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Safety and environmental benefits of intelligent speed bumps

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Abstract

Speed bumps are a common speeding prevention measure used to protect vulnerable road users, i.e. pedestrians and cyclists, near crosswalks in urban areas. They are also used to reduce traffic volumes, prevent overtaking, and allow a change in driving routine. However, conventional speed bumps have certain shortcomings, such as reduced driving comfort for all road users, potential vehicle damage and associated repair costs, delays for emergency vehicles and public transport vehicles, longer travel times and congestion, difficulties with snow removal in winter, the formation of ruts and potholes before or after such obstacles, and an increase in fuel consumption, traffic noise, and emissions of harmful gasses during braking and accelerating. Consequently, in recent years, intensive work has been done to solve the above problems by developing so-called intelligent speed bumps. Although evaluating the performance of these intelligent speed bumps in real-world environments is not yet widely available in scientific research, numerous patents have been filed in this field over the years. This paper provides an overview of several intelligent speed bumps that have been developed in recent years and discusses the results of investigations conducted on one such speed bump that is already widely used in practice.

Keywords: Traffic calming; Intelligent speed bumps; Vulnerable road users; Road safety; Environment.

1. Introduction

Road safety is a current issue all over the world. The most common cause of road accidents is excessive speed (Pérez-Acebo et al. (2020), Mei and Wang (2021)), and the number of people died in road accidents continues to increase worldwide (European Commission (2019)). According to WHO (2018), there were 1.35 million deaths only

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in 2016. Compared to the global situation, Europe is doing relatively well thanks to measures taken at national, regional, and local levels. Statistics for the European Union (EU) show that the number of traffic fatalities decreased by 43% between 2001 and 2010, and by another 21% between 2010 and 2018 (European Commission (2019)). According to European Commission (2022), nearly 19,800 people died in traffic accidents in the EU in 2021. Pedestrians and cyclists are defined as vulnerable road users and are particularly at risk in road accidents in urban areas (Plămădeală (2019)). Unfortunately, progress in reducing road deaths and injuries in the EU has stagnated in recent years, and in some countries with satisfactory road safety statistics, the number of road deaths has recently increased again (European Commission (2019)). This progress has slowed for several reasons, including a slight increase in cyclist fatalities in urban areas (European Investment Bank (2021)). For this reason, the EU has adopted the "Vision Zero" and the "Safe System" approach to reduce the number of fatalities and serious injuries on European roads. This approach refocuses road safety policy by emphasizing the prevention of fatalities and serious injuries (European Commission). It offers a combination of measures to reduce road fatalities, such as safer road infrastructure, safer vehicles, and measures to address speeding, alcohol use, seat belt use, and helmet use for cyclists (European Investment Bank (2021)).

A common speeding prevention measure used worldwide to protect vulnerable road users and ensure their safety in urban areas is the use of traffic calming devices, i.e. speed humps and speed bumps (Al-Haji et al. (2018), Pérez-Acebo et al. (2020)). These devices are usually installed in residential areas, near hospitals, schools, parking lots, or street intersections, but are not suitable for use on emergency or public transport routes (Damsere-Derry (2020), Džambas et al. (2020), Mei and Wang (2021), Lin and Ho (2022)).

Each type of traffic calming device has a different impact on mobility, accessibility, safety, cost, etc. (Al-Haji et al. (2018)). Apart from speed reduction, which can range from 20 to 40%, these devices are also used to reduce the number of traffic accidents (by 50-79%), especially those involving pedestrians and cyclists, and mitigate their consequences. Moreover, they can reduce traffic volumes, prevent overtaking, and enable a change in driving routine. They are easy to install and require low installation and maintenance costs (Al-Haji et al. (2018), Džambas et al. (2020), Mei and Wang (2021), Lin and Ho (2022)).

