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EVALUATION OF ECOLOGICAL IMPACT OF ROADS FUNCTION OF THEIR TECHNICAL CONDITION AND THE INTENSITY OF TRAFFIC FLOW
THEORETICAL APPROACH. ENVIRONMENTAL INDICATORS. CHAINS OF CAUSALITY (I)

BY

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Abstract. The first part of the paper, Part one, describes the main environmental indicators and various chains of causality taken into account when evaluating the negative ecological impact of roads and presents the influence of the pavement condition, including distresses, roughness and the intensity of traffic flow, on the environment. Based on the theoretical investigation conducted in Part one, in Part Two specific environmental classes of impact have been conceived and proposed, in order to be used in the evaluation of the current ecological status of the road transport system. Finally, technical recommendations for reducing the actual levels of ecological impact, based on the results of significant case studies conducted on national road NR 28 are presented.

Keywords: pavements; road roughness; pavement condition; ecological impact; traffic intensity.

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1. Introduction

Given the high levels of pollution recorded nowadays and the fact that, according to the European Commission, transport is responsible for 32% of Europe's energy consumption and 28% of total CO2 emissions, the development of sustainable road construction technologies and processes seems more and more important (Eurostat, 2016). Furthermore, besides the initial construction of a road pavement, the maintenance and rehabilitation strategies that will be applied represent a major factor in reducing the carbon footprint and increasing the service life of the road. A significant role in decreasing polluting emissions is played by the appropriate moment of intervention. In relation with Fig. 1, if a specific intervention strategy is applied at the optimum moment during the road lifetime, the costs, the raw materials and the energy consumption will be minimalized and the service life of the road will be significantly extended. Otherwise, if the road is not rehabilitated at the right moment, the distresses progress exponentially and the road will no longer be able to offer full safety and comfort conditions.

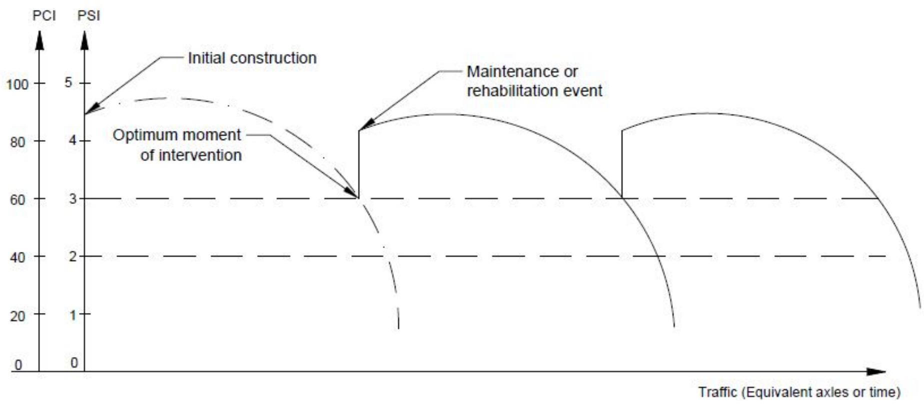

Fig. 1 – The correlation between pavement technical condition and traffic (Andrei, 2003).

Additionally, the rehabilitation investments, seen from a financial perspective, as well as in terms of material consumption and labor required, will be directly correlated with the exacerbation of the greenhouse effect. Also, taking into consideration the high level of distress of the road network, the impact of pavement condition on the environment needs to be proper assessed in order to be reduced by applying the most efficient strategies (Condurat, 2016).

2. Management of Road Activities from the Technical and Ecological Point of View

The management of the transport systems is primarily aimed at optimizing its overall performance by continuously improving their performance in order to increase transport safety and protect the environment. Road management activities concern both the planning and programming processes and the operational ones resulting from appropriate maintenance and construction, rehabilitation or upgrading works. The road traffic and construction activities have a significant negative impact on the environment due to the chemical pollution produced by the exhaust gases of motor vehicles, or the noise pollution caused by the construction machinery or current traffic, as well as by the displacement of large earth masses associated with earthworks. Moreover, pavement condition plays an important role in the ecological impact due to the increased fuel consumption, vibrations and particle matter pollution (Condurat *et al*., 2016).

Hence, it is essential to orientate management activities so as to ensure the safe and rapid transport of users while protecting the environment. Analysing the cyclical aspect of transport infrastructure (see Fig. 2), there is a need for analysis and possible prevention and mitigation of the negative impacts in every phase of the process management (Andrei, 2003).

