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Scenarios for determining strategies for traffic weight measurements in The Netherlands

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Achtergrond

Momenteel wordt informatie over het gewicht van het (vracht)verkeer op het Nederlandse wegennet verkregen uit 18 weegpunten in het hoofdwegennet, zogenaamde Weigh in Motion (WIM) systemen. Deze informatie wordt voor verschillende doeleinden gebruikt, waaronder toezicht en handhaving (door de Inspectie Leefomgeving en Transport (ILT), en het beheren en onderhouden van wegen (door Rijkswaterstaat).

Voor de periode tot en met 2025 zijn reeds afspraken gemaakt om de WIM-systemen operationeel te houden. Voor de periode daarna moet nog een investeringsbeslissing genomen worden, waarbij rekening wordt gehouden met de verschillende belangen en behoeften, de technische mogelijkheden Hierbij speelt onder andere richtlijn (EU) 2015/719 van het Europees Parlement, waarin wijzigingen en aanvullingen van de maximaal toegestane gewichten (onder andere voor weging en handhaving) in het internationale verkeer zijn vastgelegd, en waarin geëist wordt dat lidstaten vóór 27 mei 2021 invulling geven aan regels en handhaving om toe te zien op naleving van de richtlijn. Hiermee wordt ook gevraagd om een keuze te maken tussen de verschillende technieken die hiervoor beschikbaar zijn, zowel systemen in de weg, als systemen aan boord van voertuigen.

Doelstelling en aanpak

Binnen bovengenoemd kader is het doel van deze studie: het inzicht geven in de mogelijke scenario's met voor tot het verkrijgen van informatie over verkeersbelastingen van (vracht)voertuigen. De ontwikkelde scenario's geven inzicht in verschillende afwegingen die gemaakt moeten worden, en bieden hiermee ondersteuning voor het nemen van beslissingen over de langetermijnstrategie voor dynamische (vracht)verkeersbelastingmetingen.

Hiertoe zijn allereerst, mede op basis van een stakeholderanalyse, vier toepassingsgebieden onderscheiden voor het gebruik van deze verkeersbelastinginformatie. De toepassingsgebieden verschillen in de doelen die nagestreefd kunnen worden, de activiteiten van partijen die hierbij horen, en de informatie die nodig is om deze activiteiten uit te voeren. Het onderscheiden van toepassingsgebieden geeft daarmee inzicht in de verschillen in belangen en behoeften van betrokken organisaties en organisatieonderdelen.

Voor elk toepassingsgebied is vervolgens de informatiebehoefte bepaald en zijn de overlappen en verschillen in informatiebehoefte tussen de toepassingsgebieden vastgesteld. Daarnaast is een technologiescan uitgevoerd en zijn scenario's ontwikkeld. De scenario's gaan uit van het gebruik van een bepaalde technologie, en geven daarmee in meer of mindere mate invulling aan de behoefte voor de

verschillende toepassingsgebieden. Daarmee wordt inzichtelijk gemaakt welke afwegingen ten grondslag liggen aan een afgewogen investeringsbesluit (*trade-offs)*. In de bevinden zijn de verschillende toepassingsgebieden de belangrijkste overwegingen opeen rij zijn gezet. Dit geeft een structuur voor besluitvorming, waar ook de nadruk van dit onderzoek op ligt. Waar mogelijk en beschikbaar is kwantitatieve informatie over kosten en baten toegevoegd. Voor een investeringsbeslissing is verdere onderbouwing op dit punt echter wenselijk.

Huidige situatie

De WIM-systemen zoals die in het huidige wegennet functioneren, kennen een geschiedenis van meer dan 20 jaar en zijn in verschillende opzichten geëvolueerd. Zowel op het gebied gebruikte technieken en technologieën, als op de eisen van de verschillende gebruikers van de systemen, heeft ontwikkeling plaatsgevonden. De huidige WIM-systemen worden namelijk gebruikt voor zowel controle en handhaving bij overbelasting als voor het ontwerp en onderhoud van infrastructuur (wegen en bruggen).

De systemen spelen in Nederland een specifieke rol in de handhaving op overbelading wat een wettelijke verplichting vanuit Europese wetgeving is. Verder wordt de informatie die gewonnen wordt uit deze systemen als waardevol beschouwd voor het beheer en onderhoud van de infrastructuur. Wel vraagt het systeem onderhoud, dat een ander stramien kent dan het onderhoud aan het wegdek. In de laatste jaren is gebleken dat door achterstand in onderhoud verschillende systemen niet presteerden zoals bedoeld. Dit wordt momenteel hersteld.

Met de komst van nieuwe technologieën, vooral op het gebied van *on-board sensoring*, ontstaat de vraag in hoeverre andere vormen van informatievergaring en/of het combineren van informatie van verschillende systemen of technologieën, in de toekomst meerwaarde kunnen bieden. Dit betreft zowel de ontwikkelingen betreffende de huidige (*in-road*) systemen (WIM) als *on-board* systemen, en andere databronnen zoals die volgen uit andere meetsystemen zoals Fleet Management Systemen (FMS) van bedrijven en de digitale vrachtbrief.

Toepassingsgebieden

Op basis van een stakeholderanalyse en mogelijke toekomstige scenario's zijn in het onderzoek vier toepassingsgebieden onderscheiden, te weten.

1. Controle, toezicht en handhaving; ten behoeve van een eerlijke concurrentie in de EU, verkeersveiligheid, en reductie van schade van infrastructuur vinden controle-, toezicht-, en handhavingsactiviteiten plaats om overbelading van voertuigen tegen te gaan.
2. Ontwerp, beheer & onderhoud van infrastructuur; ten behoeve van veilige, beschikbare, en betaalbare infrastructuur wordt infrastructuur ontworpen en onderhouden waarbij informatie wenselijk is over de effecten van voertuigbelastingen.
3. Verkeersmanagement & -beleid; om beleid te ontwikkelen is inzicht nodig in de effecten van (beleids)maatregelen waarbij belading één van de aspecten is.
4. Logistiek; ten behoeve van een efficiënte en groene logistieke sector is inzichten in belading wenselijk.

Elk toepassingsgebied heeft haar eigen activiteiten, doelen en actoren. Sommige toepassingsgebieden (1) komen voort uit wettelijke verplichtingen en voor de meeste toepassingsgebieden (1-3) is de overheid (I&W, ILT en/of RWS) de belangrijkste stakeholder. De belangen zijn per toepassingsgebied inzichtelijk gemaakt, en waar mogelijk onderbouwd met cijfers. Beslissers kunnen echter zelf een belang toekennen aan een toepassingsgebied en daarmee dit belang eventueel anders mee laten wegen in de uiteindelijke afwegingen voor een toekomststrategie.

In het onderzoek is vastgesteld dat het beleid binnen de verschillende toepassingsgebieden kan variëren, wat kan leiden tot andere eisen aan de noodzakelijke input en technologieën (informatievereisten). Daarnaast zijn de verschillende toepassingsgebieden onderling afhankelijk en beïnvloeden ze elkaar. Beleidswijzigingen ten aanzien van de handhaving kunnen bijvoorbeeld leiden tot andere behoeftes met betrekking tot beheer en onderhoud.

Informatievereisten

De geïdentificeerde toepassingsgebieden hebben, zoals verwacht, allemaal informatie nodig over voertuig- en/of aslasten. Daarentegen zijn ook verschillen in de vereiste informatie zichtbaar. Deze verschillen uiten zich pas wanneer de informatiebehoefte nader wordt gespecificeerd. Voor controle, toezicht en handhaving van overbelading is vooral informatie vereist over de lading op vrachtwagens en het daaraan gerelateerde gewicht van het voertuig en de assen. Voor het ontwerpen en onderhouden van wegen, bruggen en viaducten is daarentegen informatie vereist over het totale spectrum aan verkeersbelastingen dat op bepaalde punten in het netwerk aanwezig is. Dit is slechts één van de voorbeelden waar het specificeren van de informatiebehoefte inzicht geeft in de verschillen in de behoeften. Daarnaast kan uit de specificatie van de informatiebehoefte pas opgemaakt worden hoe geschikt verschillende technologieën zijn.

In dit onderzoek zijn zogenaamde datakwaliteitsdimensies gehanteerd om beter inzicht te verkrijgen in de informatiebehoefte voor de verschillende toepassingsgebieden (met de nadruk op de informatie betreffende verkeersbelastingen):

- De toegankelijkheid van de data, waarbij onderscheid kan worden gemaakt tussen ‘direct toegankelijk’, ‘continue toegankelijk’ of ‘toegankelijkheid van een representatieve dataset’ voor het doel waar deze voor wordt gebruikt. De toegankelijkheid van data heeft daarnaast ook betrekking op de instantie waarvoor de informatie toegankelijk moet.
- De nauwkeurigheid van de data, waarbij het gaat in welke mate de data de werkelijke waarde benadert. Voor onder andere handhaving en (automatische) beboeting gelden strikte eisen met betrekking tot nauwkeurigheid wat van invloed is op de geschiktheid van systemen. Voor beheer en onderhoud is nauwkeurigheid in specifieke gevallen zeer relevant, bijvoorbeeld bij het beoordelen van de constructieve veiligheid van kunstwerken waarbij (extreem) zwaar beladen voertuigen met een kleine kans van voorkomen een grote rol spelen.
- De volledigheid van de informatie. Dit betreft in het bijzonder Het gaat hierbij om vragen of informatie over alle verkeer nodig is of juist een selectie van het verkeer, op hoeveel meetpunten, en op welke momenten in de tijd. In sommige gevallen is meer informatie nodig dan alleen gewichtsinformatie (zoals de

maximaal toelaatbare belasting waar ook de specifieke eisen die aan een voertuig worden gesteld van belang zijn).
- Consistentie is belangrijk voor de meeste toepassingsgebieden, met name indien de informatie wordt gebruikt om trends te identificeren.
- Bijna alle toepassingsgebieden vragen dat de informatie gedetailleerd is tot het niveau van individuele vrachtwagens en assen; hoewel sommigen er later voor zullen kiezen om resultaten te aggregeren (bijvoorbeeld voor trendanalyse).
- De mate waarin gegevens zijn geïntegreerd of kunnen worden geïntegreerd in andere gegevenssystemen (interoperabiliteit).
- De tijdigheid van de data. Deze varieert van seconden (in het geval handhaving) tot weken of maanden voor andere doeleinden.

De bovenstaande criteria zijn vooral bedoeld om de informatiebehoefte verder te specificeren en om verschillen te kunnen identificeren. Dit neemt niet weg dat in het algemeen ook andere eisen relevant zijn, zoals de vertrouwelijkheid van data, het eigendom, en de beveiliging van data. Deze eisen worden belangrijker bij het gebruik van data en informatie die uit andere bronnen komen dan uit de wegkantsystemen die momenteel de belangrijkste informatiebron zijn.

Technologiescan

In de technologiescan is gekeken naar bestaande en in ontwikkeling zijnde meetsystemen (wederom met de nadruk op verkeersbelastingmeetsystemen).

Uit de scan komt voort dat de meeste meetsystemen zich richten op een specifiek toepassingsgebied. Zo zijn de huidige metingen met *in-road* systemen gericht op handhaving, en worden deze gebruikt voor beheer en onderhoud. Metingen aan bruggen (zogenaamd *bridge WIM)* zijn over het algemeen specifiek ingericht voor het bepalen van het constructief gedrag van bruggen, en in mindere mate voor het bepalen van voertuigkarakteristieken. Metingen gedaan in voertuigen (*on-board)* zijn vooral gericht op de logistiek, maar zouden ook benut kunnen worden in bijvoorbeeld handhaving, en mogelijk ook voor beheer en onderhoud.

Redenerend vanuit de informatiebehoeften van de vier toepassingsgebieden komt men daarmee uit op verschillende technologieën. Tegelijk kunnen systemen wel voor verschillende toepassingen ingezet worden, maar gaat dit gepaard met aandachtspunten en/of beperkingen. Ontwikkelingen in (meet)technologieën zijn veelal gericht op systeemverbeteringen (nauwkeuriger, sneller, goedkoper), en in sommige gevallen op het invullen van aanvullende functionaliteiten (zoals het bepalen van de wielprentafdruk, en daarmee de bandenspanning).

Opgemerkt wordt dat er veel, en steeds meer, informatie ingewonnen en/of benaderbaar wordt. Data afkomstig van ontwikkelingen zoals de vrachtwagen-heffing, de digitale vrachtbrief, en metingen van bijvoorbeeld tellingen, leveren informatie waarvan gebruik gemaakt kan worden voor tal van doeleinden. In dat opzicht lijken de belangrijkste technologische ontwikkelingen betrekking te hebben op het verzamelen, samenbrengen, beheren, en analyseren van data. De ontwikkelingen op dit gebied gaan snel. Hier is binnen het kader van dit onderzoek in beperktere mate naar gekeken, mede omdat de oorsprong van de benodigde data uiteindelijk betrekking heeft op de metingen die uitgevoerd worden (in de weg, of in het voertuig).

Concluderend komen vanuit verschillende toepassingsgebieden verschillende informatiebehoeftes voort. Hierbij lijkt het duidelijk dat er verschillende soorten metingen (dus ook verschillende soorten technologieën) nodig zijn om te kunnen voorzien in de informatiebehoefte. Uiteindelijk komt hieruit de afweging naar voren of het belang voor een toepassingsgebied opweegt tegen de kosten van een systeem. Om verder inzicht te geven in de belangrijkste afwegingen spelen zijn vier scenario's ontwikkeld. In elk van de scenario's wordt invulling gegeven aan de wettelijke verplichting die geldt:

- Het basisscenario; dit gaat uit van continuering van het gebruik van de huidige WIM-systemen. Uitgegaan wordt dat bepaalde (al dan niet technologiegedreven) ontwikkelingen min of meer autonoom plaats zullen vinden waardoor de huidige systemen op termijn vervangen worden voor systemen met betere prestaties, aanvullende functionaliteiten, en/of lagere kosten. In de basis is een dergelijk scenario echter gelijk aan de huidige situatie.
- Een situatie waarin het aantal *in-road* metingen wordt geïntensifieerd. Concreet betekent dit een toename van het aantal WIM-stations. Hiermee wordt meer informatie ingewonnen, wat een positieve bijdrage kan leveren aan het beperken overbelading en meer inzicht geeft in de verkeersbelasting op verschillende punten in het wegennet ten behoeve van beheer en onderhoud. De toename in kosten is te extrapoleren vanuit de huidige situatie, de (extra) baten als gevolg van de toename in informatie is niet bepaald.
- Een situatie waarin metingen (enkel) *on-board* plaatsvinden. Hierbij wordt er van uitgegaan dat alle informatie over belastingen wordt ingewonnen vanuit de (vracht)voertuigen zelf. Dit is een ontwikkeling die om logistieke doeleinden al deels plaatsvindt en waarbij een duidelijke parallel aanwezig is met bijvoorbeeld de vrachtwagenheffing. De gedachte voor dit scenario is dat deze informatie ook beschikbaar komt voor andere doeleinden zoals handhaving, beheer en onderhoud, en beleidsstudies. Omdat het aannemelijk is dat dit – zeker voor de korte termijn – geen inzicht geeft in het verkeersspectrum op punten in het wegennet, geeft dit scenario minder invulling aan de informatiebehoeften met betrekking tot ontwerp en onderhoud van infrastructuur.
- Een situatie waarin zowel *in-road* metingen als *on-board* metingen gedaan worden. Een logisch vertrekpunt is dat hierbij uitgegaan wordt van het basisscenario en over de tijd steeds meer data vanuit *on-board* systemen wordt verkregen.

Er zijn meerdere variaties te bedenken binnen, en aanvullend op bovenstaande vier scenario's. De functie van de genoemde scenario's is om beter inzicht te geven in de belangrijkste afwegingen die spelen. Deze afwegingen zijn verzameld en geordend in dit onderzoek, om hiermee een gestructureerde basis te geven voor besluitvorming.

Bij het nemen van beslissingen spelen als vanzelfsprekend de kosten en de baten een belangrijke rol, maar ook de verdeling hiervan. Bij on-board systemen komen de kosten bijvoorbeeld deels terecht bij private partijen zoals vrachtwagenproducenten, terwijl ook overheidspartijen profiteren van de data (voor handhaving en beheer en onderhoud). Bij systemen in de weg is dit juist andersom: de kosten worden voornamelijk aan de overheid toegerekend, terwijl ook de private partijen profiteren.

Conclusies en afwegingen

In het onderzoek zijn verschillende scenario's gegeven voor toekomstige verkeers-belastingmetingen. Deze zijn anders voor de verschillende toepassingsgebieden. De meest waarschijnlijke scenario’s voor de vier toepassingsgebieden zijn gegeven in onderstaande tabel (*de tabel is overgenomen uit het hoofdrapport en is daarom in het Engels opgesteld*)

In de tabel zijn de toepassingsgebieden weergegeven, gecombineerd met het huidige scenario (base scenario) en de mogelijke scenario's voor de toekomst (uiterst rechtse kolom). Het zwart gearceerde scenario in de uiterst rechte kolom duidt het meest waarschijnlijke scenario aan, terwijl de veelbelovende scenario’s grijs zijn gearceerd. De scenario's die in een grijs lettertype zijn weergegeven, zijn minder waarschijnlijk.

