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Lessons Learned from Implementing a Set of Measures to Reduce Transport Congestion

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***Abstract*—Digital technologies increasingly shape various aspects of our lives, changing tools and approaches, minds and attitudes. In this context, the transport sector plays a crucial role in improving citizens' quality of life, impacting both private and public transport systems. It is essential to recognize the steady rise in the number of vehicles on the roads. While this growth can address certain well-being needs, it also presents challenges that may impede the effective fulfilment of these needs, particularly concerning capacity and timely service. This issue is particularly acute in densely populated urban areas, where traffic congestion can lead to delays in transportation, goods delivery, and commuting. The environmental ramifications of rising vehicle numbers must also be considered, as road congestion contributes significantly to air pollution due to emissions. The objective of this study is to identify and learn lessons from the implementation of various strategies aimed at reducing transport congestion, identify opportunities for optimizing private vehicle traffic flow in large cities, and propose a model that balances the interests of private car owners, municipal authorities, and urban residents' well-being. Lessons learned might suggest further model development that would integrate a time-based financial incentive system, such as the introduction of city road tolls in designated metropolitan areas, along with recommendations for enhancing roadway infrastructure and traffic management, including intelligent transportation systems. The methodology leverages data from traffic management service providers, cartographic resources, and other relevant traffic flow and satellite information. It takes into account population movement patterns, driving habits, travel time preferences, various toll fee payment options, and motivational incentives. Additionally, the study incorporates insights and best practices derived from case studies of cities globally.**

Keywords*— congestion, intelligent transport system, lessons learned, wellbeing.

I. Introduction

As the standards of human wellbeing increases, the demands and expectations of individuals and society for higher-quality products and more efficient services also increase. Road transportation is one of those sectors that ensures people's mobility, getting to work and leisure, providing daily services and delivering goods. In conditions of economic growth, the number of cars is continuously growing. According to the forecast of research house Bernstein, it will double, reaching two billion units by 2040 [1]. Although the pace of this growth in the USA and the EU has slowed down since 2005, this growth has been taken over by emerging markets, primarily China and India.

Currently, more than half of the world's population (4.4 billion people) lives in cities, and it is estimated that by 2050, seven out of ten people will live in urban areas [2] - [3]. In the European Union (EU), around 70 percent of the population already lives and works in urban areas, generating 23 percent of all transport greenhouse gas emissions [4]. Accordingly, the constant increase in road transport units has the greatest impact on metropolitan areas and cities. The large number of vehicles is one of the most important causes of road congestion. This affects the increase in the number of road traffic accidents and victims. The streets are affected by emissions from fossil fuels, which impact air quality. Congested traffic also brings noise pollution. People are late for work, suffering both time and financial losses due to traffic congestions. According to TomTom Traffic Index ranking, in 2024, in the mega and large city category worldwide, the drivers in Baranquilla, Colombia lost the time in traffic jams during rush hours the most (130 hours per year); and in Europe, this rate was the highest in London, UK (113 hours per year) [5].

To mitigate these negative impacts, governments around the world are defining a course of action,

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developing and implementing appropriate action plans and regulations. For example, the EU plans to reduce transport greenhouse gas emissions: by 55 percent till 2030 and by 90 percent till 2050 [4]. Consequently, the EU Urban Mobility Framework initiative encourages its member states to develop public transport that is emission-free, inclusive, safe, resilient, and sustainable [6]. In order to improve air quality and reduce traffic congestion, the EU has set Urban Vehicle Access Regulations (UVARs), which would allow cities to comply with EU air quality standards [7].

The transport sector and its road transport component can be considered within the framework of the Sustainable Development Goals (SDGs), contributing to the achievement of its eleventh goal, namely "Make cities and human settlements inclusive, safe, resilient, and sustainable" [8]. Fig. 1 shows the division of the SDGs into three layers, with the 11th goal included in the infrastructure layer. The interaction of all layers contributes to the achievement of human-environmental wellbeing goals.