Despite all the above advantages, the use of traffic calming devices also has certain disadvantages. These are: reduced driving comfort for all road users; delays of emergency vehicles and public transport vehicles (up to 10 s per obstacle); possible vehicle damage and related repair costs; longer travel times and congestions; difficulties in snow removal in winter; formation of ruts and potholes before or after such obstacles; higher fuel consumption (by 40-50%); increase in traffic noise and emissions of harmful gasses due to braking and acceleration (CO increases by approx. 60 %, HC by approx. 50 % and CO_2 by approx. 25 %), etc. (Al-Haji et al. (2018), Plămădeală (2019), Damsere-Derry (2020), Džambas et al. (2020), Mei and Wang (2021), Lin and Ho (2022)). Therefore, these conventional traffic calming devices are often criticized by road users in urban areas around the world.

In recent years, intensive work has been done to solve the above problems by developing so-called intelligent traffic calming devices, or more precisely, intelligent speed bumps. Although evaluation of the performance of these intelligent speed bumps in real-world environments is not yet widely available in scientific research, numerous patents have been filed in this area over the years. This paper provides an overview of several intelligent speed bumps that have been developed in recent years and discusses the results of investigations conducted on one such speed bump that is already widely used in practice.

2. Intelligent speed bumps

An alternative to conventional traffic calming devices are so-called intelligent speed bumps. Al-Haji et al. (2018) explained in their study that these new types of speed bumps are usually defined as dynamic. Namely, when a road user with excessive speed is detected, the intelligent speed bump performs the appropriate actions to reduce the driving speed, but when the driver adheres to the speed limit, the speed bump does not perform any actions. The speed and type of approaching vehicles are detected by various systems, such as loop sensors on the road or speed radar. Therefore, these speed bumps can remain deactivated if the system detects an emergency vehicle or a public transport vehicle.

Mei and Wang (2021) listed some of the benefits of intelligent speed bumps. They are as follows: increased traffic safety for vulnerable road users (pedestrians and cyclists); a more pleasant driving experience for drivers who obey the speed limit (increased driving comfort and reduced risk of vehicle damage due to the compression movement between the wheel and the vehicle body, which usually occurs with conventional speed bumps); improved traffic flow; fewer delays of emergency vehicles and public transport vehicles. Damsere-Derry (2020) also pointed out that these special speed bumps can reduce traffic noise and air pollution caused by unnecessary braking and acceleration, which are typical of conventional traffic calming devices.

2.1. Overview of developed intelligent speed bumps

Mei and Wang (2021) proposed an intelligent dynamic speed bump which can detect the type and speed of the vehicle and adjust its height depending on the vehicle speed. A physical scale model and a computer simulation model were created to obtain relevant data on comfort, safety, and deceleration effect (Fig. 1.). Each emergency vehicle was equipped with an RFID identification card. When the approaching emergency vehicle passed the speed measurement module (SMD), the microcontroller unit (MCU) received the information from the RFID identification card and the speed bump remained disabled. On the other hand, when other vehicles passed the speed measurement module (SMD), the microcontroller unit (MCU) determined the appropriate height of the speed bump based on the vehicle speed. The speed was determined by the two ring coils integrated into the roadway, and the raising or lowering of the speed bump was performed by a hydraulic pump. The authors took the vertical acceleration of the vehicle body as an evaluation parameter for the deceleration effect and simulated the relationship between the speed and the deceleration effect at different heights of speed bump. Relevant data showed that the vertical acceleration, which is uncomfortable for the human body, is about 4 m/s². They concluded that a larger acceleration could cause damage to the vehicle body and endanger the safety of the driver, and that too small an acceleration would not achieve the intended warning effect. The simulation result showed that the height of the speed bump should be reduced if the incoming vehicle speed is too high. Preparations for tests on real road sections are underway.

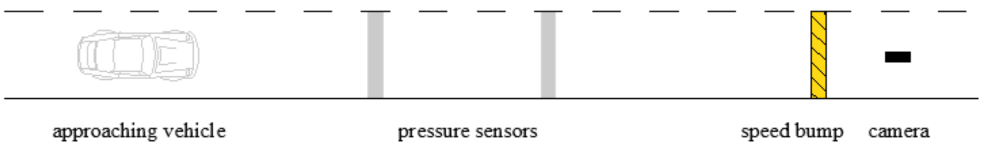

Fig. 1. Intelligent speed bump proposed by Mei and Wang (2021).

