Industrialization, Innovation and Infrastructure: from Road Quality to Quality of Life, Modern Vehicle Weighing Technologies

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***Abstract*—The Belt and Road Initiative (BRI), Silk Road transportation programs have markedly developed the roads and highways networks in Kazakhstan and other Central Asian (CA) countries. The transportation services require the proper maintenance and the tracking of loads. Monitoring needs to be improved in Kazakhstan, CA. A Weigh in Motion (WIM) technology can be used as an effective traffic management control system. We are testing the WIM application in Nur-Sultan city, Kazakhstan currently. These works create many challenges and innovative approaches to testing sensors in harsh environments, from extreme cold to hot temperatures, with intensive dust distortions. Our Talapker WIM sensors can detect different driving patterns, including everyday driving, acceleration or deceleration of more than 10km/h/s, eccentric driving (partial contact with the platform to avoid excessive weighting). Every 10th car passing through the WIM site is registered as an overloaded vehicle by gross weighting, and every 5th car is considered overloaded by axle weighting. GIS-based location allocation analysis (LAA) was performed, which revealed potential future 43 WIM locations. The WIM applications have been in development for more than sixty years already in many countries. However, the CA region is still missing the proper investigations.**

Keywords*—*WIM, Weight-in-Motion, defects, Quality, roads, industrialization, damage

I. INTRODUCTION

Economic growth, social development and climate protection measures depend largely on investment in infrastructure, sustainable industrial development and technological progress In view of the rapidly changing global economic landscape and growing inequality, sustained growth must include industrialization that, first, provides all people with access to opportunities and, second, relies on innovation and sustainable infrastructure.

Why is this goal important?

Inclusive and sustainable industrialization, together with innovation and infrastructure, can unleash dynamic and competitive economic forces that generate employment and income. They play a key role in introducing and promoting new technologies, facilitating international trade and ensuring the efficient use of resources.

Nevertheless, the world still has a long way to go to realize that potential. In particular, least developed countries need to accelerate the development of their productive sectors if they are to meet the 2030 target and increase investment in research and innovation [1].

What is the problem?

Many developing countries still lack basic infrastructure, including roads, information and communication technology, sanitation, electricity and water.

Quality roads are a guarantee of the economic security of the State and the well-being of the population. A key condition for investment, regional industry, urban and rural development, export growth and tourism development

Every year, substantial financing is allocated from the national and local budgets to improve regional road and transport infrastructure. Nevertheless, as noted by the National Centre for the Quality of Road Assets, there is still many regions in Kazakhstan where the roads infrastructure should be improved dramatically. There is an intensive planning to increase the transportation network and road quality.

The durability of asphalt concrete is important for the long-term operation of roads, expressways. However, with increasing motorization of the population and increasing interregional traffic, the road network of mega-cities has become overwhelmed by clearly non-trade traffic loads.

Traffic on studded tires in winter, as well as frequent temperature fluctuations - road workers call them the «zero crossover». Under these conditions, regional roads cannot withstand heavy traffic. For this reason, the top asphalt concrete is renewed every three years [2].

Another solution is to improve road quality and durability. With the increase in traffic on the Kazakhstan's regional roads, the problem of increasing the durability and resistance of road surfaces to cracks and the formation of gauges has seriously confronted the road complex.

II. Causes of Damage to Pavement

Incorrect design of the asphalt concrete road leads to the destruction of the road surface. Inaccurate studies, calculations and errors in the determination of traffic flow may contribute to defects on the asphalt concrete road and lead to the destruction of the road structure, Namely, the asphalt layer on the pavements will break down; the substrate will seep; the ground will weaken the pillow; and the asphalt floor will wear [3].