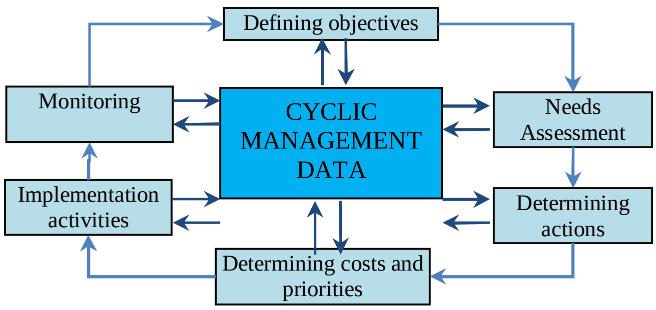

Fig. 2 – Primary Functions of Cyclic Management (Andrei, 2002).

In relation to Fig. 2, the strategic management or planning function involves analysing the transport system as a whole and is being associated with the development of long-term strategic assessments, cost development and preservation of the existing road network. Environmental issues are identified and investigated at this stage in order to avoid further implementation of costly or compromising solutions. In this respect, the consequences of such development on the road transport in the area – reduction of material resources, assessment of soil erosion possibility, including environmental deterioration caused and pollution issues – are anticipated. At this stage, the impact of road works on the social life of the area, cultural heritage and activities needs to be analysed as well.

Tactical management or programming function involves the development of multi-annual works and expenses programs specific to those road sectors that require priority intervention and the identification of opportunities for approaching new road constructions. Scheduling is based on a cost-benefit analysis, allowing feasibility assessment for each set of works.

The preparatory management or training function involves the preparation of the road construction projects and schemes. At this stage, the projects are finalized and detailed, works quantity and cost are assessed, their technical specifications are drafted and the execution contracts are prepared. A cost - benefit analysis is also recommended to confirm the feasibility of the project or the action concerned. Additionally, it is necessary to carry out a detailed assessment of the environmental impacts of each road alternative route studied and compare them in order to select the route with the least negative environmental impact, while setting out measures to prevent, reduce and mitigate those impacts (Andrei, 2002).

Executive management or operating function usually includes the operational activities that take place within a construction organization, with management decisions being set daily or weekly, including scheduling of work to be done, organization of workforce, equipment and materials, registration and evaluation, completed work and use of this information for surveillance and control. At this stage, a Life Cycle Assessment (Life Cycle Costing) is conducted to establish intervention strategies with the highest technical benefits and, at the same time, the lowest costs. This analysis allows proper management of financial funds as it provides information on the lifetime of the road from raw materials extraction, construction to recycling and its reconstruction.

In order to address the complex road problem of sustainability of transportation systems and their negative impacts on the environment, according to recent literature (Jourmard and Gudmundsson, 2010), a series of environmental indicators have been developed within the program COST 356 „EST – Towards the definition of a measurable environmentally sustainable transport" (http://cost356.inrets.fr). According to EEA (2009), an environmental indicator is defined "through a parameter describing the environmental state and its associated impact on human beings, ecosystems and materials, the environmental pressures, driving forces and the system responses, being determined by a complex process of selection".

The environmental indicators differ according to the chain of causality taken into account. Thus, the chain of causality represents a homogeneous process between the transportation system and the final result of the environmental impact produced in one step or more (Jourmard & Gudmundsson, 2010).

3. Chains of Causality Associated with Various Environmental Indicators.

In order to apply these chains of causality in the practical assessment of transport impacts, it is necessary to perform a thorough inquiry of them and to identify how intermediate impacts are dependent on individual and combined variables or decisional parameters of transport systems (Condurat, 2016). According to recent studies (Jourmard & Gudmundsson, 2010), the transport system has a number of 49 homogeneous chains of causality, which lead to the rise of various categories of environmental impact. The chains of causality include accidents, production of noise and vibrations, air pollution, soil and water pollution, impacts on land, non-renewable resources use and waste handling and greenhouse effect.

3.1. Accidents

As reported by recent studies (World Health Organization, 2010), road accidents produce about 1.24 million fatalities per year, meaning 2.2% of total mortality in 2010. Based on this assessment, a predominant increase of 2.4 million in fatalities by 2030 has been estimated, unless appropriate action will be taken. Fig. 3 shows the corresponding chains of causality associated with road accidents.

