frequency of this train service from 1 train per hour to 2 trains per hour as a product step (Poortinga, 2023).

No other product steps apply to the case study railway line mentioned in the regional PSO contracts. To conclude, Table 4-3 shows additional train services for future product steps for regional PSOs.

Table 4-3: All train services concerning the regional PSO product steps on the case study railway line.

Train service number	Train segment type (k)	Route	Frequency per hour (fh)	Contract
10	IC	Zwolle – Enschede	1	Regional PSO

4.1.4 Freight Train Developments

An assessment of the WLO high 2040 scenario in the IMA, as discussed in Section 3.3.4, shows that for 2040, an estimation of 55 freight trains per day in both directions applies to the case study railway line between Deventer and Bad Bentheim. According to the current timetable in Table 4-1, two paths per hour are available to freight trains. Given this maximum daily capacity of 96 trains in both directions, all 55 freight trains can receive capacity access.

According to the TTR Capacity Strategy for 2026, the capacity for freight trains on the railway line will increase from 2 trains per hour to 2,5 trains per hour. This proposed capacity increase is a consequence of construction works on the railway line between Emmerich and Oberhausen in Germany for 80 weeks starting in November 2024. During this period, freight trains are diverted via other border crossings, including the one on the case study railway line. This increase of 0,5 trains per hour facilitates the diverted freight trains (Brandt et al., 2022).

To conclude, Table 4-4 shows the future additional train service for freight trains.

Table 4-4: All future additional train services for freight trains on the case study railway line.

Train service number	Train segment type (k)	Route	Frequency per hour (fh)	Contract
11	FR	Rotterdam – Deventer – Bad Bentheim (– onwards)	0,5	Open access

4.1.5 Requests for Open-Access Trains

In total, the ACM received four requests for open-access trains:

- The incumbent Dutch passenger train operator announced their plan to run an international intercity service between Amsterdam C. and Berlin Obf. Given that this open-access train is already being operated in the current timetable and therefore included in Table 4-1, this open-access train service will not create a new train service (ACM, 2024).
- Another operator announced their plan to run an international train service between Amsterdam C. and Berlin Hbf. The train service will stop at Amsterdam C., Amersfoort C., Deventer, Hengelo, Osnabrück Hbf., Hannover Hbf., and Berlin Hbf. With additional stops in Hilversum and Apeldoorn, this train can be fitted into the TTR Capacity Strategy by ProRail within the 'Intercity or long-distance trains for passengers' train segment. According to the request, the frequency of the train service is seven trains per day, which roughly translates to an hourly frequency of 0,5 trains per hour (ACM, 2024).
- Another operator announced their plan to run an international train service between Amsterdam C. and Berlin Hbf. Given the low frequency of 1 train per day, this train service can be part of the ad hoc phase of TTR. Therefore, this train service is out of the scope of this research (ACM, 2024).
- Another operator announced their plan to run a regional train service between Apeldoorn and Enschede. The train service will stop at all intermediate stations. This train can be fitted into the TTR Capacity Strategy by ProRail within the 'Regional trains for passengers' train segment. According to the request, the frequency of the train service is two trains per hour (ACM, 2024).

To conclude, Table 4-5 shows the future additional train service for open access trains.

Table 4-5: All future additional train service for open access trains on the case study railway line.

Train service number	Train segment type (k)	Route	Frequency per hour (fh)	Contract
12	IC	Amsterdam C. – Berlin Hbf.	0,5	Open access
13	RE	Apeldoorn – Enschede	2	Open access

4.2 Capacity Conflicts

When assessing all train services 1 through 13 from Section 4.1, a distinction emerges between train services that do not conflict with any other train service and train services that conflict with other train services. The TTR Capacity Strategy can be applied to find whether train services conflict with one another. When two or more train services require the same capacity in the TTR Capacity Strategy, a capacity conflict emerges. Reviewing the time-distance diagram in Figure 4-1 reveals which of the thirteen train services from Section 4.1 conflict. Such a conflict emerges when multiple train services want to claim the capacity of the same train series in the time-distance diagram.

Following the review of the time-distance diagram, the following train services do not conflict with any of the other 12 train services:

- Train service 2: IC The Hague – Enschede
- Train service 3: IC Zwolle – Enschede
- Train service 4: RE Zwolle – Enschede
- Train service 6: RE Zutphen – Oldenzaal
- Train service 7: RE Hengelo – Bielefeld Hbf.
- Train service 8: FR: (Onwards –) Deventer – Bad Bentheim (– onwards)

All these train services can receive capacity access without hindrance.

Two groups of train services emerge with capacity conflicts. In each group, RUs want to claim the capacity of the same single train series in the time-distance diagram.

The first group of conflicting train services is 'Group 1'. Here, all capacity requests of the group want to claim the capacity currently occupied by train series 140, which is the name of the train series in the current timetable of 2025. Figure 4-2 highlights train series 140 with a lime green colour in the time-distance diagram, which again shows the timetable of 2025 for the railway line between Deventer (Dv) and Bad Bentheim (Bh).

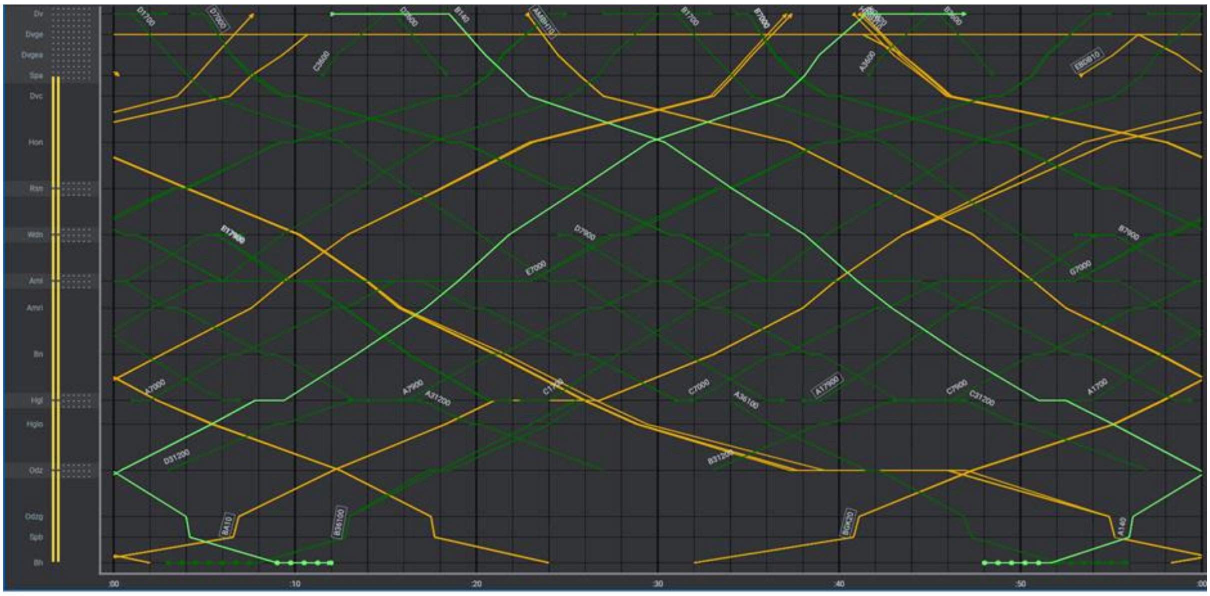

Figure 4-2: The time-distance diagram highlighting train series 140 with a lime green colour (ProRail, 2024).

Specifically, the following train services conflict with one another in 'Group 1':

- Train service 1: IC Amsterdam C. – Berlin Obf.
- Train service 9: IC Amsterdam C. – Enschede
- Train service 10: IC Zwolle – Enschede
- Train service 11: FR Rotterdam – Deventer – Bad Bentheim (– onwards)
- Train service 12: IC Amsterdam C. – Berlin Hbf.

These five train services compete for a total available capacity of one train per hour since Figure 4-2 indicates a capacity of one train series per hour per direction. Currently, train service 1 occupies half of this capacity by running 0,5 trains per hour.

The second group of conflicting train services is 'Group 2'. Here, all capacity requests of the group want to claim the capacity currently occupied by train series 7000, which is the name of the train series in the current timetable of 2025. Figure 4-3 highlights train series 7000 with a lime green colour in the time-distance diagram, which again shows the timetable of 2025 for the railway line between Deventer (Dv) and Bad Bentheim (Bh). After the station of Hengelo (Hgl), train series 7000 leaves the railway line and moves onwards to Enschede.

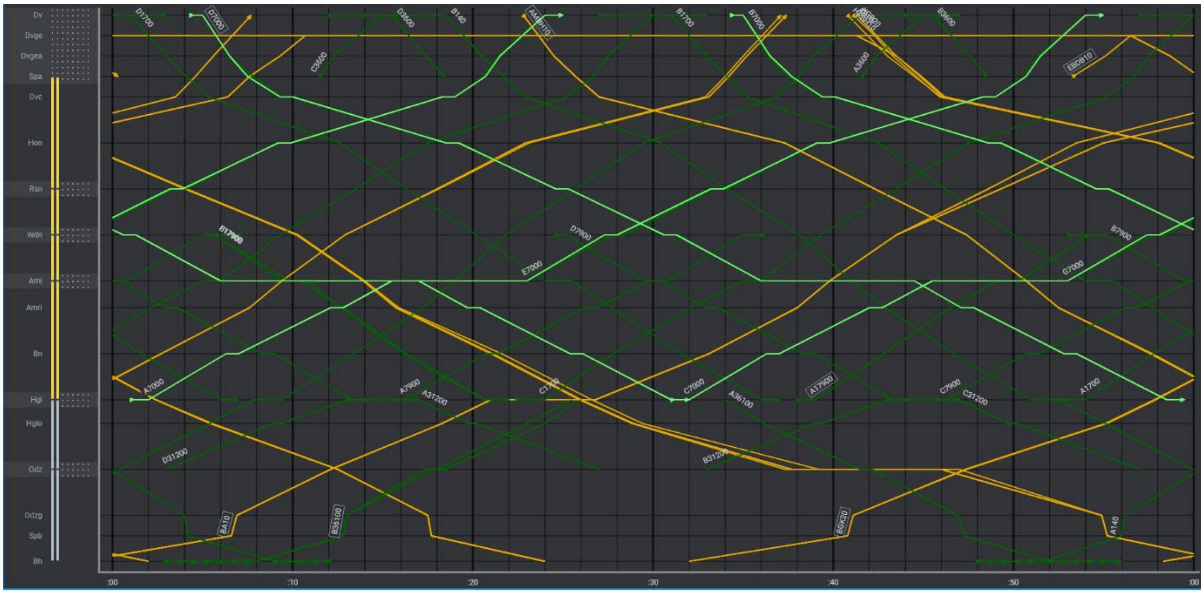

Figure 4-3: The time-distance diagram highlighting train series 7000 with a lime green colour (ProRail, 2024).

Specifically, the following train services conflict with one another in 'Group 2':

- Train service 5: RE Apeldoorn – Almelo (– Enschede)
- Train service 13: RE Apeldoorn – Enschede

These two train services compete for a total available capacity of two trains per hour since Figure 4-3 indicates a capacity of two train series per hour per direction. Currently, train service 5 occupies this capacity by running two trains per hour. Both train services are identical, with the difference being that between Almelo and Enschede, train service 5 runs only during peak hours, whilst train service 13 additionally runs outside of peak hours.

4.3 Data Resources

To apply the method to the case study railway line, gathering data is required to fill in all the input data on the train service. Section 3.5.1 discusses these inputs in general, and this section discusses how all data is gathered specifically for the case study.

- Short information on the train service:
    - Train segment type $k \in K$: To find the segment type, the 2026 TTR Capacity Strategy. An excerpt of the TTR Capacity Strategy for the line plan of the Hengelo – Bad Bentheim section is available publicly. To illustrate how the train segments per train service emerge via the TTR Capacity Strategy, Figure 4-4 shows the excerpt of the TTR Capacity Strategy.

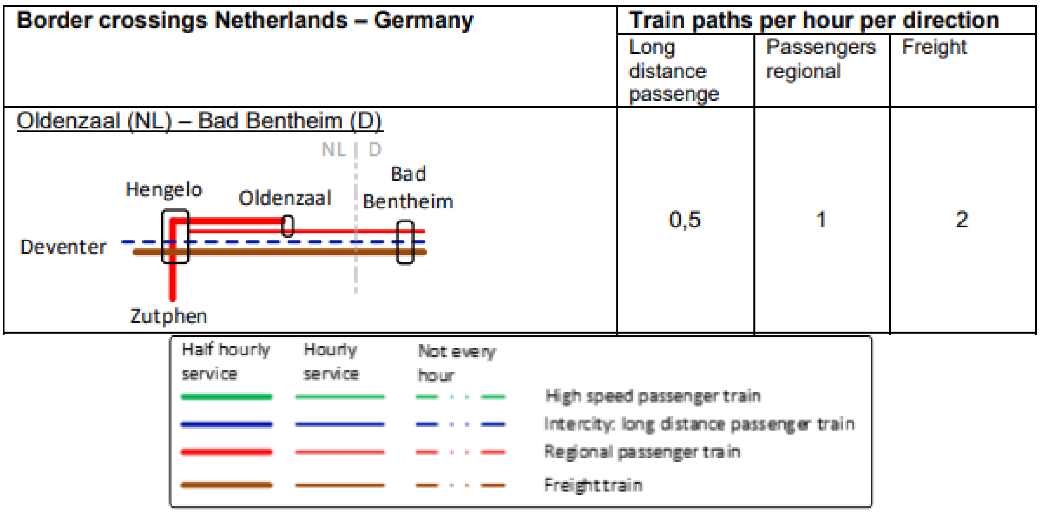

Figure 4-4: The 2026 TTR Capacity Strategy line plan for the Hengelo – Bad Bentheim section (Brandt, Visser, & Westgeest, 2022).

- Traction energy supply system $l \in L$: For the case study railway line, it is assumed that train services that run entirely via electrified lines used electric-propelled rolling stock, expecting that electric-propelled trains are cheaper in exploitation than diesel-propelled trains (Rover, 2024).
- Train frequency per hour fh: The frequency per hour emerges from the TTR Capacity Strategy 2026, as Figure 4-4 illustrates.
- Train frequency per day fd: The frequency of the train service per day for PSO trains follows the number of trains mentioned in the train traffic forecast models internally used by ProRail. These models show per train service how many train services run per day. The data emerges from the planning system DONNA and transport planning software VISUM (ProRail, 2024). The models are internally used by ProRail, making publication not possible. For the open-access train services, requests from open-access train operators to the ACM apply to find the frequency per day.

- Matrix information on the train service: Characteristics of train services associated with specific relations of two stations or commercial stops on the train service. When providing data for all possible combinations of stations or commercial stops, matrices of this data emerge. The following information is part of the discussion for each possible combination of two train stations:
  - Travel time t_{ij}: The travel time for the PSO trains emerges via the train traffic forecast models internally used by ProRail (ProRail, 2024). The travel time for open-access train services emerges via the requests from open-access train operators to the ACM.
  - Travel time alternative connection ta_{ij}: The travel time for the alternative train connection can emerge by considering all the trains in the train traffic forecast models by ProRail (ProRail, 2024). The (combination of) train services that provide the shortest alternative path (considering travel time) to transport passengers represents the alternative train connection. The travel time to this train connection is the input to the model.
  - Transfer time tt_{ij}: Based on the travel time of the alternative train connection ta_{ij}, the transfer time of the alternative train connection is distilled. This transfer time equals the amount of time spent between a pair of trains that are part of the alternative train connection. Specifically, it equals the amount of time between the arrival of the first train of a connection and the departure of the second train of a connection.
  - Transported commodity c_{ij}: The number of transported goods or passengers per train service is estimated for PSO train services in the train traffic forecast models by ProRail (ProRail, 2024). These numbers are not yet available for open-access train services. Calculating these numbers takes place utilising a ratio. Calculating this ratio is possible through the following fraction: $\frac{seat\ capacity\ of\ the\ open-access\ train\ service}{seat\ capacity\ of\ the\ PSO\ train\ service}$.
  - Frequency alternative train connection fa_{ij}: he number of train alternative connections per hour, excluding the frequency of the assessed train service, is defined via the train traffic forecast models by ProRail (ProRail, 2024). Here, the frequency of all train services that can provide an alternative train connection to the train service from the capacity request is part of the consideration. When one alternative train connection overtakes another during its voyage, removing the slower alternative train connection from the considered alternative train connections list must occur.
  - Distances between stations s_{ij}: The distance between the two stations or commercial is defined via the train traffic forecast models by ProRail (ProRail, 2024).

4.4 Results

All train services from groups 1 and 2 discussed in Section 4.2 faced an evaluation utilising the method discussed in Chapter 3. The results of this evaluation will be presented separately to each group in this section.

4.4.1 Results Group 1

Group 1 consists of train services 1 and 9 to 12. Table 4-6 presents the result of SEE criterion 1 regarding operating costs.

Table 4-6: The utility loss on SEE criterion 1 per train service from Group 1.

	1: IC Amsterdam C. – Berlin Obf.	**9:** IC Amsterdam C. – Enschede	**10:** IC: Zwolle – Enschede	**11:** FR Rotterdam – Deventer – Bad Bentheim (– onwards)	**12**: IC Amsterdam C. – Berlin Hbf.
Utility loss	6219	721	441	15	6699

Table 4-6 shows that based on SEE criterion 1, train service 12 should receive capacity access since it has the highest possible utility loss.

Table 4-7 presents the result of SEE criterion 2 regarding time-related costs.

Table 4-7: The utility loss on SEE criterion 2 per train service from Group 1.

	1: IC Amsterdam C. – Berlin Obf.	**9:** IC Amsterdam C. – Enschede	**10:** IC: Zwolle – Enschede	**11:** FR Rotterdam – Deventer – Bad Bentheim (– onwards)	**12**: IC Amsterdam C. – Berlin Hbf.
Utility loss	20073	782	0	1583	17626

Table 4-7 shows that based on SEE criterion 2, train service 1 should receive capacity access since it has the highest possible utility loss. Train service 10 has a utility loss of 0. An explanation for this outcome is that the alternative train connection to this train service is train service 3, which has the same running time as train service 10.

Table 4-8 presents the result of SEE criterion 3 regarding connectivity and accessibility.

Table 4-8: The utility loss on SEE criterion 3 per train service from Group 1.

	1: IC Amsterdam C. – Berlin Obf.	**9:** IC Amsterdam C. – Enschede	**10:** IC: Zwolle – Enschede	**11:** FR Rotterdam – Deventer – Bad Bentheim (– onwards)	**12**: IC Amsterdam C. – Berlin Hbf.
Utility loss	2880	404	333	559	2030

Table 4-8 shows that based on SEE criterion 3, train service 1 should receive capacity access since it has the highest possible utility loss.

Table 4-9 presents the results of SEE criteria 4 and 5 regarding external costs, safety, and public health.

Table 4-9: The utility loss on SEE criteria 4 + 5 per train service from Group 1.

	1: IC Amsterdam C. – Berlin Obf.	**9:** IC Amsterdam C. – Enschede	**10:** IC: Zwolle – Enschede	**11:** FR Rotterdam – Deventer – Bad Bentheim (– onwards)	**12**: IC Amsterdam C. – Berlin Hbf.
Utility loss	2966	20	-550	-307	2489

Table 4-9 shows that based on SEE criteria 4 and 5, train service 1 should receive capacity access since it has the highest possible utility loss. Train services 10 and 11 have negative values for utility loss, which implies that these have utility gains on these SEE criteria. This outcome occurs because the utility gain of not running the train is more significant than the utility loss of running more cars, buses, aeroplanes, trucks and/or ships.

When calculating the sum of the utility losses across all SEE criteria from Table 4-6 to Table 4-9, the final result in Table 4-10 emerges.

Table 4-10: The total utility loss per train service from Group 1.

	1: IC Amsterdam C. – Berlin Obf.	**9:** IC Amsterdam C. – Enschede	**10:** IC: Zwolle – Enschede	**11:** FR Rotterdam – Deventer – Bad Bentheim (– onwards)	**12**: IC Amsterdam C. – Berlin Hbf.
Total utility loss	32138	1927	230	1850	28845

Table 4-10 shows that train service 1 should receive capacity access based on all SEE criteria since it has the highest possible total utility loss. Since train service 1 runs 0,5 trains per hour and the total available capacity for this group of train service is 1 train per hour, a capacity of 0,5 trains per hour remains for the other four competing train services. Train service 12 receives this remaining capacity access as it has the second-highest total utility loss. This outcome means that train services 9, 10, and 11 cannot receive capacity access.

4.4.2 Results Group 2

Group 2 consists of train service 5 and 13. Since the two train services are identical between Apeldoorn and Almelo, the utility loss is only calculated for the railway line between Almelo and Enschede. This decision is because the difference in utility loss between the two train services will be the same regardless of the possible utility loss on the railway line between Apeldoorn and Almelo.

Table 4-11 presents all the results of SEE criteria 1 to 4 and the total utility loss.

Table 4-11: The utility loss per SEE criterion and per train service from Group 2.

	5: RE Apeldoorn – Almelo (– Enschede)	**13:** RE Apeldoorn – Enschede
Utility loss on SEE criterion 1: operating costs	90	407
Utility loss on SEE criterion 2: time-related costs	-54	-245
Utility loss on SEE criterion 3: connectivity and accessibility	192	863
Utility loss on SEE criterion 4 and 5: external costs, safety, and public health	-74	-334
Total utility loss	154	691

Table 4-11 shows that train service 13 should receive capacity access based on all SEE criteria since it has the highest possible total utility loss. There are negative values for utility loss for SEE criteria 2, 4 and 5, which implies that these have utility gains on these SEE criteria. The outcome of SEE criteria 2 occurs since passengers between the intercity stations Almelo, Hengelo, and Enschede could use an intercity service with a shorter travel time than train services 5 and 13. The utility gain corresponding to this shorter travel time to these passengers is more significant than the utility loss corresponding to the passengers who use any of the other three stations on the railway line. The outcome on SEE criteria 4 and 5 occurs because the utility gain of not running the train is more significant than the utility loss of running more cars, buses, aeroplanes, trucks and/or ships.

4.5 Comparison with the AMvB

To assess the impact of the results from Section 4.4 on the Dutch railway network, the prioritisation according to the AMvB of the train service from the case study discussed in Section 2.3 is compared with the results according to the SEE criteria. By doing this, the impact on the Dutch railway network can be derived from the change in prioritisation when the SEE criteria would replace the AMvB after 2029. This section thus provides these comparisons for the train services from Groups 1 and 2.

4.5.1 Group 1 Comparisons

The five train services from Group 1 would correspond with the following train service types from the AMvB:

- Train service 1: IC Amsterdam C. – Berlin Obf. – International public transport, excluding night trains.
- Train service 9: IC Amsterdam C. – Enschede – National public transport (public transport that is not high-speed or urban/rural regional transport) based on a PSO.
- Train service 10: IC Zwolle – Enschede – Rural regional public transport operated based on a PSO.
- Train service 11: FR Rotterdam – Deventer – Bad Bentheim (– onwards) – Standard freight transport.
- Train service 12: IC Amsterdam C. – Berlin Hbf. – International public transport, excluding night trains.