Application area	**Expected scenarios**	
	Base scenario	**Future (beyond 2025)**
1. Control, supervision & enforcement	Main source: currently 18 WIM-stations in highway network.	Base scenario Intensify in-road On-board In-road & on-board
2. Design & maintenance	Main source: currently 18 WIM-stations in highway network.	Base scenario Intensify in-road On-board In-road & on-board
3. Traffic management & policy	Current sources include data from e.g. WIM-stations and induction loops in highway network.	Base scenario Intensify in-road On-board In-road & on-board
4. Logistics	Private information sources (on-site WIM, fleet management systems)	Base scenario Intensify in-road On-board In-road & on-board

Uit een evaluatie van de afwegingen per toepassingsgebied kunnen de volgende algemene conclusies worden getrokken.

- Het aantal voertuigen met ingebouwde sensoren neemt toe. Deze informatie kan voor meerdere toepassingsgebieden worden gebruikt maar is veelal in particulier bezit. Indien de overheid deze informatie kan (en mag) verkrijgen, biedt dit kansen voor handhaving maar ook voor het ontwerpen, beheren en onderhouden van wegen, bruggen en viaducten.
- De mate waarin de overheid overbelading wil beheersen, bepaalt in hoge mate de geschiktheid van verschillende scenario's. Indien het aantal huidig aantal geregistreerde aan overtredingen met betrekking tot overbeladen voertuigen acceptabel wordt geacht, dan kan de huidige situatie ook als bevredigend

worden beschouwd. Meer controle, toezicht en handhaving kan onder andere worden verkregen door meer metingen (hetzij *on-board*, hetzij *in-road*).

- In de huidige situatie wordt door de overheid voor gewichtsinformatie vooral vertrouwd op *in-road* systemen. Voor beheer en onderhoud is het de verwachting dat dit ook in de toekomst een belangrijke informatiebron zal zijn, ook in het licht van de komst van nieuwe transportconcepten. Voor handhaving is het daarentegen niet ondenkbeeldig om te verwachten dat meer gebruik zal worden gemaakt van *on-board* systemen op basis van ingebouwde sensoren. Dit kan tot gevolg hebben dat voor beheer en onderhoud een ander (of anders ingericht) systeem mogelijk beter aansluit bij specifieke behoeftes.

Duidelijk moge zijn dat er kansen worden gezien in de scenario's met ingebouwde (*on-board*) sensoren als gegevensbron. Het is echter onduidelijk in hoeverre dit de momenteel gebruikte primaire databronnen (*in-road* WIM-stations) kan vervangen, en in welk tijdsbestek. In bredere zin ontstaan er, als gevolg van de digitalisering (zoals de digitale vrachtbrief), steeds meer mogelijkheden om data te verzamelen, beheren en te analyseren. Deze mogelijkheden kunnen van toegevoegde waarde zijn in elk van de eerder beschreven scenario's.

Voor de komende jaren achten de meeste belanghebbenden voortzetting van de huidige situatie geschikt, maar worden voor de toekomst grote kansen toegedicht aan *on-board* technologieën. Dit geeft tevens tijd om de mogelijkheden die deze technologieën bieden, samen met andere informatiebronnen, nader te onderzoeken en de informatiebehoeftes van de verschillende belanghebbenden duidelijker te specificeren.

Contents

1 Introduction

This chapter provides a short introduction on the research that is carried out, providing a short overview of the background, the goal and the adopted approach. More details on the approach can be found in each chapter.

This project was assigned by Rijkswaterstaat, the executive agency of the Ministry of Infrastructure and Water Management[1].

1.1 Background

The Ministry of Infrastructure and Water Management needs information on the weights of traffic to support the implementation of its tasks or for policy purposes. Currently, specific measuring equipment (Weigh in Motion (WIM) systems) is installed to determine the traffic load in weights of moving trucks. Until 2025, investments will be made in the maintenance of the existing portfolio of Weigh in Motion (WIM) systems. However, a substantiation is needed in order to be able to arrive at a balanced investment decision for the period after 2025.

Several developments have led to the need for a long-term vision on dynamic traffic weight measurements.

First of all, European legislation requires Member States to ensure compliance of Directives 96/53/EC and 2015/719 lay down maximum authorised weights on traffic, and requires Member States to take measures to ensure compliance with the requirements of this Directive [1]. The Directive also requires that Member States "*take specific measures to identify vehicles or vehicle combinations in circulation that are likely to have exceeded the maximum authorised weight and that should therefore be checked by their competent authorities in order to ensure compliance with the requirements of this Directive*" by 27 May 2021, which implies that Member states also decide between the available techniques for determining overloading.

Secondly, the design & maintenance of infrastructure faces various challenges in which information on traffic loads is needed. Examples of challenges include ageing of infrastructure, and trends in mobility and transport (e.g. higher number of vehicle and increasing loads). Such developments have to be accommodated whilst costs of infrastructure have to kept as low as possible. Insight into intensities alone does no longer suffices to meet these challenges [2]. Moreover, the 2012 Dutch Building Decree [3] stipulates that structures must comply to the requirements for structural safety (Eurocodes, including National Annex). In order to assess the structural safety, detailed insight is required in the traffic loads and intensities of trucks on the Dutch roads.

Thirdly, it is found that the current system is used for multiple purposes, and by various departments and/or organisations with their on specific tasks, goals, and

[1] *The working group "Zwaartekracht" has also been involved. This working group is a collaboration between the Ministry of Infrastructure and Water Management, Rijkswaterstaat, the Netherlands Vehicle Authority (RDW), the Human Environment and Transport Inspectorate (ILT), the province of South Holland, and the province of Overijssel.*

challenges. While this underlines the importance of weight measurement data, it may also pose challenges in arriving at a balanced investment decision.

For Dutch road authority Rijkswaterstaat, sustainability is a focus point in the execution of its tasks. As a result, Rijkswaterstaat would like to extend the service life of its assets and systems as much as possible and useful [2]. Rijkswaterstaat also wants to include developments in technology into considerations, particularly those developments in censoring and ICT. This requires a data strategy in which, in time, can utilize new developments in data requirements and developments in data collection techniques. Moreover, changes in the data requirements of external users and in the service provisions to external users of Rijkswaterstaat data [2].

1.2 Goal of the research

The Ministry of Infrastructure and Water Management obtains information about the weight of (freight) traffic on the Dutch road network. At the moment this information is mainly obtained from the numerous (18 systems, 9 locations, 2 directions per location) Weigh in Motion (WIM) measuring systems at different locations in the road network. These WIM measuring systems will be maintained up to and including 2025. For the period after 2025, a substantiation is needed for arriving at a balanced investment decision for the Ministry.

The aim of the current study is to develop a trade-off model, substantiated by a stakeholder and information analyses. The study mentions various scenarios for future dynamic traffic weight measurements, and results in key trade-offs for decision making. In the study available techniques, as well as new developments and opportunities are taken into consideration.

These scenarios, together with the identification of key trade-offs, provide the Ministry of Infrastructure and Water Management the basis for making a well-founded investment decision about the long-term strategy for dynamic weighing.

1.3 Approach

The adopted approach is outlined graphically in Figure 1.1, and this report has a similar structure.

First steps in the research were to investigate the as-is situation and to perform an stakeholder analysis. Based on this, various application areas were formulated. For each application are, the intended goals and purposes are outlined. Similarly, each application area is associated with performing activities that require information and technology. Information requirements per application area were formulated. These requirements would be matched with technology identified through a technology scan. Finally, all finding have been brought together to develop scenarios and identify trade-off for decision making.

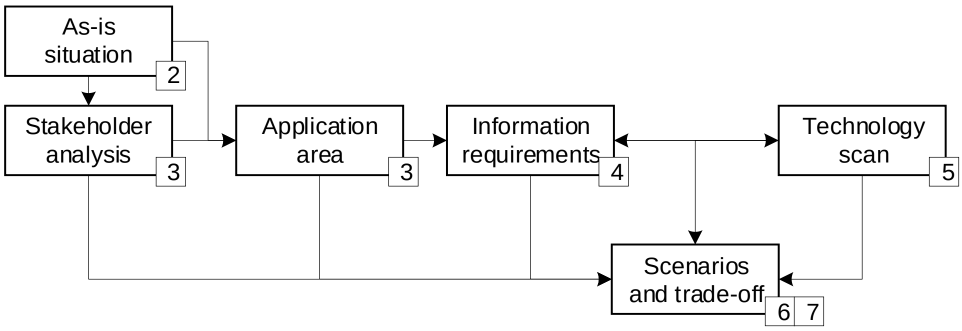

Figure 1.1 Approach and structure of report. The boxed numbers indicate the chapter numbers in this report

It should be mentioned that there are some limitations in the research, as a result of limitations in time and means.

- Experiences and information from abroad have been taken into account, but only when known and readily available. This report has been written in English to be shared abroad when deemed useful.
- Information on costs and benefit have been included to the extent that such information was readily available. Particular estimates on expected benefits of certain scenarios have been excluded from the research. As a result, this report should not be considered as a cost-benefit-analysis.
- The research did not result in an advice. In other words, no particular scenario or plan is put forward by this report. This report is aimed to structure available information, and put forward a framework to help decision making and the development of a long term vision regarding weight measurement.

1.4 Use and outline of report

The results of and the steps taken in the research have been allocated to different chapters in this report. These are shortly outlined below, including a readers guide.

Chapter 2 provides a short overview of the as-is situation in the Netherlands, current uses, the main involved actors and some of the current issues. Chapter 3 extends beyond the as-is situation and explains various application areas that were found. The chapter illustrates that there are goals that can be pursued. Information is provided in order to inform the reader on arguments and figures to assess the importance of each application area. A stakeholder overview is provided to illustrate that the application areas may vary according to the stakeholders concerned. In chapter 4 (requirements) the reader is provided with further insight in the required information, given any of the identified application areas. Chapter 5 provides a (limited) overview of existing and new techniques and provides an overview on how these techniques match with the information required. In chapter 6 the various scenarios are described that can be thought of for the short and the longer term. Finally, chapter 7 discusses – from the perspective of each application area – the main arguments put forward, and the consequences of different scenarios in a qualitative way. As such chapter 7 highlights the key trade-offs for decision making. The chapter concludes with some final findings.

2 The as-is situation in the Netherlands

Weigh-in-Motion (WIM) was first tested in the late 1950s in the United States in the so-called AASHTO road tests [4]. The tests were used, among others, for studying the behaviour of bridges under cyclic and extreme load conditions. The first type of system for dynamic weighing consisted of bending plates. From the 1970s', new technologies of sensors for WIM systems were developed in Europe, such as piezo-electric sensors.

2.1 Description

In 1998, the former Ministry of Infrastructure and Water Management conducted a pilot with a dynamic Weigh In Motion in which the use of video images was incorporated (WIM-VID, hereafter denoted as WIM), see Figure 2.1 [5]. The goal of this pilot was to gain insight in traffic loads on the Dutch highways, and using this insight to develop strategies for reducing damage of the road network by overloading. Moreover, it was investigated whether WIM systems could be used effectively for identifying overloaded vehicles (i.e. selection of vehicles for further investigation). Currently, the WIM systems are used for this purpose.

Figure 2.1 WIM-NL system consisting of a combination of in-road sensors and video images

Over the years, the accuracy and reliability of WIM systems improved. As such, the WIM systems gained interest from asset management organizations (e.g. the Dutch road authority Rijkswaterstaat) as well as organizations tasked with control, supervision and enforcement of regulations on traffic size and weights (e.g. Dutch Human Environment and Transport Inspectorate of the ministry, police forces). Asset management organizations started to obtain data that could be used in maintaining road networks, while control, supervision and enforcement organizations could use the data to identify infringements of regulations.

As a result, WIM systems have become indispensable for both purposes and various systems have been installed in the Dutch road network (Figure 2.2). At the moment, 18 systems (9 locations, devices in both directions) are installed but in the future the number of WIM stations may change. Next to preselecting overloaded vehicles for further investigation, WIM systems are used to prepare the multi-year planning for the maintenance of pavements and for determining the load models for the design and assessment of the structural safety of bridges and viaducts. Moreover, with an increasing number of design and maintenance contracts for parts of the network, similar systems are used by maintenance companies for monitoring the service level agreements with respect to traffic loads that may be expected.

Figure 2.2 Weigh in Motion systems in the Dutch highway network (2019)

As mentioned, in the last decades, the accuracy and reliability of WIM systems has been improved and the systems have evolved due to new sensors, yet, the basic principles of the measurement systems have remained the same. Next to new sensors also new technologies such as in-car measuring systems have been developed. However, until now, such systems are not used for the aforementioned purposes (asset management and enforcement) in the Netherlands.

2.2 Current uses of obtained data

As mentioned previously, at the moment, the data provided from the WIM systems is used mainly by Rijkswaterstaat and by the ILT.

2.2.1 Control, supervision & enforcement

The current portfolio of WIM systems is used for control, supervision and enforcement of overloaded vehicles. This task is performed by the Dutch Human Environment and Transport Inspectorate of the ministry (ILT).

Next to weight measurement sensors, the systems include video systems and automatic recognition of the license plates of vehicles. The system then compares the measured loads to the allowed vehicle and axis loads. It does so through access to the database of the Dutch Vehicle Authority (RDW). This database also allows ILT to contact violators. ILT keeps track of all (possible) violations and (automatically) informs the companies involved on the violations observed. This does not entail a penalty or fine, as the system is not deemed accurate enough to automatically penalize violators. By keeping track of infringements, ILT can identify particular companies, areas, routes, etc. where infringement is more frequent. The ILT informs offenders on infringement to influence behaviour, and follows with additional interventions when required. As such, the ILT uses different forms and levels of interventions varying from creating awareness with publications and influencing behaviour with benchmarking, to enforcement including fines.

Next to control and supervision, actual enforcement entails checking specific vehicles. The WIM data provides weight estimates of vehicles that is used for preselecting vehicles for static weight measurements on nearby locations.

2.2.2 Design and maintenance

For design and maintenance of infrastructure, vehicle weight data is mainly used for gaining insight in the behaviour of materials and structures under (heavy) load conditions. This insight is used for validating and calibrating models for predicting time dependent behaviour such as fatigue of steel and concrete structures, but also of pavement degradation. These predictions are used as a basis for the multi-year planning for replacement and renovations of bridges, viaducts, roads, etc.

Moreover the traffic weight characteristics (axle loads, vehicle loads, intervehicle distances, etc.) are required for developing regulated traffic load models for assessing new and existing structures under heavy traffic load conditions. The assessment of the structural safety requires information on the entire service life, which requires that trends over time are taken into account and that traffic load models are evaluated periodically. For that reason, continuous (or at least periodic measurements in a representative time frame) are required. Insight in the variation of traffic loads throughout the network (spatial variability) is obtained by performing measurements at different locations in the road network.

The information of traffic weight measurement in time and at different locations may also be used for policy studies in which the effects of certain traffic related changes and decisions are studied.

2.3 Involved parties/organisations

At this moment a limited number of stakeholders is involved in acquiring data and using the weigh in motion system for dynamic traffic load measurements with WIM measurement systems. Roughly, a distinction can be made between parties that facilitate the use of the systems and parties that use the measurement data. Most stakeholders are governmental.

The two most dominant stakeholders that can be distinguished are Dutch road authority Rijkswaterstaat and the and the Dutch Human Environment and Transport Inspectorate of the ministry (ILT) that is charged with enforcement of the weight of vehicles. The Dutch Vehicle Authority (RDW) is also an important factor in facilitating the current system.

Rijkswaterstaat Central Information Services (RWS CIV) is owner of the WIM system. As owner, they are also responsible for system maintenance. Because of private sensitive license plate information, the data, however, is not owned by Rijkswaterstaat but by ILT. In addition to the fact that ILT uses the measurement data itself for enforcement, ILT provides anonymized data to Rijkswaterstaat for asset management purposes and traffic and transport studies.

2.4 Current issues

Because the WIM systems are installed in-road, it may be obvious that the accuracy of these systems depends on the road conditions, which vary in time. The in-road WIM systems, moreover, require a particular maintenance regime, which is hard to align to the maintenance regime of the road and road network. The time between malfunction of the system and repair is often long, as many preparations are required before maintenance can be executed. As a consequence, the system down time can be high.
As a result of decreasing road condition, the accuracy of the measurements decreases too. In the last decade this has resulted in less reliable traffic weight data from the WIM systems, rendering to data unfit for the intended purposes, including enforcement. Added to this, the difficulties in planning and execution of maintenance has led to a significant decrease in the number of operational WIM-stations in the last years. Recently, extensive effort and multimillion investments have been made to bring systems back into service and operate according to specification.

Because the data of the WIM systems is used for different purposes, the requirements vary as well.

- For structural safety assessment the actual loads should be taken into account. For that reason, the accuracy, especially for heavy loaded vehicles or axles is crucial. For preselection for enforcement on the other hand, extreme values and possible outliers may be neglected because they only include a fraction of all the measurements.
- In the current systems data from vehicles driving slower than 40 km/h or faster than 130 km/h is neglected. Because a speed lower than 40 km/h is only observed during traffic jams, again, for enforcement, the effect is limited. However, it is known that during traffic jams the traffic flow changes completely because natural convoys are formed at the most right lane. For structural assessments, such events may be of utmost importance, as well as the rather small intervehicle distances that are observed in traffic jam situations.

At the moment, the information that is obtained is limited to 18 stations in the Netherlands in total. With an urge for more bridge specific traffic load information the question arises whether this is enough.

