The design of weight enforcement strategies for overloaded heavy-goods vehicles on complex road networks

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Abstract

Overloaded heavy-goods vehicles result in road infrastructure life-time reduction, market distortion and road safety reduction. Analysis of the motivations for overloading showed that competition serves as a strong motivation for companies to overload. Additionally, the currently extremely low chance on being checked should be increased, to have a violation deterring effect. In the research, four weight enforcement strategies are designed, in which both compliance-stimulating and violation-deterring enforcement measures are strategically combined. It is concluded that a strategy in which On-Board Weighing is applied for automated enforcement is expected to result in the largest reduction of overloaded heavy-goods vehicle movements. However, due to the high initial costs for installing axle load sensors on heavy-goods vehicles and calibration sessions, the costs per check are relatively high at a low number of performed checks, compared to Weigh-in-Motion based strategies. Future research should be aimed at defining the optimal subjective chance of being checked for various groups of violators.

Keywords: Overloading, weight enforcement, Weigh-in-Motion, On-Board Weighing, road network

1. Introduction

As the Netherlands is a classic trading country, trade and transport play a prominent role in the Dutch economy. On a yearly basis, 515 million tons, 82 percent of the domestic transport, is transported via road. This results in 1.400.000 tons of goods passing the Dutch road networks on a daily basis, mainly transported by heavy-goods vehicles (HGVs). Although the economic benefits for the transport sector and society as a whole are considerable, HGV transport has some drawbacks as well. On the Dutch main road network, around 15 percent of the trucks is overloaded, yearly resulting in around 34 to 300 million euros in social costs (Hersbach et al., 2011; Inspectie Leefomgeving en Transport, 2016; Ministerie van Infrastructuur en Milieu, 2015). The negative external effects of overloaded trucks can be divided in three categories: besides road infrastructure life-time reduction, overloading distorts the equal playing field and results in road safety reduction (Taylor, Bergan, Lindgren, & Eng, 2000).

Due to their weight, overloaded HGVs have a negative impact on the pavement and structures like bridges and culverts. The theoretical calculated life cycle of roads could decrease by up to 30 percent, equal to several years (Vennix, 2016). Additionally, overloading creates unfair competition in the transport sector. Since noncomplying transporters can offer lower prices in tenders, their competitiveness increases. On the other hand, benevolent transporters are less likely to be awarded contracts. Furthermore, overloading could result in reduced instability and braking capacity and a loss in motivity and manoeuvrability, especially in unexpected movements, swerving or bad weather. This results in a higher chance of accidents (Jacob & Feypell-de La Beaumelle, 2010).

In Europe, the most used weight enforcement system is Weigh-in-Motion, which consists of weight sensors build in the pavement. A literature study on weight enforcement showed a lack of knowledge on integrating individual weight enforcement measures on different geographical and institutional levels into coherent enforcement strategies, within complex road networks, consisting of multiple interwoven layers of national, regional and local roads. This led to the following research question:

> *How can the problem of overloaded heavy goods vehicles on Dutch national and regional road networks be addressed in a cost-effective way, to reduce the social costs of heavy goods vehicle overloading to a minimum?*

2. Methodology

A Design Science research approach is used, based on the method framework for Design Science Research by Johannesson and Perjons (2014). The approach is particularly suitable for the identified socio-technical problem of overloaded HGVs, since it concerns a practical problem in the transportation system, which is of large general interest for its users and the nation. In the proposed research, an artefact in the form of enforcement strategies will be designed which addresses the problem of overloaded heavy-goods vehicles on complex road networks. In , the research outline is presented within the framework for Design Science Research of Johannesson and Perjons (2014).

Figure 1 – Research framework, based on the Design Science Research framework in Johannesson and Perjons (2014)

3. Weight enforcement in dense, multi-levelled road networks

Theoretical success factors for weight enforcement

Effective enforcement contributes to the 'successfulness' of legislation. In order to achieve the desired policy outcomes, enforcement is needed in almost all cases (Gunningham, 2010). Broadly, two types of enforcement can be distinguished: a deterrence strategy and a compliance strategy (Gunningham, 2010; Hawkins, 1984; Sparrow, 2000). While the deterrence strategy focusses on penalizing offenders and can therefore be seen as a confrontational strategy, the compliance strategy is more focussed on cooperation and conciliation.