Based on the allocated service types to the train services and the priority order from the AMvB, Table 4-12 prioritises the five train services according to the AMvB. To make comparisons, Table 4-12 also includes the prioritisation from Table 4-10 on the SEE criteria.

Table 4-12: The prioritisation according to the AMvB and the SEE criteria for the train services from Group 1.

	Priority order AMvB	**Priority order SEE criteria**
1st position	Train service **9**: IC Amsterdam C. – Enschede	Train service **1**: IC Amsterdam C. – Berlin Obf.
2nd position	Train service **1**: IC Amsterdam C. – Berlin Obf.*	Train service **12**: IC Amsterdam C. – Berlin Hbf.
3rd position	Train service **12**: IC Amsterdam C. – Berlin Hbf.*	Train service **9**: IC Amsterdam C. – Enschede
4th position	Train service **10**: IC Zwolle – Enschede	Train service **11**: FR Rotterdam – Deventer – Bad Bentheim (– onwards)
5th position	Train service **11**: FR Rotterdam – Deventer – Bad Bentheim (– onwards)	Train service **10**: IC Zwolle – Enschede

*In the AMvB, train services 1 and 12 belong to the same service type since both trains are international services that do not belong to a PSO (after December 2024). Therefore, both train services initially receive the rank of the second position. Applying Article 11 from the AMvB breaks this tie.

In both the AMvB and the SEE criteria results, the top 3 consists of train services 1, 9, and 12. Given that all three train services require a capacity of 0,5 trains per hour and only a total capacity of one train per hour is available, two of these three train services can receive capacity. Train service 1 ranks in both rankings in the first or second position. This result means that according to both the AMvB and the SEE criteria, train service 1 should receive capacity access. However, the AMvB grants capacity access to train service 9 (as the 1st placed train service), whereas the SEE criteria grants capacity to train service 12 (as the 2nd placed train service). Thus, the systems do not agree on which train service should receive capacity access.

Figure 4-5 and Figure 4-6 apply to illustrate the difference in outcome according to the method and AMvB.

Figure 4-5 shows the time-distance diagram when, according to the method, train services 1 and 12 receive capacity access, as indicated by the lime green lines. In this time-distance diagram, one can see that there is capacity for one train per hour that runs across the entire line between Deventer (Dv) and Bad Bentheim (Bh). Given that train services 1 and 12 require the capacity of 0,5 trains per hour, during even hours, one of the two train services can run. During odd hours, there is capacity for the other train services.

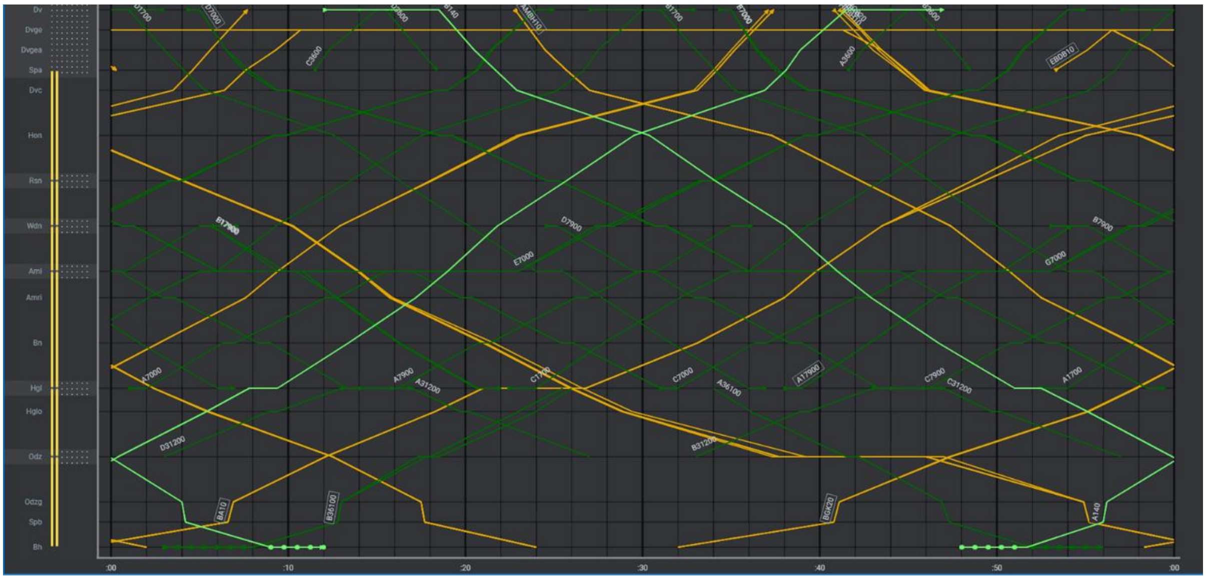

Figure 4-5: The time-distance diagram that applies according to the method for solving the capacity conflict from Group 1 (ProRail, 2024).

Figure 4-6 shows the time-distance diagram when, according to the AMvB, train services 1 and 9 receive capacity access, as indicated by the lime green lines. In this time-distance diagram, one can see that there is capacity for one train per hour that runs across the line between Deventer (Dv) and Hengelo (Hgl). Given that train services 1 and 9 require the capacity of 0,5 trains per hour, during even hours, one of the two train services can run. During odd hours, it is the opposite. Since after the railway station of Hengelo (Hgl) train service 9 leaves the case study railway line and runs onwards to Enschede, only 0,5 trains per hour use the capacity between Hengelo (Hgl) and Bad Bentheim (Bh), as indicated by the interrupted lime green line.

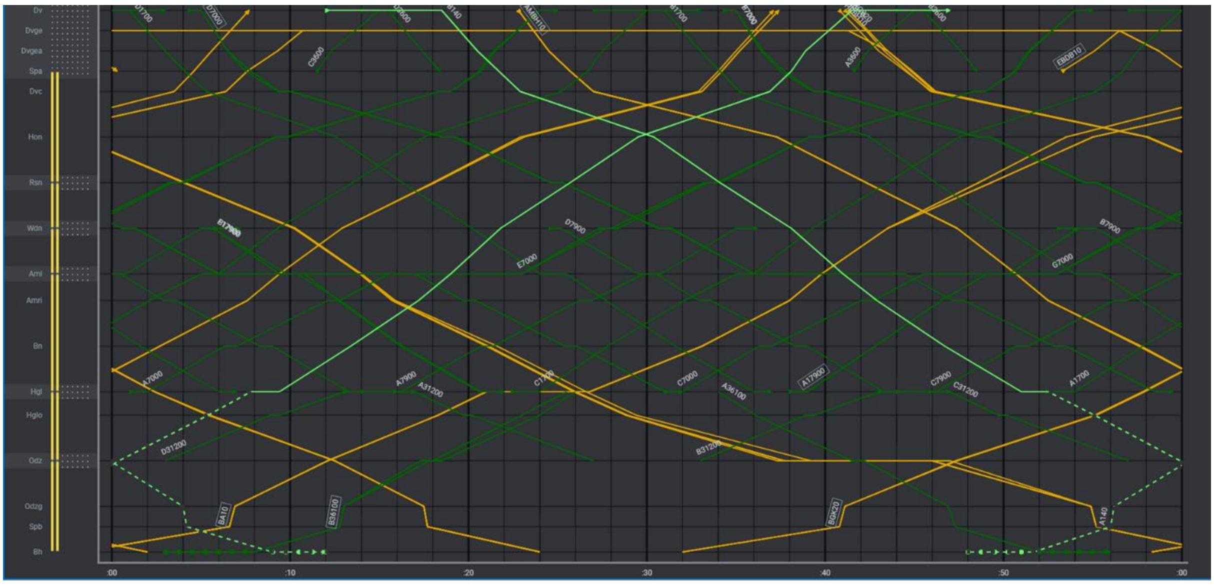

Figure 4-6: The time-distance diagram that applies according to the AMvB for solving the capacity conflict from Group 1 (ProRail, 2024).

4.5.2 Group 2 Comparisons

The two train services from Group 2 would correspond with the following train service types from the AMvB:

- Train service 5: RE Apeldoorn – Almelo (– Enschede) – Rural regional public transport operated based on a PSO.
- Train service 13: RE Apeldoorn – Enschede – Rural regional public transport.

Based on the allocated service types to the train services and the priority order from the AMvB, Table 4-13 prioritises the two train services according to the AMvB. To make comparisons, Table 4-13 also includes the prioritisation from Table 4-11 on the SEE criteria.

Table 4-13: The prioritisation according to the AMvB and the SEE criteria for the train services from Group 2.

	Priority order AMvB	Priority order SEE criteria
1st position	Train service **5**: RE Apeldoorn – Almelo (– Enschede)	Train service **13**: RE Apeldoorn – Enschede
2nd position	Train service **13**: RE Apeldoorn – Enschede	Train service **5**: RE Apeldoorn – Almelo (– Enschede)

Since both train services require a capacity of two trains per hour and in total only two train paths per direction per hour are available, only for one of the train services there is enough capacity available. The prioritisation according to the AMvB and the SEE criteria are not the same, however. The AMvB prioritises train service 5 since that train service falls under a PSO. According to the SEE criteria, train service 13 receives capacity access since it has a higher possible utility loss.

Figure 4-7 and Figure 4-8 illustrate the difference in outcome according to the method and AMvB. Off-peak hours apply to allow for proper comparisons between the two outcomes.

Figure 4-7 shows the time-distance diagram when, according to the method, train service 13 receives capacity access, as indicated by the lime green lines. In this time-distance diagram, one can see that there is capacity for two trains per hour that run between Deventer (Dv) and Hengelo (Hgl). After the railway station of Hengelo (Hgl), train service 13 leaves the case study railway line and runs onwards to Enschede.

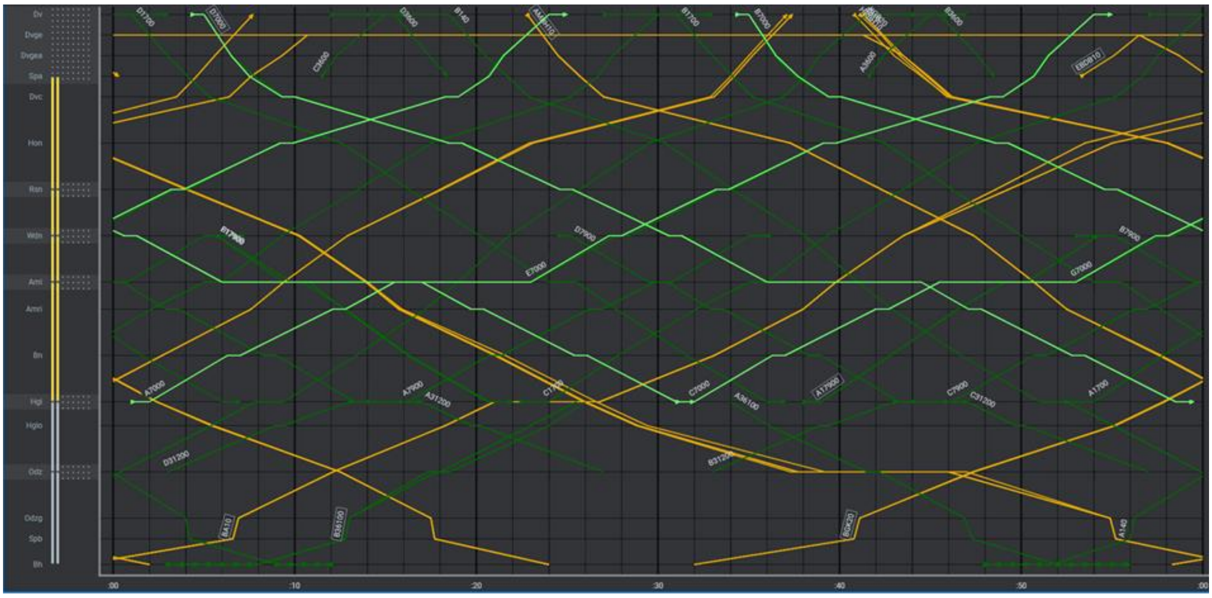

Figure 4-7: The time-distance diagram that applies according to the method for solving the capacity conflict from Group 2 (ProRail, 2024).

Figure 4-8 shows the time-distance diagram when, according to the AMvB, train service 5 receives capacity access, as indicated by the lime green lines. In this time-distance diagram, one can see that there is capacity for two trains per hour that run between Deventer (Dv) and Almelo (Aml). There is no lime green line indicated between Almelo (Aml) and Bad Bentheim (Bh) since train service 5 terminates during off-peak hours at Almelo (Aml).

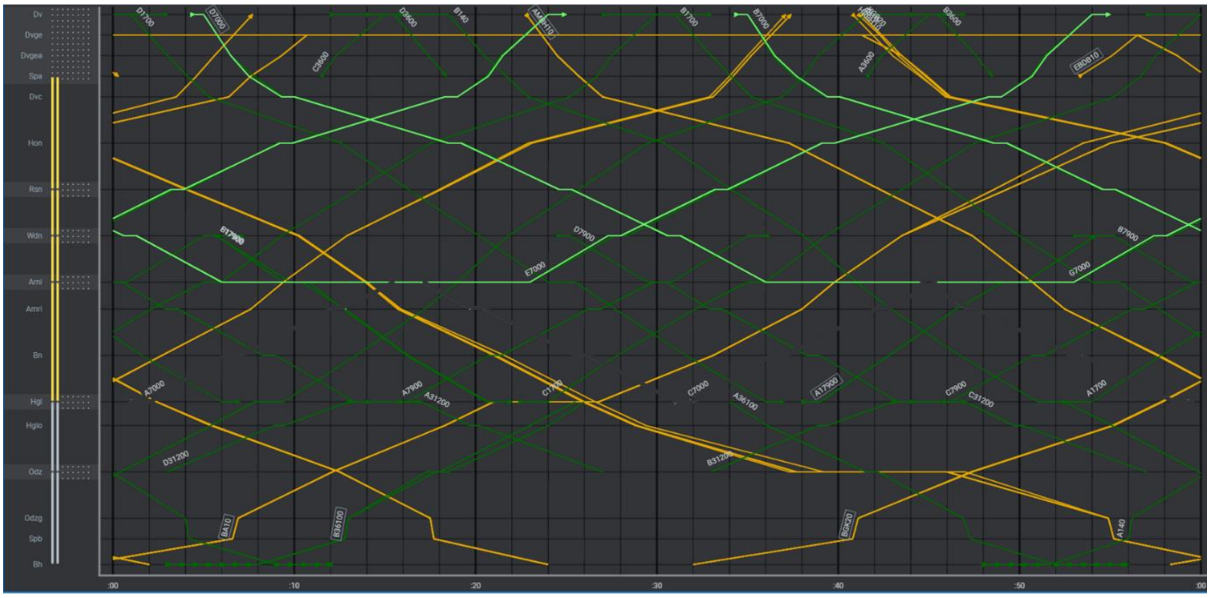

Figure 4-8: The time-distance diagram that applies according to the AMvB for solving the capacity conflict from Group 2 (ProRail, 2024).

4.6 Conclusion

This chapter evaluated the following sub-question:

- Sub-question 3: What result on capacity allocation emerges when one applies the method on the case study railway line Deventer – Bad Bentheim?

This chapter applied the method designed in Chapter 3 to solve the capacity conflicts on the case study railway line from this chapter. This showed what kind of result one can expect when applying the method.

For both groups of conflicting train services, the outcome according to the method deviates from the outcome emerging from the currently applied AMvB. Considering the case study, the method prioritises capacity requests for open-access train services. On the contrary, the AMvB prioritises PSO-led train services. Therefore, the conclusion is that when applying the method described in Chapter 3 to this case study, the outcome will entail more capacity for open-access train services. This result shows that the method does not distinguish between PSO and open-access train services, unlike the AMvB.

This result clarifies how RUs can increase the socioeconomic value of their train services and, thus, their chances of receiving capacity access. When comparing train services 1 and 12, serving more train stations and/or using rolling stock with higher capacity increases the socioeconomic value. This finding holds since these two train services only differentiate in these two aspects. When looking at train services 5 and 13, operating a train service during a more extended period and/or across a longer route increases the socioeconomic value. This finding holds since these two train services only differentiate in these two aspects.

The following two chapters in this thesis consider the results of applying the method to the case study. Chapter 5 shows to what extent strategic guidance, as discussed in Article 11, aligns with the results in this chapter. Since the Dutch Ministry of Infrastructure and Water Management provides strategic guidance to the IM, the strategic guidance can alter the outcome projected in this chapter. Chapter 6 discusses the results' meaning found in this chapter. It does this through a sensitivity analysis, interviews with experts, and discussions utilising ethical theories.

5 Strategic Guidance

This chapter discusses the influence of strategic guidance as discussed in the regulation on capacity allocation. It assesses the impact of strategic guidance on capacity allocation and how it can alter the results found in Chapter 4. The involvement of the case study railway line between Deventer and Bad Bentheim will apply again. This chapter will thus provide an answer to the following sub-question:

- Sub-question 4: How do the results from the method for the case study relate to strategic guidance?

The first section discusses how the four aspects of strategic guidance, as discussed in Article 11 of the regulation, apply to Dutch national rail policies. Afterwards, the following two sections evaluate the impact of strategic guidance on the case study railway line. Finally, the fourth section assesses the relationship between strategic guidance and the SEE criteria before the final answer to the research question emerges.

5.1 Strategic Guidance

Article 11 in the regulation defines the guidelines on which strategic guidance the European Member States can provide to the IMs. Section 2.2.2 introduced the four aspects of strategic guidance in the regulation. This section discusses how these four descriptions apply to the Dutch national rail policies.

5.1.1 Rail Transport Policies

The first aspect of Strategic Guidance entails the following description: "General objectives of national rail policy relevant for strategic capacity planning within the scope of this Regulation".

The Ministry of I&W formulates the general objectives of rail transport in the "Toekomstbeeld Openbaar Vervoer 2040" (Future Vision for Public Transport 2040), often abbreviated as TBOV. The 'contour note' of TBOV defines several objectives that the rail public transport system should fulfil.

In total, the contour note formulates the following six objectives:

- Contribution to a high-frequency train service on a circular belt of cities: offering a high-frequency train service between the Randstad, Eindhoven, Arnhem, Nijmegen, and Zwolle.
- Strong axis to country areas: connecting the Randstad with the rest of the Netherlands through faster rail transport.
- Urbanization: enhancing and maintaining accessibility to new and developing urban areas in the Netherlands.
- Regional accessibility: enhancing and maintaining accessibility to the rural areas in the Netherlands.
- International connections: enhancing international train connections between the Netherlands and neighbouring countries.
- Rail freight transport: enhancing freight transport by rail in the Netherlands (ProRail, 2020).

Table 5-1 contains a recap of all the indicators in TBOV and the objectives they assess.

Table 5-1: The objectives and their relative indicators in TBOV (ProRail, 2020).

Objective	Indicators
1. Contribution to a high-frequency train service on a circular belt of cities	⊃ Effects on capacity bottlenecks. ⊃ Feasibility to accommodate additional passenger increase. ⊃ Increase or decrease to the number of trains.
2. Strong axis to country areas	⊃ The number of accessible jobs. ⊃ The travel time between the Randstad region and other parts of the Netherlands.
3. Urbanisation	⊃ Accessibility of new residential areas. ⊃ Feasibility to accommodate additional passenger increase.
4. Regional accessibility	⊃ Higher train frequencies. ⊃ Shorter travel times.

	⊃ Additional train stations. ⊃ New direct train connections.
5. International connections	⊃ Connections between Dutch stations and (HST-)stations abroad. ⊃ Contribution to one strong axis per international border.
6. Rail freight transport	⊃ Separation of passenger transport and freight transport. ⊃ Accessibility and flexibility of train paths for freight trains. ⊃ Shorter travel times.

The objectives from TBOV can thus assess whether the train services discussed in Chapter 4 align or not align with the general objectives of the Dutch national rail policy. The indicators in Table 5-1 allow for a qualitative assessment of the train services across the six objectives in TBOV.

5.1.2 Rail Infrastructure Development

The second aspect of Strategic Guidance entails the following description: "An outlook on the development of rail infrastructure, taking into account relevant plans and strategies at a national or regional level and the work plans of the European Transport Corridors referred to in Article 53 of the [new TEN-T Regulation]".

The development of rail infrastructure in the Netherlands involves the 'Programma Hoogfrequent Spoor' (Program High-frequency Rail), often abbreviated as PHS. PHS is a program which allows for high-frequency train services along six passenger train corridors and one freight train corridor. PHS achieves a high-frequency train service by investing in the infrastructure of the six corridors. PHS thereby provides a long list of necessary expansions and alterations to the infrastructure (I&W, 2019).

TBOV follows PHS, where TBOV includes investments in the infrastructure to allow for the 'bouwstenen' to be completed. The TBOV focus group created a longlist of infrastructure expansions or alterations to the infrastructure (ProRail, 2020).

The European Commission induces investment into the railway network through the Trans-European Transport Network (TEN-T) regulation. Within TEN-T, the aim is to strive for one European rail network by connecting national networks and withdrawing barriers. TEN-T has multiple corridors, three of which run from and to the Netherlands (Graeff et al., 2020). For the core railway network of TEN-T, the infrastructure has to meet the following requirements:

- ⊃ All railway lines are electrified.
- ⊃ All railway lines are equipped with ERTMS.
- ⊃ 75% of the railway lines must allow a 160 km/h line speed for passenger trains and a 100 km/h line speed for freight trains.
- ⊃ All railway lines must accommodate trains with a weight of 22,5 tonnes and freight trains with a length of 740 meters (I&W, 2022).

The foreseen rail infrastructure investments described in PHS, TBOV and TEN-T thus represent a complete outlook on rail infrastructure development. The train services discussed in Section 4 are thus part of an assessment determining whether they align with the rail infrastructure developments.

5.1.3 Requirements and Guidelines on Rail Infrastructure Capacity Use

The third aspect of Strategic Guidance entails the following description: "General requirements and guidelines as regards the use of rail infrastructure capacity, which the infrastructure manager shall take into account in strategic capacity planning, in particular in relation to highly utilised and congested infrastructure referred to in Article 21".

TBOV stipulates which train paths should be made available to RUs, the distribution of train paths across train paths, and the frequencies of the train series. TBOV contains multiple train line maps showing all train series in the Netherlands. Designing these maps is done by assessing these train series in cohesion.

ProRail uses the train line maps to conduct an impact analysis on whether open-access train service fits within the capacity as foreseen by TBOV. This analysis compares the open-access requests and the train series on the map. When there are significant differences between the two, the conclusion is that there is no capacity for the capacity request (ProRail, 2023).

This method by ProRail can also allow for an assessment of whether the train services assessed in Section 4 fit within the train series defined by TBOV. Based on this, making conclusions on whether the train services align with the general requirements and guidelines regarding the use of rail infrastructure capacity is possible.