Fig. 3 - Chain of causality associated with accidents production (Jourmard and Gudmundsson, 2010)

3.2. Production of Noise and Vibrations

The increase in noise levels triggers serious social and behavioural effects, such as discomfort and sleep disorders. Effects on human health include hearing impairment, speech intelligibility, and aggravation of physiological and psychological disorders, such as hypertension associated with exposure to high levels of noise or mental illness and reducing cognitive performance (Jourmard

& Gudmundsson, 2010). The environmental indicators specific to noise chain of causality associated with the movement of vehicles (see Fig. 4) can be divided into three main classes, namely:

a) noise level indicators, used to describe the traffic noises according with their physical and energetic characteristics;

b) noise exposure indicators, used to describe the noise effects on exposed individuals in terms of magnitude and territorial expansion;

c) noise annoyance indicators characterize the discomfort experienced by those exposed to noise.

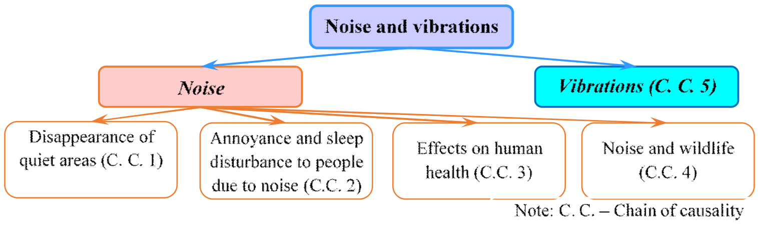

Fig. 4 – Chain of causality associated with noise and vibrations from road traffic (Jourmard & Gudmundsson, 2010).

3.3. Air Pollution

According Fig. 5, the chains of causality associated with air pollution relates to the odours produced as a consequence of SO_2 and volatile organic compounds emissions, particle contamination, decreased visibility, pollutants toxicity and photochemical pollution.

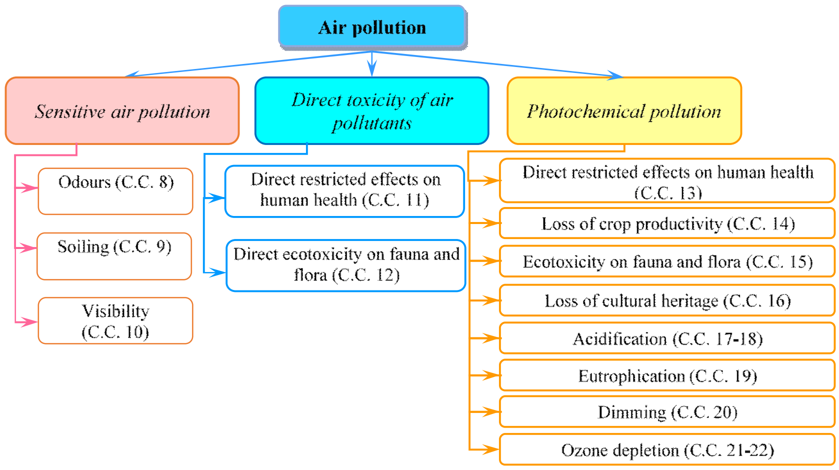

Fig. 5 – Chain of causality associated with air pollution (Jourmard & Gudmundsson, 2010).

3.3. Soil and Water Pollution

The chain of causality associated with soil and water pollution is broken down into three main categories, namely soil, surface water and groundwater, marine pollution and hydraulic changes (see Fig. 6).

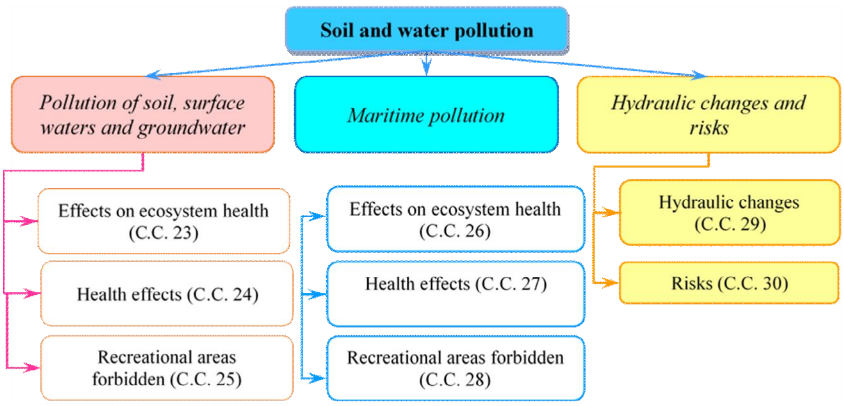

Fig. 6 – Chain of causality associated with soil and water pollution (Jourmard & Gudmundsson, 2010).

3.4. Impacts on Land

As shown in Fig. 7, the impact of the transport system on the land refers to land take, habitat fragmentation, soil erosion and degradation and alteration of landscapes.