Enforcement styles can as well be classified in enforcement as bureaucratic or strategic activity. A more standardized, bureaucratic application of enforcement has a high level of predictability, which could contribute to a good relationship between inspector and benevolent inspectees (de Bruijn & ten Heuvelhof, 2005). On the other hand, non-benevolent inspectees could strategically abuse the predictability of the enforcement activities. Strategic enforcement has a more unpredictable nature, in which anticipation and reaction on the behaviour of the inspectee plays a key role (de Bruijn & ten

Heuvelhof, 2005). For both the sanction style, as well as the pedagogic style, a bureaucratic or strategic application can be chosen, by which four possible combinations of styles are available (Figure 2).

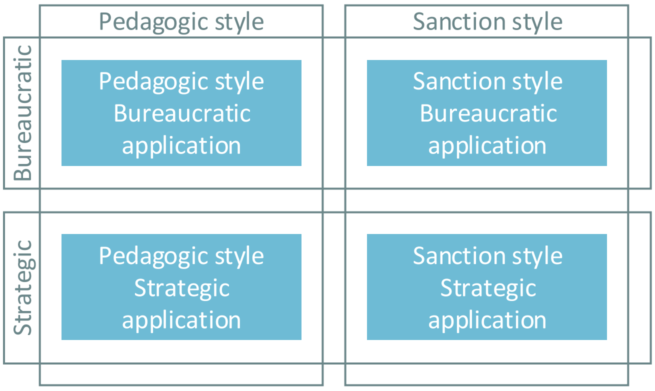

Figure 2 - Overview of enforcement styles role (de Bruijn & ten Heuvelhof, 2005)

Furthermore, de Bruijn and ten Heuvelhof (2005) describe that the inspector could use:

i. *Strategic selection* – A portfolio of inspectees and enforcement activities plays an important role in the identification of inspectees and the strategic selection of who to inspect and how to do so.
ii. *Information* – Redundancy of information enlarges the quality of the inspectors intelligence, by which strategic behaviour of inspectees can be better discovered.
iii. *Context* – The use of context and the environment of the inspectee to stimulate compliance.

A widely applied mechanism to deal with the variety in regulatees and needed variety in enforcement styles is the enforcement pyramid, proposed by Ayres and Braithwaite (1992). An enforcement pyramid provides insight in the way in which regulators could apply responsive regulation. Progressive punitive strategies are applied when lower levels of intervention fail. The strategy is communicated to the regulate in advance, to stimulate compliance in an early stage. The more persuasive and compliance-stimulating measures can be found at the bottom of the pyramid, escalating towards sanctions at the top. Starting at the bottom, regulators can find out which regulatees are well-willing and for which regulatees more deterrence based enforcement measures are suitable .

Insight in the motives and behaviour of the inspectee

The motivation for transporters to overload their heavy goods vehicles is affected by a large number of factors, of which some weigh heavier than others. The Table of Eleven is used as method to gain insight in these dimensions, for the current enforcement situation. The analysis showed that the benefits of overloading exceed the costs, in most cases. Especially in a competitive market, in which the lowest bidder is awarded the contract, overloading can be an attractive way to reduce costs and gain offers. Only for a small percentage of transporters, a lack of knowledge on relevant legislation causes violating behaviour. Within the transport sector, the amount of social control and chance of being reported on overloading are low. Since the use of Weigh-in-Motion for pre-selection on the national road network stopped in 2015, the risk of being checked became extremely low. On the other hand, the probability of being detected, when being checked is close to 100 percent; static weighing scales provide accurate, court proof evidence. Since vehicles are only sanctioned when the vehicle is overloaded by more than 5 percent (for axle loads: more than 10 percent), it is expected that a large number of transporters deliberately overloads their vehicle till this limit.

In competitive sectors like civil engineering and sea container transport, the level of compliance is significantly lower than in other sectors. Besides strong competition and low margins, the structure of the total transport chain in which the transporter operates and in which clients play an important role, has a strong impact on the tendency to overload. Given the position of transport companies within these larger chains, the competition in all subsectors and the market distortion associated with overloading, it is concluded that either an absolute waterproof enforcement system or a strategy focussed on the entire transport chain is needed.

Interests and problem perceptions of key stakeholders

Several key stakeholders in the problem were invited to a focus group session to retrieve insight in their interests and problem perceptions. Representatives from local road owners, regional road owners and the national road owner were present, as well as the Human Environment and Transport Inspectorate ILT, Dutch Vehicle Authority RDW and branch organisation Dutch Association for Transport and Logistics TLN. It was concluded that all stakeholders acknowledge the need for more enforcement and a higher chance of being checked and sanctioned. The way in which various road administrators deal with this observation however differs and it lacks effective cooperation between road owners in addressing the problem of overloaded heavy-goods vehicles.