2.5 Conclusions

From the earlier sections it is concluded that the current weigh in motion (WIM) systems and methods for using the data have a long history and have evolved in various respects. This evolution relates to the techniques and technologies used, but also to the requirements of the various users regarding the systems. Current WIM-systems are considered vitally important for both the purpose of control & enforcement on overloading, and to the purpose of design & maintenance of infrastructure. As such, the current system is of (great) added value, although several issues are encountered in current operations.

The current systems prove to be of value (despite current issues). The question rises if new technology, which is becoming available, can be even more valuable.

3 Application areas

It is important to identify and clarify varying motives in relation to weight measurement techniques, and to define application areas. Weight measurement techniques provide information that can serve different purposes. Similar, it can serve the interest of different stakeholders. Depending on the purposes and interests served, requirements regarding the needed information may change, which in turn may require other technology.

3.1 Approach

To identify application areas, the current situation in the Netherlands was investigated (see Chapter 2). By investigating uses of the current system, several application areas could be identified. To determine possible other uses, a stakeholder analysis was performed to identify current and possible future facilitators, users, and other stakeholders and their interests. The analysis took into consideration that future scenarios could also include other technologies than currently used.

The results of the analysis are structured using a *logic model* (Figure 3.1). A logic model is a systematic and visual way to present and share our understanding of the relationship among required resources, planned activities, and the expected results [6].

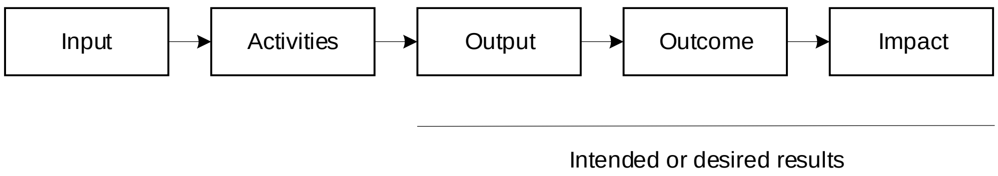

Figure 3.1: Basis logic model.

In this chapter, logic models are used to define applications areas. For example, weight measurement techniques (inputs) are used for control, supervising, and enforcement (activities), with the desired result of reducing overloading infringements (output), which can contribute to traffic safety (outcome/impact). In other words, logic models help to shows the ‘what’ and ‘why’.

In this report, applications areas have in common that they relate to traffic weight measurements. They vary in the intended purposes, required activities and required input. This chapter continues with clarification on the identified application areas, and describing the associated activities and their desired outputs, outcomes and impact. Chapter 4 will discuss in more detail the requirements per application area, i.e. the input required in terms of information. Chapter 5 will continue with matching technology with information requirements.

3.2 Identified application areas

Based on the analysis of the as-is situation (Chapter 2) and various stakeholder interests, four application areas are identified. Two criteria have determined the order in which the application areas are discussed below: (1) how often the application area has been suggested by stakeholders (see also Table 3.5), and (2) the level to which the application area is put forward based on norms and regulation. Where possible and readily available quantitative information is provided on the importance of the application area. It should be noted in advance that not all application areas are relevant to each stakeholder.

3.2.1 Control, Supervision & Enforcement of Traffic Weight

The first application area relates to the ‘control, supervision and enforcement of traffic weights’. Directives 96/53/EC and 2015/719 lay down maximum authorised weights on traffic, and requires Member States to take measures to ensure compliance with the requirements of this Directive.

Motives for requiring compliance to the maximum authorised weights relates to three aspects. First, harmonization of weight limits ensures a level playing field within the European Union, allowing fair competition. Secondly, traffic safety as overloading can negatively influence traffic safety. Thirdly, overloading causes infrastructure damage (e.g. damage to pavement, bridges) that is disproportional compared to vehicles that meet weight requirements. Although exact figures are not known, estimates range between about 35 to in excess of 100 million Euro’s in added damages to pavement and structures to the main highway network [7]. In [8] it is estimated that around 15% of all vehicles on the Dutch highway network are overloaded (it is not mentioned how this percentage is determined). The executive agency of the Ministry of Infrastructure and Water Management (Rijkswaterstaat) assumes that reducing this percentage to 10% results in 10 to 30 million Euros saved costs due to reduced damages to pavements alone[2]. Including indirect saved costs such as improved maintenance planning this yields up to 30 to 38 million, according to Rijkswaterstaat. Potential savings due to avoided damages or degradation of structures has not been calculated yet by Rijkswaterstaat, but may be similar to, or even higher than pavements.

Recent developments in traffic and transport such as platooning, increasing truck loads, increasing truck sizes (e.g. super eco combi), and connected and automated mobility (CAM), may further contribute to increasing degradation and structural safety issues of infrastructure. Developments like the heavy goods vehicle charge will likely influence the behaviour of transport companies in terms of loading and routing, which can also affect infrastructure. As a result more insight in actual loads is required by organisations such as Rijkswaterstaat and road authorities of the secondary road network to better asses the condition of infrastructure. As a result the authorities have to corporate more intensively.

[2] Based on intern Rijkswaterstaat document outlining a business case for the installation and maintenance of WIM-stations in the Netherlands. Conditions for the reduction of overloading infringement are (1) that all 18 WIM-stations are working as intended, and (2) a sufficient degree of enforcement related activities by the ILT.

Directive 96/53/EC and 2015/719 requires Member States to bring into force laws, regulations and administrative provisions and to lay down rules on penalties applicable to infringement, and to adequately address infringement related to overloading. The directives require Member States to have competent authorities perform an appropriate number of vehicle weight checks, proportionate to the total number of vehicles inspected each year in the Member State concerned.

In the Netherlands, two related but different activities can be observed in relation to the aforementioned Directives. The first activity relates to control and supervision of overloading and the second to enforcement of overloading. Control and supervision mean that compliance with i.e. vehicle weight requirements is checked, and is used to inform shippers and haulers on (possible) infringements. Enforcement includes issuing penalties (fines). In the Netherlands, both control and supervision as enforcement is done (see 2.2.1). It should be noted that there are several approaches for enforcement, including: (1) the random selection of vehicles for checks, (2) the use of e.g. WIM and history for preselection of vehicles for checks, or (3) automated checking and penalizing with use of WIM. The first and second approach require measurement equipment to be located or placed nearby the location where checks are being executed. In the Netherlands, the second approach is used.

Next to issuing fines, the ILT utilizes several other means to reduce the degree of overloading, e.g. creating awareness and influencing behaviour. As such, the ILT uses different forms and levels of interventions (e.g. from creating awareness and influencing behaviour, to enforcement including fines).

Table 3.1: Application area ‘Control, supervision and enforcement of traffic weight’

Outcome/impact	Output	Activities	Input
Fair competition in (EU) transport	Reduction of overloaded vehicles	Informing shipping and hauling companies	See section 4.2.1
Traffic safety		Supervising & control of traffic loads	
Infrastructure damage cost reduction		Regulation on maximum weights, and enforcement of regulation	

Additionally, the following remarks have been put forward:

- Any technology that is used for automated enforcement (i.e. automatic issuing fines on detection) requires certification of the equipment used. Equipment used for monitoring, control, supervision, but also pre-selection of vehicles does not require this certification.
- Directive 2015/719 puts forward particular requirements relating to on-board systems, such as that the equipment needs to be reliable, fully interoperable and compatible with all vehicle types, and automated systems for direct enforcement will require certification. More is explained in the commission implementing regulation 2019/1213(EU).

- It should be noted that checks may not only relate to the weight of traffic, but also to possible infringement on other related aspects (e.g. regulations on on-board units). For example, in the case that on-board sensors are used, specific rules may be laid done on regarding these sensors and data. In fact, this is a similar method to maintaining the Driving Hours Act using a tachograph.
- Enforcement currently only affects potential violators, thus having a minimal effect on the flow of traffic. Other approaches may have a larger impact on traffic flow, which may be undesired.
- There are a couple of aspects that limit the number of checks being performed, such as the number and locations of active WIM-stations, and the available personnel for performing checks.

It should be noted that the activities employed, strategies used, other data, and technologies (input) may be required.

3.2.2 Design & Maintenance of the Road Network

The second application area relates to the ‘Design & maintenance of the road network’. The Dutch Building Decree of 2012 stipulates that structures must comply with the standards for structural safety and durability of structures (Eurocodes). In order to fulfil this requirement, insight is required in current traffic weights and traffic intensities. In practice, information on past and current loads significantly affects the outcome of structural assessments of structures. Insights in actual loads reduces uncertainties, which typically provides evidence that structures can safely be used for longer timespans. Thus, information on the actual load may lead to savings in costs (also see the estimates of RWS regarding the costs savings of pavement maintenance mentioned in the previous section). This applies for both structural safety as traffic safety. Consequently, having no information on the actual loads may require taking measures to ensure structural safety such as traffic restrictions or early renovation. Consequently, this may lead to traffic hinder and costs.

Maintenance of infrastructures has a large impact on carbon emissions and material consumption and (societal) costs. Moreover, maintenance activities negatively affect traffic flow. The degradation of infrastructure varies depending on many variables, resulting in the need to periodically inspect pavement and structures to assess the need for maintenance interventions (varying from small repairs to renovation and replacement). Traffic loads – in particular heavy loads – play an important role in infrastructure degradation. Consequently, traffic load information contributes to a better understanding of infrastructure degradation. In turn, this allows for better planning and execution of maintenance works. This is deemed very valuable as better planning is associated with lower costs (as less corrective actions are needed). Next to maintenance, insights in traffic weights and intensities can also be of use in the design of structures and roads. In other words, design infrastructure that is fit for purpose.

As mentioned earlier, recent developments in traffic and transport such as platooning, increasing truck loads, increasing truck sizes (e.g. super eco combi), and connected and automated mobility (CAM), may further contribute to increasing degradation and structural safety issues of infrastructure. Developments like the heavy goods vehicle charge will likely influence the behaviour of transport companies in terms of loading and routing, which can also affect infrastructure. As such developments can (negatively) influence asset condition and increase costs, better insights will likely be required to monitor the effects of such developments.

In the Netherlands, a large part of the civil structures (e.g. bridges) reaches its service life. An significant increase in the governments replacement and renovation programme is observed in the Rijkswaterstaat program V&R. For that reason good and early estimates of needed replacements and renovation are required, to allocate budget accordingly and to be able to further optimise the maintenance and renovation planning.

Lastly, it is be noted that a current issue is related to aging infrastructure as many of the structures in the road network are reaching the age for which they were originally designed.

Table 3.2: Application area ‘Design & maintenance of the road network’

<table>
<tr><th>Outcome/impact</th><th>Output</th><th>Activities</th><th>Input</th></tr>
<tr><td>Structural safety</td><td rowspan="6">(better) Design & maintenance of infrastructure</td><td rowspan="3">Design and assessment of structures</td><td rowspan="6">See section 4.2.2</td></tr>
<tr><td>Traffic safety</td></tr>
<tr><td>Infrastructure cost reduction</td></tr>
<tr><td rowspan="3">Infrastructure downtime reduction</td><td>Maintenance of infrastructure</td></tr>
<tr><td>Analysing and modelling of infrastructure loads</td></tr>
<tr><td>Monitoring actual loads in relation to expected loads</td></tr>
</table>

3.2.3 *Traffic & Transport Management & Policy*

The third application area relates to ‘traffic & transport management & policy’. National and European economies depend on infrastructure, but also on quality traffic and transport management, and traffic and transport policies. Better use of the available infrastructure can result in a better economy. Activities related to these purposes concern traffic management, the planning of developing/improving infrastructure, and the development and improvement of new policies.

Such activities require information on traffic and transport on the road network. Such information typically involves information on traffic intensities, origin-destination-information, and type of vehicles. On the other hand, traffic weights may also be of interest, as this provides insights with respect to hauled tonnage, compliance to regulations, etc. Weight information can thus contribute to making better policies.

For example, The Dutch government introduces a heavy goods vehicle charge in 2023, similar to other EU member states [9]. The charging rate depends, amongst others, on the distance travelled and the vehicle type concerned (based on vehicle weight and its emission norm). To investigate if this policy affects traffic loads, routing (choice of route, shifts in choice of roads) or to investigate if the charging rate should become load dependent, information is required on the actual loads of trucks.

Table 3.3: Application area ‘Traffic and Transport Management & Policy’

Outcome/impact	Output	Activities	Input
European and national economy	(improved) traffic & transport management and policies	Traffic management	See section 4.2.3
Traffic safety		Develop traffic and transport policies	
		Monitoring traffic & transport characteristics (e.g. routes, intensities, weights)	

It is noted that the required input for the activities related to management and policy making is likely similar to the input required for the application areas mentioned before. For example, evaluation of policies regarding overloading requires information on weights of vehicles, similar to the information required to control, supervising and enforcement on vehicle loads.

3.2.4 *Logistics*

The fourth application area relates to logistics. Improving logistics means that transport sector organisations optimize the use of shipping and hauling possibilities. This means, for example, that hauling trips are planned in such a way that minimizes the time and distance travelled without cargo. Improved logistics can contribute to minimizing carbon emissions, improving profitability, and reducing the required number of trips.

Table 3.4: Application area ‘improved logistics’

Outcome/impact	Output	Activities	Input
Increased profitability of companies, and the economy as a whole	Improved logistics	Trip and route planning	See section 4.2.4
Carbon emission savings		Monitoring efficiency	

For this purpose, transport companies need to know the weights of each individual vehicle in their fleet related to the routes that are planned and executed. Such information can be obtained through various means. For example, shippers and haulers can already exchange information upfront on the goods being shipped, including sizes and weights.

3.2.5 *The interdependencies of application areas*

It is mentioned that application areas are interdependent: one application area can affect other application areas, as is shown in Figure 3.2. Theoretically, each application area can affect any other. Practically, some effects are more evident and strong than others.

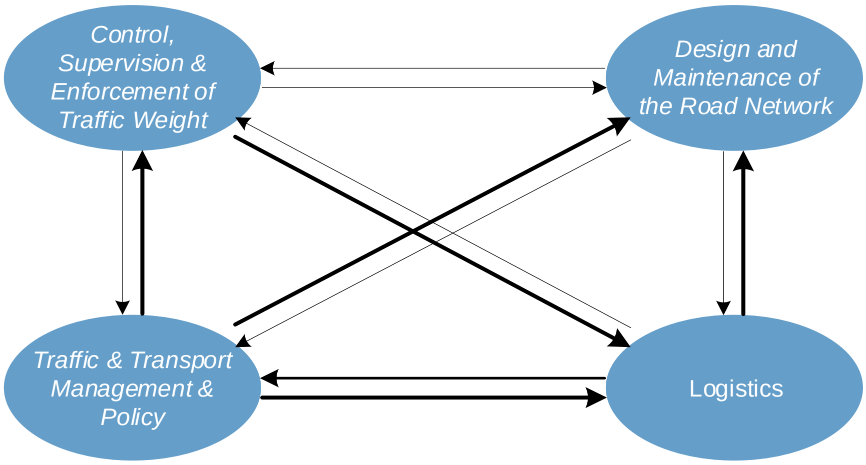

Figure 3.2: Interdependencies of application areas.

To highlight some of the likely more important dependencies.

- Control, Supervision & Enforcement strongly affects the behaviour of shippers and haulers as (a higher degree of enforcement is likely to result in a higher degree of compliance of shippers and haulers).
- The consequence of the above is that the design & maintenance of the road networks also depends on the degree of enforcement, as it in part determines what loads can be expected on the road network. For example: with high levels of enforcement, it may be assumed that the degree of overloading is (significantly) lower which can be incorporated in the structural assessment of road authorities.

Additionally, note that there may be interdependencies related to the stakeholders involved.

3.3 Stakeholders and stakeholders' interests

Table 3.5 provides an overview of the relevant stakeholders of branch organisations with respect to dynamic traffic weight measurements in the Netherlands. The table below provides a indicative overview of different stakeholders in groups (grey-marked rows). The abbreviation in the first column refers to the mostly Dutch name. A more detailed description of the respective stakeholders is given in the second column.

It is mentioned that most of the stakeholders in the table reflect the current situation. Possible new scenarios with an increased use of other information sources (like on-board sensors or multi sensor data fusion techniques) may result in different stakeholders or stakeholder interests. The actual stakeholder interests depend on final selected strategies and scenarios (Chapter 6).