Lin and Ho (2022) presented an intelligent speed bump with license plate recognition system and pressure sensors that can detect the type and speed of the vehicle and consequently activate or deactivate the speed bump in question. The authors conducted experiments with a miniature prototype system to simulate real-world application scenarios. The camera was placed in front of the speed bump to record video sequences, and the vehicle speed was determined based on the activation time difference of the pressure sensors with a fixed distance. Four springs were used to hold the speed bump structure in its rest position. These springs were compressed and restored when the speed bump was not activated. When the vehicle speed was within a predefined range or the license plate was authorized for quick access, the speed bump was deactivated to provide a safer and more comfortable driving experience. In the future, the authors plan to set up an information system with a database to retrieve and match license plates.

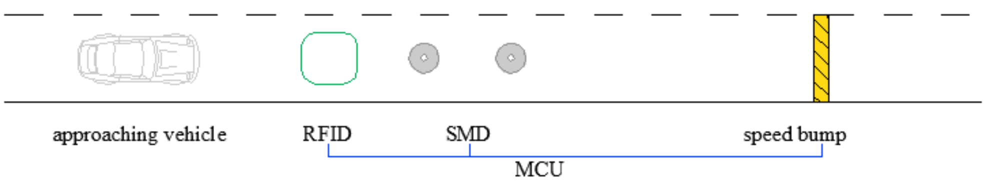

Fig. 2. Intelligent speed bump proposed by Lin and Ho (2022).

Two manufacturers from England (MAT Foundry) and Spain (Badennova) have proposed liquid speed bumps. The fluid inside the speed bump has the properties of a non-Newtonian material that is normally in a liquid state, but changes to a solid state upon impact at high speed, meaning that the hardness of this viscous fluid depends on the vehicle speed. At low speed the fluid turns into a lubricant and fills all the gaps between the particles, while at high speed it increases its viscosity due to increased friction. Therefore, when the vehicle passes the obstacle while respecting the speed limit, the speed bump does not show any resistance and does not cause any damage to the vehicle or discomfort to the driver. When the vehicle exceeds the speed limit, the fluid slows the vehicle down. By varying the amount and chemical composition of the fluid, it is possible to control at what speed the hardening provides the resistance needed to get drivers to slow down. Data on the use of these speed bumps in practise are not known to the authors of this paper.

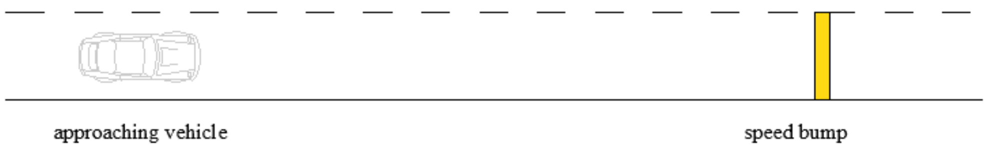

Fig. 3. Intelligent speed bump proposed by MAT Foundry and Badennova.

Edeva, a company from Sweden, has invented an active speed bump, also known as Actibump. The Actibump's detection system, which is a speed radar or inductive loop, measures the speed of an approaching vehicle. The control unit registers the speed of each vehicle and determines whether it can pass unimpeded or whether it must slow down. If the driver adheres to the speed limit, the roadway remains flat. If the driver drives too fast, the surface panel, which is controlled by rollers and the motor in bump's hatch, sinks a few centimeters into the road. This clearly reminds the driver to slow down, not only at that moment, but every time he passes that point in the future. Actibump thus provides direct feedback with a quick learning effect that immediately improves behaviour and increases road safety. In addition, emergency vehicles can be detected and pass unhindered. With a transponder accessory, a selected vehicle (e.g. an emergency vehicle) can exceed the speed limit without activating the Actibump. Each installed Actibump is monitored via the EdevaLive cloud service, which collects data from the speed radar on speeding, average speed, 85th percentile speed, and speed distribution and displays it in a web interface.