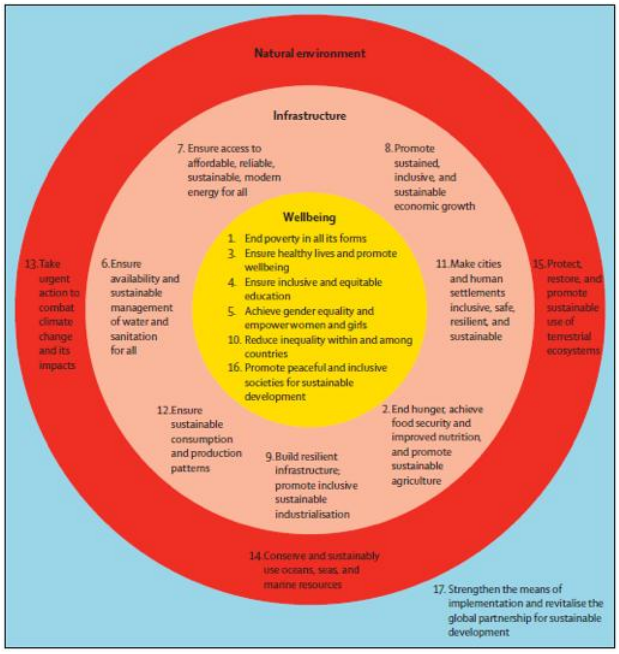

Fig. 1. Interactions framework between sustainable development goals [8].

Environmental, social and human development are important for achieving well-being goals. Several basic elements and their corresponding sectors are involved in this process, determining and directing it (Fig. 2) [9]. From the perspective of a holistic approach, it is very important to provide for the possibility of interaction and cooperation of these elements. In the field of road transport, this should apply to the delivery of goods and services to both individuals and groups of individuals and organizations. In this regard, not only the delivery of goods and services as a fact is important, but also the management of this process that ensures its efficiency, including time and route optimization, the use of smart transport infrastructure tools and technologies, and the training of people involved in the delivery process. At the same time, it should be noted that depending on the level of development of the elements indicated in Fig. 2, in specific countries and their regions their authorities can implement greater or lesser governance interventions, promoting the improvement of the relevant elements. In turn, to ensure the growth of overall well-being, the coordinated functioning of all involved elements is mandatory [9].

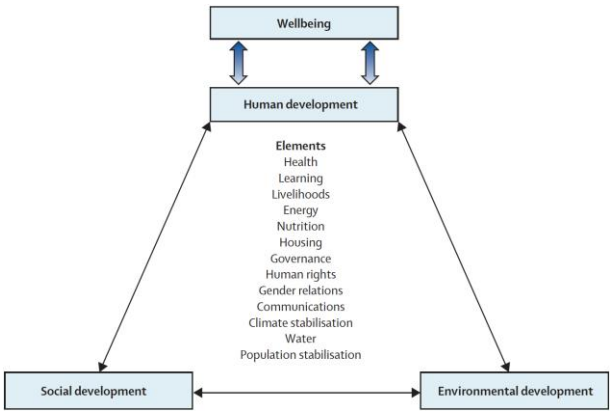

Fig. 2. Development elements contributing to human, social, and environmental development and wellbeing field [9].

In the following chapters, the study will focus on the field of road transport and the problem of road congestion, offering possible steps and recommendations to resolve the issues raised.

II. Materials and Methods

This study investigates the issues of extensive transport flows in large cities, an impact of car congestion on streets and caused environmental pollution. As a result, human and environment well-being, which is closely related to the above issues, will also be examined.

Hence, the purpose of the research is to identify and learn lessons from exponential increase in the number of road transport units in urban environments and to provide recommendations for reducing traffic congestion on the streets, and thus ensuring human-environmental well-being.

Accordingly, this study aimed to solve the following tasks:

- To find out the changes in the increasing traffic flows in cities,
- To evaluate challenges associated with the increasing number of vehicles,
- To consider various visions, regulations, activities, and measures, initiated by governments, agencies and groups,
- To develop recommendations for model development to avoid traffic jams in large cities, save the time, reduce air pollution.