5.1.4 Development of PSOs

The fourth and final aspect of Strategic Guidance entails the following description: "An outlook on the planned development of rail services operated under public service obligations, taking into account, where necessary, the views of the regional or local authorities involved".

As discussed in Section 3.3, for PSOs, the awarded PSO contracts, including future product steps, can be assessed to see whether train services align with the development of PSO train services. Also, assessing reports and documents by policymakers to find future product steps is possible again.

Therefore, through the PSO contracts and policymakers' ambitions, it is possible to determine whether the train services from Section 4 align with the developments concerning PSO train services.

5.2 Strategic Guidance on the Case Study

This section discusses how the assessed train services from Chapter 4 are evaluated along the four aspects of strategic guidance.

5.2.1 Rail Transport Policies on the Case Study

Considering the objectives and indicators in Table 5-1, the following train services aid the objectives enclosed in Dutch rail transport policies.

- Train service 9 (IC Amsterdam C. – Enschede) aligns with objective 3 on urbanisation since this train service creates additional capacity for passengers travelling between the regions of Twente and the Randstad.
- Train service 10 (IC Zwolle – Enschede) aligns with objective 4 on regional accessibility since it allows for a higher frequency of the regional intercity train service between Zwolle and Enschede.
- Train service 11 (FR Rotterdam – Deventer – Bad Bentheim (– onwards)) aligns with objective 6 on rail freight transport since it allows for a higher frequency of rail freight transport, creating higher accessibility and flexibility to freight RUs.
- Train service 12 (IC Amsterdam C. – Berlin Hbf.) aligns with objective 5 on international connections since it creates a faster travel connection between Dutch stations and (HST-) stations. It can do this by skipping the stations of Hilversum, Apeldoorn, Bad Bentheim, Rheine, Bünde (Westf.), and Berlin Spandau compared to the current IC Amsterdam C. – Berlin Obf. timetable.
- Train service 13 (RE Apeldoorn – Enschede) aligns with objective 4 on regional accessibility since the train service allow higher train frequencies, shorter travel times, and new direct train connections compared to the current regional train service.

Two train services neither align nor misalign with the objectives of Dutch rail transport policy since train service 1 (IC Amsterdam C. – Berlin Obf.) and 5 (RE Apeldoorn – Almelo – (Enschede)) do not differentiate from the currently applicable timetable.

5.2.2 Rail Infrastructure Development on the Case Study

The railway line between Deventer and Bad Bentheim is not part of any of the six corridors of PHS. Therefore, the case study of the railway line does not foresee infrastructure developments from PHS. The railway line between Deventer and Bad Bentheim is part of the North Sea-Baltic TEN-T corridor, meaning the railway line must comply with the TEN-T requirements. The railway line performs in the following way across the TEN-T requirements.

- Electrification: The entire railway line already received electrification.

- ERTMS: The railway line is not part of the current Dutch program to roll out ERTMS across several railway lines. A rollout of ERTMS between Deventer and Bad Bentheim is scheduled after 2030 (Program ERTMS, 2023).
- A line speed of 160 km/h for passenger trains: The Dutch Secretary of State of Infrastructure and Water Management requested an exemption to this requirement of the TEN-T program for the Deventer – Bad Bentheim railway line (Heijnen, 2023).
- A line speed of 100 km/h for rail freight trains: The railway line already allows a line speed of 100 km/h for rail freight trains, according to the network statement of ProRail (ProRail, 2023).
- Weight of freight trains: According to the network statement of ProRail, the railway line between Deventer and Bad Bentheim aligns with the weight class D4, which allows for freight trains weighing 22,5 tonnes (ProRail, 2023).
- Freight train length of 740 meters: Several projects are currently taking place between Deventer and Bad Bentheim to allow freight trains to stop at shunting tracks with a length of 740 meters. These projects apply to the shunting yards at Hengelo and Oldenzaal (ProRail, 2024).

Out of the infrastructure requirements mentioned above, the only applicable infrastructure development is the investment in 740-meter-long tracks for freight trains at Hengelo and Oldenzaal.

Within TBOV, scheduling took place for the following infrastructure developments to the Deventer – Bad Bentheim railway line:

- The investment in additional platforms at the Almelo and Hengelo stations.
- An increase of the maximum line speed between Hengelo and Oldenzaal from 125 km/h to 140 km/h (ProRail, 2020).

The following train services align with the infrastructure developments mentioned above:

- Train service 1 (IC Amsterdam C. – Berlin Obf.) and 12 (IC Amsterdam C. – Berlin Hbf.) align with the TBOV investment in increasing the maximum line speed between Hengelo and Oldenzaal. This finding holds because these train services run on this section of the railway line and can reach the future line speed of 140 km/h.
- Train service 11 (FR Rotterdam – Deventer – Bad Bentheim (– onwards)) aligns with the TEN-T investment of expanding shunting tracks to accommodate freight train lengths of 740 meters. This finding holds because freight trains utilise this train service and can thus benefit from the expanded shunting tracks.

No alignment or misalignment with this aspect of strategic guidance applies to the other train services since the discussed infrastructure investments do not aid or harm the possibility of running these train services.

5.2.3 Requirements and Guidelines on Rail Infrastructure Capacity Use on the Case Study

This subsection compares the train services with the line network plan from TBOV enclosed in Figure 5-1.

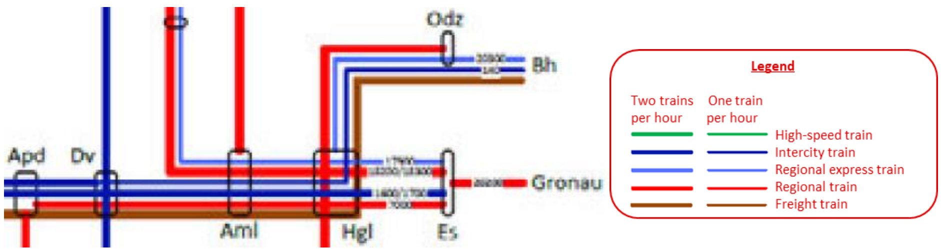

Figure 5-1: The line network plan between Deventer (Dv) and Bad Bentheim (Bh) according to TBOV and used for the impact analysis of open-access requests by ProRail (ProRail, 2023).

For the assessment of the five train services from Group 1, the following holds:

- For train service 1 (IC Amsterdam C. – Berlin Obf.) and 12 (IC Amsterdam C. – Berlin Hbf.) capacity is available in TBOV. This finding holds because the plan includes one intercity train service per hour between Deventer (Dv) and Bad Bentheim (Bh).
- For train service 9 (IC Amsterdam C. – Enschede), no capacity is available in TBOV since there is no additional intercity train service drawn on top of the current intercity service The Hague – Deventer – Enschede.

- For train service 10 (IC Zwolle – Enschede), no capacity is reserved in TBOV since there is only one regional express train service per hour drawn between Zwolle and Enschede instead of the required two.
- For train service 11 (FR Rotterdam – Deventer – Bad Bentheim (– onwards)), no capacity is reserved in TBOV since there are only two freight train service per hour drawn between Deventer and Bad Bentheim instead of the required two and a half.

Since the capacity of train services 1 and 12 is available in TBOV, there is an alignment between the train services and this aspect of strategic guidance. Since no capacity is available for train services 9 to 11 in TBOV, there is a misalignment between the train services and this aspect of strategic guidance.

For the assessment of the two train services from Group 2, the following holds:

- For train service, 5 (RE Apeldoorn – Almelo (–Enschede)) and 13 (RE Apeldoorn – Enschede) capacity is available in TBOV. This finding holds because there is a path of two regional trains per hour drawn in the plan between Apeldoorn (Apd) and Bad Bentheim (Bh).

Since train services 5 and 13 have capacity available in TBOV, there is an alignment between the train services and this aspect of strategic guidance.

5.2.4 Development of PSOs on the Case Study

The future vision map enclosed in the PSO contract awarded by I&W to NS shows which developments to the national PSO should be completed by 2033. Figure 5-2 includes the map excerpt showing the case study area.

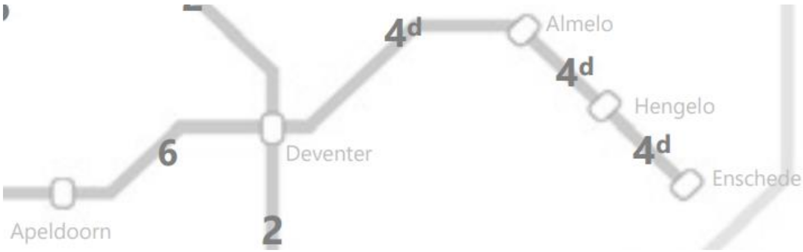

Figure 5-2: The excerpt of the future vision map from the national PSO contract applicable to the case study railway area, which shows the train frequency per hour per line section (I&W, 2023). The exponential 'd' denotes that on top of the mentioned frequency additional trains will run during peak hours.

Based on Figure 5.2, the following train services align with the provisioned PSO development:

- For train service 9 (IC Amsterdam C. – Enschede), there is an alignment with the national PSO development since train service 9 can represent the additional peak hour train service requested in the PSO contract.
- For train service 13 (RE Apeldoorn – Enschede) there is an alignment with the national PSO development, because the regional train service Apeldoorn – Enschede also runs during off-peak hours as requested in the PSO contract for the year 2033.

For the regional PSO contract, the transport plan of the Province of Overijssel is applicable. Based on this transport plan, the following holds:

- For train service 10 (IC Zwolle – Enschede), there is an alignment with the regional PSO development because achieving a total frequency of two intercity train services between Zwolle and Enschede holds when train service 10 runs.

For the other train services, no alignment or misalignment with this aspect of strategic guidance applies since the PSO contract does not specify the development of trains running outside of a PSO.

5.3 Results Overview

Figure 5-3 summarizes the results from section 5.2.

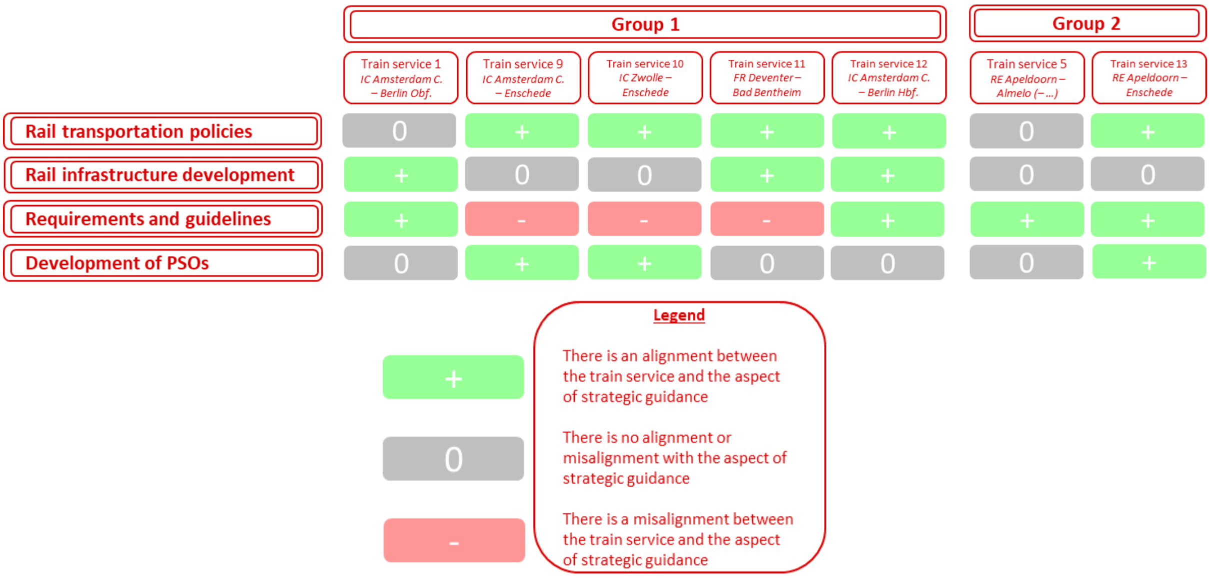

Figure 5-3: An overview of the performance of all train services from the case study on the four aspects contained in Strategic Guidance.

As indicated in Figure 5-3, within Group 1, train service 12 (IC Amsterdam C. – Berlin Hbf.) performs best on strategic guidance. Train service 1 (IC Amsterdam C. – Berlin Obf.) has the second-best scores. Within group 2, train service 13 (RE Apeldoorn – Enschede) is the preferred train service with the better scores.

5.4 The Comparison between the Method and Strategic Guidance

After the results from Sections 5.2 and 5.3, Table 4-12 and Table 4-13, which compare the prioritisations according to the AMvB and the SEE criteria, are expanded with the prioritisations from the strategic guidance.

Table 5-2 shows the three applicable priority orders for Group 1.

Table 5-2: The prioritisation according to the AMvB, the SEE criteria, and the strategic guidance for the train services from Group 1.

	Priority order AMvB	Priority order SEE criteria	Priority order strategic guidance
1st position	Train service **9**: IC Amsterdam C. – Enschede	Train service **1**: IC Amsterdam C. – Berlin Obf.	Train service **12**: IC Amsterdam C. – Berlin Hbf.
2nd position	Train service **1**: IC Amsterdam C. – Berlin Obf.	Train service **12**: IC Amsterdam C. – Berlin Hbf.	Train service **1**: IC Amsterdam C. – Berlin Obf.
3rd position	Train service **12**: IC Amsterdam C. – Berlin Hbf.	Train service **9**: IC Amsterdam C. – Enschede	Ex aequo: Train service **9**: IC Amsterdam C. – Enschede Train service **10**: IC Zwolle – Enschede Train service **11**: FR Rotterdam – Deventer – Bad Bentheim (– onwards)
4th position	Train service **10**: IC Zwolle – Enschede	Train service **11**: FR Rotterdam – Deventer – Bad Bentheim (– onwards)	
5th position	Train service **11**: FR Rotterdam – Deventer – Bad Bentheim (– onwards)	Train service **10**: IC Zwolle – Enschede	

As Table 5-2 indicates, according to the SEE criteria and the strategic guidance, the priority order agrees that train services 1 and 12 should receive capacity access. A comparison between the priority order according to the AMvB and the strategic guidance shows a disagreement on capacity access to train services 9 and 12.

Table 5-3 shows the three applicable priority orders for Group 2.

Table 5-3: The prioritisation according to the AMvB, the SEE criteria, and the strategic guidance for the train service from Group 2.

	Priority order AMvB	Priority order SEE criteria	Priority order strategic guidance
1st position	Train service **5**: RE Apeldoorn – Almelo (– Enschede)	Train service **13**: RE Apeldoorn – Enschede	Train service **13**: RE Apeldoorn – Enschede
2nd position	Train service **13**: RE Apeldoorn – Enschede	Train service **5**: RE Apeldoorn – Almelo (– Enschede)	Train service **5**: RE Apeldoorn – Almelo (– Enschede)

As Table 5-3 indicates, according to the SEE criteria and the strategic guidance, the priority order agrees that train service 13 should receive capacity access. A comparison between the priority order according to the AMvB and the strategic guidance shows a disagreement on capacity access.

5.5 Conclusion

This chapter evaluated the case study railway line between Deventer and Bad Bentheim to find the possible impact of strategic guidance on prioritising competing capacity requests through the following sub-question:

- Sub-question 4: How do the results from the method for the case study relate to strategic guidance?

This chapter evaluated whether altering the result found in Chapter 4 can occur through strategic guidance. Following the application of strategic guidance on the case study railway line in this chapter, one can conclude that such alteration will hardly occur for the case study railway line. This finding holds since the results from this chapter showed that train services in open access (train services 1, 12, and 13) align better with strategic guidance than train services included in the PSO (train services 9 and 10). In other words, train services outside the PSO could be more suited to achieve the goals (for PSO train services) included in strategic guidance than those in the PSO.

Just like with SEE criteria, RUs can opt to create train services that align better with the strategic guidance provided to the IM. By doing this, the RUs increase their chances of receiving capacity access over competing PSO train services or other open-access train services. RUs can take measures to do this following the results of Chapter 5, which are to utilise improved rail infrastructure and/or to adhere more to the TBOV line network plan. This finding holds since train services 1 and 12 receive priority according to strategic guidance based on these two aspects. Furthermore, RUs can also opt to fulfil PSO ambitions earlier and/or perform better across the Ministry's policy objectives. This finding holds since train service 13 receives priority according to strategic guidance based on these two aspects

One central question still needs to be answered: the regulation does not specify which of the two instruments, SEE criteria or strategic guidance, prevails when the two contradict each other. The regulation only states that the IM should consider both instruments when managing scarce capacity. However, a prevalence of SEE criteria or strategic guidance is required before well-founded conclusions emerge on how RUs will behave and prepare their capacity request regarding capacity allocation procedures.

6 Considerations

This chapter discusses a consideration concerning the case study results and method. This chapters consists of three parts. The first part assesses the sensitivity of the method by looking into the assumptions and parameters used. The second part contains a qualitative assessment of the method, where rail experts provide their view on the applicability of the method. The third part uses justice theories to assess the ethical impact of the results. After the completion of this chapter, the following sub-question receives an answer:

- ⊃ Sub-question 5: How indicative are the results, considering the sensitivity and applicability of the method?

6.1 Sensitivity Analysis

The sensitivity analysis first reviews the results for the total utility loss per train service of the case study railway line. Table 6-1 shows these results.

Table 6-1: The total utility loss per train service from the case study.

Train service	Total utility loss
Group 1	
1: IC Amsterdam C. – Berlin Obf.	32138
9: IC Amsterdam C. – Enschede	1927
10: IC: Zwolle – Enschede	230
11: FR Rotterdam – Deventer – Bad Bentheim (– onwards)	1850
12: IC Amsterdam C. – Berlin Hbf.	28845
Group 2	
5: RE Apeldoorn – Almelo (– Enschede)	154
13: RE Apeldoorn – Enschede	691

When looking at the results of Table 6-1, what becomes apparent is the significant magnitude of the outcome for train services 1 and 12 compared to the five other train services. Here, the total utility for train services 1 and 12 is a five-digit number, whereas the utility loss is a three or four-digit number for the other five train services. Given that the total utility loss values for train services 1 and 12 lie within a separate order of magnitude, a sensitivity analysis on these two train services is deemed most appropriate.

Table 6-2 shows the performance of train services 1 and 12 across the five SEE criteria. In addition to showing the utility loss values, the percentages compared to the total utility loss occur within brackets.

Table 6-2: The utility loss per SEE criterion for train services 1 and 12.

	Utility loss on SEE criterion **1**: operating costs	Utility loss on SEE criterion **2**: time-related costs	Utility loss on SEE criterion **3**: connectivity and accessibility	Utility loss on SEE criterion **4** and 5: external costs, safety, and public health	Total utility loss
Train service **1** (Amsterdam C. – Berlin Obf.)	6219 (19%)	20073 (62%)	2880 (9%)	2966 (9%)	32138
Train service **12** (Amsterdam C. – Berlin Obf.)	6699 (23%)	17626 (61%)	2030 (7%)	2489 (9%)	28845

Table 6-2 shows that the utility loss associated with SEE criterion 2 on time-related costs represents the most considerable portion of the total utility loss of both train services. For both train services, 61% or more of the total utility loss relates to this criterion; for the two train services across the other criteria, the percentages are 23% or less. The outcome of SEE criterion 2 thus has the most significant influence on the outcome of train services 1 and 12.

As discussed in Section 3.6.2, formula (8) calculates the utility loss on SEE criterion 2 and time-related costs. In this formula, t_{ij}, ta_{ij}, tt_{ij}, and c_{ij} are input to the method. VOT_{hkr} is a parameter value. Given that t_{ij}, ta_{ij}, tt_{ij}, and c_{ij} are dependent on the assessed train services and thus differ for each train service, the parameter values are relevant for the sensitivity analysis.

The single parameter that applies to SEE criterion 2 is the VOT. This value depends on the travel motive h, the train's segment type k, and route distance r of the train service. Neglecting the segment type k in the methods is impossible since the distinction between the freight train segment type and the other segment types is necessary to choose the correct unit of measurement (VOT as Dollar per tonne/hour for freight or Euro per hour for passengers). Therefore, a sensitivity analysis should take place for sets h and r.

Currently, the VOT value used for train services 1 and 12 is $9{,}46$ Euro per hour, weighted for sets h and p. If neglecting h is required, the three different travel motives h should each have an occurrence of 33%. If neglecting r is required, the four different distance ranges r should each have an occurrence of 25%. Considering the previous, Table 6-3 shows the new outcomes for the train services from group 1. This table shows a relative difference of +0% for train service 11 since this is a freight train service, and the value of VOT for freight trains does not differ for different values of h and r.

Table 6-3: The outcome of the sensitivity analysis for the train services from group 1. SEE criteria 1, 4, and 5 are not included, since these criteria do not use the VOT for calculations.

Train service	Not considered set	New value of VOT	Utility loss on SEE criterion 2	Utility loss on SEE criterion 3	Total utility loss	Relative difference compared to the previous result
1	h	18,03	38274	5491	52950	+64,76%
9			1492	771	3003	+55,84%
10			0	823	720	+213,04%
11			1583	559	1850	+0%
12			33609	3871	46669	+61,80%
1	r	8,34	17704	2540	29429	-8,43%
9			690	357	1787	-7,27%
10			0	381	278	+20,87%
11			1583	559	1850	+0%
12			15546	1791	26525	-8,04%

Table 6-3 still shows considerable differences in the outcome across the five train services from group 1. Train services 1 and 12 still come out as the preferred train services for both of the used values for the VOT. Again, train services 1 and 12 have outcomes described with five digits, while the other have outcomes described with three of four digits.

However, for train service 10, the total utility loss increases by 200% for $VOT = 18{,}03$. In addition for $VOT = 8{,}34$, train service 10 is the only one where the total utility loss increases. This finding highlights that the chosen parameter values can significantly impact the outcome of total utility loss, which means that alternative prioritizations can emerge.

The results of Table 6-3 also highlight how different values for the same parameter can be applied based on the chosen assumptions and method. In Table 6.3, the 'new' value of $18{,}03$ for the VOT was higher than the original value of $9{,}46$. At the same time, the 'new' value of $8{,}34$ for the VOT was lower than the original value of $9{,}46$. This finding emphasizes that choosing a specific parameter value can significantly impact the outcome.

6.2 Expert Review

Four experts participated in the interviews conducted for this section. Three experts work for the Dutch IM ProRail, and the fourth for the Norwegian IM Bane NOR. The appendix in Section 9.4 includes detailed answers to the interview questions. This section discusses the findings from the interviews in general. This appendix also discusses how selecting the respondents took place and how reporting on the interview occurred.

6.2.1 Strengths of the Method

Generally, there was a positive reception to the method discussed in Chapter 3. Often, the methods' transparency was recognised since most respondents' calculation steps were easy to follow. What helps is that the practical usage of the method takes place utilising Excel, which is currently also the case for the method Bane NOR currently applies. Because of this, it is easy for the user to reproduce what 'happens' in the method when the model possesses specific information on the train service. This finding makes the method more accessible than, for example, a method that requires programming tools.

