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Implementation of *Weigh-in-Motion* system in freight traffic management in urban areas

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Abstract

The article presents how the Weigh-in-Motion system can be used for managing Gdynia's freight traffic. Potential sites for weight pre-selection were identified in an analysis of the technical and location conditions. Situated directly in the east part of the Port of Gdynia a site was selected for a pilot implementation. Theoretical scenarios were simulated using an extended WIM system as a tool for controlling access to selected parts of the city. The results suggest that emissions can be reduced and traffic flows can be improved. The scenarios, however, are very general in character and should only be seen as an introduction into further and more detailed analyses to give a fuller understanding of the problem and the objectives of urban transport policy. In the Authors' opinion this work must be complemented with a verification of how the WIM can be introduced in Gdynia in formal and organisational terms. This should build on the experience from the CIVITAS "Dyn@mo" project. A number of statutory changes are required to allow local authorities to make a full use of the potential of WIM systems.

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Keywords: Weigh in Motion; traffic management; urban freight; traffic modelling; transport policy

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1. Introduction

Road traffic management in urban areas must rely on solutions that reflect the complexity of the problem. This includes the different needs of transport system users, demand for infrastructure and the relevant inter-relations. The latter may lead to a number of undesired phenomena. In the case of freight transport, the possible impacts may be the result of overloaded vehicles. This is particularly acute in the case of heavy goods vehicles operating on long hauls.

The problem of overloaded vehicles affects road traffic and urban transport policy in a number of ways. It leads to extensive wear and tear on roadways and puts other road users at risk. In functional terms, it also affects a city's policy on allowing heavy goods vehicles to specific parts of town. In an effort to reduce the number of overloaded vehicles and control access, a system can be used using the *Weigh in Motion* technology.

Considering the factors above, the article looks at how Gdynia could use the *Weigh in Motion* (*WIM*) system as an element of its transport policy designed to rationalise freight transport. The results that follow were produced in CIVITAS "Dyn@mo", a project in which Gdynia is the leader of a national consortium of partners.

The first part of the article presents a functional outline of WIM systems and the main reasons why they make sense. It also gives an outline of a single European standard which includes organisational recommendations. This is mentioned because of some formal requirements that were decisive for Gdynia's pilot implementation of the WIM system. Next, an overview of the procedure is given for selecting the pilot WIM location close to the Port of Gdynia. In part three of the article a model analysis is made of how the extended WIM system could be used as a tool of urban transport policy for controlling heavy goods vehicle access to selected areas of the city. This is the first time this analysis was conducted for Gdynia's freight transport system. Cities do not have effective tools for analysing and verifying such solutions (Kaszubowski, 2014). This is why efforts should be taken to develop effective methods to aid decision-making in the area of urban freight transport. The analysis is based on a comparison of theoretical control scenarios and how they affect traffic parameters and emissions (e.g.: CO_2). It is designed as a point of departure for detailed analyses using the tools developed in "Dyn@mo", i.e. a three-level transport model that has been extended with freight transport supply and demand data. The article ends with an analysis of formal and organisational conditions that determine the effectiveness of WIM on urban streets and a set of conclusions.

2. Overview of Weigh-in-Motion systems

2.1. Application areas of automatic weighing systems in transport

Weigh-in-motion systems (WIM) are designed for unobtrusive and continuous collection and monitoring of vehicle weight information. The range of collected data may vary from precise individual weight measurements for each heavy vehicle to aggregate vehicle weight profiles for selected road sections. WIM applications range from data collection for the determination and scheduling of maintenance activities to weight-related toll-fare pricing strategies and overweight vehicle detection possibly diverting the traffic to alternate routes (Yannis and Antoniou, 2005).

One of the most important drivers for WIM systems application is reduction of road surface deterioration caused by overloaded vehicles, especially when the control system is insufficient. Recent analysis has shown, that an increase of percentage overloaded vehicles from 0% to 20% can reduce the fatigue life of asphalt pavement up to 50% (Rys et al., 2015). Higher level of enforcement towards overloaded vehicles may however result in shifting of the freight that was being moved on overloaded vehicles onto vehicles compliant with regulations (Stephens et al. 2003). But it can be assumed that much less pavement damage is incurred in this situation, because the damaging effect of axle increase with relative increase of its load to the power of four.

Another domain where Weigh-in-Motion systems prove their effectiveness is improving truck safety. Overloaded trucks pose serious threats to road transportation operations with increased risks for road users, deterioration of road safety and on fair competition between transport modes and operators (Jacob and Feypell-de La Beaumelle, 2010). Of course, there are also severe impacts on the durability of infrastructure, i.e.: pavements and bridges, which influence road safety in general. When the current load exceeds the maximum permitted limit of a truck, several adverse consequences may occur:

1. Truck instability - an overloaded vehicle is instable because of the increased height at the centre of gravity. When truck's on-board stability systems are overstrained, the risk of rollover, lane departure or knife-jacking is increased
2. Braking - any weight in excess reduces the braking capacity of a truck and may even damage the braking system
3. Loss of manoeuvrability - an overloaded vehicle becomes under-powered resulting in lower speeds on up-hill slopes and over-speeding down the slope. Overtaking also takes longer incurring risks for other road users
4. Overloads can induce tire overheat
5. When dangerous goods are transported, overloads increase both risk and severity of any road incident

Actual axle loads for HGV's and gross vehicle weight can be measured with several systems, presented in Fig. 1 (Zindaric, 2015).