1. The outdated methods with technologies are often applied and materials of poor quality were used to fix roads with asphalt concrete coating. More recently, hot asphalt-concrete mixtures containing bad bitumen have been used to install and repair the roads. It caused damage to the pavement and degraded the strength of the finished mixture for asphalting the road surface. However, the construction is not on the ground, and already today the latest polymer-bitumen materials are being developed and introduced, which can significantly increase the properties of the material and the future route. Various additives to the mixture have become popular for: improved adhesion, increased water resistance and fracture formation. These additives ensure the road's resistance to minus temperatures. In order to avoid defects and deterioration of the road, it is necessary not only to use new mixtures for the laying of asphalt, but also to choose new technologies that will make it possible to stabilize and strengthen the weakened moving soils of the ground. In order to prevent damage to the coatings, use a reinforcement mesh that strengthens the road structure and extends the life of the asphalt liner.
2. Defects and wear on the asphalt concrete surface are caused by an incorrect process in road construction. Damage is caused by mistakes in laying asphalt and repairing the track. Contribute to defects in the transport of asphalt concrete solution, resulting in an incorrect temperature. When the packed mixture was compacted, the air bubbles were not removed or, conversely, the solution was too dense so that the asphalt would start to crack and disintegrate. The destruction of the track may result from poor land preparation and road construction.
3. The most frequent defects on the road surface are caused by weather conditions, when moisture penetrates the asphalt during the rainy season and the hot sunlight disturbs the upper layer of the track - the hardness of the asphalt concrete deteriorates, which leads to potholes. At sub-zero temperatures, accumulated moisture in asphalt concrete layers can increase in volume and thus destroy the structure and compaction of asphalt
4. High transport load High loads from vehicles lead to breakage of the road. The high load on the track surface is due to the heavy traffic flow, which results in the excess of the 24-hour capacity limit and as a consequence, the service life of the track is reduced. Increase in axle load due to use of road surfaces by heavy vehicles resulting in break-up of asphalt concrete, formation of tracks and cracks.

III. How do we Prevent Road Damage

At the current stage of development of the global road industry, there is a wide range of technologies and effective ways to address premature road surface wear and tear.

The measures taken will prevent further destruction of the road.

The prevention of asphalt concrete break-ups includes comprehensive measures to deal with problematic sections of the route. Timely detection of damage will prevent further formation of potholes, faults and improve the strength of the asphalt.

Damage control techniques maintain the proper traffic and performance of the track, maintain the integrity of the design and cover, and extend the life of the vehicle surface.

Currently, the freight traffic management system that controls and monitors traffic flow is poorly developed in Kazakhstan, CA. To reduce the number of overloaded vehicles and control weight parameters, a Weigh in Motion (WIM) technology can be used as an effective traffic management control system in the Kazakhstan, CA region. The WIM technology is designed to control axle and gross vehicle weight in motion. It has a wide range of applications, including pavement and bridge weight control, traffic legislation and state regulations. The WIM technology has advantages over conventional static weighing as it does not interrupt traffic flow by creating queues at monitoring stations. The WIM technology can be used not only as a weight control tool but also will perform a comprehensive analysis of other traffic flow parameters. Apart from its primary goals, detecting the weight of vehicles, WIM technology can also be viewed as a financial tool used by enforcement police to collect penalties from overloaded vehicles.

The application of WIM in Kazakhstan has considerable potential as there are no specific weight control systems. As for now, state transportation agencies developed regulations on the permissible mass of vehicles. However, these regulations are not maintained both by regulating agencies and truck drivers. Currently, there is one WIM pilot site located in Talapker, Kostanay Region, Kazakhstan. The Talapker WIM site was installed in September 2020, and it performs Gross Vehicle Weight (GVW) and Axle of Weight (AOW) analysis. The Talapker WIM sensors are capable of detecting different driving patterns, including everyday driving, acceleration or deceleration more than 10km/h/s, eccentric driving (partial contact with the platform to avoid excessive weighting [4].

3.1 Working principle of WIM

The WIM system consists of several components: data acquisition system, communication system, power supply station, sensors for load detection, inductive loop sensors used to measure vehicle parameters and camera for automatic number plate recognition. The WIM system can provide information about the vehicle's gross and axle weight, structure and class of vehicle, number of axles, daily freight traffic flow and number of overloaded vehicles. These results can be used for pavement and bridge design and control, transportation policies to control congested traffic flow and transportation survey and data evaluation. One of the significant advantages of WIM is direct enforcement policy (Figure 1). Direct enforcement is an automatic process developed to control overloaded traffic flow on-site. Vehicle parameters are automatically recorded by the WIM system to evaluate them with permissible weight limits. If a vehicle is overloaded, enforcement authorities send official penalties to the truck owner or driver. Thus, the WIM system represents a fully automatic process for detecting overweight cases [5].

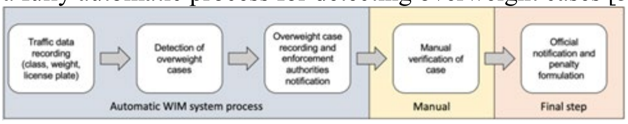

Figure 1. The WIM system working procedure

3.1.2 Comparison of different weight measuring technologies: static and dynamic (WIM)

For live load measurements, two different measuring systems can be used: static and dynamic. The dynamic measurement systems or Weight-in-Motion (WIM) technologies can detect and record vehicle parameters in motion. Static or stationary load measuring systems can determine vehicle parameters in non-moving conditions or at very slow speed.