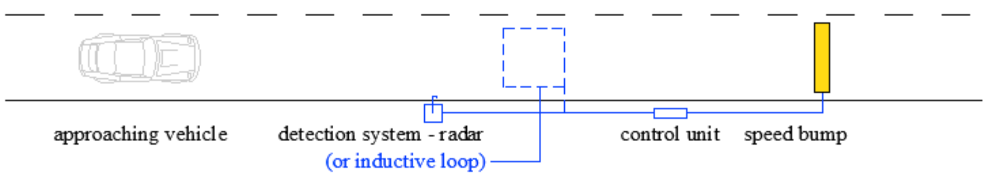

Fig. 4. Intelligent speed bump proposed by Edeva.

The Actibump has been used in Sweden, Australia, Norway, and Iceland in recent years, and its introduction is planned in some other European countries, such as Denmark and France, as well as in other parts of the world. Moreover, this is one of the few developed intelligent speed bumps that have been studied in real-world environments. The following text discusses the results of Actibumps research conducted by Edeva at two sites in Sweden.

2.2. Investigations of Actibumps

The Actibump was investigated in two studies conducted in Sweden with regard to its effects on reducing driving speed and drivers' yielding behaviour toward vulnerable road users i.e., pedestrian and cyclists (Edeva AB (2015), Edeva AB (2016)). These studies were conducted by Trivector Traffic AB on behalf of Edeva, the company that invented the Actibump. The first study (Edeva AB (2015)) was conducted near the crosswalk at one of the road intersections on Dag Hammarskjölds väg St. in the city of Uppsala. At this particular location, Dag Hammarskjölds väg St. has one northbound lane and two southbound lanes, as well as a median between the two driving directions. The crosswalk in question is located on the north side of the intersection. Two Actibumps were placed on the south side of the intersection (South - lanes 1 and 2), and one Actibump was placed in front of the crosswalk on the north side of the intersection (North - lane 3). The speed limit during the day when the measurements were made was 30 km/h. The second study (Edeva AB (2016)) was conducted near the crosswalk at one of the road intersections on Djurgårdsgatan St. in the city of Linköping. At this particular location, Djurgårdsgatan St. has one northbound lane and one southbound lane, as well as a traffic island in the vicinity of crosswalk. The crosswalk in question is located on the north side of the intersection. One Actibump was placed on the south side of the intersection (South - lane 1), and one Actibump was placed in front of the crosswalk on the north side of the intersection (North - lane 2). The speed limit is now 40 km/h, compared to 50 km/h before the introduction of the Actibump.

As shown in Fig. 5., the average driving speed at both study sites decreased after the installation of the Actibumps (Edeva AB (2015), Edeva AB (2016)). At the first site, the speed reduction was 3.7 to 6.5 km/h and at the second site, it was 10.0 to 11.1 km/h. However, it should be noted that at the second site, the speed limit before the installation of the Actibumps was 10 km/h higher than the speed limit after the installation of the Actibumps. It can also be seen that vehicles at the first location were travelling at average speeds that were fairly close to the legal speed limit (average speeds were up to +4 km/h higher than the legal speed limit before the installation of the Actibumps and up to -4 km/h lower than the legal speed limit after the installation of the Actibumps), while vehicles at the second location were travelling at average speeds that were approximately 9 km/h lower than the legal speed limit both before and after the installation of the Actibumps.

As noted in the study (Edeva AB (2018)), a traffic safety measure is generally considered successful when the 85th percentile speed is consistent with the ±3 km/h speed limit. At the first site in the city of Uppsala, the 85th percentile speed of free vehicles decreased from 40 km/h to 32 km/h. The percentage of drivers exceeding the 30 km/h speed limit was 75% before the introduction of Actibumps and 21% after the introduction of Actibumps. At the second site in the city of Linköping, the 85th percentile speed of free vehicles decreased from 47.2 km/h to 37.0 km/h. The percentage of drivers exceeding the 40 km/h speed limit was 6% after the introduction of Actibumps. Before the introduction, when the speed limit was 50 km/h, 55% of drivers exceeded the 40 km/h speed limit.