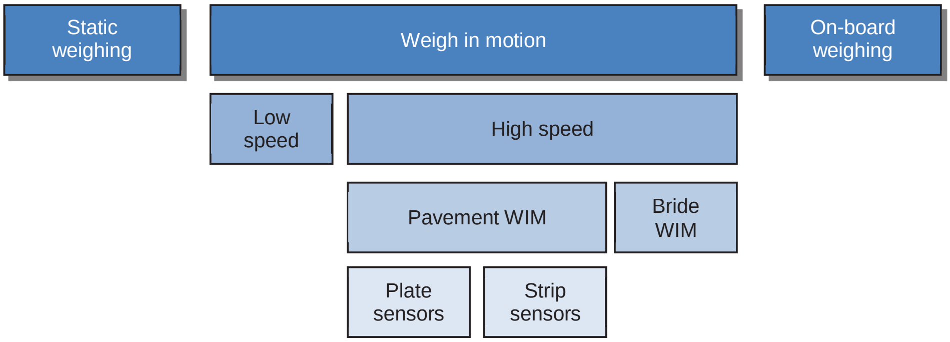

Fig. 1 Division of weighing systems

Static weighing is the most accurate method for vehicle weighing. There are three types of devices used for weighing: weighbridges, axle weighers, wheel weighers.

The weighbridges in Europe are rarely used exclusively for overloaded enforcement, unlike in the US. The main reason for this is the high construction and operational cost and large area of surface they require. The devices must be legally certified and regularly calibrated. The axle and wheel weighers are more common in Europe. They provide data on the axle loads, but their accuracy is lower than the weighbridges because vehicle manoeuvres over them can cause considerable redistribution of the loading.

To perform a low-speed WIM (LS-WIM) measurement, the speed of the vehicle must be within 5 to 10 km/h (Zindaric, 2015), which could be assumed as optimal range. Technical specifications of the WIM systems adopt maximal speed for LS-WIM at 20km/h (Jacob et al., 2002). Moreover, accelerating and braking is not allowed during the measurement process, so as to discount the dynamic behaviour of the moving vehicle. Because of this LS-WIM systems are suitable for operation in controlled areas outside main traffic flows to provide acceptable level of accuracy. Due to elimination of vehicle dynamics influence, LS-WIM systems are reasonably accurate - up to 1% for gross vehicle weights for 95% of measurements. In a few European countries such as Germany and France the LS-WIM systems are used for direct enforcement.

High-speed Weigh-in-Motion systems are often called a WIM system. They measure the dynamic axle loads of the vehicles passing at normal road speed under controlled conditions and calculate the best possible approximation of its static axle weights. Typically WIM systems provide data on: axle loads, axle group load, gross vehicle weight, number of axles, length of the vehicle, axle distances, speed and vehicle class. In general, WIM systems can be divided into two main categories (Honefanger et al., 2007):

1. External structures, either a road surface or a bridge, which is the physical framework for a WIM sensor and transfers the axle loads of the passing vehicle to the sensor without damaging the sensor material.
2. Sensor or transducer that converts the axle load into an electrical signal. The most common sensing technologies are piezo-electric or piezo-quartz materials, strain gauges and fibre optics.

From the combination of the two aforementioned technologies two different types of WIM installation may emerge:

- Pavement WIM systems, which are the main subject of this paper, and
- Bridge WIM systems

A typical pavement WIM installation consists of inductive loops that measure vehicle speed and detect vehicle type and length. Based on the width of the sensors, they are divided into two groups: plate sensors and strip sensors. Under typical conditions, plate sensors provide more accurate results than strip sensors. This comes at a cost of a more difficult installation. It cannot be done under traffic and typically requires two day road closure. Strip sensors can be installed in less than one day, making it a better option when road closure is difficult due to heavy traffic or lack of alternate roads. The main advantages of strip sensors are that they are a proven technology and provide relatively high accuracy on smooth road surfaces. However, their accuracy suffers as the road surface deteriorates, which happens particularly if they are built into flexible pavements such as asphalt with relatively weak sub-base. (Zindaric, 2015). Besides sensors based on stress caused by passing vehicle, also other technologies were tested to assess the vehicle weight and axle load. One of them is in-pavement wireless WIM, that estimates the weight of moving vehicles from pavement vibrations. Tests in selected spots in California proved this technology meets standards commonly used in the United States (Bajwa et al., 2013). Also microwave WIM sensors has been tested in laboratory conditions, where they achieved high measurement accuracy and uniformity (Liu et al., 2007).

The main idea of Bridge-WIM (B-WIM) is to put most of the measurement devices under the bridge, instead of its road surface (Žnidarič et al., 2015). B-WIM allows to weigh vehicles at highway speeds. A bridge is instrumented with strain transducers and in some cases other additional sensors which measure the bridge response due to heavy vehicles driving over it. The main advantages of Bridge-WIM systems are:

- Complete portability, without affecting accuracy
- High accuracy, especially on smooth road surfaces
- Ease of installation without interruption of traffic
- Unavoidability of bridges, so traffic must cross it
- Provision of structural information for advanced bridge assessment.

As a result of intensive research over the last two decades significant progress has been made in B-WIM accuracy and they can compete successfully with pavement WIM.A number of different algorithms has also been developed. They use full i.e.: Moving Force Identification (Gonzalez et al., 2008), wavelets (Chatterjee et al., 2006), (Hester and Gonzalez, 2012), but they have not been implemented in any available commercial B-WIM system (Žnidarič et al., 2015).

Apart from weighing used on the roads, WIM systems are also used in railway transport. An accurate estimation of the axle loads and a correct detection of overloads, imbalances and defects are a primary concern for railways management companies, because traffic safety and planning of track maintenance (Allotta et al., 2015).