The opinion on how to deal with overloading slightly differs between the stakeholders, resulting from different problem perceptions. For road owners, the impact of axle overloading on pavement life time is considerable. Therefore, they argue that axle overloading should be addressed in weight enforcement as well. For branch organisation TLN, representing the transport sector, mainly gross vehicle weight overloading forms a problem, since this strongly distorts the desired level playing field. Additionally, TLN argues for an approach aimed at the entire transport chain, since they consider the position of the transporter towards the client to be weak sometimes, due to strong competition.

Constraints and requirements for weight enforcement: design starting points

Based on the theoretical and empirical exploration of the problem of overloaded heavy-goods vehicles, a number of constraints and requirements were formulated for future weight enforcement.

Constraints

I. The weight enforcement strategy should lead to or contribute to a reduction in the number of overloaded HGVs on the Dutch road network
II. The weight enforcement strategy should comply with Directive (EU) 2015/719
III. The weight enforcement strategy should fit within the physical characteristics of the Dutch road network
IV. The benefits of the weight enforcement strategy in terms of social damage reduction should exceed the costs of the weight enforcement strategy

Requirements

V. The weight enforcement strategy should be implementable in Dutch legislation
VI. The weight enforcement strategy should consist of both bureaucratically and strategically applied compliance stimulating and violation deterring enforcement measures

VII. The weight enforcement strategy should be based on the amount of road damage transporters are accountable for

VIII. The weight enforcement strategy should allow for portfolio management and responsive regulation

IX. The weight enforcement strategy should be focussed on the entire transport chain

X. The impact of the weight enforcement strategy on the business management of complying transporters should be as low as possible

XI. Weight enforcement should be focussed on both national as well as international transporters

4. Designing weight enforcement strategies

Based on the constraints and requirements, a number of weight enforcement strategies is designed. The choice between Weigh-in-Motion and On-Board Weighing as main enforcement measure on the main road network is used as a starting point in the design of the strategies, following the first constraint.

Deployment of the main enforcement measure on the main road network

The impact of Weigh-in-Motion on the compliance level on the regional and local road network could differs significantly from the impact of On-Board Weighing and is dependent on the way in which the techniques are applied. Given the large share of deliberately non-complying transporters, applications in which the technique is only used to display the weight to the driver, were eliminated in this research. In total, four applications are further explored, forming the basis of four enforcement strategies:

I. *Weigh-in-Motion for basic enforcement* includes the deployment of Weigh-in-Motion accuracy class B systems, accompanied with Automatic Number Plate Recognition Cameras. Since accuracy class B does not allow for direct sanctioning, suspicious vehicles will be selected for reweighing on certified static scales and sanctioning, based on the pre-selection by the Weigh-in-Motion system. Additionally, cease and desist orders can be imposed, solely based on the Weigh-in-Motion measures.

II. *Weigh-in-Motion for automated enforcement* includes the deployment of Weigh-in-Motion accuracy class A systems, accompanied with Automatic Number Plate Recognition Cameras. Accuracy class A allows for direct sanctioning, solely based on the Weigh-in-Motion measurements.

III. *On-Board Weighing for basic enforcement* includes the installation of accuracy class B axle load sensors and an On-Board Unit on new heavy-goods vehicles. Road side systems retrieve the axle load information from the On-Board Unit, making use of Dedicated Short Range Communication (DSRC). Since accuracy class B does not allow for direct sanctioning, suspicious vehicles will be selected for reweighing on certified static scales and sanctioning, based on the pre-selection by the DSRC system. Additionally, cease and desist orders can be imposed, solely based on the DSRC measures.

IV. *On-Board Weighing for automated enforcement* includes the installation of accuracy class A axle load sensors and an On-Board Unit on new heavy-goods vehicles. Road side systems retrieve the axle load information from the On-Board Unit, making use of Dedicated Short Range Communication. Accuracy class A allows for direct sanctioning, solely based on the DSRC measurements.

Deployment of the main enforcement measure on the regional road network

A case study for the province of Zuid-Holland showed that the deployment of Weigh-in-Motion systems on the regional road asset is not expected to be effective, given the high density of the network and ease to avoid the measurement locations. The application of Weigh-in-Motion on the regional road asset is therefore not expected to lead to an cost-effective increase of the subjective risk to be checked and sanctioned. For the deployment of On-Board Weighing, multiple DSRC road side systems are available, including static portals, portable tripods and hand-held units. Given the lower road-side system costs and extensive possibilities for strategic application of portable DSRC tripods, the application of On-Board Weighing on the regional road asset is considered feasible.