Table 3.5: Overview of possible stakeholders with respect to dynamic traffic weight measurements

Policy makers	
I&W	The Ministry of Infrastructure and Water Management. Policies are developed by four Directorates-General in the areas of mobility, water management, aviation and maritime affairs and the environment. The Directorate-General for Mobility (DGMo*)of the Ministry of Infrastructure and Water Management develops policies in the area of roads among others. The Directorate-General for Aviation and Maritime Affairs (DGLM) develops policies in the area of aviation and maritime, but is also in charge of coordination and the quality of the ministry's international efforts.
EC	European Commission
Enforcers	
I&W-ILT*)	Dutch Human Environment and Transport Inspectorate (ILT) of the Ministry of Infrastructure and Water Management.
RDW*)	RDW is the Dutch Vehicle Authority in the mobility chain. Assigned tasks of the RDW include licensing of vehicles and vehicle parts, supervision and enforcement, registration, information provision, and issuing documents. (Dutch: Rijksdienst voor het Wegverkeer)
	Law enforcement in the Netherlands is provided by the National Police Corps (Dutch: Korps Nationale Politie)
Inspectorates and vehicle authorities	
I&W-RWS*)	Rijkswaterstaat (RWS) is the executive agency of the Ministry of Infrastructure and Water Management and is the road authority responsible for the highway network
WOW	Association of all road authorities in the Netherlands (municipalities, provinces, central government).
Private	Port companies owning assets and (public) roads (e.g. the Port of Rotterdam, Schiphol Airport, the railroad authority ProRail
Transport sector	
TLN*)	Transport Logistics Netherlands is the major trade association of Dutch transport companies
Other	Truck producers like Scania, DAF, IVECO, etc.
Building companies/contractors	
BN	Bouwend Nederland is a trade organisation that promotes the interests of companies in the Dutch construction and infrastructure sector.
DBFM	Private companies with Design Built Maintain and Finance contracts for maintaining specific parts of the road network
Producers	
ISWIM*)	International Society for Weigh-In-Motion. Branch association of producers of WIM systems
Other	Several producers of in-car and in-road technologies and producers of sensors
	Research institutes performing technology drive research such as sensor developments

*) *stakeholders that have been interviewed on behalf of the research, focus of the interviews was to establish what information is needed by the actors, given certain application areas.*

Table 3.6 show for each stakeholder group to what application area their interest mainly relates. Table 3.6 also shows the type of role the stakeholders may have. Stakeholder can facilitate a system, use a system, and/or simply be affected by use of the system. Table 3.6 illustrates that the identified stakeholders have different interests, which means stakeholders will value each application area differently. Furthermore, it can be seen that many stakeholders are both facilitating the system as using it (also see chapter 2).

Table 3.6 shows in most application areas, governmental organisations are the lead actor and thus decisive in determining future scenarios. The application area of logistics on the other hand, decisions are made by private sector actors.

Table 3.6: Stakeholders, interests and roles. The ● symbol indicates a clear interest, a ○ indicates a possible interest.

	Application area interest					**Role**		
Stakeholder	control, supervision & enforcement	design & maintenance	traffic management & policy	logistics	none / other	facilitator	user	influenced by
Policy makers (e.g. I&W, RWS)	●	●	●	○		●	●	●
Inspectorates and vehicle authorities (e.g. I&W ILT, RDW)	●		○			●	●	
Road authorities (e.g. RWS) & Contractors (building companies)	○	●	●	○		●	●	
Transport sector (e.g. TLN, shippers, haulers)	○		○	●		○	○	●
Producers (e.g. producers & service providers measurement systems)					●	●		

3.4 Final remarks

Based on the as-is situation (chapter 2) and the stakeholder analysis, four application areas have been formulated. Each application area has its own activities, goals, and actors. The importance of an application area may vary, and some of the application areas are (partly) mandatory by law. In each application area, the lead actor may vary:

- control, supervision & enforcement with government actors I&W and I&W ILT as main actors.
- design & maintenance of infrastructure with government actors RWS and I&W as main actors.
- traffic management & policy with government actors I&W and I&W as main actors.
- Logistics with private sector actors.

It was found that policies and approaches within an application area can vary, which may result in changing requirements of the necessary input and technologies. Also, each application area may affect any other areas as application areas are found to be interdependent. Consequently, choices made in regard to one application area may affect choices in other areas. It is noted that many of the policies are also partially the result of international consultation, collaboration, and regulation.

By defining application areas, it becomes clear what type of activity is required. Furthermore, it has become clear that performing such activities require input such as information on vehicle weights.

4 Information requirements

Chapter 3 described four application areas. For each application area, the related activities and motives were outlined. In this chapter, this information is used to formulate information requirements.

4.1 Approach

Chapter 3 described application areas with a number of activities. Performing these activities requires information (input) to be performed in order to achieve the desired results. In this chapter, the information need per application is elucidated. So-called ‘data quality dimensions’ are used to provide a description of the required information. Data quality dimensions help to further describe ‘what information is needed’, by highlighting aspects of quality. Many data quality dimensions are used in practice, often with slightly different definitions. In this report, a limited set of data quality dimensions is used with the main goal of pinpointing relevant aspects of information requirements. Doing so helps to identify overlaps and differences between information requirements, and helps to identify suitable technology to acquire the needed information. The table below shows data quality dimensions that seem relevant based on the interests of stakeholders. The final section of this chapter will also discuss other aspects regarding requirements that relate to data, such as privacy, security.

Table 4.1: Description of the data quality dimensions

Data quality dimension	Description	Example relating to traffic weight measurements
Accessibility	Degree to which data can be accessed, e.g. by separate organisations or individuals.	*Data, or part of the data, can be accessed by organization type A.*
Accuracy	Degree to which the data represents reality.	*Data represents the actual vehicle weight with an error margin of 5%.*
Completeness	Degree to which required data is available.	*Data is obtained on 50% of all the trips on the highway network.*
Consistency	Degree to which the data is consistent (‘equal’) e.g. within databases, between databases, over time.	*Data accuracy is consistent over time.*
Granularity / level of detail	Degree to which data is provided or aggregated, e.g. period of time, individuals versus groups.	*Data is obtained per vehicle and per axle, per axle group, per vehicle.*
Interoperability	Degree to which data is integrated, or can be integrated across data systems.	*Data obtained through different systems can be integrated into one database.*
Timeliness	Degree to which the data is available at the time that is needed.	*Data on measurements should be accessible within 10 seconds after passing a measurement station (for preselection)*

The information requirements, and data quality dimensions may vary between application areas, but can also vary within application areas.

Overlaps in data requirements result in synarchies (e.g. information can serve multiple purposes, thus representing a larger value of information). Differences in information requirements highlight areas that may require tailor made solutions (specific information for a specific (single) purpose).

The information needed per application area can be obtained through use of technology (e.g. weight measurements). In other words, information needs can be translated to technology requirements. Chapter 5 will discuss the results of a technology scan and will match technology with the information requirement put forward in this chapter.

It is noted that the information requirements have been explored within the limitations of the assignment. Consequently, the hereafter mentioned specifications should be considered indicative and subject to further clarification and definition.

4.2 Information requirement per application area

4.2.1 *Control, Supervision & Enforcement of Traffic Weight*

For activities relating to the application area ‘Control, Supervision & Enforcement of Traffic Weight’, information is required on:

- The load per axle and the total vehicle load;
- The allowed loads of the vehicle, and vehicle axes concerned, which is typically obtained through information linked to the license plate of the vehicle (truck and trailer).
- the owner of the vehicle, which is typically obtained through information linked to the license plate of the vehicle (truck and trailer).
- The time and location of the vehicle.

Table 4.2: Data quality dimensions for Control, Supervision & Enforcement of Traffic Weight

Data quality dimension	Notes
Accessibility	Data should be accessible to control, supervision & enforcement organisations (e.g. ILT, police forces, justice department).
Accuracy	The required accuracy is dependent on the choice of enforcement. For the purpose of (direct) enforcement and issuing penalties (fines), a higher accuracy is required compared to approaches with preselection. Currently: for each measured axle load, the load should be no more of than 15% in 95% of all measurements; for each measured vehicle, the loads should be no more of than 10% in 95% of all measurements;
Completeness	Data should be available proportionate to the total number of vehicles inspected each year in the Member State. The degree of completeness consequently depends on the Member State policy. Current requirement is formulated per WIM-station, stating that 99% of all truck passages should be measured by the WIM-station. It is not known what percentage is currently achieved, but several systems have been performing below desired levels in the past years.

Data quality dimension	**Notes**
Consistency	Data should be consistent in the sense that accuracy and completeness of data is consistent across time periods.
Granularity / level of detail	Data should be vehicle specific, and further detailed to individual axles of that vehicle.
Interoperability	Measured vehicle and axle weight data must be able to be related to licence plate information (allowable weights).
Timeliness	Timeliness is dependent on approach chosen. Approaches of preselection require data to be available relative quick (seconds) while direct enforcement does not.

In the as-is situation, information is mainly gathered from currently installed and operational WIM-stations in the highway network (see chapter 2).

4.2.2 Design & Maintenance of the Road Network

For activities relating to the application area 'Design & Maintenance of the Road Network' information is required on the structural response due to traffic loads. In practice this information is retrieved by information on the loads that applies for a certain location in the road network, combined with a response model of the structure for analysing the load effect. For that reason (weight) information is required on:

- The axle loads and total load of vehicles;
- Vehicle and axle characteristics, including length and width, type of vehicle, axle configuration, and tire configuration
- Traffic characteristics, including speed of traffic, traffic intensities, intervehicle distance (and distances between axle).

It is noted that a distinction can be made between activities related to (1) the design of structures and (2) assessment and maintenance of infrastructure. For the design of structures, generally conservative values are adopted that cover a certain region (e.g. all roads the Netherlands, highway road, secondary roads, etc). Based on that information a design can be made that at least complies the requirements provided that the structure is in the region specified (the application area of the code).

For maintenance, however, more specific information may be required, i.e. information that is representative (or conservative) for that particular structure (or part of the network) that is considered. More specific weight information may imply, depending on the required level of accuracy, information about the structural behaviour of a specific bridge (load-effect information).

Table 4.3: Data quality dimensions for Design & Maintenance

Data quality dimension	**Notes**
Accessibility	Data should be accessible to asset management organisations, e.g. road authorities (which might further distribute it to other parties like engineering companies and research institutes).

Data quality dimension	**Notes**
Accuracy	Data should be representative for the specific case at hand. On the one the hand, this depends on the governing limit state. For fatigue issues due to cyclic loading the accuracy of cyclic loads is important whereas for extreme loads mainly the accuracy of the extreme loads is of importance.
Completeness	Data should be available proportionate to the phenomenon governing the limit state. For fatigue failure a rather small time span (+/-1 month) may suffice whereas for accidental (extreme) loads a substantially larger timeframe is required. For determining the design loads for the full network, data is required at different locations in the network for taking into account effects due to the spatial variability of traffic loadings. Trends in loads and structural effects are estimated by the expected increase of the load in time. At the moment this is validated by calibrating the design loads periodically on the basis of measurements (approximately every 5 years)
Consistency	Data should be consistent in the sense that accuracy and completeness of data is consistent across the expected service life of the different assets.
Granularity / level of detail	The level of detail of the data depends on the effect of the load on the structural detail considered (‘influence length of the load effect’). For short span bridges and local structural components the tire load distributions and tire, axle and tandem loads may be important. For greater influence lengths (or spans) the vehicle weight or weight of multiple vehicles is more governing.
Interoperability	Depends on the required linking technological opportunities.
Timeliness	Timeliness dependent on the maintenance intervals or the expected service. In general, the data is not required very quickly (month/year/decade).

In the as-is situation, information is gathered from currently installed and operational WIM-stations in the highway network (see chapter 2). In some cases, structure specific information is obtained via monitoring systems installed on structures (e.g. Bridge WIM). Such systems are often tailor made solutions, aimed at monitoring a specific structure’s response to loads of e.g. road vehicles, such as at the Van Brienenoord bridge, see also paragraph 5.2.4.

4.2.3 Traffic & Transport Management & Policy

As policies may related to many fields (e.g. enforcement, design & maintenance of infrastructure), it can also be argued that the information requirement is similar as the combination of the information requirement of other application areas. These may relate – amongst other – to:
- Traffic intensities on the road network;
- Origin and destination information, including routes;
- Type of vehicles;
- Weight of vehicles.

Table 4.4: Data quality dimensions for Traffic & Transport Management & Policy

Data quality dimension	Notes
Accessibility	Data should be accessible to policy makers and traffic management, e.g. ministry, road authority.
Accuracy	Not clear. When assumed that policies can also include policies regarding other application areas, the required level of accuracy is similar to that of the other application areas.
Completeness	Data should be obtained on a relevant part of the road network for developing management and policies.
Consistency	Data should be consistent in the sense that accuracy and completeness of data is consistent across time periods.
Granularity / level of detail	Not clear. When assumed that policies can also include policies regarding other application areas, the required level of granularity is similar to that of the other application areas.
Interoperability	Not clear, depends on other application areas
Timeliness	In general, data is not required quickly.

In the as-is situation, information is gathered from currently installed and operational WIM-stations in the highway network (see chapter 2) and other traffic counts (e.g. via magnetic loops).

4.2.4 Logistics

For activities relating to the application area ‘Logistics’, information is mainly required on the vehicle and axle loads (including weight distribution), and the location and route information of vehicles.

Table 4.5: Data quality dimensions for Traffic & Transport Management & Policy

Data quality dimension	Notes
Accessibility	Data should be accessible the driver and company concerned.
Accuracy	Not clear.
Completeness	Depending on the need of companies.
Consistency	Not clear.
Granularity / level of detail	Data should be available per axle and vehicle, per trip.
Interoperability	-
Timeliness	Data should be available in seconds, to alert companies and drivers on possible overloading situations (e.g. during loading, or when cargo shifts during transport).

In the as-is situation, companies obtain information via different means. Some information on loads can be obtained through shipping and cargo manifests. Some companies have on-premise measurement equipment to be able to determine the loads of vehicles entering and leaving the premise. And to increasing degree, on-board units collect data that can be accessed by companies (e.g. fleet management systems (FMS)). Lastly, information may also be provided by currently installed WIM-stations in the highway network as companies are informed on detected infringements by the government (in the Netherlands the ILT).

4.3 Findings

There are overlaps in the information required in each application area. For example, all require information on vehicle loads. Contrary, there are also differences in the information required. For example: information regarding control, supervision and enforcement of overloading only requires load information on trucks, while design & maintenance requires information on all traffic passing certain points. Table 4.6 summarizes some of the findings regarding each of the data quality dimensions.
It is also important to note that although the main focus of this research is on weights, some of the application areas require information beyond vehicle and axle loads. Furthermore, part of the information can be obtained through other means such as existing databases, or other technologies already available.

Table 4.6: Notes on differences between application areas regarding data quality dimensions.

Data quality dimension	Notes
Accessibility	Varies in all application areas as the users vary too. It should be noted that if synergies are sought after (e.g. the same technology and data is used for different purposes and by different users), this will likely require additional requirements on data access. Data should only be accessible to those who are allowed to access it.
Accuracy	The need for direct enforcement plays an important role in the required accuracy levels.
Completeness	Depending on the application area, information is either needed on a part of all traffic (i.e. only trucks, or all traffic), and on whether or not information needed goes beyond weights of vehicles.
Consistency	Consistency is important to most application areas, as many may use the information for identifying trends which require consistency in the data.
Granularity / level of detail	Almost all application areas will likely require the information to be detailed to the level of individual trucks and axles; although some will later choose to aggregate results (e.g. for trend analysis).
Interoperability	Requirements regarding interoperability are relevant in cases where information is obtained through different systems. This is relevant in all application areas.
Timeliness	Timeliness varies between seconds (in cases such a enforcement through preselection of vehicles) to weeks for other purposes.

In this report, a limited set of data quality dimensions is used with the main goal of pinpointing relevant aspects of the information required. In general, several other requirements can be formulated such as:

– Confidentiality of data, particularly in relation to privacy laws. Some of the data may be personally identifiable information.
– Ownership of the data, and rules regarding user rights of the data.
– Certification, as some applications areas (.e.g. enforcement) will not only result in certain quality of data, but also proof of this quality. In practice this means periodic checks and certification by an accredited certifying body.
– Security, to prevent unapproved access to data.

Such criteria will become important in the implementation, and may be even more important in scenarios that use multiple data sources from both private and public entities. Moreover, when using data from vehicles and information from a digital cargo manifest, the rights for access must be secured. This requires additional attention when implementing.

Finally, it is noted that there are also costs associated with obtaining information. Costs typically increase when more information, or information of higher quality is required. Thus, this implies that at some point, there is an optimum where the cost of information is proportional to its value.

5 Technology scan

Technology offers possibilities to fulfil the needs and requirements of the identified application areas. Given the long term context of this study, this may hold currently (commercially) available technology as well as technologies that are still under development. An important condition for successful application of technology is that relevant organizational aspects should be properly arranged for. On the other hand, technology can be an enabler to properly organize things.

5.1 Approach

This chapter holds an overview of currently available technology and technology under development that is, could be, or could become relevant to fulfill the needs and requirements of the identified application areas. The main sources for the technology scan are literature, stakeholder interviews and the authors awareness of ongoing technological developments.

In this report technology is considered as a single or set of systems or system components that, together, are able to perform certain tasks. Figure 5.1 provides two ways of looking at weight measurement technology: as a series of process steps (left side of the figure), and as a composition of system components (right side of the figure).