Transportation management authorities tasked with managing freight transport, creating and evaluation of policy measures depend on availability and quality of vehicle data. In most cases, there are critical gaps when it comes to liking vehicle and operational characteristics, which are required for development of effective policies aimed at reduction of adverse effects of a freight transportation on infrastructure and environment (Hernandez et al., 2016). This is the case also in Gdynia, where urban freight policy does not fully respond to the characteristics of freight movements (Kaszubowski, 2016).

This opens new possibilities for utilization of WIM systems. However, they are one of the most costly and sophisticated data collection systems available for transportation authorities. How to effectively utilize the valuable WIM data beyond basic enforcement is the critical question underlying its implementation as a road freight transport policy measure. Recent research attempts to match commercial vehicles based on axle spacing and axle weights collected at WIM stations, which can help calibration of WIM sensors and estimation of truck activities such as travel times, origins-destination (OD's), empty truck movements and trip length estimation (Jeng and Chu, 2015). Different other solutions such as GPS and RFID can provide origin-destination tracking and performance statistics, but they require close cooperation with the logistics industry (NCFRP Report 25, 2013). This involves significant data privacy and cost concerns, that limit their feasibility (Fries et al., 2012). WIM systems are free from this limitations, but require accompanying technologies and algorithms to unveil their potential.

One of such application is tracking heavy vehicles based on weigh-in-motion and inductive loop signature technologies (Jeng and Chu, 2015). It is based on re-identification of individual vehicles and linking this information to data obtained from WIM stations. The information obtained from the inductive loop signature-based detection system (i.e. section travel time, section speed, vehicle classification, origin-destination, etc.) together with the WIM data (i.e. vehicle length, axle spacing, axle weights, etc.) can be applied to estimate truck activities and consequently, to evaluate policy measures regarding freight vehicles.

Another application integrating two complementary data collection devices, WIM systems and inductive loop detectors is aimed at production of high resolution truck data. For each vehicle traversing a WIM site, and inductive loop signature is collected and along with WIM measurements such as axle spacing and weight could be used as input to identify truck body type (Hernandez et al., 2016). Since truck body type can be matched with commodity carried and other operating characteristics, body class identification could be very useful in freight transport planning. Recent research in the USA show that correct classification rates in different vehicles classes reach 80-85%.

2.2. Requirements for common WIM standard in Europe

Successful implementation of WIM system requires common standard providing access to a wide array of technology solutions as well as transferable organizational schemes required to fully utilize its potential. Adaptation of unified regulations may increase the inclination of the producers to offer technology solutions at lower prices due to higher potential of their implementation. Moreover, decision makers will receive a set of guidelines to verify their capacity regarding WIM installation and potential barriers to overcome to fully utilize the system's potential. At the moment there are three existing international sets of specifications on WIM (Jacob and Loo, 2011):

1. The COST323 European WIM Specification ((Jacob et al., 2002). It applies to both Low and High speed WIM systems. It is widely used around the world by users and manufacturers. Although formally it is not an official international standard it is widely used as a reference in the testing and acceptance of WIM systems
2. The ASME E-1318 "Standard Specification for Highway Weigh-in-Motion Systems with User Requirements and Test Methods" (Astm, 2002). It defines four different types of WIM systems and is intended to facilitate the relationship between a buyer and a vendor
3. The OIML R-134 from the International Organisation for Legal Metrology is a recommendation for "Automatic Instruments for weighing road vehicles in motion". It is intended only for LS-WIM and weighing in controlled environment - in restricted areas and not on main roads
4. The Measuring Instrument Directive (European Commision, 2004) is the EU directive regulating the construction and certification procedures of several measuring instruments in order to improve free trade of these devices across Europe. The MID is a European framework for type and product approval, and recently the OIML R-134 has been included into MID

Proposed structure of WIM standard is presented at Fig. 2 (Jacob and Loo, 2011).

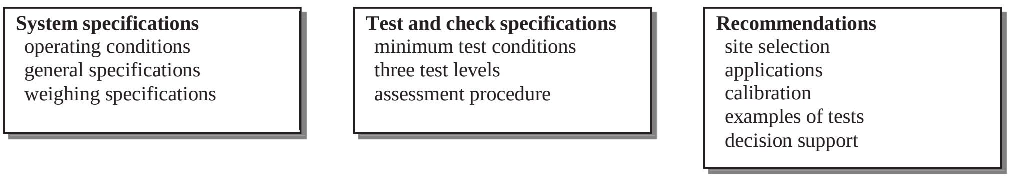

Fig. 2 Draft structure of the EU WIM standard

A detailed presentation of system specifications and test and check procedures is outside the scope of this paper. However, the recommendations section is clearly linked to the situation of WIM implementation in Gdynia. It is a non-mandatory part of the proposed WIM standard but it would contain very useful practical information on the installation and operation of WIM systems based on international examples. It contains information on site selection, possible applications, calibration etc., but also decision support procedures and data storage and transmission requirements. The latter could be useful during preparation of WIM pilot implementation in Gdynia, especially regarding the definition of responsibility sharing between several authorities and enforcement procedures. On the other hand, the example of Gdynia's pilot WIM implementation could be included into the recommendations enhancing their practical usefulness.