The respondent from Bane NOR shared some successes of the Norwegian method, which inspired the method of this thesis. The respondent stated that introducing their method led to fewer conflicts between capacity requests. The most significant reason is that following this introduction, RUs are more willing to solve conflicts within the negotiation phase that precedes the application of the method on socioeconomic evaluation. The cause is that RUs experience more 'control' over the solutions that emerge compared to when the method is applied. This behaviour occurs because the RUs cannot know the outcome of the method with certainty. These circumstances differ from those that occurred by a ranking system like the Dutch AMvB. Given the 'fixed' priority order of train segment types and train operation contracts, the RU can define beforehand which prioritisation the AMvB produces for a certain capacity conflict. Thus, the 'deterring' effects of the method lead to more negotiated conflict solutions with the RUs. Therefore, the socioeconomic evaluation method is hardly applied and is more of a 'last resort' method.

To this date, the Norwegian respondent still needs to recognise more instances of RUs 'playing the system, where RUs alter their capacity request to increase their chances of receiving capacity access. The conclusions discussed in Chapters 4 and 5 in this thesis posed the possible occurrence of this behaviour. Nevertheless, the respondent mentions that such behaviour by RUs might still emerge in the Netherlands, given the significant differences in characteristics of the railway networks between Norway and the Netherlands.

6.2.2 Weaknesses of the Method

The earlier mentioned strengths of the method concerning its transparency and accessibility can also form its weakness, according to two respondents from ProRail. The method uses several assumptions to ensure it can produce its outcomes. A higher usage of assumptions requires less input that the user should provide, which enhances the understandability of the method to the user. However, this higher amount of assumptions also increases the risk of more discriminatory results, where specific train segments receive capacity access more quickly than others. These outcomes can occur since some assumptions work more in the favour of specific train segments. A higher number of assumptions also decreases the reliability of the method since it increases the differences between the output of the method and the real-life railway network.

One respondent highlighted that more discriminatory foundations of the method could occur because of influence from transport ministries that stem from national interests. Following this, a higher occurrence of discriminatory results could lead to more objections from RUs. These RUs could challenge ENIM, the eventual developer of a method, to conduct additional studies on the validity of the method. In addition, the ACM can declare a method as 'discriminatory' if it is biased towards specific outcomes. The respondent proposes an extensive number of 'runs' of the model based on many cases, which could enhance the calibration of the method. A better-calibrated method could lead to a more non-discriminatory method, aligning with the requested non-discriminatory principles from Article 8 in the regulation and more acceptance from involved stakeholders.

Finally, there are some considerations on whether the required data for the input in the method are available. Most concerns relate to freight transport, a more capricious market. The goods requested for transportation can change on numerous occasions following, for example, geopolitical events. In addition, ProRail works with realisation numbers, which represent data of freight trains that ran in the past. However, the method requires information about freight trains running in the future, for which hardly any knowledge is available. This finding holds because freight operators request capacity access earlier than their final decision on which goods they foresee transporting and because freight operators only have to declare whether they want to transport dangerous goods. Still, knowing what goods could receive transport is crucial since different goods have different socioeconomic values. Finally, for freight trains, the destination of the goods is only sometimes known to ProRail since train series for freight trains often diverge abroad into multiple train series with different destinations.

For passenger transport, problems with gathering data on future train services emerge for open-access train services. For PSO train services, modelling data on passenger numbers by the IM, for example, is mostly possible. Passenger numbers can only be 'created' through data from similar (PSO) trains for emerging open-access train services. The more significant the difference between the open-access trains and the compared train service, the less reliable the created data is. Enhanced traffic modelling could help create missing data and support reliability, but the required computational effort is high.

6.3 Ethical Considerations

Several justice theories apply to evaluate the ethical effects of the method and its outcomes on the case study railway line. Pereira, Schwanen, & Banister (2017) present justice theories that discuss the distribution of primary goods and human capabilities. Each justice theory has guiding principles for distributing benefits and burdens fairly across individuals. Pereira et al. (2017) differentiate four justice theories: utilitarianism theory, libertarianism theory, Rawls' egalitarianism theory, and the capabilities approach. A summary of key aspects of this theory is part of Figure 6-1.

Theories of justice	Distribution of what?	Guiding principle of distribution	The fairest distribution pattern	Key authors
Utilitarianism	Welfare, well-being, utility	The greatest good for the greatest number	Whatever distribution that maximises aggregate welfare	Jeremy Bentham and John Stuart Mill
Libertarianism	Basic rights and liberties	Self-ownership	Absolute equality	Robert Nozick
Intuitionism	Different "whats", for example, resources (food, money, etc.), services (health, education, etc.)	Particular distributive problems demand different principles be applied to particular cases (rights, deserts, needs, expectations, procedural justice, etc.)	No clear distribution pattern	Brian Barry and David Miller
Rawls' Egalitarianism	Basic liberties	First principle (deontological justification)	Equal distribution	John Rawls
	Opportunities	Fair equality of opportunity as pure procedural justice	Equal distribution	
	Primary goods (rights and prerogatives of authority, income, and wealth)	Difference Principle	Maximin criterion: The distribution that maximises, subject to constraints, the prospects of the least advantaged groups	
Capabilities approach	Opportunities	Human dignity and equal respect	Equal distribution	Amartya Sen and Martha Nussbaum
	Central/basic capabilities		All should get above a minimum basic level	

Figure 6-1: Key aspects of justice theories (Pereira et al., 2017).

The method on SEE criteria shows varying performance on two justice theories. Prioritising capacity requests utilising the socioeconomic value of train services aligns with the utilitarianism theory, where 'the greatest good' should apply to 'the greatest number' (Pereira et al. (2017). Considering the method that assesses the socioeconomic value of the train service, the 'greatest good' relates here to the highest socioeconomic value and the 'greatest number' to the largest groups of customers involved. Thus, according to utilitarianism theory, the goal is to ensure that aggregated welfare is as high as possible for society. The method aligns with this theory since it calculates the magnitude of the socioeconomic impact (time spent in transport, impact on prices, external effects) and the size of the impacted group (passengers and goods).

Still, the method does not cover all justice theories. One could argue that the method contradicts Rawls' Egalitarianism theory on its' second principle, which justifies unfairly allocated socioeconomic conditions if opportunities were originally equally and fairly dispersed and the conditions aid the worths of the least-advantaged parties (Pereira et al., 2017). The method could favour small socioeconomic advantages for large groups of customers over considerable socioeconomic advantages for small groups of customers. For example, This could lead to minor improvements in intercity services used by larger groups of passengers travelling between urban areas, which receive priority over operating a regional train service serving smaller passenger groups from rural areas. If opportunities were not initially equally and fairly distributed across all individuals, for example, when the involved rural area does not have any other form of public transport, one could argue that such prioritisation violates this justice theory.

Considering the ethical effects of the method, one could, therefore, state that the method brings high 'societal revenue' to society by ensuring that the most significant benefits come to the greatest amount of individuals. However, this does not prevent burdens from coming towards specific groups within society, for some groups have to collect the burdens for others' benefits. When translating this to the context of the method, the benefits of long-distance train services that transport more significant numbers of passengers occur simultaneously with the burdens of regional train services that transport fewer passengers. This phenomenon has already become apparent in the case study in Chapter 4, since the long-distance train services between Amsterdam and Berlin (train services 1 and 12) have received priority over a regional train service between Zwolle and Enschede (train services 10).

6.4 Conclusion

This chapter evaluated the following sub-question:

- ⊃ Sub-question 5: How indicative are the results, considering the sensitivity and applicability of the method?

In general, the method has significant potential: calculating the utility loss per train service based on SEE criteria can be of societal value. Applying this method of capacity allocation leads to a train product that is beneficial to the customer. The method, in particular, is transparent and imitable. Since the method delivers a social economic balanced capacity allocation, it induces cooperative and societal-driven behaviour by RUs, which solves capacity conflict and can yield outcomes beneficial to society.

The sensitivity analysis demonstrated that the exact value of the parameters used can influence the outcome of the method. According to respondents, this same pattern occurs for assumptions considered in the method. Calibration of the method could enhance the justification of the results, which aids the non-discriminatory principle and the degree of applicability to various cases. Applicability in cases of capacity conflicts is particularly important, given the data from these cases that the method considers. The method should ensure that it aligns with available data on train services since significant amounts of information on capacity requests are unavailable to the user.

When considering the method's ethical effects, it is apparent that it induces a prioritisation that ensures the most significant benefits to the most considerable number of individuals. Such prioritisation could, however, collide with the regional desires of public transport, where regional train services receive less capacity access to allow capacity access to transport larger commodities. Therefore, the method needs to facilitate regional objectives for rail transport more by ensuring that regional train services have decent possibilities to receive capacity access.

7 Conclusion and Discussion

This chapter closes the research for this thesis. By revisiting the answers to all the sub-questions, an answer to the main research question emerges. The answer to the main research question leads to the discussion, which entails the implications of the results. This discussion leads to general recommendations and suggestions for further research, which aids the research objective:

- Research objective: To create a method that defines the socioeconomic and environmental value of a capacity request through European criteria and show the possible effects of these criteria on network utilisation and capacity allocation procedures.

7.1 Conclusion

- Sub-question 1: Which methods for applying SEE criteria are currently available, and to what extent do these methods align with the criteria defined in the regulation?

An extensive body of scientific literature on the socioeconomic evaluation of capacity requests still has to become available. Therefore, relevant knowledge and experience can only emerge from relevant examples of socioeconomic capacity evaluation, which are examples from only two European IMs. These are Trafikverket from Sweden and Bane NOR from Norway. The Norwegian method aligns better with the SEE criteria in the regulation because it is more capable of assessing train services across a broader set of criteria. Still, given the misalignment between the Norwegian and European SEE criteria, the Norwegian method requires adjustments before it can apply to other European countries..

- Sub-question 2: How does the method for capacity allocation calculate the socioeconomic value of capacity requests across the SEE criteria in the regulation?

Through the second sub-question, the development of this adjusted method took place. The created method calculates the utility loss per train service for the scenario when the train does not run. A description of the effects across the five SEE criteria emerges through a review of the effects of this lack of capacity access. One could gather these effects via the current approach of Norwegian IM Bane NOR and the scientific literature.

The method uses assumptions and parameters to find an outcome. The user provides additional input by providing information and data on the train services used in the method. The outcome of the method is a utility loss per SEE criterion for each train service. The capacity request with the highest summed utility loss should receive capacity access since preventing a high utility loss is better for society. Given the limited amount of available scientific research on the topic, this method is one of the first contributions to a method that evaluates capacity requests through SEE criteria.

- Sub-question 3: What result on capacity allocation emerges when one applies the method on the case study railway line Deventer – Bad Bentheim?

The main result following the application of the method on the case study railway line is that train services operating in open-access receive more capacity access compared to when the IM applies the current AMvB. For the case study railway lines, long-distance trains between Amsterdam and Berlin and a new regional train between Apeldoorn and Enschede receive capacity access at the cost of competing capacity requests. This result indicates how RUs can alter their capacity requests to increase their chances of receiving capacity access. These interventions to train services are additional stops of train services, higher capacities of rolling stock, longer routes of train services, and longer time windows of train operations.

- Sub-question 4: How do the results from the method for the case study relate to strategic guidance?

For the case study railway line, the prioritisation of capacity requests according to strategic guidance equals the prioritisation according to the method. Therefore, open-access train services fulfil policy objectives earlier than PSO-led train services. The exact relation between SEE criteria and strategic guidance depends on the final version of the regulation, as a prevalence of either of the two has yet to be applied. RUs can increase their chances of receiving capacity access by creating train services that align with rail transport policies, infrastructure development, the TBOV line plan, and PSO ambitions.

- Sub-question 5: How indicative are the results, considering the sensitivity and applicability of the method?

The method will indicate the actual socioeconomic value of a capacity request. This statement holds because, for the most part, the method 'objectifies' capacity requests through parameters and assumptions. Given the sensitivity of these two components of the method, a calibration of the method could ensure the non-discriminatory nature and diminish the extent to which the method is indicative. Enhancing the method's applicability is possible by tackling the ethical consideration that the method favours significant benefits to larger groups of individuals and challenges the fulfilment of regional transport policy objectives.

- Main research question: What is the indicative impact of a method on SEE criteria on capacity allocation and railway network utilisation in the Netherlands?

Two types of impacts on capacity allocation can emerge: impact on the capacity allocation processes and the capacity allocation outcomes.

Considering the impact of using SEE criteria on capacity allocation processes, RUs will behave more beneficially to society. This behaviour occurs via their capacity requests, which could have a higher socioeconomic value following the aim to increase the chances of receiving capacity access. Given that the prioritisation of capacity requests follows the socioeconomic value of the associated train services, the outcome the method produces is unknown beforehand to the RUs. These uncertainties can cause RUs to find more solutions to capacity conflicts during the negotiation phases of the capacity allocation processes. This development could lead to more efforts to find solutions for capacity conflicts and, thus, a higher acceptance of capacity requests.

Considering the impact of using SEE criteria on capacity allocation outcomes, the method prioritises open-access train services more than the AMvB currently used in the Netherlands. This finding is valid for the case study railway line and the method designed in this thesis. This prioritisation result follows the notion that the method does not evaluate train services on whether they are part of a PSO.

This result on capacity allocation outcome is indicative, given that the method 'objectifies' the characteristics of train services. The method uses assumptions and parameters to calculate utility losses, and these two aspects of the method influence its sensitivity. Calibrating the method through multiple runs of the method on cases of capacity allocation can tackle the concerns but can lead to new outcomes. In addition, the eventual relationship between strategic guidance and SEE criteria in the final regulation is crucial to the outcome of capacity allocation.

The method did not provide an outcome with more prioritisation of regional train services. Given that the method considers the magnitude of the socioeconomic benefits and the size of the population receiving these benefits, this method could give less priority to benefits of train services used by minorities, like regional train services. Thus, this method should improve its ability to support the regional accessibility function of rail public transport.

7.2 Discussion

This section discusses the significance of the conclusion section for scientific research and the current state of rail transportation governance in the Netherlands. Afterwards, it provides several recommendations for further method improvement.

7.2.1 Scientific Contribution

As shown in Chapter 2 of this thesis, little scientific literature on the socioeconomic evaluation of capacity requests is available. Desk research only found one scientific article and two examples of European methods. Given the limited body of scientific research on the topic, this thesis is thus one of the first scientific contributions in the field. The method developed in this thesis is thus one of the first proposals for evaluating capacity requests on their socioeconomic value.

The method has a significant usability to allocate capacity through SEE criteria. The method can cope with all train segments included in the TTR capacity strategy and calculate the utility losses across the criteria defined in the regulation. The method is sophisticated, given that its fundament contains the calculation of utility losses per capacity request, grounded in the award-winning Random Utility Theory (RUT). Another argument stipulating the value of the method is that it is closely related to best practices on SEE criteria, given that it has the method designed by Norwegian IM Bane NOR as a blueprint. Scientific literature allowed for adjustments that make the method applicable to the SEE criteria defined in the regulation.

Still, the method in this thesis can evaluate capacity requests across socioeconomic and environmental criteria. Since this thesis is one of the first scientific contributions, several new contributions could follow. These new contributions could provide adjustments to the method used in this thesis. In addition, new contributions can provide completely new methods based on, for example, the Swedish method by IM Trafikverket. Such a method can use the insights from the feasibility study currently rolled out by RISE and VTI, as discussed in Section 2.5.4.

Following the previous paragraph, indicators and arguments other than those used in the method of this thesis can thus lead to a substantiated capacity allocation outcome. Future scientific researchers are thus encouraged to find whether other methods with different structures can further improve the possibility of conducting capacity allocation through these SEE criteria. By doing so, the concerns raised in answering the main research question in Section 7.1 could receive a solution.

7.2.2 Impacts on Rail Governance

As discussed in the conclusion section, the method could lead to a higher occurrence of open-access train services receiving capacity access at the cost of PSO train services. In the extreme case, this outcome may result in a decrease in the market share of PSO-led train services. This finding could misalign with recent railway governance developments in the Netherlands, given that the Dutch Ministry of Transport and Water Management awarded the national PSO in 2023 and that the PSO train services have a higher priority in the AMvB. The prioritisation of capacity requests according to SEE criteria could thus lead to a new organisation of rail passenger transportation in the Netherlands, with more competition on the tracks and fewer steering opportunities for the Ministry. Still, the developments described here are only a result when the method designed in this thesis and the selected assumptions and parameters apply.

The degree to which the development of more competition on the tracks and less steering opportunities for the Ministry occurs partly relies on what strategic guidance the Ministry can bring and how it relates to the SEE criteria. What also influences this development is the extent to which the Ministry adopts a coordinating role concerning seamless travel across multiple RUs and the cohesion of the total network, which it can acquire through, for example, legislation and transport policies. One such measurement can be to give TBOV a legal status, which stimulates the development of train services according to TBOV's line plans and helps the cohesiveness of the total network.

One consideration regarding the coordination of rail passenger transport applies to scenarios where open-access train services receive capacity access over PSO train services. When train stations are served solely by open-access train services, there is a risk that they will not receive service when an RU withdraws some or all of its open-access train service runs. This situation can occur since an open-access RU is not legally obligated to justify its performance to a governing body, which is different when an RU operates in a PSO at its request. Therefore, it becomes necessary to create protocols or legislation that guarantee that certain train connections remain operational when open-access train services are withdrawn or not established.

7.2.3 Recommendations

Chapter 2 of this thesis argues why the Norwegian method for socioeconomic assessment of capacity requests is more suitable as a 'blueprint' for a new European method than the Swedish method. A fundamental difference between both approaches is that capacity requests are accepted or rejected in their complete requested form in Norway. In contrast, in Sweden, alterations to the request are allowed if accepting a higher number of capacity requests is possible. These alterations could include additional running time for certain trains or placing the train series (significantly) earlier or later in the timetable hour pattern. These outcomes provide additional solutions to capacity conflicts. Therefore, a scientific recommendation for further improvement of the method in this thesis is to make it capable of changing the capacity request to some extent to allow for more accepted capacity requests to emerge. A suggestion for such improvement could revolve around the rejected capacity requests by the method. One could consider alterations to these capacity requests to still grant this requested capacity access, albeit in a different form. The prioritisation order emerging from the method should streamline the decision-making on which rejected capacity requests require an evaluation first. In general, the feasibility study by VTI and RISE as discussed in Section 2.5.4 could, once it is completed, motivate scientific research following this recommendation.

The method in this thesis shows how objectively describing the performance of a train service is possible by calculating the associated socioeconomic value. However, given the diversity between and the complex nature of train services, it is arguable whether it is justified to objectify railway train services. This consideration holds because the number of assumptions presented in Section 3.4 showed that certain information on train services is lacking and, therefore, requires replacement through these assumptions. In the end, the outcome of socioeconomic values per train service is only partially objective given that the used assumptions are sometimes partly hidden or explicit, harming the method's imitability. Although assumptions remain necessary to ensure that the method can cope with varying train segments, there are arguments to recommend improving the method by replacing some of the assumptions in Section 3.4 with additional input variables or parameters from the scientific literature. In the end, this can enhance the quality of the method.

The method of SEE criteria uses several parameters. The values of these parameters correspond with different years. For example, the price factors per travelled kilometre relate to data from 2020, whereas the VoTs for each travelled hour relate to 2012. These parameters only partially have the same monetary value, given that there is a rate of price increase during these years. The method created in this thesis does not consider this price increase. Therefore, improving the method by considering a base year for all monetary parameters is possible. The answer on which base year to select can emerge from the scientific literature. A consistent monetary value of the parameter applies through processing an inflation correction considering the difference in years between this base year and the data's year of origin.

Furthermore, the ethical considerations in this thesis highlighted how the method can impact train stations operated through a small number of train services. These train stations risk not receiving service by any train, considering the method could prioritise train services from other segments with a higher socioeconomic value. In addition, there exists a risk of a train station losing its connections when RUs operating in open access withdraw their train services. To ensure the consistency of operation within a particular train segment and the accessibility of regions, one could consider the inclusion of minimal frequencies in the method. Specific minimal frequencies are currently included in Article 8 of the AMvB, as discussed in Section 2.4. Following the discussion in Section 7.2.2, the possibility of open-access train services creating a vacuum when RUs withdraw these train services requires consideration. Therefore, scientific research can enhance the method in this thesis by evaluating whether it is justified to include minimal frequencies in the method.

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9 Appendices

9.1 Appendix: Allocation Methods

Across Europe, many methods are available for allocating capacity on congested railway lines. These methods define which capacity access should be honoured and which should not. Broman, Eliasson and Aronsson (2018) summarise several possible allocation methods. These methods are:

- Administrative procedure.
- Negotiations.
- Social-cost-benefit analysis.
- Dynamic track charges.
- Auctions.

Several capacity allocation procedures induced by the regulation derive from these five methods. Since the regulation is the foundation of the proposed application of SEE criteria for capacity allocation in Europe, understanding these five methods is vital. This appendix aids this finding by providing a compendium on the five methods. This section discusses these methods by assessing the article from Broman et al. (2018) and the literature from other authors.

9.1.1 Administrative Procedure

In several European countries, solving conflicts between capacity requests takes place through administrative procedures. The procedures often compare the involved capacity requests along several priority criteria. The request that fits these criteria better is thus granted the capacity access at the expense of the other capacity request(s). The RUs that do not see their capacity request fulfilled need to either cancel their request or make amends to their request, as stated by Broman et al. (2018).

Several journal articles have touched upon the numerous criteria used within European countries. Barradale & Cornet (2018) provide a long list of 28 possible assessment criteria for sustainable transport appraisal, divided into three categories: 'Direct project impacts', 'Indirect societal impacts', and 'Environmental impacts'. Stojadinović, Bošković, & Bugarinović (2019) also provide a list of criteria, which are so-called 'priority criteria'. These criteria distinguish three critical categories: 'Main criteria', 'Additional standard criteria', and 'Additional specific criteria'. In addition, for each criterium, the European countries where the criterium is currently inducing capacity allocation are listed in Figure 9-1. Two articles specifically focus on one country, where Gibson (2003) looks at so-called 'decision criteria' applied in the UK. Montero & Melero (2022) examine the prioritisation criteria applied in Spain. Stojadinović et al. (2019) summarise the following hierarchal order for train prioritisation based on the administrative procedures used in most EU countries: international and intercity passenger trains, regional and local passenger trains, intermodal freight trains and finally, other freight trains.