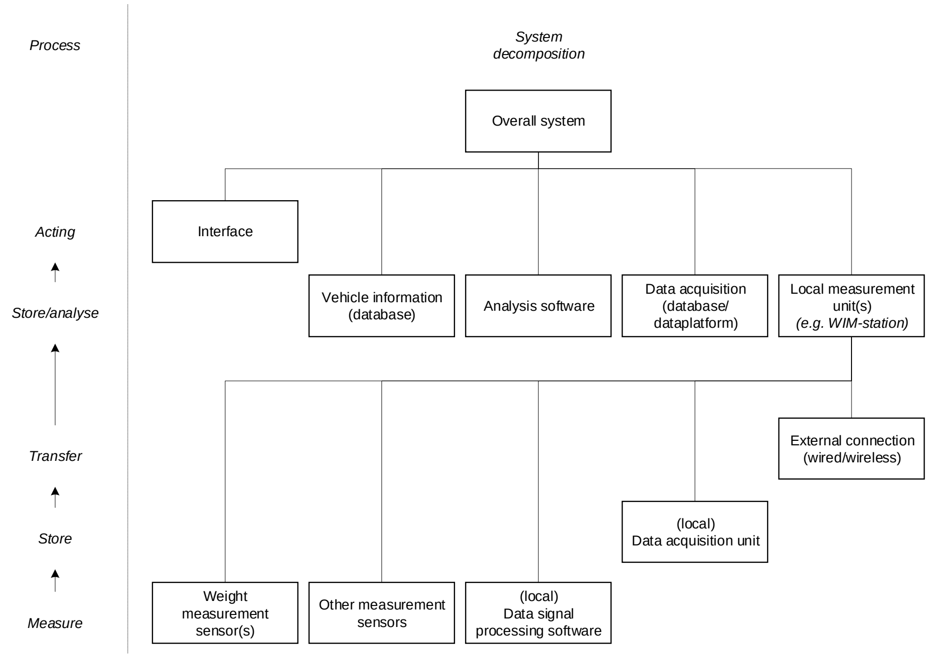

Figure 5.1: Weight measuring systems views as the process and system decomposition

Based on the above, the technology overview provided in this chapter will discuss:
- Weight sensing techniques and technologies (section 5.2);
- Related sensing technologies (section 5.3);
- Technologies related to transfer, storage, analysis a visualizing data (section 5.4)

To illustrate how technology may be combined into integral systems, several (inter)national examples are provided in section 5.5. Finally, section 5.6 discusses to what extend the technologies match the requirements as discussed in chapter 4.

It is mentioned that the technology scan focusses mainly on weight measurement technologies and techniques. The use other sources such as digitalization of cargo manifests are not considered in the technology scan. In section 5.4 data transfer, storage and analyses techniques are considered separately.

5.2 Weight sensing techniques

This section holds an overview of sensing technologies that can provide the full set of information that traditional WIM systems provide, up to individual axle loads. The weighing technologies can be classified into three main categories, i.e. static weighing, Low Speed WIM (LS-WIM) and High Speed WIM (HS-WIM). These main categories can be divided in underlying sub-categories, eventually ending up at specific sensor technology solutions. For example: in-road WIM systems may use strips using piezo electric sensors, bars equipped with strain gauges, but may also use fibre optic measuring devices. The classification used in this study follows the classification given in [10], see Figure 5.2. Next a description and reflection on important aspects is given up to the level of the boxed area in Figure 5.2.

		Possible speed when weighing		
Weighing technique		**No**	**Low**	**High**
Static weighing		▪		
In-road WIM	Scales and plates		▪	▪
	Strips and bars		▪	▪
	Fiber optic tubes		▪	▪
Bridge WIM			▪	▪
On-board WIM		▪	▪	▪

Figure 5.2: Overview of different weight sensing techniques, based on [10]

It is noted that the systems described below are many viewed from the perspective of obtaining load information. In some cases, the technology can also be used for other purposes, e.g. such as determining tire pressures. Such additional features are mentioned briefly, as this may be valuable but not the main focus of this research.

5.2.1 Static weighing

Static weighing is an accurate method for weighing the (static) Gross Vehicle Weight GVW as well as axle -and wheel loads. Vehicles need to stand still on the measurement equipment. Measurement equipment used for this method holds: weighing bridges, and fixed or mobile weighing scales or plates.

Static weighing systems are proven technology and widely, commercially available. As far as known, no new developments are foreseen. The fact that the vehicle has to stand still may be seen as a disadvantage of static weighing, because of disruption of the transport operation. Moreover, it requires a suitable place with sufficient space and people for operation. The length of such a measuring area is at least 3 times the length of a vehicle and some additional space for handling activities. For circumventing this disadvantage, in-road WIM systems may be used. For application at exit gates, tax gates and/or truck resting areas, however, the system may be less disruptive.

5.2.2 *In-road Low Speed WIM*

Weigh In Motion (WIM) systems are characterized as low speed when the maximum vehicle velocity when measuring the weight is less than about 15 km/hour. LS-WIM systems are generally equipped with weighing scales or plates and are mostly applied in dedicated areas outside the regular road network. Due to the low velocity, dynamic effects of the vehicle are minimized, which increases the accuracy of the measurement and to ensure that the measured tyre impact forces are actual static values. Mostly load cell scales based on different sensing technologies are used.

Figure 5.3: Low Speed WIM load plates for measuring the wheel or axle load

It may be obvious that LS-WIM still causes disruption of the transport operation, however less compared to static weighing. Applications at exit gates, tax gates and/or truck resting areas are feasible. Moreover such systems may be usable for traffic jam conditions (provided that the speed is less than the maximum required speed).

Alike the static weighing systems, LS-WIM systems are generally based on proven technology and commercially widely available.

5.2.3 *In-Road High Speed WIM*

High speed weighing measurements take place in the regular traffic lanes under free flow conditions at normal speed, mainly for measuring axle and vehicle loads, vehicle length and axles and intervehicle distances. Tire configurations, for example, are currently not measured. The high speed provides that the systems may be used in any network. Mostly, these kind of systems are calibrated in a velocity regime between 30-40 to 80-100 km per hour.

High speed WIM systems are generally equipped with strips or bars that are incorporated (like a joint) in the asphalt road. In that case the measured loads include dynamic effects of the vehicle and due to road vehicle interaction. By using a system that is isolated from the top layer, interaction of the road structure to the measurements is circumvented. For that reason the smoothness of the road ahead of the WIM system should be rather high [24], circumventing vehicles from 'bumping' ahead of the measuring system. It may be obvious that deterioration of the asphalt may affect the smoothness of the asphalt as well [25].

Alternatively the measuring device may be a part of the asphalt top layer, e.g. when a tube with fibre optic sensors is embedded in the asphalt. In such a case tire configurations can be measured but deterioration of the asphalt (e.g. rutting, deformation) affects the behaviour of the top layer, and thereby the quality of the measurements because the road is part of the system installed. Moreover, temperature and strain rate depending behaviour of the asphalt should be taken into account when calibrating the system.

For the above mentioned reasons specific requirements are given for the selection of WIM-locations, and the road and asphalt conditions. Consequently, maintenance of the top layer affects the system accuracy as well (or the accuracy depends on proper and frequent maintenance of the road). It is mentioned that the maintenance of the road is considered more challenging due to the specific requirements set forth, but also because the WIM system sensors are located in the top layer of the asphalt.

The driving behaviour and environmental conditions may affect the accuracy too, which further underlines the importance of proper selection of the WIM system location. Finally the performance of HS-WIM systems also depends on the type, number and configuration of sensors and the quality of the data processing algorithms. Many sensor technologies are available for this type of weighing technique.

Figure 5.4: High speed WIM systems for load measurements, licence plate recognition (video) and 3D-profile scanning (reference sterela-its.com)

Most systems that are being offered by the market, are equipped with additional features (see also Figure 5.4) such as time and speed measurements from which the axle distance may be calculated, video camera's with licence plate recognition. Moreover, less common but also available, laser scanners can be added for determining the three-dimensional profile of the vehicles. When the vehicles are tagged, also the vehicle tag may be transmitted and received remotely. In the future maybe more additional features may be added to HS-WIM systems. It may be obvious that most of those features may also be available for LS-WIM and static load measurements.

HS-WIM systems are provided by different commercial producers. The International Society for Weigh-In-Motion (ISWIM) provides a platform for users and producers of such systems. Most sensor technologies used in WIM systems, are considered as common technology.

There are, however, developments in which less conventional sensor technologies are used for traffic measurements. An example is the use of fibre optic technologies in which the fibres are embedded in the (lower) asphalt layer [11]. Such a system provides a potential advantage because the road and road maintenance are becoming easier (the sensors are not located in the top layer of the road). On the other hand, however, the asphalt conditions may play an even bigger role in the system's accuracy (the road located above the sensor will act as a sensor plate) and consequently. System monitoring and calibration consequently becomes more important. No studies have been found that outline the performance of these systems, possibly because it is an new development.

Most future developments that are expected to HS-WIM are related to the accuracy of the system and algorithms that are used for processing the data. At the moment research is carried out to what extent HS-WIM systems may be used for direct enforcement. Besides the technological challenges (i.e. getting accurate enough systems) also organizational challenges must be taken into account. A system used for direct enforcement requires continuous attention in terms of keeping the accuracy provenly at the required performance level for jurisdiction, and systems will likely need to be certified by a certification body. Moreover, for direct enforcement, legislation that's is based on static weights needs to be adapted to account for the dynamic weight. The technical developments and political approval probably will take a rather long time (> 5 year).

Other developments include using WIM systems for obtaining other information that may be relevant. Such an example is to use the measurement to estimate if vehicle tires pressure are within acceptable limits. Low tire pressure is considered dangerous in terms of traffic safety and identified and notifying such vehicle can contribute to vehicle safety. The tire pressure also plays a role in the load effects on structures and roads, and thus is considered relevant information for design an maintenance purposes.

5.2.4 Bridge WIM

The WIM systems described in the previous sections described WIM systems installed in-road, usually with the purpose of determining certain vehicle characteristics (e.g. vehicle weight, axle loads). In the case of a bridge WIM system, sensors are attached to a bridge or viaduct. These sensors measuring the effect of the traffic passing bridge on the (structural) behaviour of the bridge. Bridge WIM systems are usually installed to obtain specific information on the structural behaviour or condition of that specific bridge. In 2014 TNO installed a bridge WIM system at the van Brienenoord bridge in the Netherlands (A16) for demonstrating the use of the system with respect to fatigue related damage. The system has been operational for about 5 years.

However, the system can also be used to obtain information on vehicle loads. In this case the bridge becomes part of the measuring device (more so than compared to in-road WIM). Based on prior knowledge about the structural behaviour of the bridge under traffic loading the dynamic gross vehicle weight, axle and wheel loads can be calculated from the measured response [12], depending on the structure and the position of the measurements. It may be obvious that the accuracy depends strongly on the quality of the model that is used for calculating the bridge response under dynamic conditions. Vice versa, Bridge WIM provides accurate information about the actual bridge response given the traffic load that is passing the bridge that is monitored. This may be valuable information for structural assessment of that specific bridge.

Compared to the WIM systems explained in the previous sections, the commercial availability of Bridge WIM is rather limited. Nevertheless a few international vendors offering Bridge WIM services commercially (e.g. SiWIM). The remaining applications are provided by research institutes and universities. For assessing the structural safety, load effect measurements are quite a common technology, especially for (steel) structures with fatigue symptoms.

For the future, developments are envisaged that relate to the use of different sensors of sensor technologies (i.e. fibre optics, accelerometers, non-contact techniques). It is expected that the developments are mainly meant for improving the cost-effectiveness of such systems. Moreover, developments towards using alternative or more advanced analysis algorithms are foreseen, resulting in an improvement of the accuracy or obtaining relevant information from measurements on bridges that are carried out for other purposes.

For now it is considered not feasible that Bridge WIM systems will be appropriate for (direct) enforcement. The main reason is that the method is based on indirect weight measurement of one or more vehicles or axles. Moreover, similar organizational and legal challenges are faced as for HS-WIM (section 5.2.3)

5.2.5 On-Board weighing

Dynamic on-board weighing systems constantly measure the vehicle or axle weight using sensors inside the vehicle. The measurements can be performed when the vehicle is standing still (resulting in static weight values) but also continuously when the vehicle is on the move. The continuous nature of the measurement depends on the measurement frequency. When the measurements are carried out on a moving vehicle, dynamic effects are included in the measurements.

On-board weight measurements are usually related to the axle. The vehicle load may be derived from the various axle loads. The on-board measuring data may be combined with GPS-location data, for example for monitoring specific transports on the road network. Such data is currently being used by companies (transport companies, vehicle manufacturers and service provides) in fleet management systems.

In the Netherlands, fleet management information is not used (other than experimentally) for governmental purposes such as enforcement and maintenance. In Australia, on-board weight measurements are incorporated in the Intelligent Access Program (IAP). Australia has significant experience with type approval certification of On-Board mass monitoring systems [13]. In this case, government parties have access to the data being collected on-board. For more detailed information about the IAP see section 5.5.4.

Since most of the technical issues are covered, the largest challenges for introducing such a system, is probably the lapse time for procedures and for making agreements about the use of privately owned information. Moreover, it is difficult to achieve full coverage of all (relevant) transports on the road network. On the technical side, data processing to translate the measuring results of moving trucks to traffic loads on specific locations in the network needs to be arranged for. This is expected to be technically feasible.

5.2.6 Comparison of the different systems

In the previous sections, different technologies for performing traffic weight measurements are elucidated. In this section an overview of the different systems is given, as well as the usage, accuracy and coverage with respect to the road network.

From the literature it appears that both static an LS-WIM measurements yield an accuracy of a few percent of the measured weight. For static measurements values of 1% for the GVW and 2% for the axle loads are found. For LS-WIM measurements the estimated accuracy is a little less (2% to 3%) whereas the accuracy for on-board systems is found varying between 1% and 3%. For the HS-WIM an accuracy of about 10% is claimed.

It is noted that for most systems the accuracy of the sensor is given under calibration conditions. For systems that measure continuously or systems that measure moving loads, this accuracy yields the dynamic load. If the accuracy on the static load needs to be determined an estimate of the dynamic effects must be made. In such a case the accuracy is governed by the component with the largest uncertainty. It may be obvious that for static measurements no dynamic effects are included, whereas for LS-WIM the dynamic effect are almost negligible as well.

For on-board measuring systems as well as Bridge and HS-WIM, Bridge WIM on-board measurements the dynamic effects cannot be neglected since the response under dynamic conditions is measured. For that reason the system is also calibrated under dynamic conditions but with respect to static loads. As a results calibration may depend on the vehicle speed and the condition of the vehicle, the road and the structure (depending on the system).

For HS-WIM systems it possibly it may be assumed that dynamic effects can be neglected, provided that the road ahead the WIM system is flat and smooth and that this does not change in time. This requires good maintenance and regular calibration of the system in order to guarantee this.

For Bridge WIM systems it must be taken into account that also the structural behaviour plays an important role with respect to the measured response of the bridge. Therefor dynamics effect due to the vehicle, the bridge as well as the interaction between the vehicle and the bridge must be taken into account.

Finally, it is mentioned that it must be taken into account that the accuracy is affected by lateral forces, for example due to braking and accelerating vehicles, and curved movements. This is especially important in urban areas.

5.3 Related sensing technologies

In this section an overview is provided of technologies and measuring system that may contribute to the long term vision of dynamic traffic weight measurements. Such systems, and the information they provide can additional information which may be used in combination with the information obtained to weight measurements. For example, measurements of the number of vehicles (per vehicle type/category) may be combined with load measurements to determine correlations in loads. And it should be mentioned that there technical developments may lead to additional data and better data quality, and developments may also lead to the increased acquisitions of data (e.g. the implementation of the heavy goods vehicle charged will result in around 70 measurement points in the highway network).

Note that the overview presented here is not aimed to provide a complete nor in-dept overview.

5.3.1 Magnetic loops

Magnetic induction loops are located at many locations. In the Dutch road network over 20.000 magnetic induction loops provide data about traffic flow, speed and intensities. The latter classified in three, or five categories. The data are openly available through the Nationale Databank Wegverkeersgegevens (NDW).

Developments focus on a more reliable classification and distinction of individual (truck) axles by using additional roadside equipment (camera’s with axle recognition).

A possibility for using the results of the data of the magnetic induction loops may be that with a limited number of fixed WIM stations in the road network, an estimate of the traffic flow and other locations in the road network can be made, provided that the traffic composition and mixture of vehicles is comparable at both locations. At the moment, the municipality of Amsterdam is experimenting with combining data of magnetic loops, conventional WIM systems and camera vehicle recognition.

5.3.2 Traffic camera’s

Camera’s with licence plate recognition are commonly at WIM-systems throughout the word, among others, for enforcement purposes. Moreover, camera’s and recognition techniques are used for other purposes as well, for example for traffic through-put and traffic safety monitoring. In the future they even may provide an alternative for the magnetic induction loops or for automated classifying the vehicles. In the future cameras may also be part of on-board systems, for example for determining the location of the vehicle in the road network.

Since the cameras may record privacy related information (licence plates, drivers, etc), legal issues will always play a role for allowing to use such data.

5.3.3 GPS tracking

An evident and widely used application of satellite technology is GPS-tracking. This technology is an essential part in the IAP described in section 5.5.4. The technology is also likely to be used for heavy goods vehicle charging. The accuracy varies with the system that is considered.

5.3.4 Tyre (pressure) monitoring

Developments are deployed and pilots are performed with respect to in-road sensing technologies that provides information about passing vehicles and tyres, additionally to the conventional weight information. Examples that can be mentioned are axle -and tyre configuration, axle spacing, axle width and tyre characteristics such as the tyre pressure and uneven load distribution. A pilot example is the Tyre Anomaly and Classification System as used in the A16 motorway in the Netherlands, [14] and [15].
Tyre pressure monitor systems may offer the opportunity to make WIM stations more complete for control, supervision and enforcement, traffic safety, traffic flow, etc. Moreover it may offer opportunities for road users (including logistic operators) for reducing risks of operational disturbance due to flat tyres, and possible increase of the fuel consumption due to improper tyre pressure.