Deployment of additional enforcement measures on both the main and regional road network

The violation-deterring nature of the four selected main enforcement measures is expected to lead to over-enforcement and strategic behaviour by the sector, if not complemented with additional strategic violation-deterring and compliance-stimulating enforcement measures. Therefore, additional enforcement measures are deployed in the creation of the four strategies:

- *Strategic manual selection* includes the deployment of several enforcement teams on both the main as well as the regional road network, on strategic locations. Since the teams use portable weighing mats, they can be deployed strategically, e.g. on avoidance routes, specific subsectors or parts of the network strongly suffering from overloading. In OBW-based enforcement, the hit rate of manual selection can be increased by the use of DSRC hand-helds.
- *Information and persuasion* includes the communication of enforcement measures and policy goals to the sector, building up on the relationship between inspector and inspectee. The use of whitelists could be a compliance stimulating measure focussing on image.
- *Covenants* between governmental bodies and subsectors or geographically clustered transporters could provide benefits for both parties.
- *Explicit prohibition on overloading in contracts* where a governmental body acts as client, accompanied with sufficient administrative (and physical) checks.

Combination of measures into enforcement strategies

Together, the measures are combined into coherent strategies, which are visualised in Figure 3.

Figure 3 – Overview of measures in enforcement strategies, categorized according to de Bruijn and ten Heuvelhof (2005) (Figure 2)

5. Effectiveness and efficiency of weight enforcement strategies

The costs of the designed enforcement strategies include the costs of investment, operation and technical enforcement systems, supportive materials and personnel. First order benefits include a reduction in road infrastructure damage and longer life-time, a reduction of market distortion and increased road safety. Second order benefits include a reduction of traffic jams due to additional road works (as a consequence of the shorter life-time of road infrastructure) and incidents caused by heavy-goods vehicle overloading.

The societal costs of road infrastructure life-time shortening have been quantified in different studies, each resulting in a different value. In one of the more recent studies, the social costs of overloading on road infrastructure life-time reduction are quantified at 34 to 100 million euros for the main road network (Hersbach et al., 2011). Due to a lack of data on the amount of incidents in which overloading played a role, it appeared not to be possible to estimate the social costs of decreased road safety caused by overloading. It neither appeared to be feasible to quantify the social costs of market distortion due to overloading.

The execution of a full cost-benefit analysis appeared not to be feasible within this study, due to the existence of a broad range of conscious and unconscious complying and noncomplying actors, for each of which the effects of different enforcement measures are different. Secondly, the differences between subsectors and types of transports complicate the construction of a cost-benefit analysis. For each subsector, the reaction on various types of enforcement is expected to differ. For example for long-haul international transport, a national network of WiM systems might be an optimal solution. At the same time, for shorter agricultural transports, the deployment of a WiM system on the main road network makes no sense. Thirdly, the geographical layout of the road network influences the effectivity of enforcement. Finally, a number of other, more external and intangible factors, are likely to affect the amount of overloading, including economic tide and the acceptation of the policy goal and specific measures.