The traditional method of load measurement on the roads used in Central Asia is applying the static measurement technique. The significant advantage of this method is the accuracy of the system and its applicability as a reference point for conducting experiments and calibrating weighing equipment. The stations are portable, the carryover process and installations are simple, but the difficulty is that the measurement of each axle should be performed separately, which is time-consuming. One measurement on average takes up to 45 minutes, and the process requires two people: the driver, to move the truck, and the operator, to monitor the process. Such time-consuming operations usually create traffic jams on the road [6].

Stationary scales called Truck Weigh Stations perform the load measurement of non-moving or slowly moving trucks. The stations are located off the road, and trucks need to exit the road to go through the scales. The appearing problem is that overloaded trucks can choose alternative routes not to have to go through the Truck Weigh Stations (ibid). In addition, if several trucks are already selected to pass by the weighting station, there is a possibility that during the measurement of those trucks, other overloaded vehicles will pass by and get unnoticed by the operators (Jacob and Bernard, 2010). Therefore, static weight measuring is not reliable, complicated and takes a lot of time.

The alternative way is applying weight-in-motion technology, which is a modern way of monitoring vehicle weight on roads. The sensors of the WIM system are built up inside the pavement and can report the wheel load, axle load and configuration for trucks in motion. The technology showed its efficiency and is widely used worldwide [7].

3.2 Concept of pilot High Speed WIM implementation in Talapker

The Talapker WIM station is the first test site in Kazakhstan, which was chosen to identify local features of freight traffic to solve the overloaded vehicle problem. The WIM sensors were installed in September 2020, and it is working to this day. From September 2020 to April 2021, 159,114 vehicles crossed the WIM platform on the Talapker site. A methodological analysis of vehicle flow in Talapker was conducted to evaluate Gross Vehicle Weight (GVW) and Axle of Weight (AOW) separately in relation to the total number of passing vehicles, their types, speed, time and driving manner.

Vehicle parameters are conducted on-site and has full range vehicle flow data: time of crossing, license plate, speed, acceleration, gross and axle vehicle weight and type of vehicle (Figure 2).

Figure 2. Talapker WIM data acquisition

3.3 Spatial analysis using Location Allocation algorithm

The methodology includes WIM location analysis using ArcGIS software. For this purpose, the location-allocation algorithm (LAA) was used to analyze the most suitable and effective sites for WIM installation. LAA represents the geospatial analysis designed to determine the optimal location for service provision. It is widely used in retail business and public institutions, e.g., schools, hospitals and police, to locate their branches across the city or specific area. The main principle of the algorithms lies in connecting different facilities that provide services and their demand points to which services should be efficiently supplied, taking into account human, financial and time resources. The LAA was applied to identify suitable locations for WIM stations across the road network in Kazakhstan.

To conduct analysis, it was necessary to identify demand points to which WIM sensors should be allocated. For this purpose, data was taken from the geofabrik.de online geospatial database for determining the country boundaries and road network. In this type of analysis, road branches were considered demand points to which WIM sensors are assigned. The more elaborate investigation of WIM sensors distribution has revealed evasive flow capturing problems, referred to as locating law enforcement facilities to detect traffic violations where drivers deviate from their initial route to avoid any penalties imposed from overweighting or speeding. Taking into consideration extensive road networks, it is possible to suggest that overweight truck drivers will avoid routes with WIM sensors installed on and, as a result, will follow “WIM free” road branches. Therefore, it was necessary to cover the whole road network system in Kazakhstan, including minor road branches, to ensure there is no evasive flow of traffic. However, from an economic point of view, it was reasonable to include only primary and secondary road types that have either international, state or regional significance. Another essential factor for this type of problem was population density. Input characteristics were assigned in such a manner to ensure that a higher number of WIM sensors are installed on areas with the highest density[8].

IV. RESULTS

4.1 Talapker pilot HS - WIM site results

According to the results obtained in the Talapker WIM site, the total number of passing vehicles differs significantly from month to month. As shown in the graph below, freight traffic flow substantially increases during the summer-autumn season. Despite overloaded vehicles (GVW > 44 tons, AOW > 11 tons) represent a small portion of the total number of passing vehicles, there is still a significant presence. For example, in October, the busiest traffic flow was a total of 24,423 vehicles passing (Figure 3). Among the total number of passing vehicles in October 2020 (7,37%) of vehicles are recorded to have excessive gross vehicle weight and 3,270 (13,39%) excessive axle vehicle weight.

Taking into consideration comparison of GVW and AOW distributions, it is seen that, although some of vehicles meet gross weight requirements, they might have an overloaded axle weight (Table 1).