Criteria	Countries applying the listed criterion
Main criteria	
PSO train service	Croatia, Czech Republic, Denmark, Greece, Hungary, Luxembourg, Poland, Portugal, Romania, Slovakia, Slovenia, Spain (12 countries)
High-frequency passenger train service	Austria, Belgium, Finland, France, Germany, Italy, Nederland, Switzerland (8)
Fast, international and domestic passenger trains**	Austria, Belgium, Bulgaria, Czech Republic, Estonia, Finland, Germany, Hungary, Italy, Luxembourg, Nederland, Norway, Poland, Slovakia, Slovenia (15)
Other passenger trains (low-frequency, regional and slow passenger train types)	Belgium, Bulgaria, Finland, Greece, Hungary, Norway, Romania, Spain (8)
Train service based on a framework agreement	Austria, Czech Republic, France, Germany, Hungary, Italy, Norway, Slovenia, Spain, Switzerland (10)
Combined freight train service	Croatia, Czech Republic (2)
International or fast freight train service	Bulgaria, Czech Republic, Finland, Germany, Hungary, Nederland, Norway (6)
Additional criteria	
Additional standard criteria	
Train service that runs on a longer route or with more train-kilometres	Bulgaria, Croatia, Czech Republic, Finland, France, Hungary, Italy, Portugal (8)
Train service operating more days during the year	Bulgaria, Croatia, Czech Republic (primary criterion), France, Hungary, Italy, Spain (7)
Train service with interval timetable or higher frequency per day or week	Austria, Czech Republic, Finland, Hungary, Italy, Switzerland (6)
Additional specific criteria	
Train service that generates higher total income from access charges for IM	Belgium, Germany, Switzerland (primary criterion) (3)
Earlier submitted a request for a TP	Bulgaria, Hungary, Slovenia (3)
Service that better utilizes infrastructure capacity	Slovenia, Spain (2)
Socio-economic analysis	Norway, Sweden (primary method for priority assessment) (2)
TOC with better utilization of TPs in the previous timetable	Croatia, Germany, Poland (3)
Train service with longer travel time	Croatia, Hungary (2)
Highest bidder procedure (sealed-bid first-price auction)	Germany, Poland, Slovenia, Switzerland (4)

Notes: *the order of applied priority criteria, which is stated in network statements of some IMs may vary;
**fast, international and domestic passenger trains have the highest train rank in Belgium, Bulgaria, Estonia, Italy and Poland.

Figure 9-1: An overview of priority criteria used by European IMs on congested railway lines (Stojadinović, Bošković, & Bugarinović, 2019).

Often, the conceivable priority criteria vary when comparing multiple European countries with one another. In some countries, however, different sets of priority criteria are used within the same country and by the same IM. An example of this applies to Germany, where research by Berenschot (2021) found that the German high-speed lines use different criteria than the rest of the German railway network.

However, a downside of using administrative procedures as an allocation method is often a need for more harmonisation between the priority criteria used within the same or between different IMs. Therefore, Tomes (2022) thus concludes that the procedure is not necessarily ‘efficient’. Another weakness of the method, according to Broman et al. (2018), is that the procedure leads to corner solutions where all capacity goes to the prioritised train segment or train service and nothing else to the others. This corner solution might be less beneficial to society than another optimal solution.

9.1.2 Negotiations

A conflict between capacity requests can also occur through negotiation, where the involved RUs and the IM cooperate to find a solution that benefits the involved RUs and IM the most. Capacity allocation regularly considers the negotiation system before the system of administrative procedures is applied. According to Broman et al. (2018), the system is applicable to solve more inconsiderable conflicts between capacity requests since significant train series alterations can cause more timetabling conflicts and are thus more challenging to solve through negotiation. A drawback of the system is that it often needs more clearness. However, since it is not a rule-based method, it is hard to reproduce the negotiation procedure.

9.1.3 Social-Cost-Benefit Analysis

The social cost-benefit analysis (SCBA) method can also allow capacity allocation. Broman et al. (2018) state that the method allows for assessing the social welfare that a solution might enhance. In this case, SCBA can thus be used to evaluate the societal effects of capacity requests. The alternative with the best societal cost-benefit ratio can receive priority since it is assumed to add the most to social welfare. However, a downside of this method is that it requires confidential information such as revenues and customer information and that commercial operators with monetary aims are less willing to provide this information than state-owned railway undertakings.

9.1.4 Dynamic Track Charges

The method of dynamic track charges presented by Broman et al. (2018) entails an alternative method for charging infrastructure. RUs pay access charges to the IMs for infrastructure usage. Usually, the RU pays the IM a fixed amount. The access charge is flexible using the dynamic track charges method. The required payment by the RU is lowered or increased based on the demand from the RU for using the infrastructure. The access charge finalises at the level where demand from the RUs meets the supply by the IMs. Peña-Alcaraz, Sussman and Pérez-Arriaga (2014) mention a drawback to this system: not all information about the financial possibilities for paying the access charges by the RU is available to the IMs.

9.1.5 Auctions

The final allocation method discussed by Broman et al. (2018) is an allocation method that auctions capacity to the RUs. Here, the RU with the highest bid receives capacity access. This method also aims to let the demand for train services from the RU and the supply for train series by the IM meet. Within this method, however, the IM can handle detailed knowledge from the RUs since the RUs bid straight on capacity. Stojadinović et al. (2019) present the auctioning method as a method that fits with European goals to decentralise the railway system and to allow for more competition on railway networks since the method approaches all participating RUs in the auction equally.

Multiple auctioning types can be applied when conducting a capacity allocation process. Isacsson & Nilsson (2003) researched four auctioning systems: first-price ascending auctioning, first-price one-shot auctioning, second-price ascending auctioning, and second-price one-shot auctioning. Their research found that all four mechanisms are generally efficient for capacity allocation and are comparable concerning whether they are lucrative enough. Stojadinović et al. (2019) evaluated two hybrid-type two-phase auction mechanisms (Anglo-Dutch and second-price Amsterdam auction) and two standard-type auction mechanisms (English and sealed-bid first-price auction). Their research found that hybrid auctioning, where the auction consists of multiple rounds, with each round having a different auctioning system, is a better solution since it can help IMs allocate their capacity the best equitably and fairly.

Still, Affuso (2003) mentions several drawbacks to the system. For example, the high level of interdependence between trains due to multiple train services using the same tracks implies that it is hard for the IM to manage compact auctions to complex railway networks on objectives other than profit maximisation. Furthermore, the author also states that non-commercial RUs might only be able to bid as little during an auction for a train series as commercial RUs can since non-commercial RUs might be dependent on governmental subsidies unless the government does indeed supply the non-commercial RUs with a rather large subsidy. Situations where commercial and non-commercial RUs can bid for the same train series could not lead to a fair market since commercial RUs assumably have more financial resources and could drive out non-commercial RUs. This matter could be reverted when the government subsidises non-commercial RUs more than the expected profits of the commercial RUs, which would simultaneously cause new debates on the fairness of the subsidies.

9.2 Appendix: Timeline

To provide an overview of the critical introduction years of implemented regulation and market developments in the Netherlands, the timeline in Figure 9-2 applies.

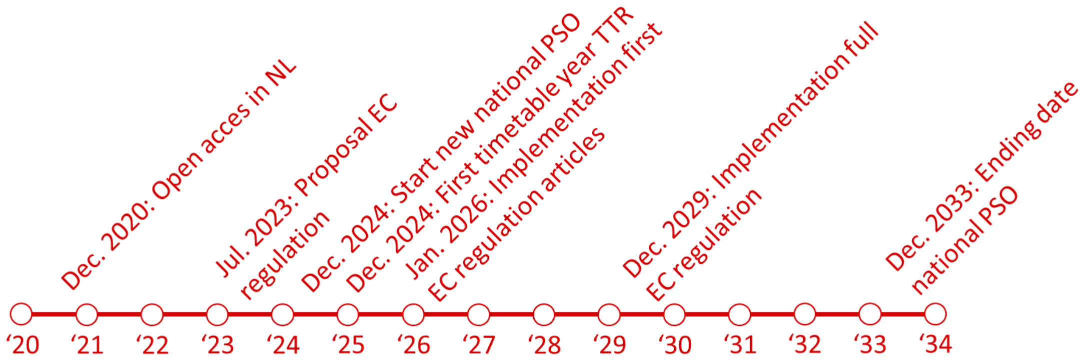

Figure 9-2: Key years for regulation implementation and Dutch market developments.

The following vital moments emerge from Figure 9-2:

- 13 December 2020: The timetable year 2021 was the first year the Dutch railway network was partly opened to open access (Metzlar & With, 2024).
- 11 July 2023: The EC introduced the regulation on rail capacity use (European Commission, 2023).
- 15 December 2024: The new national PSO to run trains on the main railway lines in the Netherlands starts (Ministry of I&W, 2023).
- 15 December 2024: The first timetable year in which the timetables based on TTR will apply across Europe (Brandt et al., 2022).
- 1 January 2026: The first articles of the EC regulation are implemented (ProRail, 2023).
- 9 December 2030: The complete regulation of the EC is implemented (ProRail, 2023).
- 11 December 2033: The viability of the national PSO ends (Ministry of I&W, 2023).

9.3 Appendix: Method Overview

The mathematical formulation used for this thesis is denoted in Table 9-1.

Table 9-1: An overview of the mathematical formulation used for this thesis.

Sets of indices			
G	for each transport mode	$g \in G$	{transport mode #1, transport mode #2,…, transport mode #m}
H	for each travel motive	$h \in H$	{commuter, business, other}
I	for each departure station/stop	$i \in I$	{station #1, station #2,…, station #n}
J	for each arrival station/stop	$j \in J$	{station #1, station #2,…, station #o}
K	for each train segment	$k \in K$	{High-speed train for passengers, Intercity or long-distance trains for passengers, Regional trains for passengers, and Freight trains}
L	for each traction supply type	$l \in L$	{Electric, Diesel}
R	for each route distance category	$r \in R$	{0, 250 >}
Input variables			
k	the train segment type of the train service		-
l	the traction supply type of the train service		-
fh	the frequency of the train service per hour		trains per hours
fd	the frequency of the train service per day		trains per day
t_{ij}	the travel time of the train service between locations i and j		time in hours
ta_{ij}	the travel time of the alternative train connection between locations i and j		time in hours
tt_{ij}	the transfer time associated with the alternative train connection between locations i and j		time in hours
c_{ij}	the transported commodity as a number of passengers or a freight in tonne hour between locations i and j along the train service		number of passengers / goods in tonnes
fa_{ij}	the frequency of the alternative train connection per hour between locations i and j		trains per hour
s_{ij}	the distance between locations i and j		kilometres
Parameters			
e	the elasticity of train travel		-
pf_k	the price factor for price to customers per train segment type k		euro per kilometre (for $k \neq freight\ train$) or euro per tonne-kilometre (for $k = freight\ train$)
VOT_{hkr}	the Value of Time, depending on the route distance of the train service r, the travel motive h, and the train segment k.		euro per hour (for $k \neq freight\ train$) or euro per tonne-hour (for $k = freight\ train$)
ms_g	the percentage of passengers shifting from the train to alternative transport mode g		percentage
u_g	the utilisation rate of transport mode g		persons/tonnes per vehicle
ec_g	external cost factors per transport mode g		euro per kilometre

Utility losses

$V_{operation}$	the utility loss on operating costs (SEE criterion 1)	-
$V_{time-cost}$	the utility loss on time-related costs (SEE criterion 2)	-
$V_{connectivity}$	the utility loss on connectivity and accessibility (SEE criterion 3)	-
$V_{external}$	the utility loss on external costs (SEE criterion 4) + safety and public health (SEE criterion 5)	-
V_{total}	the total utility loss (across all SEE criteria)	-

The following formulas are used for the method:

⊃ The formulas used for intermediate calculation steps on SEE criterion 1:

1) $$LOS_{incl,ij} = t_{ij} + \frac{60}{fa_{ij} + fh} \cdot 0{,}5$$

2) $$LOS_{excl,ij} = ta_{ij} + \frac{60}{fa_{ij}} \cdot 0{,}5 + tt_{ij} \cdot 2$$

3) $$ca_{ij} = c_{ij} \cdot \left(\frac{LOS_{incl,ij}}{LOS_{excl,ij}}\right)^{e}$$

4) $$cl_{ij,train} = c_{ij} - ca_{ij}$$

5) $$\triangle q = \frac{\sum_{i=1}^{n}\sum_{j=1}^{o} ca_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{o} c_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{o} c_{ij}} \cdot 100\%$$

6) $$\triangle p = \frac{\triangle q}{e}$$

⊃ The utility loss for SEE criterion 1:

7) $$V_{operation} = \triangle p \cdot pf_k \cdot \sum_{i=1}^{n}\sum_{j=1}^{o}(s_{ij} \cdot ca_{ij})$$

⊃ The utility loss for SEE criterion 2:

8) $$V_{time-cost} = \left(\sum_{i=1}^{n}\sum_{j=1}^{o}(ta_{ij} - t_{ij} + 2 \cdot tt_{ij}) \cdot c_{ij}\right) \cdot VOT_{hkr}$$

⊃ The utility loss for SEE criterion 3:

9) $$V_{connectivity} = \left(\sum_{i=1}^{n}\sum_{j=1}^{o}\frac{\frac{60}{fa_{ij}} - \frac{60}{fa_{ij} + fh}}{60} \cdot 0{,}5 \cdot c_{ij}\right) \cdot VOT_{hkr}$$

⊃ The formulas used for intermediate calculation steps on SEE criterion 4 + 5:

10) $$cg_{ij,g\neq train} = cl_{ij,train} \cdot ms_{gr}$$

11) $$sg_{ij,g\neq train} = \frac{cg_{ij,g\neq train}}{o_g} \cdot s_{ij}$$

⊃ The utility loss for SEE criterion 4 + 5:

12) $$V_{external} = \left(\sum_{g=1}^{m}\sum_{i=1}^{n}\sum_{j=1}^{o} sg_{ij,g\neq train} \cdot ec_g\right) - MAX(s_{ij}) \cdot fd \cdot ec_g$$

⊃ The total utility loss across all SEE criteria:

13) $$V_{total} = V_{operation} + V_{time-cost} + V_{connectivity} + V_{external}$$

9.4 Appendix: Interview Results

For the input to Chapter 6, several interviews took place. This appendix shows all the answers by the respondents on the research questionnaire. Besides some additional (follow-up) questions, the three respondents from sections 9.4.2 to 9.4.4 received five questions. The questions have the following formulation and motivation:

- Question 1: What information is available on the passenger and freight trains that use the train series?

The output of the method is mainly dependent on the input to the method. Thus, data availability on the train service is vital to the method's success. Therefore, the interviewees answered a question about information on train services that are currently available.

- Question 2: Could it become possible to calculate the transported commodity of a train that foresees operation in the future? If yes, how?

Most of the data used for the case study considers data from the past. Estimating the information on trains running in the future occurs through past performances. However, several train services that did not run in the past could foresee operation in the near future. For these trains, collecting data could be more complex. Thus, the respondents answered whether finding information about these trains was possible.

- Question 3: To what extent is objectifying the characteristics of a train service possible?

The method uses several assumptions, as discussed in Section 3.4. These assumptions are required to ensure that the method can assess a wide range of train services regarding train segments, route distance and transported commodity. The need to use assumptions raises the question of whether it is, in fact, possible to objectify a rather complex train system. This question, therefore, evaluates whether it is possible to objectify the often complex characteristics of train services.

- Question 4: To what extent is objectively calculating the socioeconomic value of a train service possible?

After objectifying the characteristics of train services, calculating the socioeconomic value of the train service is required. These calculations require an additional round of assumptions. This question is therefore asked to the interviewees to ensure that calculating the socioeconomic value is justified.

- Question 5: To what extent is the method from this thesis properly applicable to calculate the utility loss per train service, and can the method easily be rolled out on a European level?

Chapter 3 explains why the method relates to the method used by the Norwegian IM Bane NOR. Given that ENIM will finalize the method on SEE criteria later, the eventual method could be significantly different from the method from this thesis. The respondents, therefore, were asked about their views on the method of this thesis. The more successful the method from this thesis could be, the more likely ENIM could also choose it.

The fourth respondent received a different set of questions. This situation occurred because the opportunity to hold the interview with this expert became known very late, and no time was available to check whether the questions above were relevant to this respondent.

This appendix only mentions the function of the respondents to ensure privacy.

9.4.1 Interviewing Approach

The approach used to conduct the interviews entailed the following steps:

1. The first step involves selecting respondents. For the interviews of this thesis, a so-called ‘convenience sample’ was considered. This convenience sample includes respondents with expertise close to the thesis’ subject and/or easy to approach. Throughout this approach, the respondents from Section 9.4.2 to 9.4.4 emerged. The fourth respondent from Section 9.4.5 emerged outside of this approach since the opportunity to interview this respondent emerged at the last minute.
2. Except for the fourth respondent, the respondents received an email invitation to the interview. They were informed about the topic of the thesis and the plans to record the interviews.
3. The questions presented at the beginning of the chapter occurred during the interviews, except for the fourth respondent. During the interview, the audio was recorded. The recordings were

used to write the reports of the interviews in Sections 9.4.2 to 9.4.5. The interviews were not transcribed, given that they were not used to create the method of this thesis but merely to evaluate the final design of the method and the outcome of the case study.

4. After the interview, the reports from Sections 9.4.2 to 9.4.5 were produced. Contacting the respondents took place once more to read through these reports and provide adjustments if necessary. After processing the adjustments, the final versions of the report were added to this appendix.

9.4.2 ProRail – Freight Transport Specialist

Table 9-2 includes general information on the expert.

Table 9-2: All general information on the first expert.

Function	Specialist on freight transport
Organisation	ProRail
Date	30 May 2024
Time	13:00h – 14:00h
Location	ProRail headquarters: Moreelsepark 3, Utrecht, The Netherlands

- Question 1: What information is available on the passenger and freight trains that use the train series?
- Answer 1: ProRail works with realisation numbers. These numbers show how many trains ran in the past. The most exciting data shows what volumes and types of freight got transported between a pair of locations. For most experts, the time freight trains run is less relevant. Also, the route is often less relevant since limited routes are available for freight trains in the Netherlands.
  Note: A fundamental difference between passenger and freight trains is that they are supply- or demand-driven. That is why more knowledge about freight trains running on railway lines is often needed.

- Question 2: Could it become possible to calculate the transported commodity of a train that foresees operation in the future? If yes, how?
- Answer 2: ProRail can make a prognosis on future freight trains. However, this is not always easy: around 85% to 90% of rail freight transportation in the Netherlands got transported from and to a foreign country. Furthermore, the transported goods can be very different for each train. These commodities also change each year. For example, after the war in Ukraine started in 2022, the transportation of coal became more critical.

- Question 3: To what extent is objectifying the characteristics of a train service possible?
- Answer 3: One should consider that freight transportation is an open market, where freight RUs sign contracts that allow for running a train in the upcoming year. That means some RUs do not know whether they will run a particular train after that year. In addition, the exact destination of certain goods is often only known at the last minute. Furthermore, freight trains running within the Netherlands along the same route can have different foreign destinations, making it difficult for the Dutch IM to specify the destination of the transport goods. Thus, the freight train market is very dynamic, making it harder to objectify the train series of freight trains.

- Question 4: To what extent is objectively calculating the socioeconomic value of a train service possible?
- Answer 4: The socioeconomic value of a freight train depends mainly on the type of goods that the train transports. Resources or semi-finished products often have a higher socioeconomic value, considering these trains have fewer restrictions regarding arrival time at the following location for the next step in the production process. There are, therefore, too many aspects of freight transportation to calculate the socioeconomic value of the train feasible.
  Still, calculating the socioeconomic value of trains can be helpful: Freight trains that transport resources or semi-finished products could have a higher socioeconomic value than some passenger trains. In addition, the socioeconomic value of passenger trains can be higher during peak hours than during non-peak hours.

- Question 5: To what extent is the method from this thesis properly applicable to calculate the utility loss per train service, and can the method easily be rolled out on a European level?
- Answer 5: What gets attention concerning the Norwegian method is that the Norwegian IM created their classification of types of freight. In the Netherlands, we use the 'Standard goods classification for transport statistics' (NST) classification; the Norwegians use something else. A new method that EU countries will use might have to comply with this NST classification.
  Still, freight trains have a higher socioeconomic value on several occasions than passenger trains, and this method might aid in finding the correct prioritisation of capacity.

9.4.3 ProRail – President at Rail Freight Corridor Rhine-Alpine EWIV

Table 9-3 includes general information on the expert.

Table 9-3: All general information on the second expert.

Function	President at Rail Freight Corridor Rhine-Alpine EWIV
Organisation	ProRail
Date	3 June 2024
Time	13:00h – 13:45h
Location	Online, via Microsoft Teams

- Question 1: What information is available on the passenger and freight trains that use the train series?
- Answer 1: When a RU requests capacity access, it does not yet know what kind of goods it will transport with that train on the day of operation. The freight RU only has to indicate whether it transports dangerous goods concerning the external safety of trains.

- Question 2: Could it become possible to calculate the transported commodity of a train that foresees operation in the future? If yes, how?
- Answer 2: There are not any opportunities. We will only know what they transported after the trains ran. If an RU requests capacity for a moment in two months, they do not know the commodity transported on the day of operation.

- Question 3: To what extent is objectifying the characteristics of a train service possible?
- Answer 3: *The answers to questions 4 and 5 provide the answer to this third question.*

- Question 4: To what extent is objectively calculating the socioeconomic value of a train service possible?
- Answer 4: Applying socioeconomic criteria for capacity allocation can succeed if a calibration with, for example, 1000 runs on the method occurs. This calibration ensures that no train segment receives a continuous prejudice over other train segments. The second condition requires the 'keeping your back straight' principle to apply to all stakeholders involved. Some Ministries tend to protect their railway systems. Thus, avoiding 'internal forces' from within the railway sector is essential.
  Still, the method could be favourable since it ensures that it grants capacity to the most beneficial trains to society. In the end, infrastructure is expensive, so it is vital to use it smartly.

- Question 5: To what extent is the method from this thesis properly applicable to calculate the utility loss per train service, and can the method easily be rolled out on a European level?
- Answer 5: At first, the method has several arbitrary aspects. This finding means that chances for discussions to occur are high. Many runs are required on the method to ensure its' calibration. Suppose a particular train segment is hardly prioritised based on the method. In that case, the operators associated with these segments might induce studies showing that a different method is necessary. In addition, the ACM could, at the request of the involved RUs, state that the method is discriminatory.
  There is a possible success of this method inspired by the Norwegian approach, but one could wonder whether calculating with the method at a fast pace is possible. It should be fine.

9.4.4 ProRail – Advisor Traffic Modelling and Transport Prognosis

Table 9-4 includes general information on the expert.

Table 9-4: All general information on the third expert.

Function	Advisor traffic modelling and transport prognosis
Organisation	ProRail
Date	4 June 2024
Time	13:00h – 13:45h
Location	Online, via Microsoft Teams

- Question 1: What information is available on the passenger and freight trains that use the train series?
- Answer 1: We could use traffic models to gather information. We could estimate the effects of a lack of capacity access to the complete network. For example, when a train service between Amsterdam and Bad Bentheim is out of service, one could calculate how many passengers will not travel. The traffic models can also calculate the modal shift. It is thus possible to 'model' the required data. However, using traffic modelling is not feasible if one wants to do a quick-scan analysis.

- Question 2: Could it become possible to calculate the transported commodity of a train that foresees operation in the future? If yes, how?
- Answer 2: For future open-access trains, it can be possible to use information on PSO trains if these PSO trains run in a similar pattern as the open-access trains. After all, a passenger does not care about which RU it uses. If the open-access train is more demand-driven and deviates more from PSO trains, it will be harder to find data about it with existing tools.