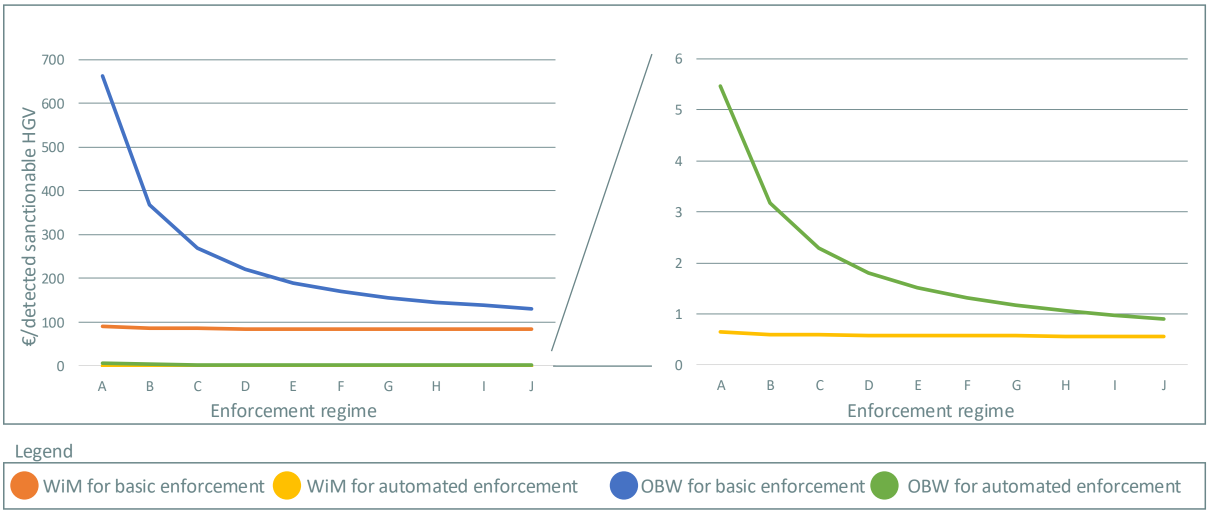

Figure 4 – Costs per check for the four designed weight enforcement strategies

Estimating the internal efficiency of the enforcement strategies however appeared to be feasible, providing an indication of their possible cost-effectiveness. The efficiency of the enforcement strategies, expressed in enforcement costs per sanctionable HGV detection, is visualised in Figure 4. The efficiency was calculated by dividing the yearly enforcement costs by the number of sanctionable HGV detections. The Figure shows the efficiency for weak (A) to though (J) enforcement regimes. Due to the high investment costs for the installation of axle load sensors on HGVs in On-Board Weighing based strategies, the costs per sanctionable detection are extremely high at a low amount of performed checks. For Weigh-in-Motion based strategies, the costs per check only slightly decrease at higher numbers of checks, due to significantly lower investment costs and constant costs per check. In general, the efficiency of the two automated enforcement strategies is relatively high.

6. Conclusions

Especially the benefits of overloading and investments needed to comply with maximum weight regulations, form the main incentive for violating behaviour. The lack of social control and extremely low chance of being checked do not have the compliance stimulating effect needed to reduce the amount of overloaded HGVs.

It is concluded that the strategy On-Board Weighing for automated enforcement, deployed on the main and regional road network, is expected to generate the largest decrease in the number of overloaded HGV transport movements on both the main and regional road network. Hereby, static road portals and portable tripods, equipped with Dedicated Short Range Communication (DSRC) beacons are placed on the road network. These devices derive real-time and historical axle load data from all HGVs, which are obligatory equipped with axle load sensors and an on-board DSRC unit. The strategy is complemented with strategic manual DSRC based enforcement, increasing the subjective probability on being checked. Additionally, by whitelisting and extensive communication of regulations and enforcement measures, transporters are further incentivized to comply. Finally, a prohibition on overloading should be included in contracts in which a governmental body acts as client. A risk profile based on an OBW measurement database serves as the input for all other enforcement measures.

7. Discussion and recommendations for future research

Discussion and limitations of the research

The first limitation of this research relates to the external efficiency or cost-effectiveness of the designed strategies. The probability of various groups to comply with or violate maximum weight regulations differs from subsector to subsector and from transporter to transporter. This probability depends on a large number of factors, including the economic climate, competitive position and exact deployment of enforcement activities. It therefore appeared not to be possible to include all effects for all groups in a full quantitative cost-benefit analysis. However, the qualitative estimation of the effects of the four strategies provides insight in their relative effectiveness. Although based on the research outcomes it could be expected that all four strategies designed will result in a higher compliance level, the social damage reduction does not necessarily outweigh the enforcement costs.

The second limitation of this research is related to the small case study, to determine the feasibility of the deployment of the main enforcement measures on the regional road network. The road asset of the province of Zuid-Holland was used in a small case study. It should be noted that the HGV intensities on this regional road network are high, compared to other provinces. This could have resulted in a higher cost-effectiveness of weight enforcement on this specific network. The deployment of WiM on the road asset of the province of Zuid-Holland is not considered feasible, partially due to the high network density.

The third limitation of this research can be found in the evaluation of the designed strategies. It appeared to be difficult to discuss the outcomes of the research in detail, especially within the time set for one interview. Instead, the respondents were guided through the research outcomes, based on the principles of informed argument. The responses should therefore be interpreted as a good, but not necessarily complete indication of the real opinion and interest of the participants and organisations they represented.

Recommendations for future research

A recommendation for future research relates to the subjective chance of being checked and subjective chance of being sanctioned. The relationship between enforcement activities and compliance level is highly dependent on the subjective risk of being checked and being sanctioned. Improved knowledge on this highly complex relationship is needed to be able to define the number of fixed and random check locations required to achieve a certain l. Existing literature shows that the subjective risk of being checked depends on the objective risk of being checked, the inescapability and unpredictability of checks, communication of enforcement measures and visibility of enforcement measures. Further research is needed to define the optimum mix between these factors, aimed at increasing the subjective risk of being checked. Quantitative model- or scenario studies could provide these insights.

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