While the above mentions in-road technologies for tyre (pressure) monitoring, there are also on-board possibilities for tyre (pressure) monitoring.

5.3.5 Stress-in-Motion

Stress-In-Motion (SIM) systems are able to measure multidimensional (3D) tyre-road contact stresses (the tyre profile) under moving tyres. The first SIM sensors consisted of a matrix of sensors measuring vertical forces of tyres passing at low speeds. These systems have been used for advanced pavement design, detailed vehicle classification, tyre safety and road safety. As far as known this technology is not widely applied anymore. Nevertheless the system may be used for more accurate predicting wheel print sizes that play a role for local damage phenomenon such as ravelling of asphalt and fatigue of orthotropic steel bridge decks. As a matter of fact Stress-in-Motion measurements are quite equal to the tyre (pressure) monitoring mentioned in section 5.3.4.

5.3.6 Glass fibre sensor technologies

In the last decade, sensor technologies based on glass fibres are used more frequently. A new generation of sensors is developed, e.g. FBG (Fibre Bragg Grating, and applied for different applications, among others, for dynamic WIM systems. Advantage of these kind of systems is that the lateral contact stress distribution can be measured and that sensors are embedded in the asphalt, making maintenance easier. On the other hand, compared to conventional WIM systems, an increased effect of the road condition on the reliability of the results may be expected for such systems. Several pilots have been initiated in the last years [11], among others in the A15 in the Netherlands.

5.4 Other relevant technologies

After having addressed relevant sensing technologies in the previous sections, this paragraph focusses on other relevant technologies to come from data to information which can be acted upon from the various application areas. As the primary focus of this study was on dynamic weighing, this is done in a more condensed way than the sensing technologies.

5.4.1 Data transfer technologies

After acquiring raw data with sensing technology the next logical step is often to transfer the raw (or locally analysed) data to the location or service where data is stored and analysed. The various forms of data transfer are briefly described below.

Physical data-transfer
Transfer of data through physical devices like external hard-drives. This way of transferring data is quite outdated and seldomly applied in continuous monitoring applications. Therefore, it is not expected to be a suitable solution for (dynamic) weighing of trucks.

Cabled data-transfer
Transfer of data through cables (copper or fibre optic). This a common and reliable way of transferring data to fixed locations. Therefore it’s is expected to be a suitable way to transfer data from fixed (dynamic) weighing stations. Practically this means that these stations need to be provided with a cabled communication connection.

Wireless data-transfer
Transfer of data through various types of wireless communication forms (e.g. 4G, wifi, in the future 5G). Within the context of transportation, this type of data transfer is or becomes essential for traffic management, Intelligent Traffic Systems, and developments towards Advanced Driver Assistance Systems and Autonomous Driving. Wireless data transfer technology is and could become more important for

(dynamic) weighing. Especially for scenarios with On-Board weighing technology (Vehicle to Infrastructure communication).

In some cases, a combination of technology is also possible. For example a wireless data-transfer from vehicle to a gantry which has a wired connection.

5.4.2 Data storage technologies

Data storage technology includes options like local data-servers, cloud storage and data-base technology. This type of technology is widely available commercially. The best choice for data storage technology for (dynamic) weighing proposes depends, amongst others, on the type of scenario (i.e. integral addressing multiple application areas vs. single application area solutions), the chosen sensing technology and organisational aspects like the necessity to store (raw) data.

5.4.3 Data analysis technologies

Data-analysis technology addresses translating raw measurement data to interpretable information. Application wise, this can be performed locally (close to or on the sensing technology, edge computing), after data transfer or in a combination of both (first steps local, more in depth analysis after transfer). Regarding the application areas of (dynamic) weighing it is likely that a combination of both is most suitable.

Typology wise there are various types of data analysis, some important ones for the context of (dynamic) weighing are briefly described below.

Digital Signal Processing
Signal processing techniques to pre-process raw data for more interpretative analysis purposes. This includes ‘general’ operations like e.g. filtering, spike removal, peak picking. Although the type of operations is quite generic, it is important that domain specialists are involved in this process, e.g. to apply the correct filter settings to avoid filtering out relevant information.

Statistical and reliability analysis
Deriving statistical properties from the data. Generally spoken this can include obtaining e.g. distribution type, mean, standard deviation, etc. Further in-depth statistical analysis depends on the specific needs of the application area under consideration.

As an example reliability classification of data and extrapolation to extreme value traffic loads is important for assessing the structural safety within the application area **Design & Maintenance**. This is done by means of a combination of statistical fitting, Monte Carlo analysis and structural engineering models.

Domain knowledge driven analysis
This type of analysis uses sensor data but is driven by domain related knowledge and models. An example in the context of maintenance of structures is updating the road network generic traffic load model with use of data from load measurements on or near the structure under assessment. This with the objective to obtain a more

realistic (hopefully less conservative) assessment for that specific structure. Other application areas will have their own domain knowledge driven analysis methods.

Data driven analysis
Data analysis techniques that are strongly driven by data and rely less on domain specific knowledge or models. Examples are Machine Learning, Neural Networks, Data-fusion and Automatic Image Recognition. With the drastic increase in the availability of data, so did the interest in this type of analysis. Related to the context of this study, Automatic Image Recognition may be of special interest for vehicle type classification.

In light of the increasing possibilities of acquiring data on vehicles (both in-road and on-board) and to access multiple data sources, data fusion may by a key technology for the future. Such technology may become most important in scenarios where data is obtained from multiple sources (measurements, databases, etc.). By using multiple data sources more consistent, accurate information may be obtained which is more valuable.

5.4.4 Visualization and user-interaction

This type of technology supports the ability of users to act upon information from analysed data (the last step in the flow-chart from Figure 5.1). Visualisation and user-interaction can be aimed at different goals depending on the needs of the stakeholders involved, examples are:
– Exploration : interactive exploration of data, outcomes and relations.
– Explanation : providing in-depth insight in relations between data.
– Promotion : visual story telling of the core features and results.
– Decision : summary of options, impact and costs.
– Action : call for action of user.

Technology-wise, this involves software like (web-based) dashboards, (interactive) graphing and querying, scenario analysis, and automatic alerting and proposals for action. In general this type of technology is widely available, commercially as well as open source. The main challenge to come to fit-for-purpose solutions for specific applications is to configure and integrate the available technology based on the stakeholder(s) need(s).

Related to the context of this study this step could hold automatic monitoring of the performance of WIM-stations and access to the output through a GIS-dashboard (see section 5.5.3), generation of standardized reports on traffic loading, and/or automatic communication or fining in case of overloaded vehicles.

5.5 Integral monitoring systems

This section gives some relevant (international) examples of integral system where multiple individual technologies are combined, serving one or more application areas.

5.5.1 *WIM based direct enforcement program (Hungary)*

In 2018, after a period of two years of legislative preparation, Hungary started live testing of their National Axle Weight Measurement System featuring 107 WIM stations [16. This case offers an example of the use of in-road measurements (WIM stations) with the aim of having ‘full’ network coverage and a the possibility for ‘direct enforcement’.

Some of the lessons learned of this test period are [16]:
- In-bulk purchase of technology improves cost-effectiveness.
- Efficient utilization of equipment already presents the national road toll system was crucial for financial feasibility.
- Maintaining public trust is a big challenge when adopting direct enforcement with many WIM sites (malfunctioning of one site can have large consequences for the public opinion).
- So far, a package of mitigation actions has proved to be effective in preserving public acceptance.

From [16] it is finally concluded that the next step in the test is to review the effects and practical consequences of the legislative changes. This example is informative for scenarios that aim at direct enforcement with High Speed WIM. Having such an accurate and extensive WIM system is also valuable for design and maintenance related aspects for the road network.

5.5.2 *Data -and model fusion for bridge load rating (USA)*

This integral system combines a WIM-station, traffic camera’s and strain sensors on a bridge combined with a structural response model to obtain insight in the effects of traffic loading on the I-275 north bound corridor between Newport , Michigan and Romulus (USA), Figure 5.5.

The system is elucidated in [17] and can be seen as a bridge-WIM system for structural assessment and shows that taking advantage of combined vehicle load information and a bridge response model results less uncertainties with respect to the assessment of the structural reliability of existing structures.

Figure 5.5: Newburg Road Bridge in the I-275 north bound traffic over the East Newburg Road in Monroe, Michigan, USA [17]

This example is informative to scenarios which aim at accurate monitoring of the effects of heavy traffic loading on the structures and pavement in infrastructural corridors. This is likely to enable optimization within the application area Design & Maintenance.

5.5.3 *Geographical Information System applications (Netherlands)*

Geographical Information Systems (GIS) are used to capture, store, analyze and present geographically related data and information. Regarding the context of (heavy) traffic operations on road networks there are three relevant developments in the Netherlands that are worth mentioning.

NDW Dexter
Dexter is a web application from the Nationale Databank Wegverkeersgegevens (NDW) through which users can obtain (open) historic traffic intensity data [18]. The data are measured by magnetic loops in the road surfacing (section 5.3.1). Amongst others, the application includes a geographical user-interface to query data, see Figure 5.6. This application doesn't contain information about vehicle or axle loads.

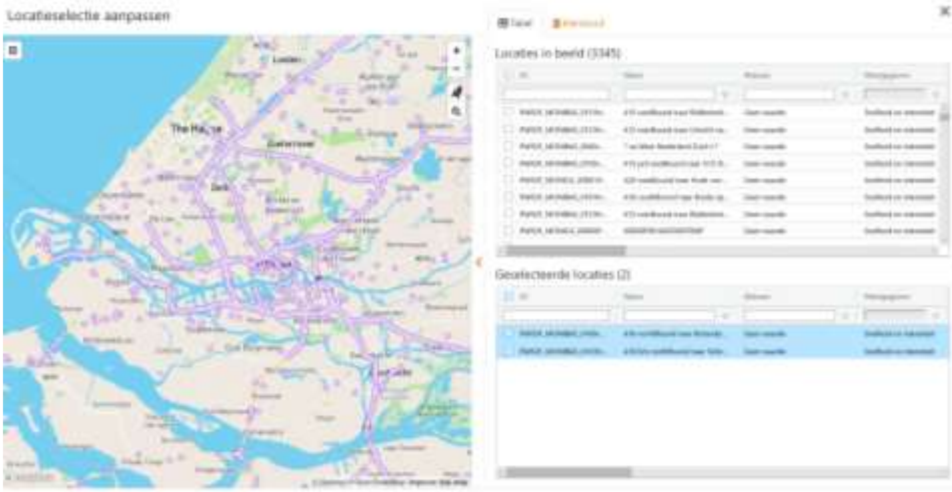

Figure 5.6 Graphical user-interface of NDW Dexter web-application for traffic intensity data [18]

Traffic Load Map
Driven by the need for more accurate (object specific) assessment of structures within the Dutch road network, TNO started a research program towards the development a of 'traffic load map'. The development combines available data (i.e. WIM, Bridge-WIM and magnetic loops) with statistical inter -and extrapolation models to obtain the best possible load information at specific locations within the network. The development is meant for making this information available through a user friendly GIS-interface, see Figure 5.7. This type of application mainly suits the application areas Design & Maintenance and Traffic and Transport Management & Policy.

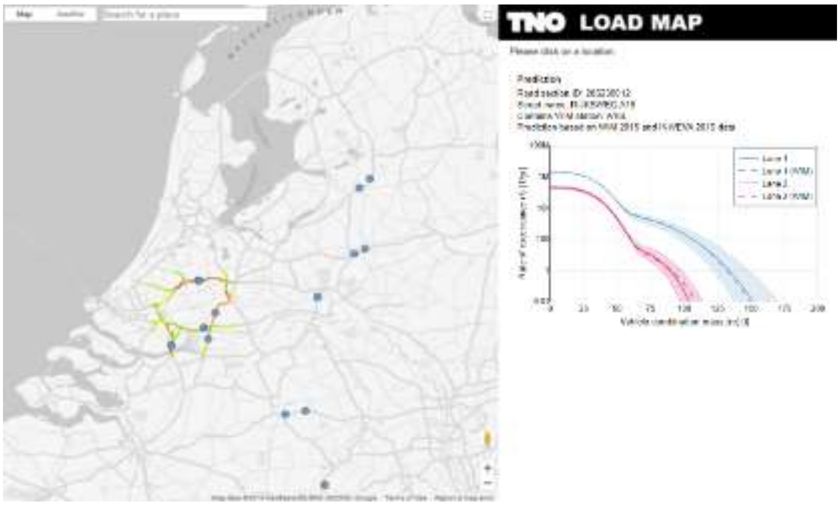

Figure 5.7 Example view of Traffic Load Map development at TNO Structural Reliability

Urban Strategy Platform

From the context of accelerating and improving spatial planning in urban areas the Urban Strategy Platform (USP) has been developed by TNO [19]. In the platform, relevant data-sources like traffic data, air quality data, noise emissions, etc. are combined with advanced simulation models for predicting KPI's for urban planning. Coupling this to computation power, user-interaction and visualization technologies public authorities, policy makers and urban planners may be enabled to quickly develop, assess and communicate about urban strategy scenarios through a visually attractive interface. The concept is visualized in Figure 5.8. The USP is used by various municipalities and provinces in the Netherlands (e.g. Amsterdam, Rotterdam, Tilburg, Noord-Holland) but also in Shenzhen, China.

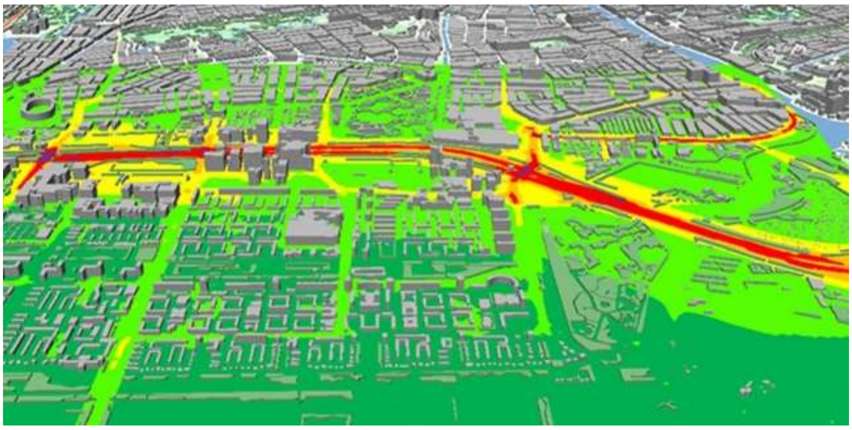

Figure 5.8: Schematic overview of Urban Strategy Platform

After translation to the freight traffic operations on the road network, this example may be related to the load map mentioned earlier. The example may be informative for scenarios in which multidisciplinary predictive capability is important, i.e. integrally considering the effect of policy changes on mobility, environment and asset-management. As such it is expected to be most relevant for the application areas Management & Policy, and Logistics. However the example may also suit uniformity, availability and predictive capability, which is beneficial for Design & Maintenance application area.

5.5.4 Intelligent Access Program (Australia)

The IAP holds commercial telematics services (certified by Transport Certification Australia) developed in a program with Australian road agencies. Trucks enrolled in IAP are monitored by means of GPS technology and an In Vehicle Unit including On-Board WIM. The output of this monitoring is checked for compliance with location, temporal, speed and weight criteria. More information about the IAP can be found in references [20] and [21].

Besides Australia, Sweden also did a pilot with the IAP. This was done in strong collaboration with, and making use of existing services as used in Australia. Reference [22] describes the experiences from this international collaboration.

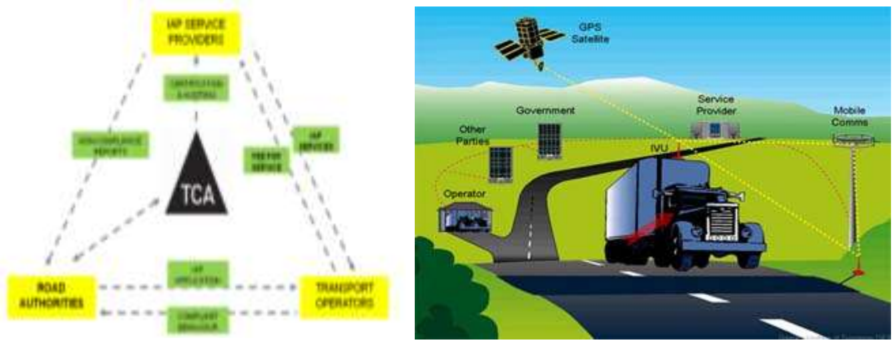

Figure 5.9: Illustration and organizational structure of IAP Australia [21

The Intelligent Access Program (IAP) from Australia is informative for scenarios which aim at coverage and positive incentives for all application areas, more specifically:

– **Control & Enforcement:** improved control over heavy vehicle operations on the road network. Potential to involve (commercial) telematic service providers in the enforcement task (certification remains required).
– **Design & Maintenance**: improved insight and control over heavy vehicle loads (special transports) on the infrastructure network. Potentially resulting in more optimal/efficient structural assessments and special transport permitting.
– **Management & Policy**: improved insight in (demand for) heavy vehicle operations on the road network. This could support better policy making on this topic (e.g. including durability).
– **Logistics**: potentially more access and/or increasing mass allowance for heavy vehicle operations. This could support cost-effectiveness and achievement of durability goals.