- Question 3: To what extent is objectifying the characteristics of a train service possible?
- Answer 3: The more considerable the number of assumptions, the less reliable and the more prone the method will be to wrong results. Thus, the more assumptions one makes, the more sensitive one's method will be. The assumptions thus influence the applicability of the method.

- Question 4: To what extent is objectively calculating the socioeconomic value of a train service possible?
- Answer 4: If one train service has a utility loss of 1 million and another of ten thousand, it is easy to use socioeconomic criteria to allocate capacity since the result is clear. However, when the result is 1,5 million versus 1 million, then it becomes more challenging. Socioeconomic criteria are thus helpful in filtering out the 'excesses', but there remains a need for additional study on the remaining train services.

- Question 5: To what extent is the method from this thesis properly applicable to calculate the utility loss per train service, and can the method easily be rolled out on a European level?
- Answer 5: What comes to mind first is that the method is pretty simple. Its strength is that it is easily accessible since it does not contain too many steps. Calculating the effects of what happens when a train does not receive capacity access is imitable. The method should be simple if one wants to do this capacity allocation right.
  The downside is that several processes are simplified, so one should carefully apply the method in an 'absolute' way. However, this method is excellent for capacity request comparisons. One can opt to calibrate one's model to improve it further. In the end, one's strengths are often one's weaknesses.

9.4.5 Bane NOR – Senior Legal Advisor

Table 9-5 includes general information on the expert.

Table 9-5: All general information on the fourth expert.

Function	Senior Legal Advisor
Organisation	Bane NOR
Date	6 June 2024
Time	11:00h – 11:30h
Location	ProRail headquarters: Moreelsepark 3, Utrecht, The Netherlands

- Question 1: What are Bane NOR's experiences concerning using the Norwegian socioeconomic criteria method?

- Answer 1: Very few instances of Bane NOR using the method exist. This finding holds because in Norway, like (with the AMvB) in the Netherlands, conflict resolution mainly occurs through prioritisation ranking based on the train service types. Applying the method is possible only when there is a conflict between similar trains, for example, two PSO trains or two open-access trains. Still, one could consider the method a success since fewer conflicts emerge. The method is used less due to fewer conflicts between trains. Thus, the method is often a last resort.

- Question 2: Is it possible to elaborate more on how the introduction of the method of socioeconomic value calculation meant that the method itself is used less by Bane NOR?
- Answer 2: We see that train operators adapt to the system. What precedes the application of the method is a negation phase between Bane NOR and the involved train operators. The train operators often favour finding a solution during the negotiation phase since, during this phase, the operators have more influence on the outcome of the conflict resolution than when the method is applied. There is, therefore, more 'pressure' to find a solution during negotiations, leading to solving fewer conflicts through the method.

- Question 3: Are there examples of operators 'playing the system' where operators create train services with a higher chance of receiving capacity access?
- Answer 3: There are hardly any instances of 'playing the system' by train operators.

- Question 4: What is the cause that it does not often happen that train operators' play the system' by providing train services that expectedly perform better according to the socioeconomic criteria method by Bane NOR?
- Answer 4: Partly, the explanation is that there is no extensive 'sharp' usage of the model and that solutions emerged through dialogue. Another point is that the Norwegian rail network differs from most continental European networks. If we take the Netherlands as an example, there is an actual network, with many connections crossing the country in all directions and plenty of possibilities to run "creative" routes. The Norwegian network is star-shaped, with lines "beaming" out from Oslo – and few/no diversionary routes or possibilities to cross from one primary connection to another. This finding makes our network more transparent in that it would be easily noticeable if someone applied to run a train to/from an area of the country with little/no market demand.

- Question 5: Given that Norway is not a part of the European Union (EU), why does Bane NOR still have to comply with European Regulations?
- Answer 5: Norway, alongside the 27 EU members, Liechtenstein and Iceland, is part of the European Economic Area (EEA). That is why European transport regulation also applies to Norway. Still, there is a delay in the commissioning of the regulation for non-EU countries Norway, Liechtenstein, and Iceland since it takes around three years after the acceptance of the regulation by the European Parliament before the regulation applies to these three countries.

- Question 6: What is the strength of the Norwegian method of calculating the socioeconomic value of trains?
- Answer 6: The main strength is that the method is transparent because it is clear 'what happens' in the method regarding calculation steps. Here, it is possible to find the origin of every outcome value. In addition, everyone can download the calculation tool in Excel from our website, which enhances transparency further. Thus, train operators know what to expect.

- Question 7: How can one compare the Norwegian capacity conflict resolution with the Swedish capacity conflict resolution?
- Answer 7: Generally, the organisation of the passenger railway markets of Sweden and Norway are very different. Norway has three leading operators that operate through a PSO; in Sweden, many trains operate in open access. Sweden has more experience with the application of socioeconomic criteria because of this. In addition, the Norwegians have a more informal approach to capacity conflict resolution than the Swedes.

9.5 Appendix: Scientific Paper

The pages following this page show the scientific paper.

Allocating Rail Capacity through Socioeconomic and Environmental Criteria

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***Abstract*—On railway lines with scarce infrastructure capacity, allocation methods allow for the assessment of the capacity requests from railway undertakings. The European Commission introduced a regulation to ensure a uniform approach to capacity allocation across all member states through socioeconomic and environmental criteria. However, relevant experiences and methods related to such criteria are hard to come by across Europe, meaning that such criteria' impact on capacity allocation is unknown. In this paper, we provide a method that applies the European criteria and can give insight into the possible impact of this new way of allocating capacity. The railway line Deventer – Bad Bentheim case study allows for the application of the method and defines its possible impacts. Compared to the current Dutch approach of distributing capacity scarcity, open-access train services have higher chances of receiving capacity access. The result shows how railway undertakings will behave more beneficially to society during capacity allocation procedures following the implementation of the method. Recommendations to improve the method are to reduce the number of assumptions, provide an inflation correction across all monetary parameters and consider using minimal frequencies.**

I. Introduction

In July 2023, the European Commission (EC) proposed a European regulation for capacity use on the European railway network (hereafter: 'the regulation'). According to the EC (2023), the regulation aims to harmonise the allocation of capacity on the European rail network across all European Union (EU) member states and thus enhance rail transport within the union. The regulation includes several innovations, including the use of socioeconomic and environmental (SEE) criteria that the infrastructure manager (IM) can apply during the annual allocation process for conflict-solving between different train type segments (long and short-distance passenger rail transport and freight rail transport) and between different train service requests by competing railway undertakings (RUs) within these segments.

Several EU member states currently have their prioritisation method for capacity allocation. When the use of a railway line is congested, and negotiations between RUs and IM do not lead to a solution, these methods allow for a decision on which request from an RU receives capacity access. This principle means that the prioritised rail transport service receives capacity access and that other rail transport services receive capacity access within the remaining capacity or not at all if no capacity is left. In a situation of complete scarcity, the IM starts a capacity enhancement plan that assesses how the available capacity on the concerned railway line can increase to aid the issues. Afterwards, the IM conducts a conflict-resolving procedure, deciding which conflicting train service requests receive the capacity right.

The national priority rules per country will be replaced in 2030 by the SEE criteria from the regulation. Therefore, IMs want to get insight into the potential impact of the SEE criteria on capacity per train type segment and whether this will affect the optimal use of the infrastructure. The list of IMs includes Dutch IM ProRail, which manages one of Europe's most dense railway networks according to Bešinović (2020).

Within Europe, only in Norway and Sweden, there exists experience with SEE criteria, according to Stojadinović, Bošković, & Bugarinović (2019). This finding implies that, for most European IMs, the use of SEE criteria will replace the current capacity allocation methods. Since train services can differ in running time and stopping pattern and train services interact on densely used railway networks, network effects caused by the change in allocation method can occur. Following the introduction of the four European legislative regulation packages that induced competitive pressure between RUs, hypothetically, the SEE criteria can impact the behaviour of RUs during capacity allocation procedures. Therefore, one can conclude that *the impact of the proposed European approach for capacity allocation through a method on SEE criteria is unknown in terms of the effects on the railway network and the capacity requests.*

The Norwegian and Swedish approach to SEE criteria could indicate what these impacts could be. However, their methods apply to national rather than European SEE criteria. Therefore, the research aims to *create a method that defines the socioeconomic and environmental value of a capacity request through European criteria and show the possible effects of these criteria on network utilisation and capacity allocation procedures.*

II. LITERATURE REVIEW

A vital input to the timetable of a railway line is the train service that use it, according to Liebchen (2006). Here, the train path defines the position of a train across a specified route on the infrastructure as time progresses. Besinovic and Goverde (2018) state that 'the maximum number of train paths that can run on the infrastructure within a certain period given the traffic pattern, operational characteristics or timetable structure' defines the practical capacity of a railway line. The practical capacity depends on the capacity balance, which shows the distribution of capacity across the number of trains and the stability of the timetable, including the available buffer times, traffic heterogeneity and the average speed of the trains. When the practical capacity is maximum, the railway line receives the declaration 'congested'. Here, fulfilling all capacity requests from RUs is limited, and the capacity scarcity must be distributed across RUs, leading to not all RUs receiving capacity access. Here, the 'access' stands for the access to use an excerpt of the railway network during a given time window, according to Perennes (2014).

NATIONAL AND EUROPEAN CAPACITY REGULATION

The most significant innovation of the regulation proposed by the EC is using socioeconomic and environmental criteria (SEE criteria) applied during the annual allocation process for conflict solving between train-type segments and between train service requests by competing RUs within these segments. Article 8 discusses these SEE criteria and regulates the management of scarce infrastructure capacity (European Commission, 2023). If negotiation between RUs does not provide a solution to the conflict, the following five SEE criteria are applied to allocate scarce infrastructure capacity non-discriminately:

1. Operating cost for operators of rail transport services and the resulting impact on prices for customers of rail transport services;
2. Time-related cost for customers of rail transport services;
3. Connectivity and accessibility for people and regions served by the rail transport services;
4. Emissions of greenhouse gases, local air pollutants, noise and other external cost of rail transport services and by their likely alternatives;
5. Safety and public health implications of rail transport services and their likely alternatives (EC, 2023).

The regulation proposed that the European Network of Infrastructure Managers (ENIM) develop the methods for applying these criteria (EC, 2023). The regulation closely relates to the Timetable Redesign for Smart Capacity Management project (TTR). However, TTR does not provide the frameworks to apply SEE criteria.

Currently, in The Netherlands, the allocation of rail capacity takes place through an 'Algemene Maatregel van Bestuur' (AMvB) (general administrative measure) titled 'Besluit capaciteitsverdeling hoofdspoorweginfrastructuur' (Decree Capacity Distribution Main Rail Infrastructure). After declaring the infrastructure congested, priority rules mentioned in Article 10 of the AMvB will determine which capacity request receives priority. These priority rules consider the service type of the associated train movement (ProRail, 2023). The characteristics of the involved capacity requests, such as operation costs and travel time, are often not assessed. Thus, the current Dutch capacity allocation procedures hardly provide frameworks for applying SEE criteria.

SCIENTIFIC LITERATURE ON CAPACITY ALLOCATION

Currently, there are five valid types of capacity allocation methods, according to Broman, Eliasson and Aronsson (2018). These five types of capacity allocation methods are:

- Administrative procedures: procedures that compare capacity requests along several priority criteria, which vary significantly across Europe (Stojadinović et al., 2019).
- Negotiation: The involved RUs and the IM cooperate to find a solution that benefits the involved RUs and IM the most (Broman et al., 2018).
- Social cost-benefit analysis (SCBA): When assessing all the solutions to the capacity conflict, the solution that contributes most to social welfare is the best choice over the alternative solutions (Broman et al., 2018).
- Dynamic track charges: The access charge the RU pays to the IM is in or decreased based on the demand from RUs to use the infrastructure, leading to a selected number of RUs that receive capacity access (Broman et al., 2018).
- Auction: The RU is most willing to pay the IM for using a train path and receiving capacity access. (Isacsson & Nilsson, 2003)

Looking at the five types of capacity allocation methods, the proposed application of SEE criteria best fits the administrative procedures (for using criteria) and the SCBA (for assessing the societal effects of capacity requests). Therefore, it is not the case that just one of the five types directly corresponds with the requested method on SEE criteria.

Montero, Finger, and Gortazar (2023) concluded that the experiences with socioeconomic criteria used in Sweden align with the goals of the proposed regulation by the EC. At the same time, the experiences with SEE criteria in other countries besides Sweden are significantly limited. Given these circumstances and the fact that the regulation sterns from the near past, the amount of scientific literature available on SEE criteria is limited.

Best practices

The remaining two 'best practices', therefore, are the methods used by Norwegian IM Bane NOR and Swedish IM Trafikverket, which are the only two IMs that apply SEE criteria according to Stojadinović, Bošković, & Bugarinović (2019). Swedish IM Trafikverket shifts the train paths from the capacity requests in the time diagram to find solutions for capacity conflict. In the end, the socioeconomic value of each emerging plan (timetable) is calculated and used to choose the socioeconomically preferred conflict resolution (RISE & VTI, 2024). Norwegian IM Bane NOR calculates the loss of utility when a specific capacity request does not receive access (Bane NOR, 2023). Calculating these values takes place by looking at the travel time increase to customers, the modal shifts performed by customers, the external effects following the modal shift and the additional operational costs to RUs (Oslo Economics, 2022). Ultimately, the capacity request with the highest possible total utility loss receives capacity access, ensuring that the total utility loss to society is as low as possible.

Considering the above, the method used by Norwegian IM Bane NOR is favourable over the one used by Swedish IM Trafikverket. The Norwegian method can align with a broader range of train service characteristics more quickly than the Swedish approach since it does not merely assess the time and duration of train services. Therefore, the method used in Norway could align more easily with the European SEE criteria.

According to this literature review, an example of a method that applies SEE criteria comes from Norway. Therefore, this method can be a 'blueprint' for the rest of Europe. Still, there needs to be more knowledge on what specific method can allocate capacity utilizing the SEE criteria from the proposed European regulation. Thus, the Norwegian method needs adaptation before a suitable method for these European criteria emerges. This requirement is the knowledge gap in this research.

III. Method

The method developed for the research assesses the impact of capacity allocation through SEE criteria. It calculates the utility loss across the five SEE criteria when a capacity request receives no capacity access. The term ‘utility’ is derived from the Random Utility Theory (RUT), as Liebe, Cranenburgh, and Chorus (2023) discussed. Kirkbride-Smith (2014) poses that utility is ‘an economic term referring to the total satisfaction received from consuming a good or service’. RUT is also used within the method by Bane NOR for the socio-economic valuation of capacity requests. The capacity request with the highest total utility loss receives capacity access, thereby keeping the utility loss that occurred through the rejected requests as low as possible.

Assumptions

The method considers several assumptions which allow for an objective description of train services. Appendix 1 includes the list of assumptions.

Effects of Rejected Capacity Requests

To find the effects that occur when capacity requests are rejected, the following approach applies:

- The approach first evaluates if and how the effects across the SEE criteria receive consideration through the Norwegian IM Bane NOR method. Here, valuable concepts or calculation procedures from the method that align with the five SEE criteria descriptions from the regulation can emerge.

- Suppose the examples from the Norwegian IM do not provide relevant concepts or procedures to evaluate effects across the five SEE criteria descriptions in the regulation. In that case, scientific literature can provide new insights.

Across the five SEE criteria discussed in Section 2 of this paper, the following effects emerge when there is no capacity access for a particular capacity request:

- SEE criterion 1 'operating costs': The Norwegian approach does not entirely fit with a European method on SEE criteria. This finding holds because Bane NOR's method assumes that a train can run empty at another time when there is no capacity access, which is unlikely to occur for densely used railway networks or networks that feature integrated timetables (Bane NOR, 2023) (Van de Velde, 2023). Still, an RU has to cover its fixed costs across fewer operating trains. To cover these costs, the price to customers to use the remaining train service could increase if the RU decides to cover the costs across their customers (Vuuren, 2002). The price can increase further since the number of customers using the train services will decrease, since a lower frequency makes train travel less attractive (Eisenkopf & Burgdorf, 2022). The total price increase across all customers is a utility loss since spending the associated amount on other aspects of society is impossible.
- SEE criterion 2 'time-related costs': the alternative trains through which passengers and goods receive transport can have a longer travel time than the travel time from the rejected capacity request (Oslo Economics, 2022). In addition, the alternative train connection could consist of one or more transfers. This transfer takes three times as long as the experience of passengers, according to Bertollini (1999). The increase in travel time and the 'penalty' on time spent transferring between trains across all customers is thus a loss in utility. Waiting time is also an aspect that could relate to time-related costs. Still, waiting time is not considered for this criterion since it is included in the calculation for SEE criterion 3, and preventing double counting is necessary.
- SEE criterion 3 'connectivity and accessibility': Connectivity considers, among others, the waiting time for customers, according to Barradale & Cornet (2018). The waiting time for customers increases when there is no capacity access since the frequency of all trains in the timetable decreases. Chen et al. (2019) state that lower frequency harms accessibility since it harms the easiness of reaching destinations. The waiting time increases across all customers following a decrease in frequency, which is a utility loss to society. According to Barradale & Cornet (2018), connectivity also relates to travel and transfer time, but these aspects are already part of the assessment of SEE criterion 2. Furthermore, connectivity relates to access/egress times, but the impact of this aspect is minimal in The Netherlands, according to Givoni & Rietveld (2007)
- SEE criteria 4 and 5, 'external costs' and 'public health' are considered simultaneously since these externalities of rail transport are interdependent. Maibach et al. (2008) summarize external impacts of train services in one general external effect. Customers could opt to perform a modal shift when there is no capacity access to the preferred train service. The additional external effects of these alternative transport modes, deducted from the external effects of train services, are a utility loss to society. Therefore, the utility loss to society equals the external effect of increasing the usage of alternative transport modes minus the external effects of the train from the rejected capacity request.

SEE CRITERION 1: 'OPERATING COSTS'

To calculate the increase in the price of train travel to customers, one should evaluate the decrease in the number of customers using the train service following a rejection of a capacity request. This decrease becomes apparent through the calculation of the level of Service (LOS) between locations i and j for scenarios that both include ($LOS_{incl,ij}$) and exclude ($LOS_{excl,ij}$) the capacity request. This LOS depends on the travel time, the waiting time (dependent on the train frequency), and the transfer time (Hogenberg, 2024). Although the LOS does not include an assessment of operational costs, it is applicable to calculate the modal shift, which is required to find the possible utility loss on operating costs. In general, formulas (1) and (2) apply for the calculation of the $LOS_{incl,ij}$ and $LOS_{excl,ij}$:

1) $$LOS_{incl,ij} = t_{ij} + \frac{60}{fa_{ij} + fh} \cdot 0{,}5$$

2) $$LOS_{excl,ij} = ta_{ij} + \frac{60}{fa_{ij}} \cdot 0{,}5 + tt_{ij} \cdot 2$$

Formula (1) calculates the LOS ($LOS_{incl,ij}$) that applies when the capacity request receives capacity access and is thus part of the timetable. It finds the LOS by adding the travel time (t_{ij}) and the waiting time between stations i and j along the train service from the capacity request. The waiting time depends on the interval between trains, calculated by dividing 60 minutes by the frequency of the train service from the capacity request (fh) and the other trains (fa_{ij}). This deviation is multiplied by half, assuming that the arrival of passengers at the platform is distributed uniformly across time.

Formula (2) calculates the LOS ($LOS_{excl,ij}$) when the capacity request receives no capacity access and is thus not part of the timetable. Now, the travel time of the alternative train connection (ta_{ij}) is applicable, representing the fastest alternative train connection to passengers or goods. The frequency of the train service based on the capacity request (fh) is no longer applicable. In addition, transfer time (tt_{ij}) applies since the alternative train connection can consist of transfers. As discussed earlier in this section, passengers experience transfer time three times as long as the actual transfer time. Given that transfer time is already part of the travel time of the alternative train connection, the transfer time is multiplied by two instead of three to prevent double counting.

The decrease in the number of passengers or goods transported per train $cl_{ij,train}$ between locations i and j follows from formulas (3) and (4).

3) $$ca_{ij} = c_{ij} \cdot \left(\frac{LOS_{incl,ij}}{LOS_{excl,ij}}\right)^{e_k}$$

4) $$cl_{ij,train} = c_{ij} - ca_{ij}$$

When rejecting the capacity request, formula (3) calculates the transported commodity ca_{ij} along the alternative train connection. Calculating this number occurs by multiplying the commodity number across the train service from the capacity request c_{ij} with a ratio following the outcomes for $LOS_{incl,ij}$ and $LOS_{excl,ij}$. This ratio represents a division of $LOS_{incl,ij}$ by $LOS_{excl,ij}$, subject to the elasticity of train travel e as an exponential. This elasticity is equal to $-0{,}7$ according to Thommen & Hintermann (2023). Formula (4) calculates the decrease in passengers ($cl_{ij,train}$) or goods using the train service.

To calculate the relative difference in the number of passengers or goods transported per train as a percentage $\triangle q$, formula (5) applies:

5) $$\triangle q = \frac{\sum_{i=1}^{n}\sum_{j=1}^{o} ca_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{o} c_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{o} c_{ij}} \cdot 100\%$$

Formula (5) finds the relative difference in the number of passengers by comparing the number of passengers when the capacity request is accepted (c_{ij}) or rejected (ca_{ij}).

The relative difference in price to customers per train as a percentage $\triangle p$ follows from formula (6):

6) $$\triangle p = \frac{\triangle q}{e}$$

Formula (6) follows the formula on the price elasticity of demand (Thomas, 2024).

The total additional expenditure by the remaining train customers depends on the price factor pf_k, the price of one kilometre of train travel for train segment k. The value of the price factor is 0,14 euro per kilometre per passenger for passenger trains (Dielesen, 2024) and 0,02 euro per tonne-kilometre for freight trains (Visser, 2020). It also depends on the size of the transported commodity ca_{ij} and the distance s_{ij} between locations i and j.

Finally, formula (7) calculates the utility loss on operation costs:

7) $$V_{operation} = \triangle p \cdot pf_k \cdot \sum_{i=1}^{n}\sum_{j=1}^{o}(s_{ij} \cdot ca_{ij})$$

Here, $V_{operation}$ is the utility loss on the operating costs of the train service per day. Formula (7) calculates how much additional expenditure customers make on train travel. The expenditure emerges by multiplying the price increase ($\triangle p$) with the price factor (pf_k). The total additional expenditure across all travels occurs by multiplying this outcome with all remaining transported passengers or goods (ca_{ij}) and the associated distances (s_{ij}) between location i and j.

SEE CRITERION 2: 'TIME-RELATED COSTS'

The increase in travel time follows from the difference between the travel time associated with the train service t_{ij} and the travel time associated with the alternative train connection between location i and j. The transfer time is also part of the evaluation for the alternative train connection. The total time increase requires multiplication with the Value of Time VOT_{hkr} depending on the train segment k, the travel motive h and the route distance of the train service r. Table III-1 shows the VOTs for passenger trains.