Taking into account type of vehicles that have excessive weight parameters in both GVW and AOW distributions, following can be distinguished:

1. Single Unit 3 or more axle (Figure 4).
2. Semitrailer 4 or more axle (Figure 5).

It was important to identify driving patterns to evaluate its effect on GVW and AOW distribution (Figure 6).

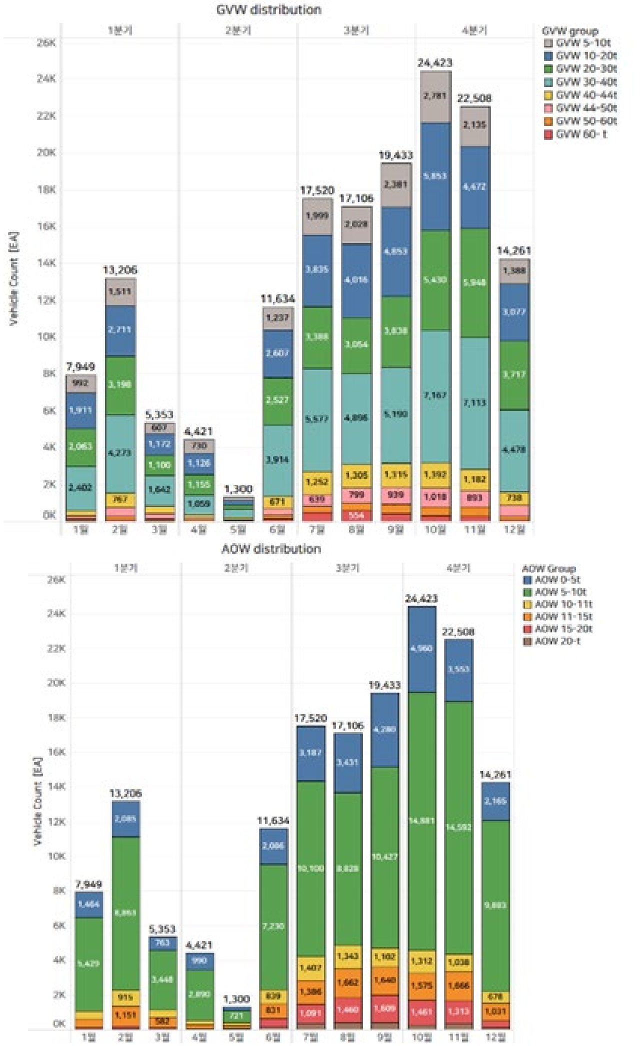

Figure 3. Analysis of the total number of passing vehicles per month by GVW and AOW distribution

Tab. 1.
Number and percentage of overloaded vehicles per month by GVW and AOW distribution

	GVW distribution			AOW distribution		
Month	Total number	Number of Overloaded	Percent of overloaded	Total number	Number of Overloaded	Percent of overloaded
1	7949	313	3,94	7949	593	7,46
2	13206	746	5,65	13206	1343	10,17
3	5353	408	7,62	5353	695	12,98
4	4421	165	3,73	4421	279	6,31
5	1300	108	8,31	1300	212	16,31
6	11634	678	5,83	11634	1479	12,71
7	17520	1469	8,38	17520	2826	16,13

8	171 06	1807	10,56	171 06	3504	20,48
9	194 33	1856	9,55	194 33	3624	18,65
10	244 23	1800	7,37	244 23	3270	13,39
11	225 08	1658	7,37	225 08	3325	14,77
12	142 61	863	6,05	142 61	1535	10,76