In order to solve these tasks, the analysis of scientific, methodological and regulatory sources on the research topic was employed. The insights of researchers and professionals in the relevant fields, both on official websites of national government regulatory documents, and in databases recognized in the scientific community,

such as SCOPUS, Clarivate (Web of Science), and IEEE Xplore, were searched for and used as well. The methodology exploited the data from traffic management service providers, cartographic resources, as well other appropriate traffic flow and satellite information. Best practices derived from case studies globally are also taken into account.

III. Results And Discussion

A. Results

As individuals prioritize their well-being, there is an associated expectation for enhanced living standards. Addressing these evolving demands necessitates the deployment of more efficient technological solutions, especially within the transportation sector. The volume of vehicles on roadways continues to experience steady growth. While this increase may fulfil certain dimensions of well-being, it concurrently poses challenges that can hinder the effective satisfaction of these needs, particularly regarding capacity constraints and the timeliness of services. This issue is particularly pronounced in densely populated urban areas, where traffic congestion can lead to delays that adversely impact transportation efficiency, goods delivery, and daily commuting. Furthermore, the environmental repercussions of the rising vehicle numbers are considerable, as road congestion exacerbates air pollution through emissions from motor vehicles.

The challenges associated with the growth of road transport, especially in large cities, have been thoroughly analysed by Meneguette, I, et al. [10]:

- Traffic jams,
- Mobility issues,
- Roadway traffic collisions,
- Environmental sustainability,
- Financial expenditures,
- The imperative for Intelligent Transportation Systems (ITS).

The continual rise in the number of vehicles is directly associated with the growing incidence of accidents on roads. Consequently, road congestion adversely impacts travel times, leading to longer durations for the delivery of goods and the provision of services. This generates frustration among drivers and passengers, leading to heightened tension and conflicts that could be avoided in vehicles caught in traffic congestion. Furthermore, the rising number of vehicles contributes to traffic congestion, establishing a cycle that is challenging to resolve.

The significant rise in the number of road transport units is impacting mobility. While the increasing number of vehicles may initially suggest improved movement of people within urban areas, it is also leading to congestion and overburdened streets in major cities. This situation results in traffic jams and road accidents, ultimately hindering overall mobility. The high volume of vehicles on the roads contributes to significant traffic congestion, which adversely affects the efficiency of public transportation systems. This can lead to increased overcrowding on public transport options. As a result, passengers may find themselves spending prolonged periods in traffic, which can discourage them from utilizing these services. Consequently, many residents opt for personal vehicles, which exacerbates traffic congestion and contributes to environmental pollution from vehicle emissions.

The rise in the number of vehicles results in heightened traffic congestion, which subsequently contributes to an increase in road traffic accidents. These incidents not only exacerbate traffic delays but also pose significant risks to the safety of drivers, passengers, and pedestrians involved.

An increase in the number of vehicles on roads leads to a higher level of harmful emissions. This deterioration in air quality adversely affects our health and contributes to the challenges of global climate change.

Time spent in traffic has a direct correlation with financial implications, impacting both productivity and profitability. Municipalities must focus on the planning and management of transport flows, as well as maintaining, updating, and modernising roads and associated infrastructure. Additionally, they need to implement environmental protection measures, all of which necessitate considerable financial resources.

To address the challenges mentioned earlier, there is an urgent requirement for the implementation of advanced technologies and services, including Intelligent Transportation Systems (ITS). The relevance of ITS has been recognized for many years, with its initial concept being proposed in the last century [11]. The fundamental objectives and strategic directions of this initiative remain under consideration: ITS are designed to enhance road safety through the deployment of video surveillance cameras, which enable real-time monitoring of traffic conditions and facilitate the management of significant transport flows. Additionally, ITS aim to mitigate environmental impact by leveraging vehicle networks and employing data dissemination and exchange methodologies.