3. Concept of pilot High-Speed WIM implementation in Gdynia

3.1. Actual HGV's traffic volumes distribution

The point of departure for selecting WIM locations in Gdynia was to analyse the existing HGV traffic and identify the busiest streets. The following vehicle categories were analysed: lorries without trailers, lorries with trailers or semi-trailers and buses. The results were referred to the estimated share of overloaded vehicles in accordance with data from Poland’s existing WIM systems. Finally, the choice of WIM sites was made with reference to:

1. Average daily heavy vehicles traffic in Gdynia
2. Structure of heavy vehicle traffic
3. Number of overloaded vehicles
4. Technical conditions of road and roadway condition
5. Road rank and type of traffic (local, transit)

Heavy vehicle traffic was identified using a 2012 road traffic study conducted for the needs of TRISTAR implementation, a traffic management system. Heavy vehicle traffic was the heaviest within the Estakada Kwiatkowskiego with heavy vehicles reaching up to 8 600 per day (17-23% of traffic). This is because the road provides the main access to the Port of Gdynia. The other sections with heavy HGV traffic showed a significantly lower percentage ranging from 2 300 to 3 200 vehicles a day, which is from 5.8% to 10% of traffic. On some sections HGV traffic reaches 3% to 5% or the occasional 500 vehicles per day. Table 1 shows traffic volumes and the share of HGVs on 10 selected road sections in Gdynia.

Table 1. Traffic at selected road sections in Gdynia with share of heavy vehicles

No	Section	Traffic (veh/24h)							Share of heavy veh.(%)
		M	P	D	L	L-T	O	Total	
1	Estakada Kwiatkowskiego #1	0	21736	2509	1138	6171	0	31554	23.2
2	Estakada Kwiatkowskiego #2	0	37578	3202	1726	6883	0	49389	17.4
3	Wiśniewskiego	177	26920	2015	1775	17447	47	32381	10.0
4	Ring Road (km 314+500)	109	28731	3345	1295	1151	5	34636	7.1
5	Morska #1	254	34745	3385	1205	1222	0	40811	5.9
6	Morska #2	328	34596	2731	2188	153	298	40294	5.8
7	Warszawska	20	8460	489	554	0	0	9523	5.8
8	Kielecka	35	10990	593	582	44	11	12255	5.1
9	al. Zwycięstwa	59	28026	1479	1418	136	0	31118	5.0
10	Morska #3	178	25637	1662	968	305	7	28757	4.4
M - motorbike, P- personal car, D - delivery van, L- lorry two axles, L-T - lorry with trailer, O - other									

The data and some additional measurements were used to develop Gdynia’s HGV traffic cartogram which will be used for a pre-selection of vehicle weigh-in sites. Figure 3 presents an enlarged area of access to the Port of Gdynia, which features the heaviest HGV traffic.

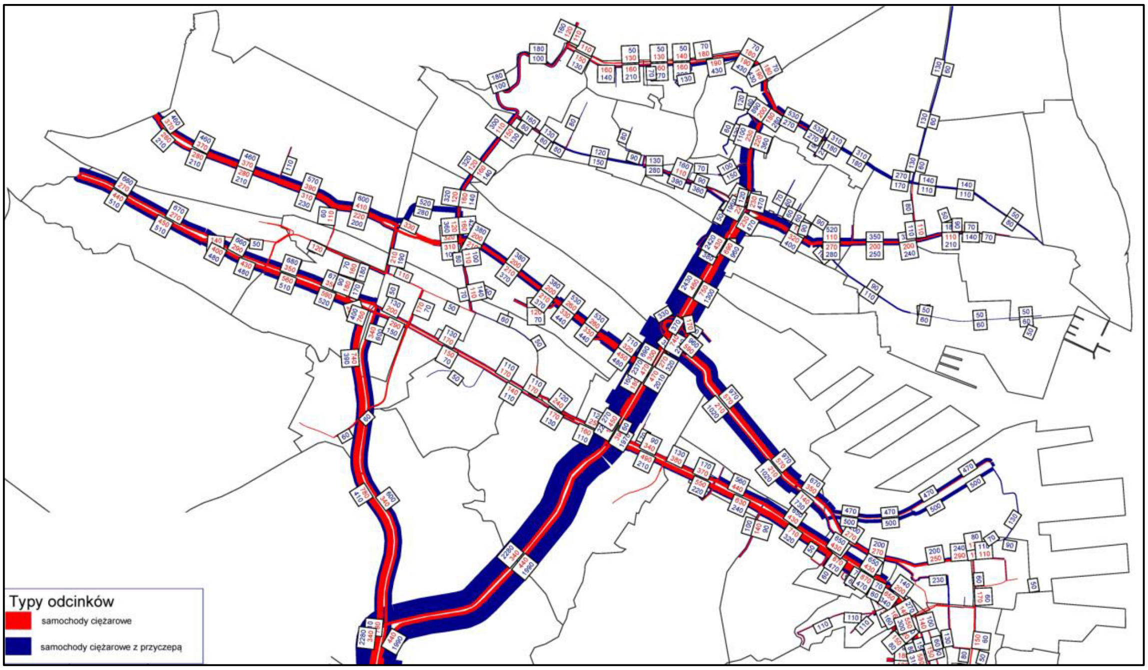

Fig. 3 Heavy vehicles traffic in relation to Gdynia's port activity

The data clearly identify the directions used by heavy vehicles in Gdynia. Most of the traffic generates at or from the Port of Gdynia, which shows that it is very much a transit type of traffic. These observations were used to developed a preliminary concept of locating heavy vehicle weighing stations.