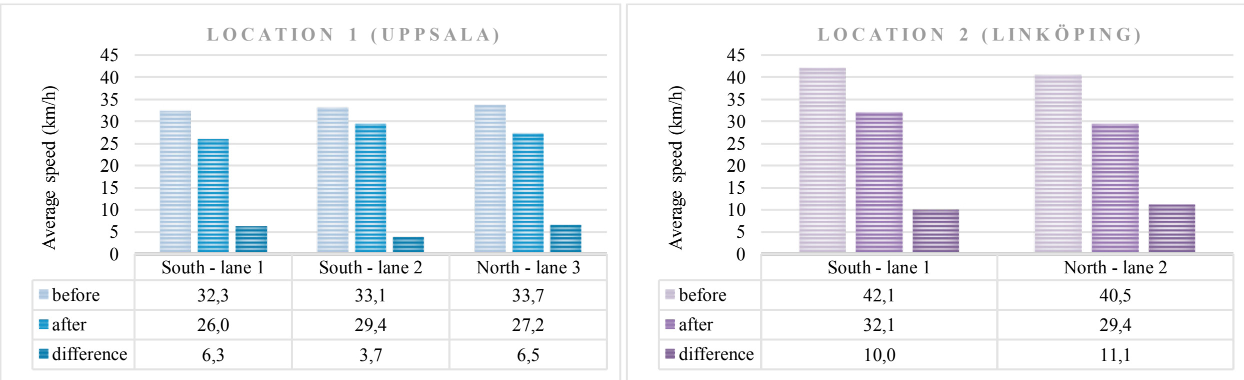

Fig. 5. Average vehicle speeds before and after implementation of Actibump (a) in Uppsala, Sweden (Edeva AB (2015)); (b) in Linköping, Sweden (Edeva AB (2016)).

As shown in Fig. 6., the percentage of drivers yielding the right-of-way to weaker road users at the crosswalks increased after the installation of the Actibumps at both study sites, but not equally in both driving directions (Edeva AB (2015), Edeva AB (2016)). At the first location, the percentage of drivers yielding the right-of-way to weaker road users increased by 35% in the southbound lanes (lanes 1 and 2) and by only 5% in the northbound lane (lane 3). At the second location, the situation was pretty much the same. The percentage of drivers yielding the right-of-way to weaker road users increased by 14% in the southbound lane (lane 1) and by only 6% in the northbound lane (lane 2). On these northbound lanes, where drivers failed to yield the right-of-way to pedestrians and cyclists to a greater extent, Actibumps were installed immediately in front of the crosswalks in question.

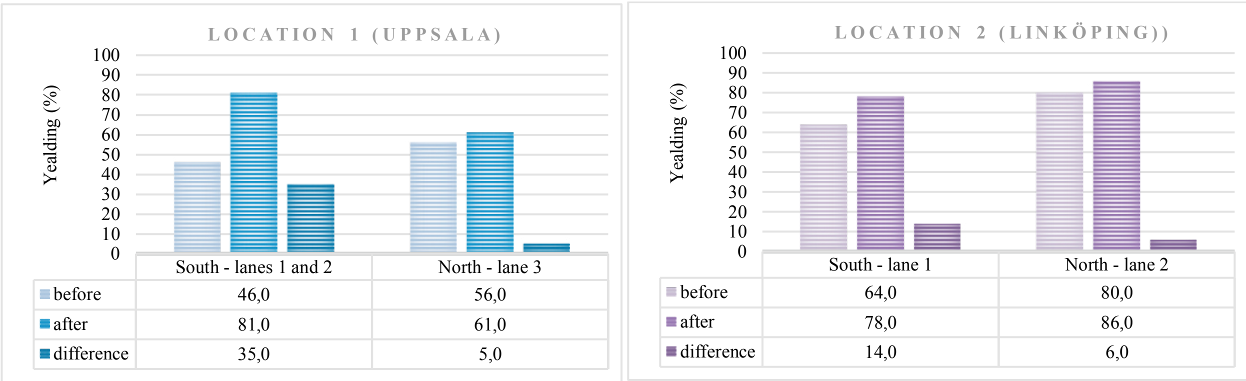

Fig. 6. Share of drivers yielding towards vulnerable road users before and after implementation of Actibump (a) in Uppsala, Sweden (Edeva AB (2015)); (b) in Linköping, Sweden (Edeva AB (2016)).