Over time, municipalities recognize emerging challenges and collaborate with researchers to develop and implement enhanced ITS capabilities. For instance, in order to improve road safety and optimize traffic management, the exploration of Vehicular Ad hoc Network (VANET) technology is being conducted for applications such as traffic flow detection, vehicle coordination, and locating various road services [12] - [13]. Concurrently, efforts are being made to identify solutions that safeguard VANETs against potential cyberattacks [14].

Artificial intelligence algorithms integrated within ITS offer drivers the valuable insights on road congestion, enabling them to adjust their routes and optimize travel plans. This leads to time and fuel savings, ultimately contributing to lower emissions and reinforcing sustainability initiatives [15] - [16].

The European Telecommunications Standards Institute has established a European standard for Intelligent Transportation System (ITS) architecture, which includes

four ITS subsystems: the Vehicle ITS Subsystem, Roadside ITS Subsystem, Personal ITS Subsystem, and Central ITS Subsystem [17]. These subsystems facilitate multi-layer peer-to-peer communication and data exchange among one another (Fig. 3).

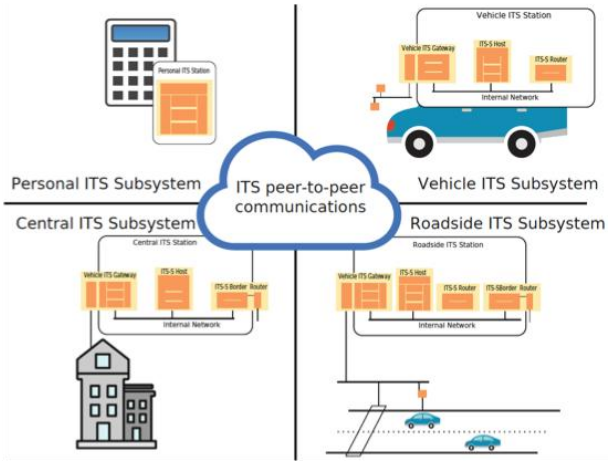

Fig. 3. European ITS architecture [17].

The European Union (EU) has recognized the importance of sustainable and smart human mobility as a critical component of overall well-being [4]. In response, it has developed appropriate regulations and established various working groups, organizations, and initiatives that are currently functioning effectively:

- Sustainable urban mobility / Urban Mobility Framework Initiative,
- Trans-European Transport Network (TEN-T),
- Sustainable urban mobility: planning and monitoring,
- Urban public transport and shared mobility,
- Active mobility: walking and cycling,
- Urban Vehicle Access Regulations,
- Zero-emission urban freight logistics and last-mile delivery,
- Urban mobility and climate-neutral cities,
- EU Urban Mobility Observatory,
- European Alternative Fuels Observatory,
- European mobility week,
- CIVITAS Initiative,
- Expert Group on urban mobility.

The European Union countries are also implementing measures to achieve the aforementioned goals. For example, the Latvian Ministry of Transport has carried out an assessment of transport sector policy and determination of future perspectives [18] and developed a plan of measures to ensure sustainable mobility [19].

B. Discussion

Taking into account the considerations presented in the previous chapters, we might propose and recommend possible solutions for model development to avoid traffic jams in large cities, save citizens' time, and reduce air pollution. Consequently, these solutions can contribute to improving human-environmental well-being.

These possible solutions can be set out in the form of recommendations:

a) Review and change the regulations in which vehicles can enter the central part of the metropolis.

This recommendation may ask municipality authorities to activate several measures:

- Access regulation,
- Permits issued on residential basis (paid passes),
- Permits issued depending on time of day and peak hours (paid passes – mobile payments),
- Offering multiple incentives to drivers to discourage them from using private cars in the city centre (central part of the city or designated districts and areas),
- Improvement of public transportation system (new routes, more busses, trams and trolleybuses, their frequency, quality, safety).

b) Mobility planning and facilitation on regular basis.

c) To enhance the mobility of residents and faster access to the desired location in the city, the creation of public transport lanes in large cities must be clarified and improved.

d) Public transportation lanes must be controlled so that others do not travel on them.

e) Create and implement reverse lanes.

f) Organize delivery of goods and waste removal only at night and off-peak hours.

g) Consider shifting working hours by one hour for employees in state and local government institutions.

h) Creation (if it is not done before) and launching Intelligent Transportation System (ITS) in order to monitor and manage traffic flow, improve safety, reduce environmental impacts.