3.2. Variants of WIM stations considered for implementation

Drawing on the heavy vehicle traffic data, 14 potential WIM stations were identified. At that stage, the objective was to reduce the share of overloaded vehicles as much as possible. Figure 4 shows the locations that were considered. The next stage of the analysis was to verify the initial choices of locations. To that end, a number of criteria were applied, in particular:

- Making use of existing infrastructure
- Condition of roadway
- Geometric road location
- Administrative factors

Finally, the following were the reasons why a WIM station location was rejected:

- Condition of roadway could cause too much error
- Strong vertical alignment and bendiness
- Sections that could lead to vehicles braking and accelerating frequently, i.e. Sections that have frequent signalised junctions
- Sections on bridges
- Sections that are administratively not managed by Gdynia

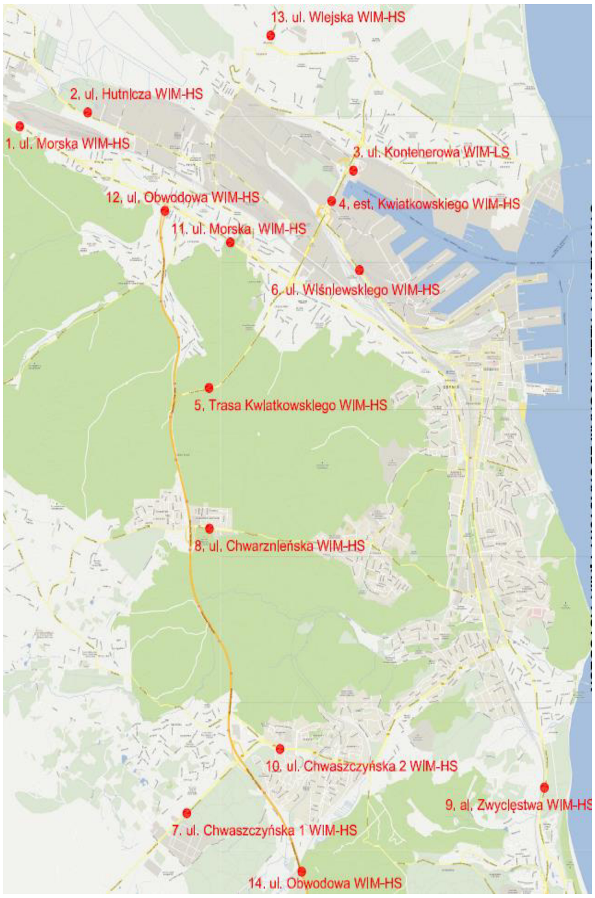

Fig. 4 Locations initially considered for WIM stations installation in Gdynia

Five points were considered further in the analysis as shown in Figure 5. If installed, WIM stations would operate in two modes:

1. HS-WIM stations designed specifically to preselect overloaded vehicles
2. LS-WIM stations designed for more accurate measurements at a lower speed at the cost of having to direct vehicles to control stations. The optimal location for this type of station is the exit from the container base at the Port of Gdynia

Fig. 5 Reduced number of WIM locations according to a predefined set of verification criteria.

For the verified set of potential WIM station locations a set of detailed variants was developed looking at the number of stations and the technologies. The cheaper variant comprised weights installed in 2 points and the more expensive variant included three weights. In terms of the technologies used, the weights were either accurate enough for weight pre-selection or more accurate to allow legalised measurements with variable message signs to inform drivers of exceeding the limits. A more accurate technology to automatically calculate fines for overloaded lorries could only be used if the right regulations are in place. The legal and organisational arrangements of the project are discussed in section 5. Table 2 shows the final scope of analysis of potential HGV weighing stations in Gdynia.

Table 2. Detailed variants of WIM stations

Location variant		Type of WIM technology	
		A. Only pre-selection	B. Legalised weighing with variable message sings for information
I.	2 weighing points	1. Morska 2. Wiśniewskiego	1. Morska 4. Kontenerowa
II.	3 weighing points	1. Morska 2. Wiśniewskiego 3. Kwiatkowskiego	1. Morska 3. Kwiatkowskiego 4. Kontenerowa

The first to be rejected was station WIM-LS no. 4 in Kontenerowa street going to the Port of Gdynia container and ferry terminals. Vehicles could be weighed in agreement with the port and terminal authorities before trucks leave the port. The city does not need to be involved. Location no. 3 in Kwiatkowskiego street was also rejected. This is because drivers could deliberately avoid it by taking a different exit from the Tri-City Ring Road towards Morska street. Even though this road is extensively used by trucks, the arrangement would not be effective and some of the heavy vehicle traffic could actually move to Morska, a street which already suffers from too much traffic. One way to solve this would be to locate the WIM station on the Tri-City Ring Road before the exit to the port. This section, however, is not managed by the city because it is a national road.

Finally, two WIM locations were considered optimal: one in Morska street and one in Wiśniewskiego street (no. 1 and no. 2). The Wiśniewskiego location is good for weighing vehicles going to the east port. This is the only road for HGV traffic, making a WIM station indispensable. The east side of the port is due to change its function and there are plans to move the ro-ro ferry terminals there, a factor that will further increase the number of heavy vehicles in the future. WIM station no. 1 in Morska street works well for preselecting vehicles going to container terminals of the west port and for transit traffic enforcement. Both weight pre-selection stations WIM-HS plus the WIM-LS weight in the container terminal provide the basis for building a city-run system for pre-selecting HGVs and eliminating overloaded vehicles. Building on the recommendations, the city of Gdynia decided to install the WIM-HS station in point no. 2. Construction and installation works were planned for December 2015. The pre-selective vehicle weigh-in-motion system comprises the following elements:

- Weigh-in-motion station for both directions of traffic
- Video registration zone for both directions of traffic
- Asphalt pavement with foundation in compliance with b+(7) measurement accuracy according to cost 323 specification
- Internet connection to ensure access to data from the pre-selection station in real time using an on-line application that can be accessed from anywhere using a browser, and to ensure that data from the pre-selection station can be sent to the server
- Safety barriers to protect gantry poles from impact
- Design and construction of a lay-by with a weight point as required by the inspectorate of road transport for taking certified measurements

4. Modelling of the WIM system potential influence on traffic conditions

The previous section presented the locations recommended for Gdynia’s WIM-HS system. Because the project is a pilot implementation, two locations were chosen situated on urban streets with a lot of HGV traffic and, by the same token, a strong possibility of reducing the number of overloaded vehicles. The choice of the locations depended on the destinations of the trucks using these streets. At present, (late 2015) the Wiśniewskiego station is being constructed.

The higher the number of vehicle weight pre-selection points, the more effective the WIM system will be, especially if the points are consistently deployed across the area. Measurements should be taken at as many urban area entry points as possible. This should stop drivers from avoiding weight points and eliminate overloaded vehicles early on, before they reach their destination. In addition, an extended WIM system may become an element of truck traffic management by controlling access to specific parts of the city. The effectiveness of a comprehensive WIM system can be measured with the following measures:

- Change of vehicle travel time in the street network
- Less traffic in central areas
- New traffic conditions (e.g. Time lost, queue length, number of stops)
- Changes in miles travelled
- Estimated changes in the impact on the environment

In an effort to estimate the potential effects of controlled access for different classes of trucks, a transport modelling and analysis package was used called SATURN (Simulation and Assignment of Traffic in Urban Road Networks). The model of the transport system developed under CIVITAS "Dyn@mo" is an element of the Multilevel Model of Transport Systems developed for the city of Gdynia (Oskarbski et. al, 2014). This tool is used at tactical level of planning and operational activities. Tactical level includes the provision of data to develop decision-making papers (network and corridor studies, feasibility studies), development projects of traffic arrangement, traffic control and evaluation of planning solutions effectiveness as well as for traffic management purposes. The objective of research is the transport network taking into account a sequence of street sections and intersections parameters (arrangement of traffic, traffic control) in this case. This model is used to analyse the scenarios of traffic arrangement modifications as well as to estimate the efficiency of planned modifications. The model can be powered and calibrated with data from the TRISTAR system. A mezoscopic model developed with SATURN software is based on Four Stage Transport Modelling procedure taking into account simulation of traffic at intersections.

Three WIM scenarios were analysed. They were defined to estimate theoretically the effects of restricted access in spatial terms (a city within its limits or a central zone) and in type terms (specific classes of heavy goods vehicles):

1. Scenario 0 (baseline) – existing situation with no system to control HGV access using WIM
2. Scenario 1 – reduced HGV traffic in Gdynia thanks to WIM. Vehicle checks are to be conducted on a cordon that includes access to the city along its boundaries (Fig. 4), reduced access for vehicles having a maximum authorised mass above 18 tonnes
3. Scenario 2 – reduced HGV traffic in Gdynia city centre thanks to WIM. Vehicle checks are to be conducted on a cordon that includes access to Gdynia's city centre, reduced access for all vehicles having a maximum authorised mass above 5 tonnes

Table 3 shows results of the simulation of how traffic volumes change in the particular streets. It gives examples of the number of total vehicles (C), number of heavy vehicles having a maximum authorised mass up to 18 tonnes (UC3) and the number of heavy vehicles with trailers and semi-trailers having a maximum authorised mass above 18 tonnes (UC4).

Table 3. Traffic volumes at selected road sections in Scenario 0 and Scenario 1 during morning peak hours

	Scenario 0		Scenario 1		Scenario 2	
	morning peak	afternoon peak	morning peak	afternoon peak	morning peak	afternoon peak
Transient queues [v/h]	799,5	1162	797,1	1128,2	796,0	1149,0
Over-capacity queues [v/h]	605,6	1595,9	446,4	1519,7	521,7	1523,2
Total travel time [h]	5511,7	7845,3	5349,5	7624,7	5409,5	7953,6
Overall average speed [km/h]	40,8	35	41,6	35,2	41,4	34,1
Travel distance [km]	225007,6	274872,5	222305,2	268099,2	224124,3	271172,2
Total trips loaded	31951,9	39106,2	31553,3	38436,1	31784,7	38855,5
Fuel consumed [l/h]	19790,6	26490,9	19574,6	25756,9	19796,7	26496,4
Total number of stops during one hour	141087,9	308374,7	176569	292083,9	176482,7	308348,9

During the simulation it was assumed that the mass of the load would not change. If access for heavy vehicles is to be restricted, the goods will be delivered with smaller vehicles that can use lower class roads (as a consequence, less traffic on main drags where WIM is to be installed).

Table 4. Detailed traffic characteristics selected scenarios during morning and afternoon peak hours

WIM station number	Scenario 0			Scenario 1			Scenario 2		
	C	C1	C2	C	C1	C2	C	C1	C2
1	4	0	0	3	0	0	4	0	0
2	1712	95	89	1623	95	0	1682	44	6
3	3808	118	181	3615	118	0	3842	81	73
4	3022	146	92	2936	146	0	3007	59	115
5	3554	218	234	3373	120	0	3548	50	101
6	1709	83	120	1559	79	0	1694	71	99
7	1550	25	8	1551	25	0	1552	58	69
8	2399	64	110	2293	66	0	2376	103	56
9	4693	258	332	4387	260	0	4703	146	75
10	2641	18	2	2664	18	0	2625	137	233

The results of the simulation presented in Table 3 show that in Scenario 1 compared to Scenario 0 there was a significant reduction in the number of vehicles both on entering the city and in the city centre. Heavy vehicle traffic could be reduced on the main drags as a result of less HGV transit traffic in HGV restricted areas and as a result of using smaller vehicles which can use lower class roads. By comparing Scenario 2 to the baseline scenario (S0) we could see a significant reduction in HGVs on access roads to the city and no heavy vehicle traffic on entries into the city centre of Gdynia.