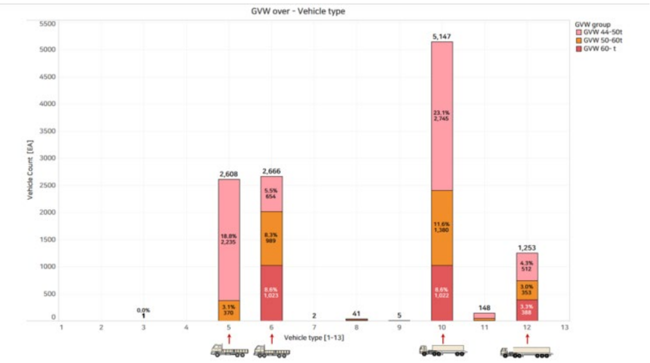

Figure 4. Analysis of the GVW overloaded number of passing vehicles per type

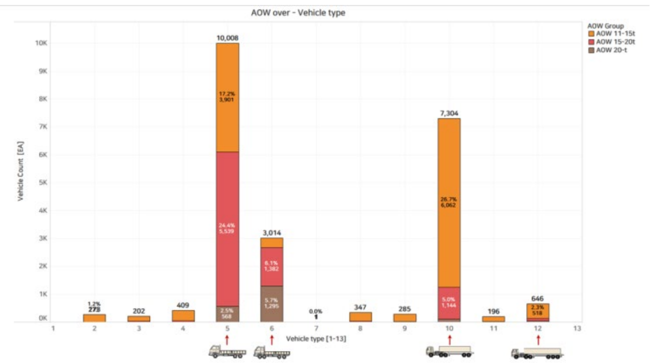

Figure 5. Analysis of the AOW overloaded number of passing vehicles per type

According to results, the most common driving pattern in normal GVW distribution is “normal” driving, while in overloaded GVW distribution, drivers tend to follow “out of lane” driving pattern. This feature can be explained by the fact that drivers prefer to escape weight control censors. An abnormal driving pattern refers to partial contact of the axle with the platform to avoid overloading. Unexpectedly, eccentric driving is present in the same portions both in normal and overloaded GVW distribution. A more significant number of eccentric driving pattern cases was expected in the overloaded GVW distribution, where drivers cheat and “hide” overloading by having partial contact (Figure 7).

In normal AOW distribution, most drivers follow a normal driving pattern; about 18% have an eccentric pattern, and approximately 7% are in the “out of lane” pattern. As in normal AOW, in overloaded AOW distribution, most drivers follow the typical driving pattern; about 40% and 15% have an “out of plane” or eccentric driving pattern.

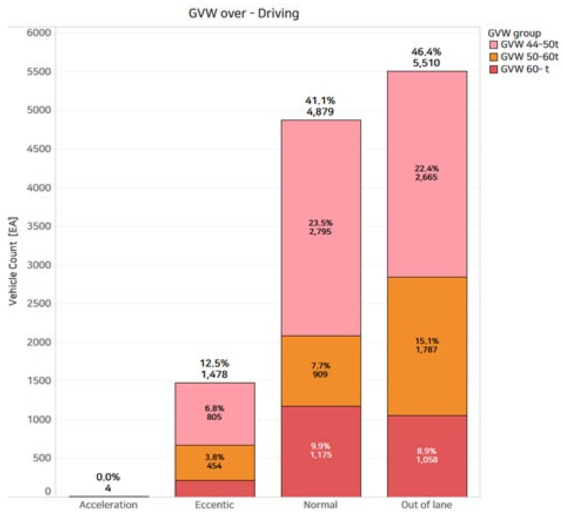

Figure 6. Analysis of the GVW normal and overloaded number of total vehicles per driving pattern

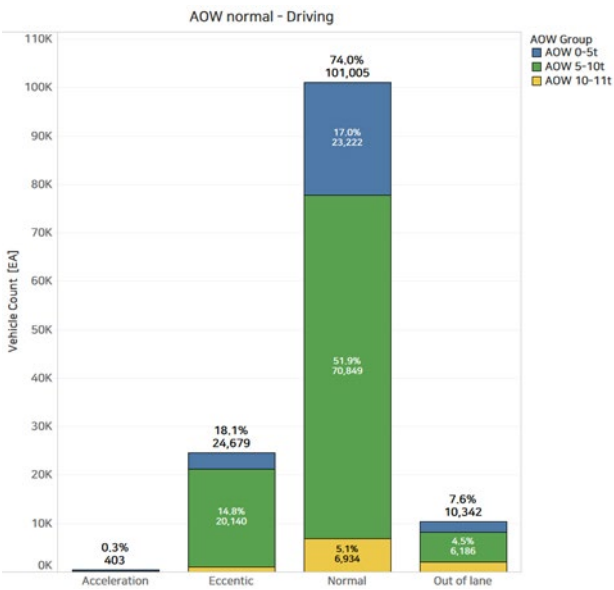

Figure 7. Analysis of the AOW normal and overloaded number of total vehicles per driving pattern

In general, results demonstrate that the normal driving pattern is the standard option. Since the Talapker site is an HS-WIM station, drivers are not required to reduce speed while passing the platform. In this regard, the acceleration or deceleration pattern is insignificant. It is also important to notice that in both overloaded GVW and AOW distribution, the “out of lane” pattern has a significant portion.

Results from the pilot Talapker HS WIM site demonstrated the significant necessity in adopting WIM technology in Kazakhstan. According to the results, up to 10% and up to 20% of passing vehicles have overloaded gross vehicle weight and axle vehicle weight, respectively. The significant scale of the problem of overloaded vehicles can be considered a severe problem for road conditions and safety.

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