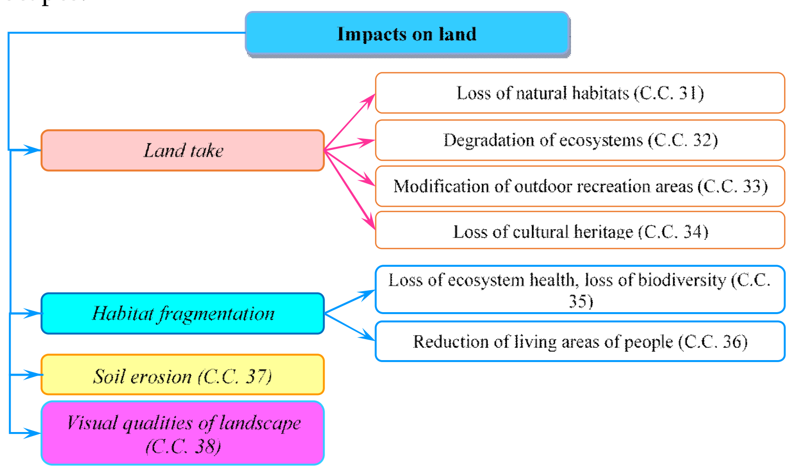

Fig. 7 – Chain of causality associated with impact on land (Jourmard & Gudmundsson, 2010).

In the case of habitat fragmentation, the main indicators describing this phenomenon are composition, shape and connectivity indicators of the inhabited area (Rutledge, 2003). The indicators describing the basic characteristics of habitat fragmentation composition are the number and range of the inhabited area. In the assessment of infrastructure projects, these indicators are used to determine the minimum area of individual habitats. The shape indicators quantify the complexity of corresponding habitat areas. The areas could be homogeneous (with a circular shape) or a more complicated geometrical shape (Didier & Thompson, 2010). The connectivity indicators measure the connectivity degree of inhabited area or isolation between areas. Connectivity is a key element of the habitat structure and is defined by the extent to which some obstacles obstruct the movement of the species between different areas (Tortorec, 2013).

3.5. Non-Renewable Resource and Waste Handling

Non-renewable resources are of particular interest in the transport, being used as well as energy sources (fossil fuels) and as construction materials. Since the rate of their regeneration is very limited, it is essential to develop fuels and alternative energy sources and to recycle existing structures in order to limit the existing current dependence on non-renewable materials (see Fig. 8).

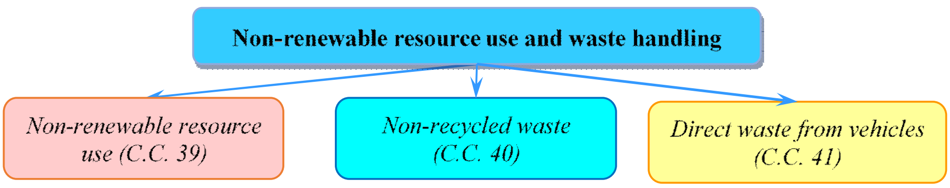

Fig. 8 - Chain of causality associated with non-renewable resource use and waste handling (Jourmard & Gudmundsson, 2010).

3.6. Greenhouse Effect

The most significant indicators describing the greenhouse effect are: Global Warming Potential (GWP), Global Temperature Change Potential (GTP), and health indicator of greenhouse effect impact. GWP expresses the contribution of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF6) to global warming. Further, this paper will present the influence of road roughness and traffic flow in the acceleration of the negative environmental impact produced by the transport infrastructure.

4. The Influence of Road Roughness and its Impact on the Environment

The literature shows a direct connection between the characteristics of road roughness and fuel consumption and, therefore, the increase of greenhouse gases emissions. Thus, based on case studies undertaken in research projects developed within the study performed by Highway Development and Maintenance Management System – HDM it has been demonstrated that an increase of 1 in the indicator IRI m/km will lead to an increase in fuel consumption (Fuel consumption – FC) by 2% in the case of automobiles, irrespective of their moving speed (Fig. 9).