When analysing the detailed results of traffic parameter calculations shown in table 4, we can see that the majority of morning peak parameters suggest that Scenario 1 ensures the best conditions of traffic thanks to the elimination of HGV transit traffic. This variant offers the highest mean speed, the lowest fuel consumption and the shortest queues on entries in the shortest travel time. It is important to note that Scenario 1 parameters are very close to Scenario 3 results where HGV traffic into the city centre is to be reduced. In the afternoon peak traffic conditions in the city deteriorate slightly due to an increase in vehicles in the street network as a consequence of goods having been reloaded to smaller vehicles. The deterioration goes unnoticed by road users.

An important element of analysing the impacts of HGV traffic reduction, is understanding the emissions generated by transport. These include:

- CO - carbon oxide
- CO_2 - carbon dioxide
- NO_x - nitrogen oxides
- HC - hydrocarbons
- PM10 - particulate matter

One of the most frequent measures of transport projects is CO2 emission. Figure 6 shows CO_2 and CO emissions for the variants in question.

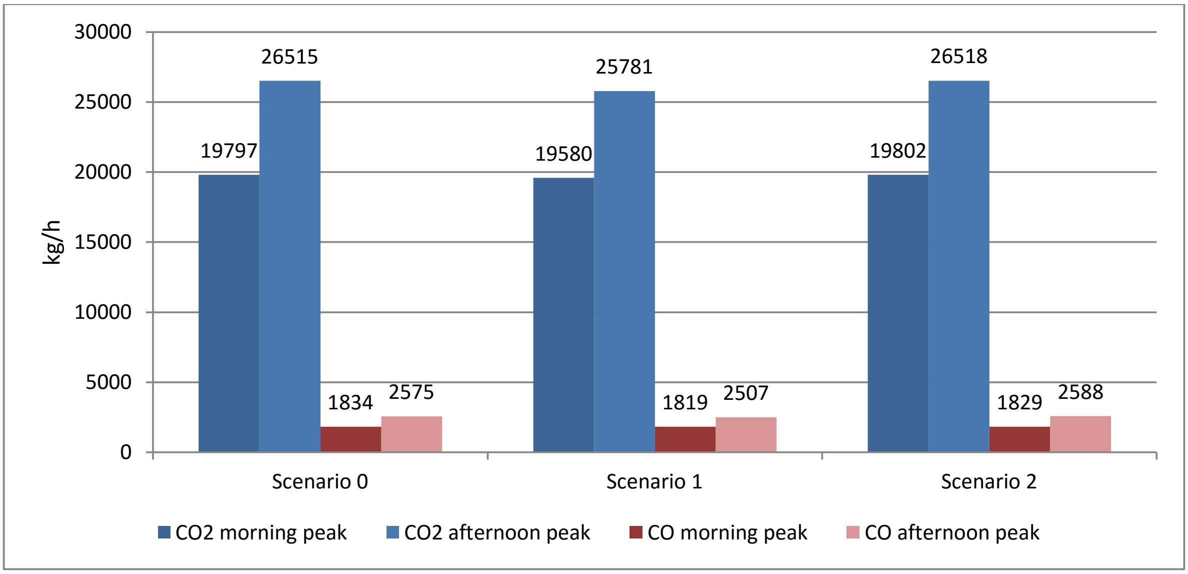

Fig. 6 CO_2 and CO emission level for selected scenarios

The resulting CO_2 and CO emissions are derived from the traffic parameters in the particular variants. Scenario S1 has emissions lower by 734 kg/h in afternoon peak and 270 kg/h in morning peak compared to the baseline scenario. This is 2.8% and 1.4% of the baseline values, respectively. Scenario 2, on the other hand, only offers a marginal reduction in emissions compared to baseline. The results are similar for CO emissions, where Scenario 1 offers the strongest potential reduction. The restrictions in scenario 1 and scenario 2 contribute to a slight reduction in NOx, and HC levels compared to baseline as shown on Fig. The reduction is observed mostly during afternoon peak hours 7.