This may include appropriate smart technologies, incorporated in the common joint ITS, for example:

- Sensors,
- Smart, i.e. intelligent traffic, road intersection lights,
- Video surveillance equipment 24/7,
- etc.

i) ITS integration in the Smart City concept, including artificial intelligence tools and 5G/6G technologies.

j) Digital Twins and Dynamical modelling of traffic flow and road infrastructure.

k) "Vox Populi".

The advantage of this approach is that the majority of city's inhabitants may express their thoughts about more suitable solutions both for citizens-car-drivers, citizens-pedestrians, and municipality. As a result, the municipal government obtains the opinion of citizens on making transport flow more efficient, or rather, on planning the organization of traffic more successfully.

l) Municipality transportation infrastructure developers ought to take into account and need to find out following issues:

- Average travel time of 10 km during peak hours: generally, it is longer than off-peak due to congestion. For instance, according to the TomTom Traffic index, it takes 20 minutes 20 seconds to drive a 10 km section in the central part of Riga during the peak of congestion,
- Peak hour toll: reasonable amount and exact timeframe on dedicated road sections to enter a congested area,
- Off-peak toll,
- Consider a motivational component for drivers, for example, the public transport refund (vouchers) as the part of road toll payment,
- Designated area where public transport vouchers (if they are planned to be issued) can be redeemed - used to pay for public transport tickets,
- The compliance of current public transportation prices with the city's sustainability and well-being policy,
- Park and ride solutions.

m) Considerations for wider use of electric vehicles:

- The issue of increasing the number and density of electric charging stations in countries and cities where this problem exists must be addressed,
- Another challenging issue is reducing the time drivers spend waiting for their vehicles to be charged at these stations. Technologies that can reduce this time should be explored. Another solution could be to create battery swapping stations for electric vehicles that can quickly swap batteries, similar to what is done at Formula One racing stages,
- The increasing part of electric cars in urban traffic reduces the total amount of harmful emissions from all vehicles in urban traffic, contributing to the achievement of sustainability goals,
- Electric cars can relieve general vehicle lanes by moving along public transport lanes,
- However, it should be noted that as the number of electric cars increases significantly, city governments will have to make decisions both on prohibiting the use of public transport lanes for them and on reducing or even abolishing parking privileges in central parts of cities.

IV. Conclusions

The wellbeing thing encompasses a wide range of human-environment interaction issues. It must be acknowledged that today's people almost cannot imagine their daily lives without vehicles. They provide citizens with invaluable benefits in terms of fast and efficient service delivery and mobility, improving their quality of life. On the other hand, the exponential growth in the number of road vehicles is causing congestion on city streets and state highways. Furthermore, vehicles powered by fossil fuels pollute the air people breathe and significantly contribute to global warming. Hence, some kind of balance must be found between the set of all those elements that contribute to the development of human, social and environmental components within the wellbeing framework, thereby also achieving an improvement in the human well-being itself.

Governments and municipal leaders around the world have recently activated measures to reduce fossil fuel emissions, mitigate global warming, and thereby achieve sustainability goals and ensure human-environmental well-being. Organizations and target working groups are being created and are successfully working on research and drafting regulatory documents to promote population mobility, develop the environmentally safe public transport, support the use of fossil fuel free cars, as well as improve and implement intelligent transport systems.

Applying digital twin technology capabilities in road traffic modelling, testing and integrating would allow for the more effective evaluation and planning of road traffic infrastructure, avoiding potential pitfalls that affect the formation of road congestions and declining in human-environmental well-being.

The recommendations provided in the discussion section of Chapter III of this article might be used for planning and developing transport infrastructure and flows not only in mega and large cities, but also in smaller towns and villages, as well as within the road network of a country or a union of several countries.

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