5.6 Evaluation per application area

In the sections before an overview is given of the available technologies for dynamic traffic weight measurements. As indicated implicitly each technology has its own advantages and disadvantages and is therefore better or less suitable for a the identified application areas as distinguished in section 3.2.

In this section the different application areas are considered on the basis of which the most appropriate technology or measuring system matching specific information requirements.

5.6.1 Assessment of technologies

Chapter 4 described information requirements for each of the application areas. As mentioned these requirements may influence the selection, the design, and/or the configuration of the technologies. The table below discusses in what way the data quality dimension used in chapter 4 are affected by the technology that may be chosen.

Table 5.1: Required technologies depending on the data quality dimensions

Data quality dimension	Notes on technology required
Accessibility *(degree to which data can be accessed, e.g. by separate organisations or individuals)*	The accessibility of the data is governed by organisation and technology. For example: data can be supplied by hauling companies (in case of on-board weighing units), or by government (in case of in road-systems). Technological, there are possibilities for collecting, and sharing data with involved parties, provided mutual agreement. *(also see timeliness)*
Accuracy *(degree to which the data represents reality)*	The degree of accuracy is highly dependent on the type of technology chosen. For direct enforcement, high levels of accuracy are required which cannot be provided by in-road systems, unless several systems are places in a series to eliminate dynamic effects. As a consequence, the number of required WIM-stations in row would increase significantly. Low speed WIM, and static WIM systems do offer such levels of accuracy, but do influence travel time, or required personnel, as is currently employed in the Netherlands. On-board systems also provide this accuracy, yet, the information obtained is limited to the vehicle that is equipped for on board measurements. As a result, insight is gained only in a specific part of the traffic load spectrum, making it less suitable for design and maintenance purposes *(also see completeness)*
Completeness *(degree to which required data is available)*	The degree of completeness depends on the number of stations as well as the position of these systems in the road network (in case of in-road systems) or the number of vehicles installed with measuring equipment for on board measurements (in case of on-board systems). Higher levels of required completeness typically require exponential higher numbers of systems. *(also see granularity / level of detail)*

Data quality dimension	Notes on technology required
Consistency *(degree to which the data is consistent e.g. within databases, between databases, over time)*	The degree of consistency mainly depends on measuring system degradation combined with the degree of measuring system performance assessment. For current in-road systems, it is known that regular checks and maintenance is required for sustaining measurement performance. For on-board systems, the consistency is for example determined by the requirements with respect to calibration and certification.
Granularity / level of detail *(degree to which data is provided or aggregated, e.g. period of time)*	Most technology can accommodate the required level of detail with respect to measured weights (e.g. axle or vehicle loads). For other relevant parameters (e.g. intervehicle distances), on board systems are basically not equipped. *(also see completeness)*
Interoperability *(degree to which data is integrated, or can be integrated across data systems)*	Can be accommodated in any system, usually by applying standards. May require additional attention if data is obtained through different types of systems (e.g. in-road versus on-board).
Timeliness *(degree to which the data is available at the time that is needed)*	The degree of timeliness depends on the manner In which data is obtained or collected. This can vary through live connections (with WIM-systems, or wireless connectivity with on-board unit), through delayed delivery of information (e.g. only when vehicles are checked, pass a checking point, of submit data at a later stage). *(also see accessibly)*

5.6.2 Control, Supervision & Enforcement of Traffic Weight

The best fitting weight measuring system for the application area Control, Supervision & Enforcement of Traffic Weight is, among others, determined by the vision and strategy that is adhered to. Basically, the as-is situation may be satisfactory when there is no need further reduce the degree of overloading incidents. The current method seems cost effective and requires limited personal effort. On the other hand, the current method implies a limited part of the number of trips is being monitored and checked. Moreover an additional measuring system is required (LS-WIM or static) for measuring the static vehicle and axle weights. For enforcement, the current WIM station is only suitable for pre-selection.

If the strategy, focusses on an automatic fining systems without the traffic flow being affected, the use of in-road systems (multiple systems at one location) may be most favorable system. In such a case, however, quite a lot of WIM locations (maybe even more than the 9 locations that are monitored now) are required for obtaining a satisfactory coverage of the road network. It may be obvious that this will also affect the costs (installation, management, maintenance). Moreover, algorithms need to be developed for converting the dynamic measuring data to reliable, static weights and Dutch legislation needs to be adapted for facilitating such a strategy. It may be clear that all mentioned aspects require time, possibly 5 to 10 years.

Considering the costs and required technology, it may be more obvious that focus is given to on-board systems when a high degree of coverage is strived at. In such a case the responsibility for obtaining all the required information lies with the carrier, while the government can focus on system certification, information monitoring and information handling, comparable to the tachograph system that is used for drivers to comply with the Driving Hours Act. Also for such an approach implementation time must be taken into account for because several questions still that have to be answered, e.g. how to deal with foreign license holders and certifying and testing such systems. The technology, however, is available.

5.6.3 Design & Maintenance of the Road Network

For management and maintenance it is important that a representative reflection for the traffic spectrum for the Dutch situation is obtained, taking into account effects as spatial variability and relevant variations in the distribution of vehicles (weight distribution, vehicle characteristics, intervehicle distances, etc.). Depending on the precise goal, the information needs may vary.

For the design of structures, a relatively conservative view of the load may be assumed, representing only the worst scenario. In that case, a limited number of WIM systems at normative locations in the network will suffice. The load distribution is not necessarily representative for the whole network. This actually reflects the as is situation. Of course, the data must be reliable, especially when the number of stations is limited.

The actual intervehicle distances are part of the spectrum that is required. For on-board systems is seems not easy to achieve this kind of information. Research is needed to determine if a combination with other data sources and measurement systems can offer this information. Moreover, on-board systems only provide information about the vehicles that are equipped with an on-board measuring system, which is only a limited part all vehicles at a certain location. Also obtaining the intervehicle distances form on-board systems seems less straight forward. For these reasons, on-board systems seem less appropriate for the application area Design & Maintenance.

For assessing the structural safety of existing structures or for the assessment of specific parts of the network, more detailed (location specific) weight and traffic distributions are required (compared to the design). This may be obtained by installing multiple weigh in motion systems providing more detailed information about the spatial variability.

In the most extreme case, when information is required of a single, specific bridge, theoretically a bridge specific device needs to be installed. Because, in such a case, however, the load effect is governing (rather than the load itself), it may be more beneficial to use a bridge-WIM system. It is important to realize that such a case mostly indicates an incident.

5.6.4 Traffic & Transport Management & Policy

Traffic & Transport management and policy regarding the planning and development or improvement of infrastructural networks basically refer to the application areas mentioned in the previous sections. Therefore, depending on the specific issues, similar information is required as for the application area that is considered, i.e. Control, Supervision & Enforcement (section 5.6.1) and/or Design & Maintenance (section 5.6.2). For that reason the most beneficial system also depends on both of the before mentioned the application areas.

5.6.5 Logistics

As noted in chapter 3, improving logistics is mainly (and maybe even solitary) beneficial for the transport sector. For improving logistics and the planning of hauling trips, on board system seem most appropriate because information on the vehicles or a fleet of vehicles is required. Moreover, in such a way, the data is gathered, owned and managed by the hauling and shipping companies.

For applying the information also for other purposes, agreements need to be made with governmental parties. In such an agreement a trade-off must be made as to which information must remain private or information that needs to be made public.

5.6.6 Final remarks

From the technologies described in this chapter it appears that most systems focus on a specific application area and that developments focus on system improvement. Form the sections above, moreover, is may be clear that different technologies are required to fulfil the needs for the different application areas. As a consequence, for fulfilling all needs, for all application areas, a system using multiple technologies is required.

Depending on the level of ambition and the priority given to a specific information requirements, different consideration can be made. The assessment and decision on this lead to various possible scenarios. These are elucidated in the following chapter.

In the decision to be made it may be obvious that the cost play an important role, but also of the division of costs and benefits. For example, in the as-is situation, Rijkswaterstaat bears the cost of the installing and maintaining the WIM-stations, while the ILT bears the cost for data management and all activities related to supervision and enforcement. Both the costs, as the division of cost may vary in other alternatives. When companies become responsible for installing and providing on-board measurement, they will likely bear the costs of this equipment. In short, going from an in-road scenario to an on-board scenario will likely result in (partly) shifting costs from governmental organisation to private organisations.

6 Scenarios

Chapters 3 and 4 provided insights in possible application areas (chapter 3) and the information required for each application area (chapter 4). Chapter 5 provided an overview of possible technologies and furthermore showed that de needs identified in chapters 3 and 4 sometimes require different technological solution. Consequently, choices need to be made between various (technical) scenarios.

6.1 Approach

A first consideration in developing scenarios is that each application area has its own main actors, and its own scenarios. On the other hand, it was also found that each application area will require (to some extend) information on vehicle weights for which technology has been identified in the technology scan. As a consequence, several main scenarios can be formulated. Some considerations are as follows:

- The scenarios, or most of the scenarios, should be possible scenarios for each application area.
- The number of scenarios that can be developed is practically infinite. The main purpose of scenarios is the put forward several different lines of though as a basis for discussion and to identify key trade-offs. Therefore, the number of scenarios should be limited. Of course, this does not mean that variation between scenarios, variations within the scenarios, or even totally different scenarios can be developed in time.
- There is already an ‘installed base’ of operational systems, which needs to be included in the decision making. Most notably these are current WIM-stations in the highway network. But also on-board measurements may be viewed as the installed base from the viewpoint of the private sector.
- There is an obligation to ensure compliance of European directives. This means that at any time, a system needs to be in place to control and enforce legislation on vehicle weights. In the model, it is assumed that this means that either the current systems are used until a better alternative becomes operational.
- One of the key differences in technology relates to the difference between in-road and on-board systems, and furthermore is outline in the European Directive. The scenarios should include this aspect.
- Some scenarios may not be feasible at the moment, or the near future, but can be considered in the farther future.

The next paragraph will discuss the scenarios that have been formulated, mainly based on the abovementioned aspects and the results of chapter 5. In chapter 7, the scenarios are considered together with insights gained throughout the research to provide information on the relevant trade-offs per application area.

6.2 Formulating scenarios

Four scenarios have been formulated, based on the finding in chapter 5, and have been illustrated in the figure below.

- A base scenario (section 6.2.1) entails continuation of the current as-is situation.

- A scenario in which in-road measurement are intensified (see 6.2.2) meaning that more in-road systems will be installed in the road network.
- A scenario focusing on the use of on-board units (section 6.2.3) for obtaining weight measurements.
- A scenario that combines in-road measurement and on-board units (section 6.2.4).

6.2.1 Base scenario (continuation of as-is situation)

Considering that there is an installed base of equipment (the currently active WIM-systems in the road network), this can be considered a first scenario. In this situation, it is assumed that the current set up of the system (number and location of in-road WIM-systems) is deemed sufficient for the various actors and application areas. Consequently, the performance, benefits and costs of the current systems can be considered to be similar as under normal operation conditions. This also means that some of the issues currently being experienced (see Chapter 2) will not be solved by opting for this scenario.
This base scenario can be considered as the starting point for transferring to future scenarios (see below), or as the plan for the foreseeable future.

With respect to the costs for this base scenario, currently, capital investments are, or have been, made by Rijkswaterstaat to bring several (around 10) WIM-stations back into service in 2019 and 2020. Once back into service, Rijkswaterstaat estimates the costs of maintaining all WIM-stations as mentioned in the ‘as-is situation’ to be around 1,3 to 1,4 million Euros annually[3], excluding costs for repair (which are estimated by Rijkswaterstaat at 3 million Euros) and costs for the activities of the ILT, so only partially indicates the costs of this base scenario.

Other considerations include:
- There are other WIM-technologies being employed (e.g. fibre optics), which can be considered as an alternative technological solution for this scenario. Such technology may be beneficial in terms of measuring performance, and or costs. It is advisable to investigate current application of such sensors more thoroughly to assess these systems merits. Furthermore, a generic trend is that more data can be obtained from the measurements being taken.

It should be noted that the private sector is not relying on data from in-road measurements performed by Rijkswaterstaat and ILT, but rely on self-obtained information when required.

6.2.2 Intensifying in-road measurements

Currently, about 18 WIM-systems are installed on 9 locations in the road network. One scenario entails intensifying measurements by increasing the number of systems and locations. Consequently, this offers more data on vehicle and axle weights, which is beneficial to most of the application areas. The level of control and possibilities for enforcement increase, although this may also require additional

[3] Based on intern Rijkswaterstaat document.

effort in terms of checks being performed. More data will be available for asset management and for policy making.
More information can also be provided to shipping and hauling companies, providing them more insight on potential infringements on overloading. Although it can be argued that this information is of limited additional value to information that is obtained by companies themselves (e.g. on-board measurements).

Other considerations include:

- There are other WIM-technologies being employed (e.g. fibre optics), which can be considered as an alternative technological solution for this scenario. Such technology may be beneficial in terms of measuring performance, and or costs. It is advisable to investigate current application of such sensors more thoroughly to assess these systems merits. Furthermore, a generic trend is that more data can be obtained from the measurements being taken (see also section 6.2.1). For example tire pressure monitoring may be an additional service offered by such systems.

6.2.3 Use of on-board systems

Given the possibilities of on-board measurements of weights, one scenario is focused on the use on on-board systems. The data of on-board units can be transferred in different ways, but likely via gantries in the road network. This scenario opens up several opportunities, particularly for the application areas relating to control & enforcement, traffic and transport management & policy, and logistics. Information on loads is collected more comprehensively. It is noted, however, that implementing such advanced used, still requires some changes in data handling and data accessibility towards the future. Moreover, this scenario is considered a setback from the perspective of design and maintenance of infrastructure, as not all required data is collected for this purpose.

Other considerations include:

- As this scenario is comparable to the implementation of the heavy goods vehicle charge, there may be synergies found (use of same infrastructure (gantries), similar market structure, and lessons learned).
- Implementation of such systems will require time as trucks and trailers need to be equipped with sensors and on-board units. Consequently, a transition period is likely needed. Implementation is either forced (by law) or by other incentives. A transition period may be required, specifically for categories of vehicles not suitable for on-board weighing. On the other hand, it is possible to put into force regulations regarding new vehicle types or concepts. For example, permits for new vehicles may only be issued when the transporter offers certain load information on the vehicle.
- Developments in relation to transferring data can be reviewed in the future. For example, 5G may offer a more cost-effective solution for transferring data from vehicles compared to data transfer trough gantries.

6.2.4 Combination of in-road and on-board systems

A combination of systems can be considered as a possible scenario too, as both technologies offer benefits to different purposes. The most evident downside of this

scenario are the costs and effort to support multiple technical solutions at the same time.
Considering the base scenario, the most likely form of the scenario entails continuation of the base scenario with an increasing degree of on-board systems over time. This scenario opens up several opportunities, particularly for the application areas relating to control & enforcement, traffic and transport management & policy, and logistics. Information on loads is collected more comprehensively, potentially the most comprehensive of all scenarios.
This will require a plan that shows what incentives exists for applying on-board systems (particularly in the case that in road systems are used for control and enforcement purposes).
Over time, a decision may be made to transfer from having two technologies in place to having one in place (which would most likely be on-board systems), or to downscale use of a technology (most likely in-road systems).

Other considerations include:
- Compared to the scenario with only on-board systems, this scenario actually has to technologies that can be used to determine vehicle and axle weights. This leads to the question to what extent it is required to put legislation into force to implement on-board systems. This because in-road systems would likely comply with the legal duty to enforce on regulations on vehicle weights. It can be considered too put regulations into force regarding (on-board) measurements for new transport concepts (for example the super eco combi truck). There is currently uncertainty how such concepts will affect the infrastructure, and specific knowledge of the load effects of these vehicles may help in the safe development and implementation of such concepts.
- This scenario will, likely more than other scenarios, depend on advanced data transfer, storage, and analyses technology. In this scenario, data from (many) different sources is obtained and combining this data can be valuable.

7 Conclusions and trade-offs

In the previous chapter, different scenarios for future traffic weight measurements are given. The main purpose of scenarios is the put forward several different lines of though as a basis for discussion and to identify key trade-offs. Four scenarios have been described and based on the analyses (chapter 3 to 5), it was shown that the most favourable scenario(s) differ per application area. In other words, different applications require different scenarios. This chapter will summarize the main arguments per application area, and will illustrate key trade-offs per application area. Overall trade-offs and conclusions are elucidated in section 7.5.

7.1 Control, supervision and enforcement

For the application area control, supervision & enforcement the main actors and decision makers are the Dutch Human Environment and Transport Inspectorate (ILT) and the Ministry of Infrastructure and Water Management.

