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Safety effects of dynamic speed limits on motorways

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ABSTRACT

Dynamic speed limits (DSL) are limits that change according to real-time traffic, road or weather conditions. In DSL-schemes road users are typically informed of speed limit changes by electronic signs that are housed within gantries situated above lanes. Dynamic speed limit systems are increasingly applied worldwide, usually on motorways. One of the objectives of dynamic speed limits is to improve traffic safety through reductions in speed variations within and across lanes and between upstream and downstream flows.

This paper shows the results of an empirical evaluation of the effects on traffic safety of a dynamic speed limit system on motorways in Flanders, Belgium. The evaluation was done by means of a before-after analysis of crashes, completed with a cost-benefit analysis.

The results show that the number of injury crashes decreased significantly (−18%) after the introduction of the system. A separate analysis for serious and fatal injury crashes revealed a non-significant decrease of 6%. A distinction according to crash type showed an almost significant decrease of 20% in the number of rear-end crashes whereas the number of single-vehicle crashes decreased by 15% (ns). However, no effect was found for side crashes.

In addition to the analysis of the effects, a cost-benefit analysis was applied. The costs of the implementation of these systems were compared with the benefits of crash prevention. The cost-benefit analyses of the crash effects showed a benefits-to-costs ratio of approximately 0.7, which means that the costs tend to exceed the benefits. Taking into account the important margins of uncertainty with respect to both costs and benefits, we have also explored how the net benefits are affected by some key assumptions. The general conclusion is that there is no convincing evidence that the costs of the system currently outweigh the expected benefits in terms of crash prevention.

1. Introduction

On the majority of the roads, fixed speed limits represent the appropriate speed for average conditions. However, in order to take account of the real time traffic, road and weather conditions, dynamic speed limits (DSLs) can be applied (European Commission, 2010). DSL systems are activated at a given time, as a consequence of traffic volume or other environmental conditions (Islam et al., 2013; OECD, 2006).

Variable speed limits are often used as a synonym for DSLs. However, according to the OECD (2006) the term ‘variable speed limits’ refers to systems that are activated through general criteria (e.g. time of the day, season and certain weather conditions), which are usually set

by generic legislation. In some countries the speed limit is reduced in case of rain, or speed limits nearby school zones are reduced at school start or end times.

The focus of the present study is on DSLs, which are applied as a consequence of the real time situation. Through these systems, speed limits can be adapted remotely, either automatically by an algorithm or manually by an operator. This makes it possible to show different speed limits at different times of the day and different days of the week (Van Nes et al., 2010). DSLs are introduced to harmonize traffic flows which is assumed to improve both throughput and traffic safety. The traffic safety improvement is targeted through reductions in speed variations within and across lanes and between upstream and downstream flows

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(Lee et al., 2004; Islam et al., 2013). Throughput improvement is expected due to the speed harmonization benefits (Fudala and Fontaine, 2010). DSLs are sometimes also used in order to reduce vehicle emissions and road noise (Papageorgiou et al., 2008).

DSL systems are also applied on motorways in the Flanders region in Belgium. The variable speed limit is denoted by electronic signs that are housed within gantries situated above motorway lanes. Speed limits imposed by DSL systems are compulsory and have – according to the road authority – three main objectives (Vlaams Verkeerscentrum, 2015):

- (1) Increase safety: upstream from an incident (e.g. traffic jams, crashes, road works) speed limits can be temporarily lowered in order to reduce the mean speed, lead the traffic smoothly to the incident and avoid the occurrence of crashes;
- (2) Indicate obstructions: DSLs can lead away traffic from a blocked lane;
- (3) Improve traffic flow through homogenization of speed: at moments with a high traffic flow, speed limits will be reduced, which will lead to a more homogeneous traffic flow and to less manoeuvres. Furthermore, headways are assumed to become smaller, which means that the available space is used more efficiently and the probability of traffic jams is subsequently lower.

This paper addresses the effects of DSL systems on traffic safety. As will be shown in Section 2, quite a number of studies analysed the effects of DSLs through simulation models and driving simulator studies. However, we didn't find peer reviewed empirical studies that analysed the impact on traffic safety. Furthermore, to our knowledge, no literature about the cost-effectiveness of DSL systems is available. The present study therefore analyses the traffic safety effect of DSL systems in Flanders, Belgium, based on an empirical analysis of observed crash data. The effects are analysed through an empirical Bayes before-and-after study, which compares the crashes after the implementation of the measure with the number of crashes before, and controls for confounding variables. The empirical analysis is complemented by a cost-benefit analysis of the applied DSL system.