4. Discussion and conclusions

Speed bumps are a common speeding prevention measure used worldwide to protect vulnerable road users, i.e., pedestrians and cyclists, near crosswalks in urban areas. Speed bumps are also used to reduce traffic volume, prevent overtaking, and allow a change in driving routine. Their main shortcomings are reduced driving comfort for all road users, possible vehicle damage and related repair costs, delays to emergency vehicles and public transport vehicles, longer travel times and congestion, difficulties with snow removal in winter, the formation of ruts and potholes before or after such obstacles, and an increase in fuel consumption, traffic noise, and emissions of harmful gasses from braking and accelerating.

In recent years, intensive work has been done to solve the above problems by developing so-called intelligent speed bumps. When a road user is detected speeding, the intelligent speed bump will perform the appropriate actions to reduce the driving speed. However, if the driver adheres to the speed limit, these speed bumps do not perform any actions and the roadway remains flat. Therefore, these speed bumps provide a more pleasant driving experience for drivers who adhere to the speed limit. Although evaluating the performance of these intelligent speed bumps in real-world environments is not yet widely available in scientific research, numerous patents have been filed in this area over the years.

The intelligent speed bumps proposed by Mei and Wang (2021), Lin and Ho (2022), and Edeva are quite similar in operation. Namely, they can detect the speed and type of approaching vehicle with various detection systems and activate the speed bump through control devices. Although the activation mechanisms of these speed bumps differ, the final effect is the same, i.e., they create an obstacle on the roadway by raising or lowering the speed bump. In addition, these systems are capable of detecting emergency vehicles and/or public transport vehicles and allowing them to pass unimpeded over the deactivated speed bump, i.e., flat roadway. The intelligent speed bumps proposed by MAT Foundry and Badennova are made of a fluid that has the properties of a non-Newtonian material that is normally in a liquid state but changes to a solid state upon impact at high speed. In other words, this intelligent speed bump does not require detection systems and control units, and therefore cannot detect the type of approaching vehicle. In this study, the results of Actibump research conducted by Edeva were analyzed, as it is one of the few developed intelligent speed bumps that have been studied in real-world environments.

The Actibump has been investigated in two studies conducted in Sweden with regard to its effects on reducing driving speed and drivers' yielding behaviour toward vulnerable road users. The research results showed that average speed and 85th percentile speed decreased at both study sites (average speed decreased up to 11.1 km/h and 85th percentile speed decreased up to 10.2 km/h) and that the percentage of drivers exceeding the speed limit was significantly lower (as much as 54 %) after the introduction of Actibump. However, the percentage of drivers yielding the right-of-way to weaker road users at the crosswalks increased after the Actibumps were installed at both study sites, but not equally in both driving directions. Indeed, when the Actibumps were installed immediately in front of the crosswalks in question, drivers failed to yield the right-of-way to pedestrians and cyclists to a greater extent (the percentage of drivers yielding the right-of-way to weaker road users increased by only 5 to 6%).

In light of the above considerations, the following conclusions can be drawn. The use of intelligent speed bumps such as Actibump can certainly contribute to speed reduction in urban areas and lead to a more pleasant driving experience for drivers who obey the speed limit, improved traffic flow, fewer delays to emergency vehicles and public transport vehicles, and reduced fuel consumption, traffic noise, and air pollution caused by unnecessary braking and acceleration. On the other hand, it is questionable whether these devices can oblige drivers to yield the right-of-way to weaker road users at crosswalks to a greater extent, since they can only force them to drive below the legal speed limit, which is usually set at 30 or 40 km/h. In addition, conventional speed bumps will probably continue to be used predominantly due to their low installation and maintenance costs. As stated in the Edeva brochure (Edeva AB (2023)), the cost of an Actibump installation for two lanes is about € 50,000 and the technical lifetime of an Actibump is about 10-12 years.

The authors of this paper believe that the possibility of installing such intelligent speed bumps should also be considered in Croatia, but with clear recommendations for their installation. Indeed, a large number of different types of conventional speed bumps and speed humps are installed in this country, and it is obvious that those responsible in municipal institutions do not coordinate on their selection. A potential problem may be that there are no universal guidelines to help select the appropriate type of traffic calming devices in a given location, and only a relatively small number of previous studies have focused on evaluating their effectiveness and their safety and environmental benefits.

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