Table III-1: Train VOT for passenger transport in The Netherlands (euro per hour) (Wardman, Chintakayala, de Jong, & Ferrer, 2012)

		Distance r between stations in kilometres			
		5 - 24	**25 - 99**	**100 - 249**	**250 >**
Travel motive (h)	**Commuter**	5,09	6,88	8,93	10,61
	Business	21,65	29,3	38,03	45,18
	Other	4,38	5,93	7,69	9,13

To find the distribution of passengers across travel motives h, Table III-2 applies.

Table III-2: The division of travel motives across train passengers (Drost, 2014).

Travel motive (h)		
Commute	**Business**	**Other**
69%	3%	28%

The freight train VOT equals 1,77 euros per tonne per hour (Binsuwadan et al., 2022).

Finally, formula (8) calculates the utility loss on time-related costs:

8) $$V_{time-cost} = \left(\sum_{i=1}^{n}\sum_{j=1}^{o}\left(ta_{ij} - t_{ij} + 2 \cdot tt_{ij}\right) \cdot c_{ij}\right) \cdot VOT_{hkr}$$

Here, $V_{time-cost}$ is the utility loss on the time-costs of the train services per day. The travel time can increase since alternative connections transport passengers or goods via a train service with more intermediate stops or a longer running time. Therefore, there is a difference in travel time between the alternative connection (ta_{ij}) and the train service from the capacity request (t_{ij}). Since the alternative train connection can consist of transfers between trains and the transfer time (tt_{ij}) is experienced three times as long, according to Bertolini (1999), the transfer time also needs to be assessed. Since the transfer time (tt_{ij}) is a part of the travel time for the alternative connection (ta_{ij}), to prevent double counting, formula (8) must multiply the transfer time (tt_{ij}) by two instead of three.

To calculate the total time increase for all involved passengers or goods and the value of this time increase, formula (8) multiplies the time changes with the transported commodity (c_{ij}) and the Value of Time (VoT_{hkr}). The multiplication concerns all possible combinations of departure i and arrival j locations.

SEE CRITERION 3: 'CONNECTIVITY AND ACCESSIBILITY'

The increase in waiting time depends on the decreased frequency of the available trains to the customer. Formula (9) calculates the utility loss on connectivity and accessibility:

9) $$V_{conn.} = \left(\sum_{i=1}^{n}\sum_{j=1}^{o}\frac{\frac{60}{fa_{ij}} - \frac{60}{fa_{ij}+fh}}{60} \cdot 0{,}5 \cdot c_{ij}\right) \cdot VOT_{hkr}$$

Here, $V_{conn.}$ is the utility loss on connectivity and accessibility of the train service per day. To define the time interval between the trains, in formula (9), the time window of 60 minutes needs to be divided by the frequency. By subtracting the time interval of the frequency without the train service $\left(\frac{60}{fa_{ij}}\right)$ from the time interval of the frequency with the train service $\left(\frac{60}{fa_{ij}+fh}\right)$ the increase in waiting time emerges. All waiting times require calculation for all relations between locations i and j. The outcome is divided by 60 to find the numbers per hour. Since there is the assumption of a uniform distribution of passengers or goods across the hour, the outcome is multiplied by 0,5. Finally, the result requires a multiplication by the transported commodity c_{ij} and the Value of Time VOT_{hkr}.

SEE CRITERIA 4 AND 5, 'EXTERNAL COSTS, SAFETY, AND PUBLIC HEALTH'

As already discussed, the additional external effects occur through a modal shift ms_{gr} from the train to another modality g, depending on the route distance r. Table III-3 and Table III-4 show the possible values for ms_{gr}.

Table III-3: The division of train passengers across possible modal shifts from the train to three other modalities (Jernbanedirektoratet, 2022).

		Transport mode (g)		
		Car	**Bus**	**Aeroplane**
Distance between stations in kilometres (r)	**0 - 69**	80%	20%	0%
	70 - 199	90%	10%	0%
	200 >	80%	10%	10%

Table III-4: The division of goods across possible modal shifts (Jonkeren, 2020)

Transport mode (g)	
Truck	**Ship**
68%	32%

The magnitude of the modal shift comes from the decrease in the number of passengers and goods transported following the rejection of the capacity request. Calculating this decrease $cl_{ij,train}$ is possible by utilising the LOS. Calculating the LOS took place already for SEE criterion 1. To find which passengers or goods shift to which alternative transport mode $cg_{ij,g\neq train}$, formula (10) applies:

10) $$cg_{ij,g\neq train} = cl_{ij,train} \cdot ms_{gr}$$

Formula (10) calculates how many passengers or goods receive transport ($cg_{ij,g \neq train}$) via alternative transport mode g, based on the decrease in passengers or goods (that look for an alternative transport mode instead of a train) ($cl_{ij,train}$) with the percentage of passengers or goods that will select a specific alternative transport mode g (ms_{gr}).

Through the utilisation rate u_g of transport mode g and the distance s_{ij} between locations i and j the calculation of the increase in covered distance by alternative transport mode g between locations i and j emerges. Table III-5 and Table III-6 present the values for the utilisation rate u_g.

Table III-5: The average amount of passengers transported per vehicle (Tooren et al., 2024) (Johnston & Harris, 2019) (CBS, 2024)

Transport mode (g)		
Commuter	Business	Other
1,05	15,3	133

Table III-6: The average amount of goods transported per vehicle in tonnes (Forkenbrock, 1999) (CBS, 2024)

Transport mode (g)	
Truck	Ship
14,8	3500

Here, formula (11) applies:

11) $$sg_{ij,g \neq train} = \frac{cg_{ij,g \neq train}}{u_g} \cdot s_{ij}$$

Formula (11) calculates the distance the other transport modes will cover following the modal shift of passengers and goods from the train to other transport modes ($sg_{ij,g \neq train}$). This distance depends on the number of passengers or goods that use the alternative transport mode ($cg_{ij,g \neq train}$), the number of passengers or goods that utilise one vehicle of the transport mode on average (u_g) and the distance (s_{ij}) between the locations i and j.

The following calculation step multiplies the extra covered distance by other transport modes with the external cost factors. Table III-7, Table III-8 and Table III-9 summarize all the external cost factors. The external cost factor for aviation is 16,05 euros per trip (Maibach et al., 2008).

Table III-7: The external costs for train transport in euros per kilometre (Maibach, et al., 2008).

		Train segment type (k)			
		High-speed trains for passengers	Intercity or long-distance trains for passengers	Regional trains for passengers	Freight trains
Traction supply type (l)	Electric	0,74	0,74	0,62	1,12
	Diesel	1,67	1,67	2,08	4,37

Table III-8: The external costs for passenger transport modes in euros per kilometre (Maibach, et al., 2008).

		Train segment type (k)		
		High-speed trains for passengers	Intercity or long-distance trains for passengers	Regional trains for passengers
Traction supply type (l)	Electric	0,74	0,74	0,62
	Diesel	1,67	1,67	2,08

Table III-9: The external costs for freight transport modes in euros per kilometre (Maibach, et al., 2008).

Transport mode (g)	
Truck	Ship
0,29	7,94

The external impact of the train service from the capacity request, which will now not occur following the rejection of the capacity request, is subtracted from the external impact of the additional trips with the other modalities. This calculation takes place through formula (12).

12) $$V_{external} = \left(\sum_{g=1}^{m} \sum_{i=1}^{n} \sum_{j=1}^{o} sg_{ij,g \neq train} \cdot ec_g \right) - MAX(s_{ij}) \cdot fd \cdot ec_g$$

Here, $V_{external}$ is the utility loss on the effects associated with external impact, safety and health. Formula (12) evaluates the external impact of the additional usage of the alternative transport modes based on the outcome of the extra distance covered by these transport modes ($sg_{ij,g \neq train}$). This evaluation takes place by multiplying all distance increases with the external cost factors (ec_g) from Maibach et al. (2008) across all combinations of locations i and j and across all alternative transport modes g. This total external cost increase across all alternative transport modes gets subtracted by the external cost increase that would occur if the train service received capacity access since this external cost increase is 'prevented' when there is no capacity access ($MAX(s_{ij}) \cdot fd \cdot ec_g$). The multiplication of the route distance of the train service between the beginning and terminating station ($MAX(s_{ij})$) with the external costs of train transport (ec_g) and the frequency of the train service per day (fd) represents the subtraction.

TOTAL UTILITY LOSS

The total utility loss equals the sum of all utility losses across SEE criteria 1 to 5. Here, formula (13) applies:

13) $$V_{total} = V_{operation} + V_{time-cost} + V_{conn.} + V_{external}$$

V_{total} represents the total utility loss associated with the train service from the capacity request. The capacity request with the highest total utility loss receives capacity access.

CASE STUDY

The research uses a case study railway line to assess the impact of the method described in the previous subsections. This chosen case study is the railway line between Deventer (NED) and Bad Bentheim (GER). In total, 13 capacity requests apply to this railway line. The capacity requests emerge from the following sources:

- The current timetable, which follows the time-distance diagram in Figure 1 in Appendix 3.
- Ambitions for the national (I&W, 2023) and regional PSO (Poortinga, 2023).
- Freight train developments according to the 'Integral Mobility Analysis' (IMA) (ProRail, 2021) and the TTR capacity strategy (Brandt et al., 2022).
- Requests for open-access trains presented to the Authority for Consumers and Markets (ACM, 2024).

From the thirteen requests, the train services in Table III-10 conflict. The conflicting train services conflict within one of two groups: Group 1 and Group 2. Within Group 1, there are train services competing for capacity used in the current timetable by train service 140, shown in Figure 2 in Appendix 3. Within Group 2, there are train services competing for capacity used in the current timetable by train service 7000, shown in Figure 3 in Appendix 3. The upcoming Tables denote the train segment type (k), the route, the frequency per hour (fh) and the contract type (Public Service Obligation (PSO) or open-access). The abbreviations for the train segment types are IC for Intercity or long-distance trains for passengers, RE for Regional trains for passengers, and FR for Freight trains..

Table III-10:The conflicting train services on the case study railway line.

Train service number	Train segment type	Route	Frequency per hour	Contract
Group 1				
1	IC	Amsterdam C. – Berlin Obf.	0,5	Open access*
9	IC	Amsterdam C. – Enschede	0,5**	National PSO
10	IC	Zwolle – Enschede	1	Regional PSO
11	FR	Rotterdam – Deventer – Bad Bentheim (– onwards)	0,5	Open access
12	IC	Amsterdam C. – Berlin Hbf.	0,5	Open access
Group 2				
5	RE	Apeldoorn – Almelo (–Enschede)***	2	National PSO
13	RE	Apeldoorn – Enschede	2	Open access
*	Runs according to the national PSO until December 2024			
**	Only operates during peak hours			
***	Only runs between Almelo and Enschede during peak hours			

GENERAL ADMINISTRATIVE MEASURE

To assess the impact of the method, a comparison between the outcome of the method on the case study railway line and the current capacity allocation method in The Netherlands takes place. The current capacity allocation method is the 'Algemene Maatregel van Bestuur' (AMvB) (general administrative measure). When declaring the infrastructure congested, priority rules mentioned in Article 10 of the AMvB will determine which capacity request receives priority. These priority rules consider the service type of the associated train movement (Eerste Kamer der Staten-Generaal, 2024). Appendix 2 includes the service types and priority rules.

IV. RESULTS

The method calculated the utility loss per criterion from the conflicting train services from the case study. Results are available for the two groups of conflicting train services separately.

UTILITY LOSSES FOR GROUP 1

Group 1 consists of train services 1, 9, 10, 11, and 12. Table IV-1 presents all the results of SEE criteria 1 to 4 and the total utility loss.

Table IV-1: The outcome for the utility losses per train service and criterion for Group 1.

Utility loss per criterion	Criterion 1	Criterion 2	Criterion 3	Criterion 4 + 5	Total utility loss
1: IC Amsterdam C. – Berlin Obf.	6219	20073	2880	2966	32138
9: IC Amsterdam C. – Enschede	721	782	404	20	1927
10: IC: Zwolle – Enschede	441	0	333	-550	230
11: FR Rotterdam – Deventer – Bad Bentheim (– onwards)	15	1583	559	-307	1850
12: IC Amsterdam C. – Berlin Hbf.	6699	17626	2030	2489	28845

Table IV-1 shows the following per criterion:

- SEE criterion 1 'operating costs': Train service 12 should receive capacity access since it has the highest utility loss.
- SEE criterion 2 'time-related costs': Train service 1 should receive capacity access since it has the highest utility loss. Train service 10 has a utility loss of 0. An explanation for this outcome is that the alternative train connection to this train service is train service 3, which has an equal running time to train service 10.
- SEE criterion 3 'connectivity and accessibility': Train service 1 should receive capacity access since it has the highest utility loss.
- SEE criteria 4 and 5, 'external costs, safety, and public health': Train service 1 should receive capacity access since it has the highest utility loss. Train services 10 and 11 have negative values for utility loss, which implies that these have utility gains on these SEE criteria. This outcome emerges since the utility gain of not running the train is more significant than the utility loss of running other transport modes.
- Total utility loss: Train service 1 should receive capacity access based on all SEE criteria since it has the highest total loss. When train service 1 receives capacity, there is capacity left of 0,5 trains per hour. Train service 12 receives this remaining capacity access as it has the second-highest total utility loss. This outcome means that train services 9, 10, and 11 cannot receive capacity access.

Utility losses for Group 2

Group 2 consists of train services 5 and 13. Since the two train services are identical between Apeldoorn and Almelo, the utility loss is only calculated for the section between Almelo and Enschede. This decision holds because the difference in utility loss between the two train services will be equal regardless of the utility loss on the section of the train service between Apeldoorn and Almelo.

Table IV-2 presents all the results of SEE criteria 1 to 4 and the total utility loss.

Table IV-2: The outcome for the utility losses per train service and criterion for Group 2.

Utility loss per criterion	Criterion 1	Criterion 2	Criterion 3	Criterion 4 + 5	Total utility loss
5: RE Apeldoorn – Almelo (– Enschede)	90	-54	192	-74	154
13: RE Apeldoorn – Enschede	407	-245	863	-334	691

Table IV-2 shows that train service 13 should receive capacity access based on all SEE criteria since it has the highest total utility loss. There are negative values for utility loss for SEE criteria 2, 4 and 5, which implies that these have utility gains on these SEE criteria. The outcome of SEE criteria 2 occurs since passengers between the intercity stations Almelo, Hengelo, and Enschede could use an intercity service with a shorter travel time than train services 5 and 13. The utility gain corresponding to this shorter travel time to these passengers is more significant than the utility loss corresponding to the passengers who use any of the other three stations on the railway line. The outcome on SEE criteria 4 and 5 occurs because the utility gain of not running the train is more significant than the utility loss of other transport modes.

Comparison with AMvB for Group 1

The five train services from Group 1 would correspond with the following train service types from the AMvB discussed in Appendix 2:

- Train service 1: IC Amsterdam C. – Berlin Obf. – International public transport, excluding night trains.
- Train service 9: IC Amsterdam C. – Enschede – National public transport (public transport that is not high-speed or urban/rural regional transport) based on a PSO.
- Train service 10: IC Zwolle – Enschede – Rural regional public transport operated based on a PSO.
- Train service 11: FR Rotterdam – Deventer – Bad Bentheim (– onwards) – Standard freight transport.
- Train service 12: IC Amsterdam C. – Berlin Hbf. – International public transport, excluding night trains.

Based on the allocated service types to the train services and the priority order from the AMvB, Table IV-3 prioritises the five train services according to the AMvB. Table IV-3 also includes the prioritisation from Table IV-1 on the method to make comparisons.

Table IV-3: The prioritisation according to the AMvB and the SEE criteria for the train service from Group 1.

Position	Priority order AMvB	Priority order SEE criteria
1st position	Train service 9: IC Amsterdam C. – Enschede	Train service 1: IC Amsterdam C. – Berlin Obf.
2nd position	Train service 1: IC Amsterdam C. – Berlin Obf.*	Train service 12: IC Amsterdam C. – Berlin Hbf.
3rd position	Train service 12: IC Amsterdam C. – Berlin Hbf.*	Train service 9: IC Amsterdam C. – Enschede
4th position	Train service 10: IC Zwolle – Enschede	Train service 11: FR Rotterdam – Deventer –
5th position	Train service 11: FR Rotterdam – Deventer – Bad Bentheim (– onwards)	Train service 10: IC Zwolle – Enschede

*	The tie between train paths 1 and 12 is broken through Article 11 from the AMvB

In the AMvB and the SEE criteria results, the top 3 consists of train services 1, 9, and 12. Given that all three train services require a capacity of 0,5 trains per hour and one train per hour is possible, two can receive capacity. Train service 1 ranks in both rankings in the first or second position. This result means that according to the AMvB and the SEE criteria, train service 1 should receive capacity access. However, the AMvB grants capacity access to train service 9 (as the 1st placed train service), whereas the SEE criteria grants capacity to train service 12 (as the 2nd placed train service). Thus, the systems do not agree on which train service should receive capacity access.

Figure 4 in Appendix 3 shows the time-distance diagram following the result according to the method. Figure 5 in Appendix 3 shows the time-distance diagram following the result according to the AMvB.

COMPARISON WITH AMVB FOR GROUP 2

The two train services from Group 2 would correspond with the following train service types from the AMvB discussed in Appendix 2:

- Train service 5: RE Apeldoorn – Almelo (– Enschede) – Rural regional public transport operated based on a PSO.
- Train service 13: RE Apeldoorn – Enschede – Rural regional public transport.

Based on the allocated service types to the train services and the priority order from the AMvB, Table IV-4 prioritises the five train services according to the AMvB. Table IV-4 also includes the prioritisation from Table IV-2 on the method to make comparisons.

Table IV-4: The prioritisation according to the AMvB and the SEE criteria for the train service from Group 2.

	Priority order AMvB	Priority order SEE criteria
1st position	Train service 5: RE Apeldoorn – Almelo (– Enschede)	Train service 13: RE Apeldoorn – Enschede
2nd position	Train service 13: RE Apeldoorn – Enschede	Train service 5: RE Apeldoorn – Almelo (– Enschede)

Since both train services require a capacity of two train services per hour and only two train services per hour are available, only one capacity request can receive capacity access. Still, the prioritisation according to the AMvB and the SEE criteria is unequal. The AMvB prioritises train service 5 since that train service relates to a PSO. According to the SEE criteria, train service 13 receives capacity access since it has a higher total utility loss.

Figure 6 in Appendix 3 shows the time-distance diagram following the result according to the method. Figure 7 in Appendix 3 shows the time-distance diagram following the result according to the AMvB.

V. DISCUSSION

The results indicate that for both Groups 1 and 2, the prioritisation of capacity requests according to the method and the AMvB are unequal. The method favours for Group 1 train services 1 and 12 (open-access) and for Group 2 train service 13 (open-access). The AMvB favours Group 1 train services 1 and 9 (open-access and PSO, respectively) and Group 2 train service 5 (PSO). The notion that the AMvB appears to favour PSO train services aligns with the finding that the AMvB, in general, prioritises PSO train services over open-access train services. This finding holds since, in Appendix 2, only between positions 4 to 7, non-PSO trains receive the favour over PSO trains.

The new method could lead to more opportunities for open-access train services to claim capacity access since the SEE criteria do not distinguish between PSO and open-access train services. RUs could increase their chances by providing train services that, according to expectations, have a higher socioeconomic value. The results in the following manner indicate the opportunities to do so:

- Despite train services 1 and 12 providing a similar intercity train service between Amsterdam and Berlin, train service 1 performs better in terms of socioeconomic value than train service 12. These two train services deviate slightly since train service 1, compared to train service 12, stops additionally at Hilversum and Apeldoorn and has a higher capacity with 120 additional seats. Increasing the number of intermediate stops and/or using rolling stock with a higher capacity could thus become a measure to RUs to transport more passengers and increase the socioeconomic value of their trains.

- Despite train services 5 and 13 providing a similar regional train service between Apeldoorn and Enschede, train service 13 performs better regarding socioeconomic value than train service 5. These two train services deviate slightly since train service 13, compared to train service 5 also operates between Almelo and Enschede during off-peak hours. Increasing the length of the train route and/or running trains during both peak and off-peak hours could thus become a measure for RUs to transport more passengers across longer route distances and increase the socioeconomic value of their trains.

The finding, following from the method and the case study raised in this article, that open-access operators can receive capacity access more often soon could indicate several developments. First, this finding could influence the steering of the railway network by the Dutch Ministry for Infrastructure and Water Management since the PSO train services could get a lower market share. In addition, the collective of RUs on the railway network could become diffuse, leading to a less recognisable and integrated system for customers. Still, governing bodies can reclaim their influence and ensure network cohesion through strategic guidance that Article 11 of the regulation could provide. However, how strategic guidance relates to the SEE criteria is still being determined at the moment of writing this article.

VI. CONCLUSION

Two types of impacts on capacity allocation can emerge: impact on the capacity allocation processes and the capacity allocation outcomes.

Considering the impact of using SEE criteria on capacity allocation processes, RUs will behave more beneficially to society. This behaviour occurs via their capacity requests, which could have a higher socioeconomic value following the aim to increase the chances of receiving capacity access.

Considering the impact of using SEE criteria on capacity allocation outcomes, the method prioritises open-access train services more than the AMvB currently used in the Netherlands. This finding is valid for the case study railway line and the method designed in this thesis. This prioritisation result follows the notion that the method does not evaluate train services on whether they are part of a PSO.

Several recommendations are available to improve the method further:

- Reducing the list of assumptions in Appendix 1 is possible by adding more parameters or variables to the method. This adoption could enhance the correspondence between the theory and practice behind the method.
- Given that the sources behind the parameters in the method are from varying years, the inclusion of an inflation correction for all monetary values in the method could be of added value.
- Consider including minimal frequencies in the method since it can uphold the public function of rail public transport when the market share of PSO train services diminishes.

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APPENDICES

APPENDIX 1. ASSUMPTIONS IN THE METHOD

The method considers several assumptions, allowing for an objective description of train services. The following list of assumptions applies to the method:

- The timetable is symmetrical, which simplifies the computational effort.
- The train segments from and the train series created in the TTR capacity strategy apply, ensuring cohesion between the method and TTR. The train segmentation from TTR also implies that trains transport only passengers or goods.
- Separate calculations for peak and off-peak hours are allowed, making it feasible for the method to accommodate additional trains during peak hours. Weighting both calculations makes finding an outcome for the entire day feasible.
- The increase in costs that RUs need to cover following a rejected capacity request is covered entirely by increasing the transport price.
- The length of the train is not part of the assessment since the length of the train can be undecided right until the moment of operation.
- Because of the availability of data, only data applicable to railway lines in The Netherlands are part of the evaluation. Thus, international train services are only compared from and to the international border.
- When data on future train services is unavailable, a multiplication with a ratio of the data from current train services can supply data on future train services.
- All transported commodities are distributed equally across the hour.