For the trade-off in selecting the future scenario, the following considerations must be taken into account:

- Traffic safety, Infrastructure damage cost reduction, and fair competition in (a level playing field in the EU) transport are negatively affected by overloading. Consequently, overloading should be reduced to a minimum.
- There is a legal duty of Member states bring into force laws, regulations and administrative provisions and to lay down rules on penalties applicable to infringement, and to adequately address infringement related to overloading. requires Member States to have competent authorities perform an appropriate number of vehicle weight checks, proportionate to the total number of vehicles inspected each year in the Member State concerned.
- Stakeholders such as the Dutch Human Environment and Transport Inspectorate (ILT) believe that to adequately and efficiently address infringement, measures should extend (far) beyond physical enforcement and should include extensive supervision, support, and creating awareness in the transport sector. Such policies are currently already being employed, but may be more effective when required technology and data becomes available.
- To some degree, physical enforcement will remain needed. No clear opinion is currently expressed concerning ‘direct enforcement’.
- Stakeholders such as the Dutch Human Environment and Transport Inspectorate (ILT) indicate that with increasing volumes of traffic and transport, control, supervision and enforcement will depend more heavily on digital solutions (given that there seemingly are limitations in staffing).
- There are several developments in transport linked to (heavy)goods transport, for example the heavy goods vehicle charge and the digital cargo manifest. This may provide additional useful information, in the tasks of the government.
- There is an increase in use of onboard systems by the private sector, although the resulting data is only made available to vehicle manufacturers and shipping/hauling companies. Currently, access by government to such information is not available. No centralised database or data platform exists.

- There are possibilities in ICT-development, opening opportunities for developing suitable databases and/or data platforms.

Currently, 18 in-road WIM-stations are installed in the Dutch highway network. For the future, most stakeholders consider a system with the use of on-board sensors as suitable future scenario. The main arguments for such a future scenario are:

- On-board systems are increasingly being used, implying that data can be collected in the future by on-board sensors. This implies also that the transport sector considers on-board units as a valuable investment.
- The completeness of the data obtained through on-board data can far exceed that of in-road systems (provided that most, if not all (heavy) vehicles have on-board systems). As such, bigger impact is to be expected in relation to the reduction of overloading. When a high degree of completeness is desired, a scenario of on-board units is likely more cost-effective compared to in-road systems that aim at similar levels of completeness[4].

It must be taken into account, however, that several issues remain in relation to on-board scenarios at this moment.

- Data obtained by on-board sensors is currently owned and governed by private parties. For using this data for the purpose of control, supervision and enforcement, regulations have to be put in place to ensure the accessibility of the data and that the data cannot be altered.
- A plan needs to be put in place to govern the exchange of data, and how to control compliance to regulation by all parties.
- A review is needed to assess the possibilities of installing on-board sensors on all vehicles, given the diversity in vehicles, suspension systems, etc.
- A plan is needed on how to ensure all relevant vehicles are using on-board sensors at a certain moment in time. Such a plan may consider a step by step approach in which new (types) of vehicles become equipped standard with certain sensors and on-board units.

In any case, a trade-off is made regarding the costs and the value of scenarios. More insight is needed in the business case of this decision, that needs to take into account:

- Potential revenues resulting from increased enforcement (fines), which is relevant in case of increasing degree of enforcement (on-board scenarios, but also intensifying in-road measurements.
- Cost savings in degreased damage done to infrastructure (assuming that better enforcement leads to less damage).
- Other societal benefits and costs, that can be associated with increasing degrees of control and enforcement. Examples of societal benefits are fewer road accidents due to better loading, fair competition, etc.
- Costs of different scenarios. Intensifying in-road measurements will require increased investments compared to the as-is situations. The costs of a scenario with on-board sensors will many related to the implementation and maintenance of a ICT-platform. As this situation is comparable to the introduction of the heavy vehicle charge, insight in the costs may be gained there. It should be noted that part of the costs may be carried by the private sector, as the use of on-board sensors is currently increasing.

[4] A study performed for a provincial road authority reaches a similar conclusion [29].

- Implementation time of a scenario focusing on on-board systems.

7.2 Design & Maintenance of the Road Network

Rijkswaterstaat is charged with the asset management of the road network and is the most relevant stakeholder for the application Design & Maintenance of the road network (followed by other road authorities such as provinces and municipalities). Rijkswaterstaat has a service level agreement (SLA) with the ministry of infrastructure and water management (I&W). Note that developments within the field of logistics and enforcement also affect the needs in relation to design & maintenance of the road network.

The following considerations must be taken into account in the trade-off for selecting a future scenario:

- The Dutch Building Decree of 2012 stipulates that structures must comply with the standards for structural safety and durability of structures (Eurocodes). In order to fulfil this requirement, insight is required in current traffic weights and traffic intensities.
- Aging infrastructure raises additional questions regarding the remaining (service) life of structures. Reducing the uncertainties in traffic loads leads to less conservative structural assessments. As a result more reliable and location specific traffic weight information becomes more important for the (safety) assessment of structures. Absence of such information would force road authorities to take other measures such as setting traffic limitations.
- A large replacement and renovation programme for aging structures is currently being executed and numerous additional structures are expected to reach a moment when large interventions are required.
- There are changes in traffic and transport resulting in different loads on roads and structures thereby affecting the remaining service life and safety level of structures and roads. Changes result from changing traffic and transport numbers (i.e. more vehicles and goods) to changes in vehicle types(weight, sizes, etc.). Such development may increase infrastructure degradation, and increase the importance of obtaining information on loads on infrastructure.
- Both design and maintenance of infrastructure requires asset management organizations such as Rijkswaterstaat to predict future conditions in order to be able to plan maintenance ahead (depending on the type of maintenance, sometimes years prior to execution).
- There are distinctions in information requirements depending on the type of assets (i.e. roads, steel and concrete structures, large and small span structures, etc.) and the purpose (i.e. design, maintenance) that is considered. For both purposes, information on the effects of (traffic) loads is needed, yet, the required accuracy of information may vary.

For the trade-off for future scenarios it must be taken into account that currently mainly measurements from in-road WIM stations are used and that most stakeholders consider that in-road measurements will be required in the future as well. The main argument is that in-road measurements provide a complete view of traffic characteristics and loads for a specific part of the network. It is currently unclear if this data can be obtained (easily) by other means (e.g. through on-board sensors). As long as the measurements are reliable and representative for other locations, in-road measurements are considered as the most suitable data source regarding design & maintenance of infrastructure.

The above does not exclude the use of other data-sources now and/or in the future. For example, specific measurement systems such as Bridge-WIM will likely also be employed in cases where detailed information is required on specific bridges. Moreover, stakeholders indicate interest in the possibilities of using data which is obtained through other means (e.g. on-board or induction loops), for example when more reliable estimates of the traffic loads on different parts of the network are required.
It is recommended to investigate the possibilities provided by obtaining data from on-board measurements, particularly in relation to new developments in traffic and transport concepts such as platooning.

7.3 Traffic & Transport Management & Policy

For the application area traffic & transport management & policy, the ministry of infrastructure and water management (I&W) and Rijkswaterstaat work together in relation to developing policies. The information requirements relate to the information from the previous application areas (section 7.1 and 7.2). Moreover, the application area logistics (section 7.4) is relevant. For the application area traffic & transport management & policy, the ministry of infrastructure and water management (I&W) and Rijkswaterstaat work together in relation to developing policies. The information requirements relate to the information from the previous application areas (section 7.1 and 7.2). Moreover, the application area logistics (section 7.4) is relevant.

In the trade-off for selecting the future scenario with respect to traffic weight measurements, it must be considered that in this research, information for policy making can be related to any other application field. Consequently, the information requirements will be similar to what is required for other application areas. In this research, information for policy making can be related to any other application field. Consequently, the information requirements will be similar to what is required for other application areas.

As a result, for the trade-off for future scenarios, data resulting from in-road and on-board measurements may be considered likely, as both are foreseen scenarios in other fields. data resulting from in-road and on-board measurements may be considered likely, as both are foreseen scenarios in other fields.

7.4 Logistics

The main actors in the field of logistics are parties from the private sector such as shipping companies, haulers, transport companies, vehicle manufactures, etc. I&W is considered as a less prominent stakeholder.

Development within the field of policies and enforcement affect the needs in relation to logistics.

Relevant considerations regarding the trade-off with respect to traffic weight measurements in the future, are:
- There are increasing efforts being made by companies to become more (cost)efficient and sustainable (reduce carbon emissions).
- There is a trend of digitalization. For example, vehicle manufacturers are increasingly provide ding (additional) digital services that utilize in-car measurements and telematics.

Companies are increasingly using on-board measurements in their operation. Fleet management systems show in practice that also private companies experience the importance of these developments. As a results, the developments will be more or less an autonomous development. This may be an aspect of consideration for the trade-offs made in other application areas.

7.5 Trade-offs and general conclusions

Considering the summary in the previous sections (7.1 - 7.4) the trade-off scheme shown in Table 7.1 can be constructed. In the table, the application areas are given, combined with the current (base) scenario and the possible scenarios for the future (utmost right column). Thus the base scenario column describes the as is situation per application area. The future column shows the various scenarios discussed in the previous chapter, and the black shaded scenario indicate most likely scenario given the arguments presented in this research. The grey shade fields show scenarios that also seem promising, or offer a suitable alternative. The scenarios shown in a gray letter type is less likely, i.e. are unlikely to fulfill the needs stated per application area.

Table 7.1: Overview of current and expected future scenarios for each application area.

Application area	**Expected scenarios**	
	Base scenario	**Future (beyond 2025)**
1. Control, supervision & enforcement	Main source: currently 18 WIM-stations in highway network.	Base scenario
		Intensify in-road
		On-board
		In-road & on-board
2. Design & maintenance	Main source: currently 18 WIM-stations in highway network.	Base scenario
		Intensify in-road
		On-board
		In-road & on-board
3. Traffic management & policy	Current sources include data from e.g. WIM-stations and induction loops in highway network.	Base scenario
		Intensify in-road
		On-board
		In-road & on-board
4. Logistics	Private information sources (on-site WIM, fleet management systems)	Base scenario
		Intensify in-road
		On-board
		In-road & on-board

Several general conclusions can be drawn from evaluating the trade-offs in each application area.

- There is an increasing degree of vehicles with on-board sensors which collect data that is relevant to multiple application areas. This data is currently only used by transport companies and vehicle manufacturers and is privately owned. If the degree of use of on-board sensors increases, and access by public authorities can be obtained, this can offer a valuable and cost-effective opportunity. The data obtained can serve multiple purposes. It is important to monitor the degree of use of such sensors, and to assess the quality of the data obtained. This may offer more insights in the possibilities, and suitable moment in time. Regulation may increase the uptake of such technology if needed.
- The degree in which the government wants to control overloading incidents highly determines the suitability of different scenarios. If the current degree of overloading incidents (estimated 15% of vehicles on the highway network are overloaded) is deemed acceptable, the as-is situation may also be deemed satisfactory. However, business cases made from the viewpoint of road maintenance imply that a decrease in overloading incidents will likely result in benefits in terms of cost savings (less damage to infrastructure). To have a more impact on overloading, more control, supervision and enforcement is needed and this can be obtained through more measurements (either by more in-road measurements, or on-board).
- In the as-is situation, the application area of control, supervision & enforcement and the application area of design & maintenance rely on the same system: the currently installed WIM-systems. The application area of design & maintenance will likely remain relying on this system, while the other application area may start to rely on other data (obtained through on-board sensors) over time. Redesign of the current system may be appropriate in this case to fit better to the needs of the remaining purposes severed. For example, a different number of stations and/or other locations may be more favorable for the purpose of design & maintenance of infrastructure.
- There are several developments in traffic and transport that result in increasing number of vehicle with increasing loads. New transport concepts are under development (e.g. platooning, the super eco combi, etc.) that on the one hand offer benefits in terms of mobility, economy and the environment. At other hand, such developments may also contribute to the increased degradation of infrastructure and safety issues. Such developments may play a particular role in adopting an (long term) plan regarding weight measurement. For example, particular regulations may be set forth for such vehicles regarding sharing weight information. It is noted that the appearance of foreign vehicles and policy also play an important role in these developments. Therefore, it is recommended to study these effects on the given scenario's separately.

In application areas, opportunities are seen in scenarios using on-board sensors as data sources. It is yet unclear to what extent this can replace current used data sources (in-road WIM stations), and in what timeframe. As a result, most stakeholders consider continuation of the current as-is situation suitable for the coming years. This allows for time to further investigate the possibility offered by new technology, the uptake of such technology in practice, and to more clearly specify the information required by each stakeholder.

In any case, it is likely that obtaining data from multiple sources (in-road and on-board, public and private) combined with advanced analytics offers many possibilities for the future. This is most evident in a scenario where data is obtained through in-road as on-board measurement, but can apply to any scenario that is foreseen or scenarios where different technologies are combined. This does require investigating the possibilities, limitations, and constraints of collecting, assessing and analyzing such data. Given the diversity of data sources, the different purposes served (different application areas), and the number of actors involved, it will require a joint effort to come to a shared and collective approach.

8 References

[1] Directive (EU) 2015/719 of the European Parliament and of the Council of 29 April 2015 amending Council Directive 96/53/EC data.europa.eu/eli/dir/2015/719/oj

[2] Rijkswaterstaat. i-Strategie 2.0. Rijkswaterstaat verbindt, versie 1.00, Rijkswaterstaat, d.d. 24 juni 2019 (in Dutch)

[3] Bouwbesluit 2012 rijksoverheid.bouwbesluit.com/Inhoud/docs/wet/bb2012

[4] Highway research Board. The AASHO road test. Report 7 (summary report). Special Report 61G (publication no. 1061). National Academy of Sciences-National Research Council Washington, D.C., 1962

[5] Drouen, C.B.W. and Henny, R.J. Project WIM-VID Final report. Results and conclusions of the project Weigh-in-Motion in combination with Video. Report number P-DWW-98-042, Dienst Weg- en Waterbouwkunde, 1998 (in Dutch)

[6] W.K. Kellogg Foundation Logic Model Development Guide, February 2006

[7] Beleidsregel van de Minister van Infrastructuur en Milieu (Beleidsregel last onder dwangsom Wet wegvervoer goederen overbelading), Nr. IenM/IVW-2011/14476, 9 december 2011. Staatscourant nr 23236, d.d. 21 december 2011

[8] Engel, A.W. van den. Cabotage in het goederenvervoer over de weg. Panteia rapport GJ/C10468/2013/0026, februari 2014

[9] Vrachtwagenheffing Nederland, Globaal ontwerp heffingssysteem (2018)

[10] Van Loo, H and Žnidarič, A. Guide for Users of Weigh-In-Motion. An introduction to Weigh-in-Motion. ISWIM, International Society for Weigh-in-Motion, May 2019

[11] Karabacak, D.M., O'Dowd, J.a., Hopman, L.J., Singer, J.M., Asphalt embedded fibre optic weight-in-motion technology, ICWIM8 - Proceedings, 2019

[12] Richardson, J. et. al. On the use of bridge weigh-in-motion for overweight truck enforcement. In int'l journal of Heavy Vehicle Systems 21(2), page 83-104, January 2014

[13] C. Koniditsiotis, J. Gordon, Learnings from On-Board mass type approvals, ICWIM8 - Proceedings, 2019

[14] Proefproject Rijkswaterstaat, A16: proefproject meetsysteem voor bandenpech bij vrachtwagens, 2019

[15] International Road Dynamics Inc., Tire Anomaly and Classification Brochure, www.irdinc.com

[16] B. Ronay-Tobel et al., Ministry for Innovation and Technology Hungary, Weight Enforcement Network of Hungary, ISWIM8 conference, Prague, 2019

[17] Jerome P. Lynch et al., University of Michigan, Fusion of Weigh-in-Motion System and Bridge Monitoring Data for Bridge Load Rating, SHMII-9 conference, St. Louis, 2019

[18] Nationale Databank Wegverkeersgegevens, NDW Dexter web-application, https://dexter.ndwcloud.nu/opendata

[19] Borst, H.C., Salomons, E.M., Lohman, W.J.A., Zhou, H. & Miedema, H.M.E. Urban strategy: Noise mapping in instrument for interactive spatial planning. In proc. 8th European Conference on Noise Control 2009 (EURONOISE 2009), Edinburgh, PART 3, 31, pp. 1-9

[20] Intelligent Access Program Australia, https://www.nhvr.gov.au/road-access/access-management/intelligent-access-program-iap

[21] C. Walker, The Intelligent Access Program (IAP) in Australia, A flexible regulatory framework for trucks, Rijkswaterstaat Magazine, October 2016

[22] C. Walker, Improving regulatory and compliance options through international policy transfer and collaboration. The Australian and Swedish experience with remote vehicle monitoring under the Intelligent Access Program (IAP)

[23] EU H2020 FLEX-RAIL project, Deliverable D2.1 Review of trends, transport sector innovations and blue-sky projects, final draft, October 2019

[24] COST 323 Weigh-in-Motion of Road vehicles final report (1993-1998). Jacob, B., O'Brien, E. and Jehaes, S. eds.. Laboratoire Central des Ponts et Chaussées, Paris 2002 [25] G. Andeweg, H. van Loo, H. van, Akker, E.G.P. van den, Kieft, J.N. en Roos M. Redesign Weigh in Motion. Functionele Specificaties. Rijkswaterstaatdocument versie 1.0 (definitief), d.d. 1 april 2010

[26] Aarts, L. et al. Belasting weginfrastructuur door zwaar vrachtverkeer. Beleidsvoorbereidende studie voor het rijkswegennet, Rijkswaterstaat, 10 februari 2014

[27] Study on heavy vehicle on-board weighing (final report). Oehry, B., Haas, L. and Van Driel, Cornelie. Rapp | Trans report 19 December 2013

[28] Van Velzen, M. The design of weight enforcement strategies for overloaded heavy goods vehicles on complex road networks. Master thesis, Delft University of Technology, august 30, 2018

[29] Wegbeheerders ontmoeten Wegbeheerders (WoW). Praktijkbundel overbelading

9 Signature

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