Section 2 provides an overview of previous studies that analysed the effects of DSL systems. Studies that analysed the effects on the traffic flow as well as studies that analysed the traffic safety effects are included in this section. In Section 3 the data, the methodology and the results of the evaluation of the effects on traffic safety are described; Section 4 describes the cost-benefit analysis. The results are discussed in Section 5 and conclusions are listed in Section 6.

2. Literature review

A number of peer reviewed studies analysed the effects of DSL systems. These effects have mainly been stated in terms of traffic safety and traffic operations. In a recent paper, Lu and Shladover (2014) reviewed studies on DSLs and classified these studies as three types: simulations for algorithm development and evaluations, DSL implementation and field testing, and a combination of DSLs with ramp metering. We will briefly discuss the literature that has attempted to assess the effects of DSLs, by means of simulations as well as through field studies. Combinations of DSLs with ramp metering are outside the scope of this paper and not further treated.

2.1. Simulation models

Many authors developed simulation models to assess the effects of DSLs. Islam et al. (2013) studied the effects on mobility. In the best case scenario, DSL control with a 5-min speed limit update frequency and a 10-km/h maximum speed difference between two successive time steps, they reported a 33% reduction of total travel time. Fudala and Fontaine (2010) did this for work zones specifically. They found potential of

DSLs to delay the onset of congestion and to help produce more rapid recovery from congestion, provided that demand volumes are not too far above the zone capacity. When demand volumes are high, they found no benefit over static speed limits. The simulation also showed the importance of appropriate DSL sign location and effective algorithm design. Habtemichael and de Picado Santos (2013) analysed the operational benefits of DSLs under different traffic conditions. They studied the combination of different compliance rates and congestion levels and found that the operational benefits depended on these two factors. The system had the highest operational benefits during lightly congested traffic conditions, little benefit during uncongested conditions, and no benefit during heavily congested conditions.

Also impact of DSLs on traffic safety was assessed by means of simulation models in a number of papers. We briefly discuss them. Lee et al. (2004) used a real time crash prediction model integrated with a microscopic traffic simulation model. They found that temporarily reducing speed limits during risky traffic conditions can reduce the crash potential. The greatest reduction occurred at the location with a high traffic turbulence. Abdel-Aty et al. (2006a,b) studied how traffic safety could be increased at a motorway in Orlando. They found DSLs can be used to improve safety, through the implementation of lower speed limits upstream and higher speed limits downstream of the location where crash likelihood is observed in real time. This improvement was present in the case of medium-to-high-speed regimes but not in low-speed situations. They furthermore analysed the potential for crash migration and found that the crash potential relocates to a location downstream of the detector of interest. Overall the safety of the freeway was improved (Abdel-Aty et al., 2006a,b). In a later study, Abdel-Aty et al. (2008) continued on this research and found that DSLs can be used to reduce crash risk and prevent crash occurrence in free-flow conditions and conditions approaching congestion. Habtemichael and de Picado Santos (2013) found however somewhat different results. In their study the most favourable traffic safety effects were found during highly congested traffic conditions, followed by lightly congested conditions and the least during uncongested situations. Furthermore, they found that the effects are highly dependent on the level of driver compliance.

Lee et al. (2006) studied the safety benefits of DSLs and used simulated traffic conditions on a freeway in Toronto. They found that real time DSLs can reduce the overall crash potential by 5%–17%. Also Islam et al. (2013) analysed this impact. They proposed a model predictive DSL control strategy. The safety impact was quantified through a real time crash prediction model for an urban freeway corridor in Alberta. The results indicated that the DSL can improve safety by 50%.

2.2. Field studies

The effect of DSL systems was also analysed through empirical studies. Lu and Shladover (2014) reviewed evidence from field studies that assessed effects on traffic flow and traffic safety in the UK, Germany, the Netherlands, France and the United States. The effects reported on traffic operations were mixed. Some authors reported a reduction of travel times (Chang et al., 2011; Hoogendoorn et al., 2013). Some studies reported an improvement in throughput (Chang et al., 2011; Kwon et al., 2007), but others not (DeGaspari et al., 2013). Papageorgiou et al. (2008) reported that effects on traffic flow are highly dependent on the saturation level of traffic with improved traffic flow at overcritical occupancies (dense traffic), but deteriorated traffic flow efficiency (lower average speeds) at undercritical traffic conditions.

Multiple studies reported favourable effects on road safety for the implemented VSL strategies, but interestingly, none of the field studies that assessed effects on traffic safety has been published in peer reviewed journals and their methodological rigour is hard to assess. The road safety literature (Hauer, 1997; Elvik, 2002) has extensively reported that accident studies that don't take into account confounding

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