Appendix 2. Service types and priority rules in the AMvB

The AMvB defines the following train service types:

- Public Service Obligation (PSO): train services provided at the request of and through a contract with a governmental body. In The Netherlands, these PSOs must comply with the 'Wet Personenvervoer 2000' (Law Passenger Transport 2000).
- International train service: a train service connecting destinations between The Netherlands and neighbouring countries.
- National train service: a train service connecting destinations only within The Netherlands.
- High-speed passenger transport: a train service that uses the high-speed infrastructure in The Netherlands with a minimal speed of 250 km/h.
- Urban ('stadsgewestelijk') regional public transport: regional trains serving stations on railway lines with 'urban' stations as identified on map 1 of the AMvB. Most railway lines with 'urban' stations generally represent the railway lines within and from/to the Randstad area in The Netherlands.
- Rural ('streekgewestelijk') regional trains: Regional trains serve most of the stations on railway lines with 'rural' stations as identified on map 1 of the AMvB. Most railway lines with 'rural' stations exist outside the railway lines within and from/to the Randstad area in The Netherlands.
- Standard freight transport: transport of freight by train utilising standardised train series, of which the speed, length and acceleration characteristics apply through the Dutch network statement (Eerste Kamer der Staten-Generaal, 2024).

According to the tenth article of the AMvB, the following priority order is applicable, starting with the train type with the highest priority and ending with the train type with the lowest priority:

1. International public transport and international high-speed passenger transport operated based on a PSO.
2. Urban regional public transport operated based on a PSO.
3. National public transport (public transport that is not high-speed or urban/rural regional transport) based on a PSO.
4. International public transport, excluding night trains.
5. National high-speed passenger transport based on a PSO.
6. International high-speed passenger transport.
7. Rural, regional public transport operated based on a PSO.
8. Urban regional public transport.
9. National public transport.
10. National high-speed passenger transport.
11. Rural, regional public transport.
12. Standard freight transport.
13. Other passenger transport.
14. Trains without a transport function (Eerste Kamer der Staten-Generaal, 2024).

APPENDIX 3. TIME-DISTANCE DIAGRAMS

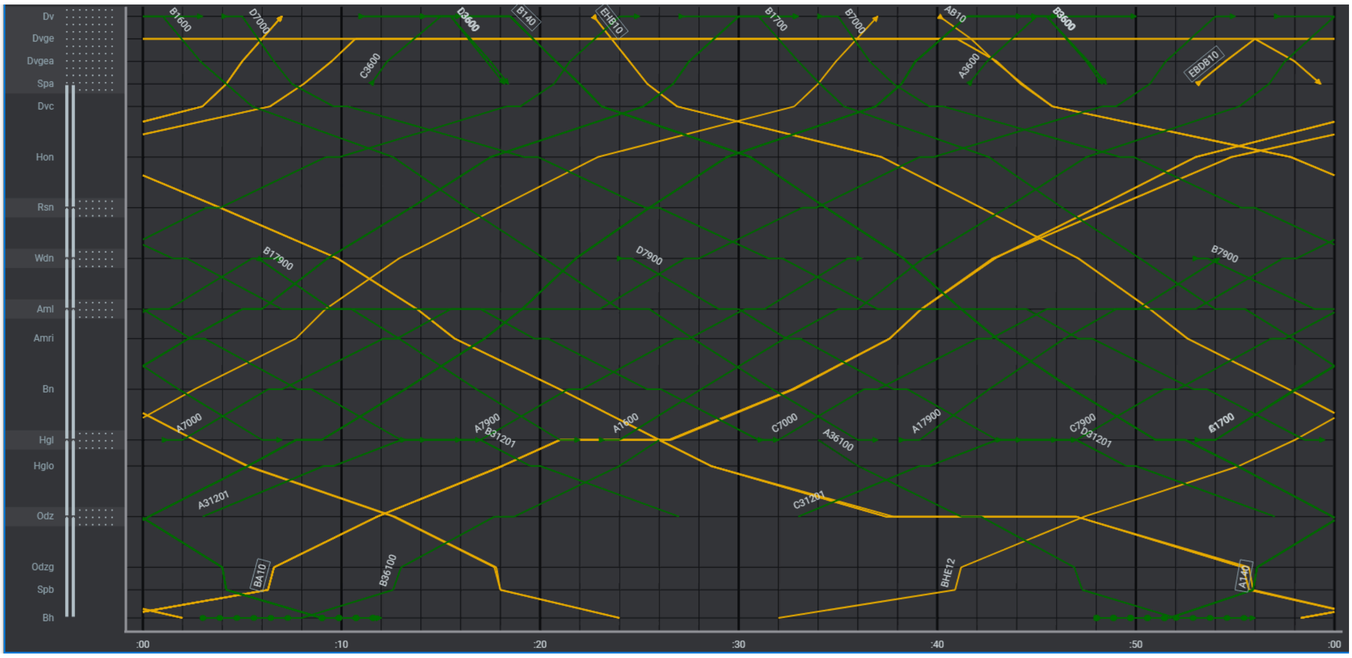

Figure 1: The time-distance diagram for a basic hour of the timetable of 2025 applicable to the railway line between Deventer (Dv) and Bad Bentheim (Bh) (ProRail, 2024).

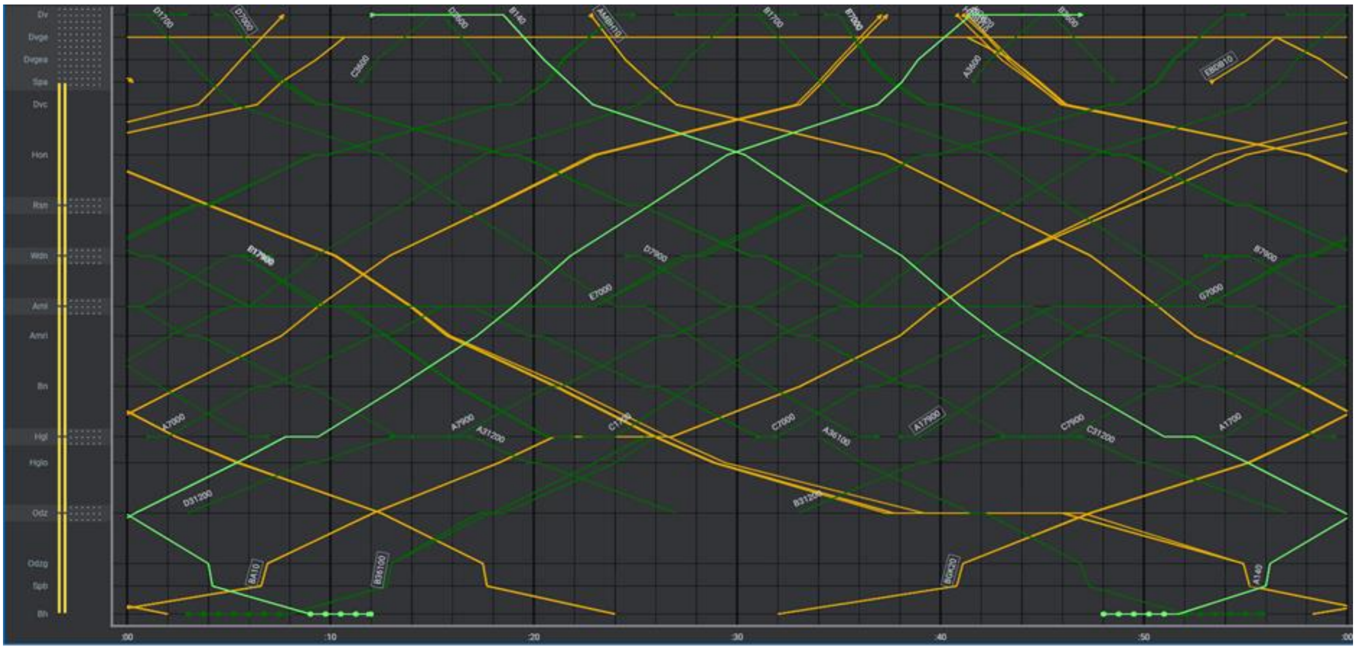

Figure 2: The time-distance diagram highlighting train series 140 with a lime green colour (ProRail, 2024).

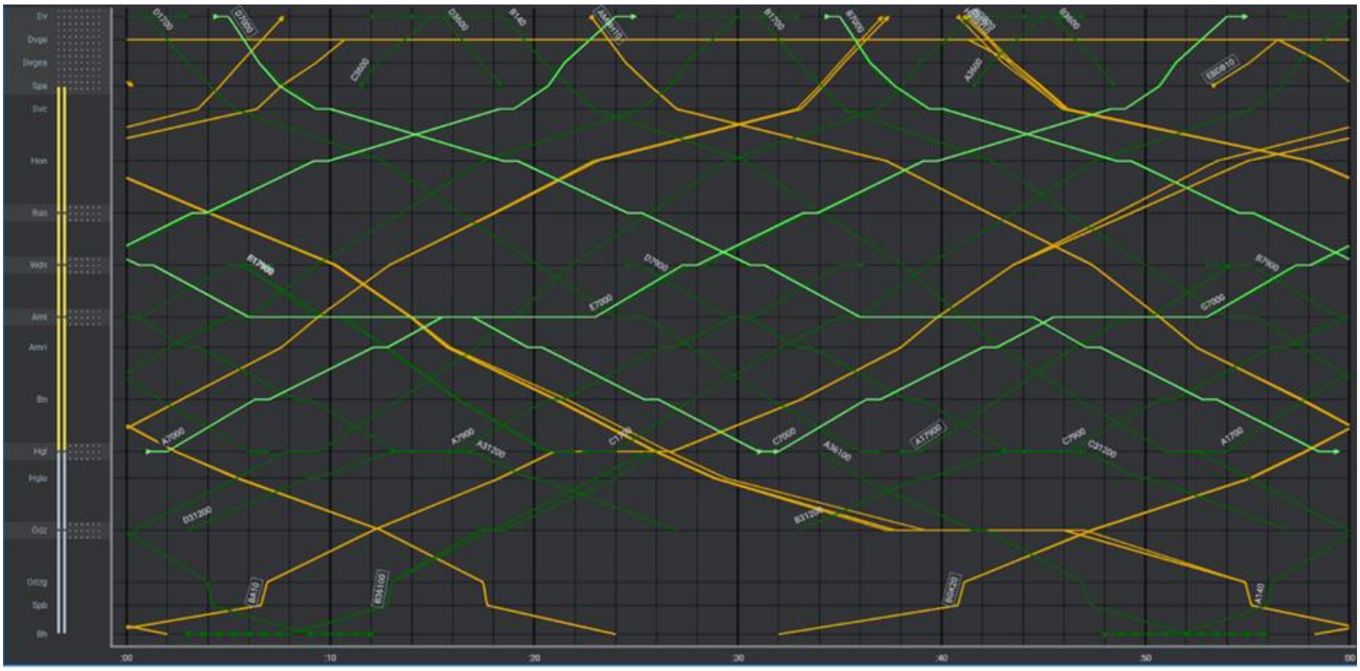

Figure 3: The time-distance diagram highlighting train series 7000 with a lime green colour (ProRail, 2024).

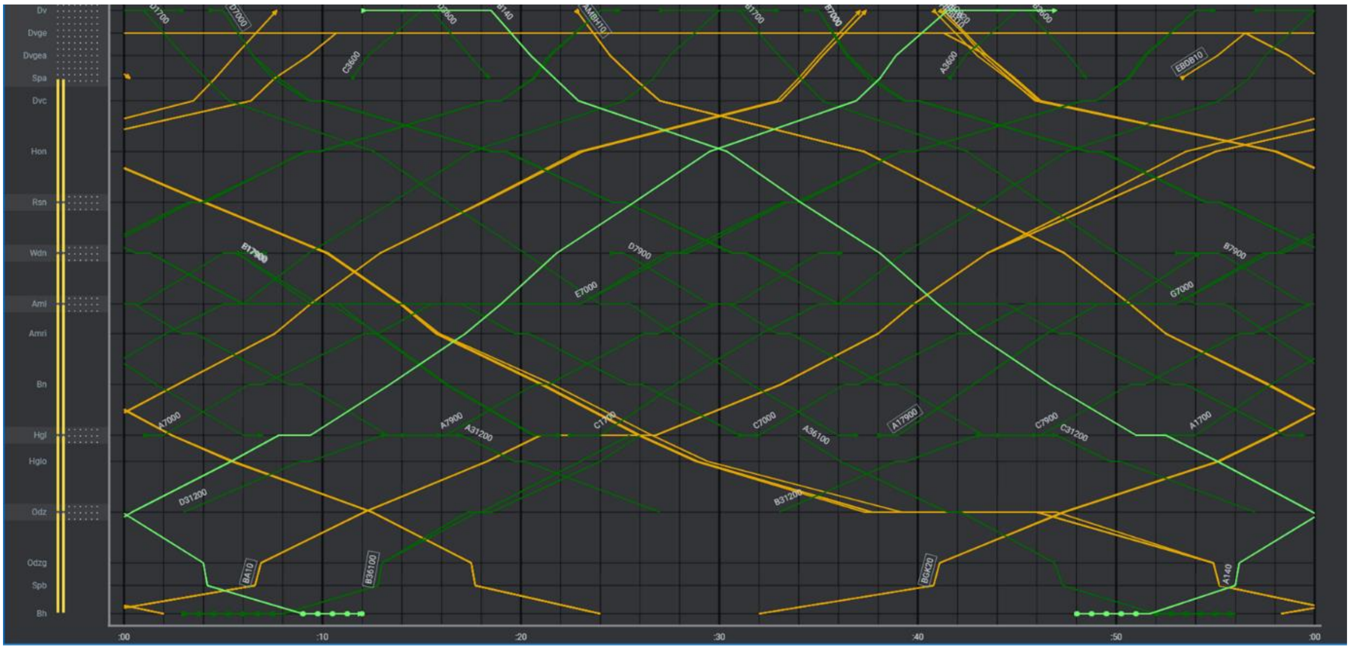

Figure 4: The time-distance diagram that applies according to the method for solving the capacity conflict from Group 1. The train service emerging from the conflict solution has a lime green colour (ProRail, 2024).

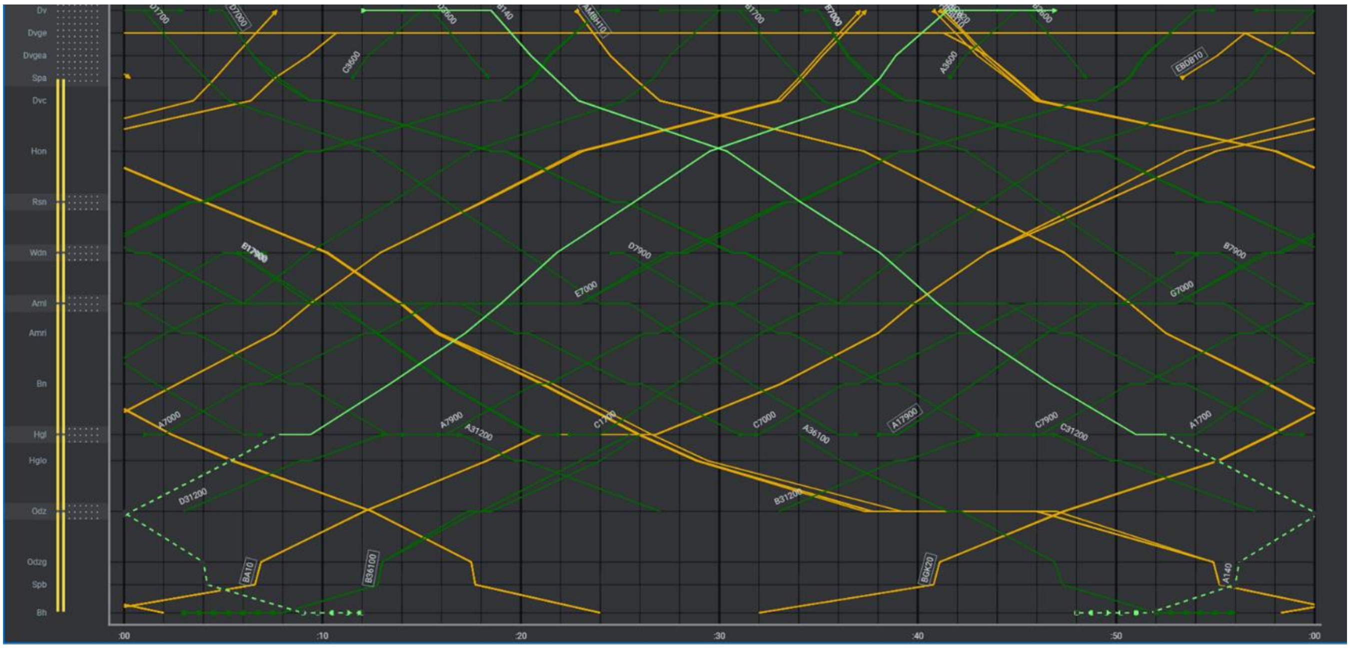

Figure 5: The time-distance diagram that applies according to the AMvB for solving the capacity conflict from Group 1. The train service emerging from the conflict solution has a lime green colour. An interrupted line denotes a train service that runs once every two hours (ProRail, 2024).

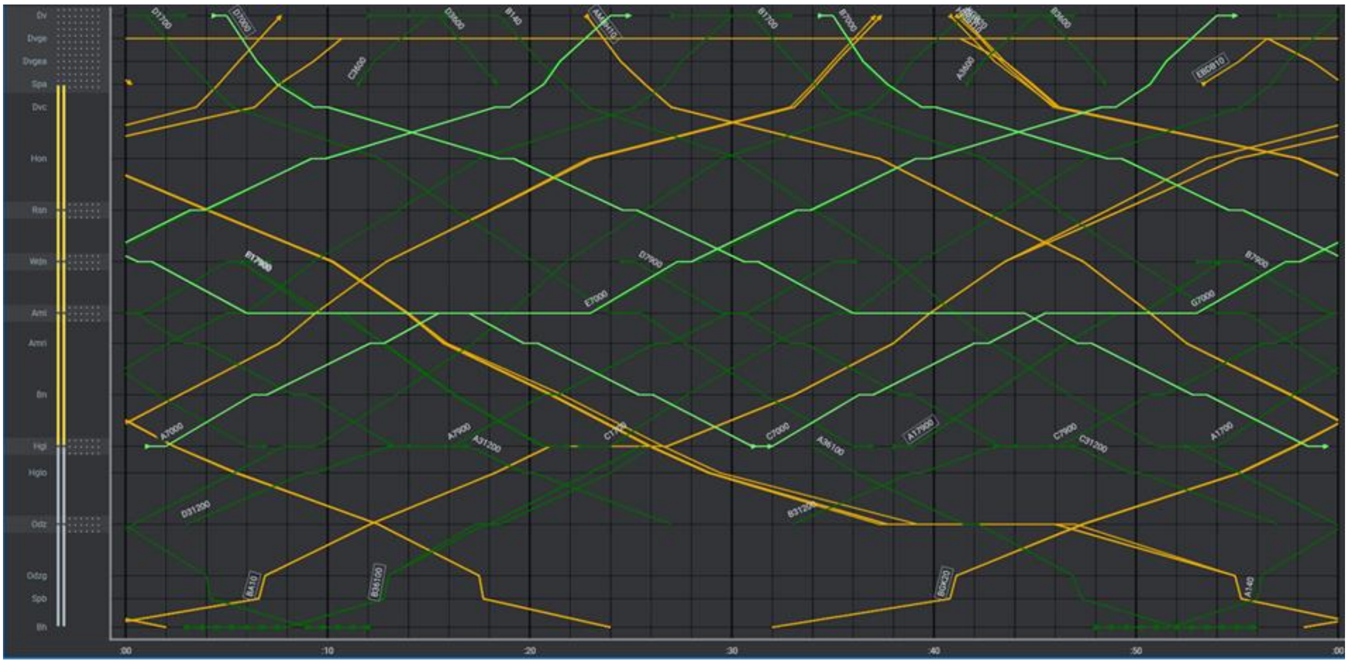

Figure 6: The time-distance diagram that applies according to the method for solving the capacity conflict from Group 2. The train service emerging from the conflict solution has a lime green colour (ProRail, 2024).

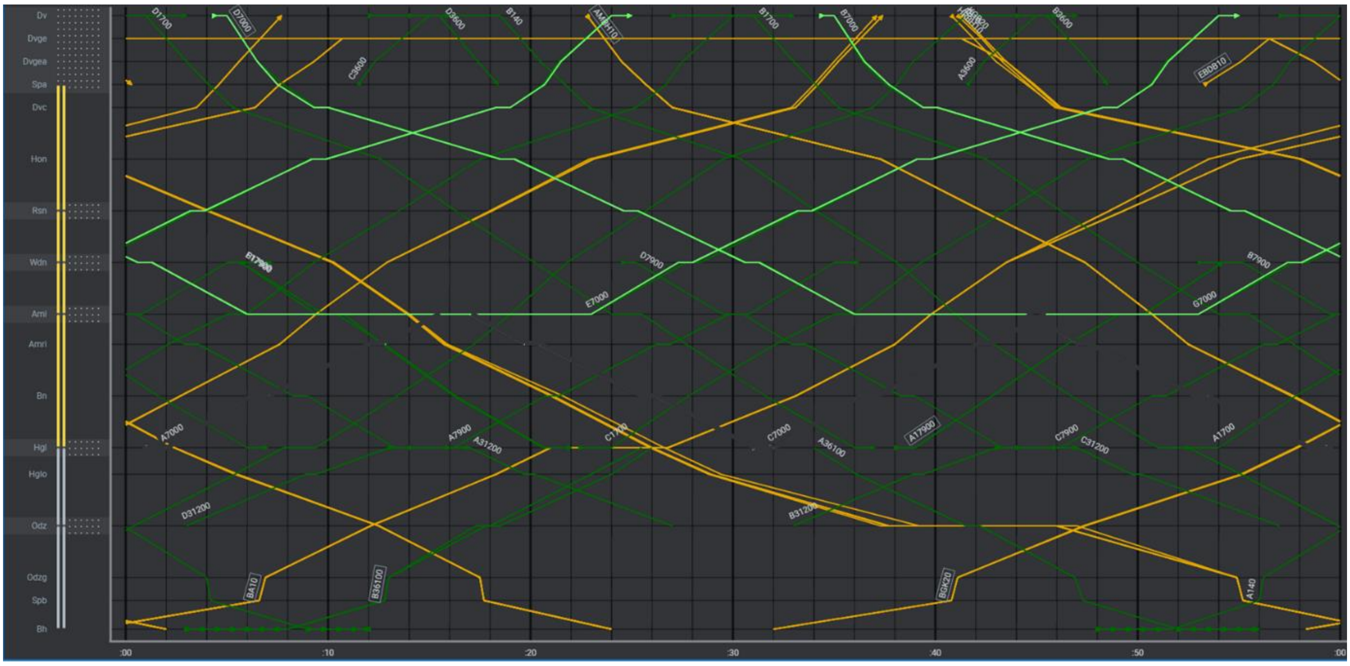

Figure 7: The time-distance diagram that applies according to the AMvB for solving the capacity conflict from Group 2. The train service emerging from the conflict solution has a lime green colour (ProRail, 2024).