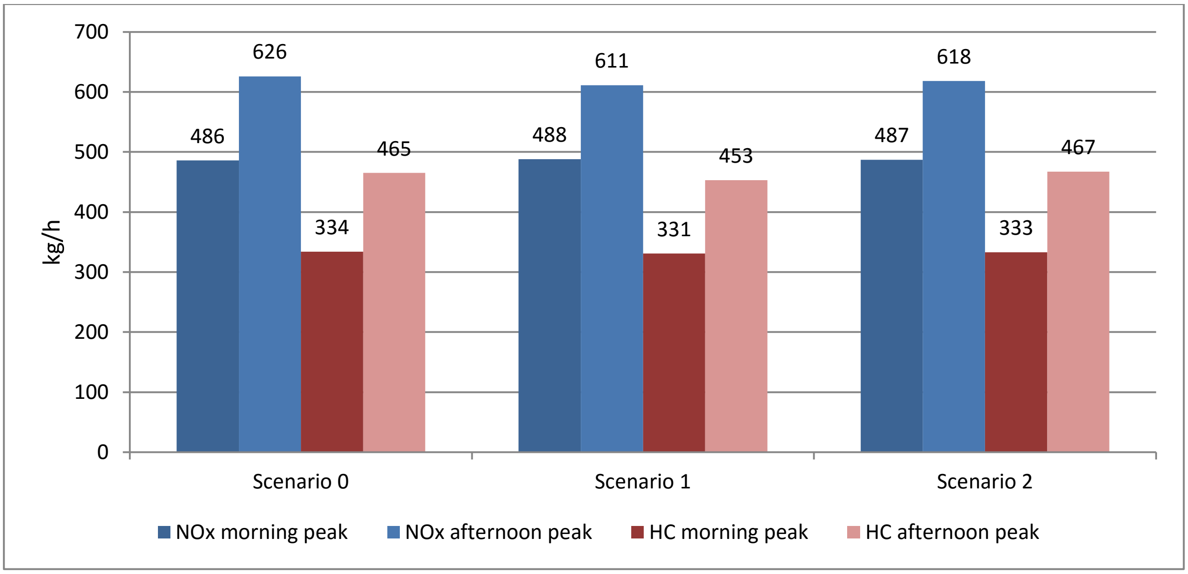

Fig. 7 NO_x (nitrogen oxides) and HC (hydro carbonates) emission level for selected scenarios

These analyses show that transport system modelling tools can be used to estimate the effectiveness of new heavy vehicle traffic solutions. To ensure that the results are credible, more detailed traffic models are needed to take account of the demand for deliveries and the transport services. Estimating the effects of new solutions is a separate issue. When referred to the scale of the city's entire transport system, the results such as reduced emissions, will not always be conclusive. It seems reasonable, however, to assume that urban freight transport problems tend to occur in specific areas. How serious they are depends on the concentration and impact that influence many of the aspects of how the city operates and the life of its inhabitants. In this situation it is important to be specific and accurate in defining a concrete problem and its consequences so that the appropriate steps can be taken to reduce the impacts.

5. Organisational and legal considerations of the system

The WIM is a tool which can effectively help to reduce the number of overloaded vehicles and the damage to the road infrastructure caused by these vehicles. The system can also be very helpful with vehicle access control based on vehicle mass. The increasing use of these systems means that the legal and organisational ramifications must be ensured. Under the current law, these vehicles can be checked by the Police and the Inspectorate of Road Transport.

Checks on roads can only be carried out by individuals who act on behalf of road authorities that run local authority roads. While these people are authorised to check all types of vehicles using public roads, they can only check for these types of violations:

- Regarding the size, mass or axle load
- Damage to or destruction of road
- Polluting or littering the roads

During a check, those acting on behalf of road authorities can:

- Stop vehicles
- Ask road users to show their id, instruct them how to use the road or vehicle and check vehicle documents
- Check the technical condition, equipment, load, size, mass or axle load of a vehicle on a road

- Use control or measurement devices designed in particular to examine the vehicle, identify its size, mass or axle load and violations of the environmental protection law
- Not allow a vehicle to be used if it exceeds the authorised mass or axle load or damages or destroys the road

As can be seen from the list of authorised checks by those acting on behalf of road authorities, they can also check overloaded (non-normative) vehicles, by using, among others, control or measurement devices. They are not allowed to use recording equipment. The downside of the work of those representing road authorities is that they can only conducts their checks (which includes remote operation) if assisted by a Police officer or an Inspectorate of Road Transport inspector.

Those acting on behalf of road authorities cannot conduct road checks on their own. They can only be subsidiaries to the work of Police officers and Inspectorate of Road Transport inspectors.

In theory there are ways to allow the Police and municipal guards to enforce these requirements using recording equipment. Unfortunately, secondary legislation renders the relevant primary legislation impossible to implement. The recent legislative changes are geared towards reducing the remit of municipal guards. It is also likely that the Inspectorate of Road Transport will become part of the Police. All this is not good for an effective use of WIM systems. In addition, there are no regulations in place to allow authorities to punish drivers for offences detected using a WIM system. The current law only allows WIM to be used for vehicle pre-selection. If a vehicle is found to be overloaded, it must be referred to a stationary vehicle weighing station to confirm WIM findings, even though the available technologies ensure that weigh-in-motion is very accurate.

To ensure that these violations are effectively dealt with, new legislation is needed to:

- Extend the remit of municipal guards to allow them to check vehicles for non-normative elements (including mass and axle load) and use pre-selection weights and other devices that are not recording devices within the meaning of the law (Road Traffic Law Act of 20 June 1997)
- Change the ordinance (ordinance of the minister of transport, construction and maritime economy of 14 March 2013 concerning the location, marking and measurements by recording devices)
- In addition, we should consider allowing those acting on behalf or road authorities to check mass and axle load on their own using recording devices

6. Conclusions

WIM systems can offer an effective tool for access control of not just overloaded vehicles but also other vehicles depending on their weight. If access is to be restricted, an in-depth analysis is needed to ensure that the original goals are met. A hasty change may deteriorate traffic. Such analyses can be aided with transport system models that compare different scenarios of change and how they affect traffic and the environment.

If WIM systems are to be used effectively, the legislation must be revised to allow road authorities and municipal guards to extend their checks. It is also important to allow the Inspectorate of Road Transport to do more. The revised law should allow penalties without vehicles having to go from a WIM station to a stationary weighing station. It should also be legal to use the WIM system for controlling vehicle access.

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