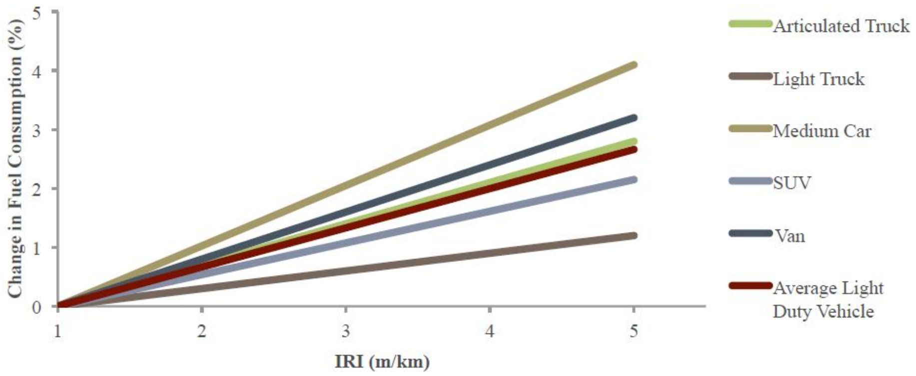

Fig. 9 – The influence of pavement roughness on the fuel consumption (Zaabar, et al., 2010)

For heavy vehicles this increase would be 1% FC correlated with a speed of 96 km/h and 2% for 56 km/h (Zaabar *et al*., 2012).

In this context, the impact of pavement roughness on fuel efficiency has been also assessed in the Research Center Concrete Sustainability Hub (CSHub) using data from the monitoring program of long-term behavior of road pavements Long Term Pavement Performance (LTPP). To achieve this objective, road data regarding roughness have been primarily related to the type of materials and road pavement. The accumulated data on traffic patterns, combined with LTPP data highlighted the impact of traffic type and pavement surface qualities overtime. Finally, these analyses have been combined and correlated with the fuel consumption model commonly used by the World Bank to estimate the connection between pavement roughness and fuel consumption over the lifetime of a road. Pavement roughness impact assessments, coupled with the deterioration rate of the road structure and the current guidelines for structural design are meant to facilitate and streamline the application of management activities associated with the road design and maintenance systems in order to minimize fuel consumption and greenhouse gas emissions, while limiting their maintenance funds if possible. Therefore, based on the LTPP case study results obtained during 1990 and 2004, regarding the relationship between fuel consumption and road roughness, it was found that only the quality of the road surface contributes to the increase in fuel consumption. Thus, a higher quantity of CO_2 will be released into the atmosphere if the roads have poor roughness characteristics (Greene *et al.*, 2013). Moreover, degraded road pavement is more likely to produce more road accidents ending in life loss and material damage. Increasing the vibration level can have negative effects on both the population in that area and on neighboring buildings. There is the possibility of long-term adverse effects of vibrations on historical buildings, especially for degraded ones. Vibrations can also interfere with sensitive processes such as those in hospital operation rooms, scientific research laboratories, and high-tech industries. The suggested optimal prevention strategies and solutions to reduce vibration to an acceptable level include regular road pavement maintenance, traffic flow and vehicle speed control improvement, roadside rehabilitation, land improvement in the road bed, location of the communication path at a sufficient distance to adjacent buildings, positioning of soil protection barriers as well as isolation systems for construction (Hunaidi, 2000).

5. The Influence of Pavement Condition and its Impact on the Environment

The technical pavement condition of the roads significantly influences the environment because a high distress road involves greater fuel consumption compared to a new road and an increase in the amount of exhaust gas emitted into the atmosphere. Also, a poor quality of the road surface will lead to increased vehicle wear, noise and vibration caused by the traffic, creating a hostile environment both for the residents of the area and for the fauna and flora related to the area. An inadequate technical pavement condition of road surface courses also involves increasing costs associated with vehicle operation through premature wear as well as travel time for both passengers and freight (TRB, 2006). By implementing intervention strategies to bring road pavements to a higher quality level, there are certain negative impacts that can lead to high environmental imbalances in the event of not taking appropriate prevention, mitigation and compensation measures. Through the execution of road works, greenhouse gas emissions are emitted from the combustion of fossil fuels from construction equipment and the ecosystem equilibrium is affected by the fragmentation of habitats. This phenomenon also occurs as a result of the progressive increase of traffic flow due to repairing the degraded sectors, the road becoming a physical barrier (barrier effect) for the animals in the surrounding areas, affecting the possibility of seeking food, shelter or pair. The barrier effect consists in creating an obstacle to the free migration of animal species through transport infrastructure and related traffic (Horobet, 2013). By increasing the annual average of vehicles, the risk of fatal collisions increases for the animals crossing the obstacle, leading to a decrease in the number of animal species living in the area crossed by the road transport infrastructure. Exhaust gases discharged by road construction machinery change the hydrological regime, disrupting the biological functions of the population and animal species, and altering the available food resources. If, from the chemical point of view, air pollution does not have major effects on vegetation, particle pollution (dust) may have negative results. These occur predominantly in dry periods, with no precipitation and on small areas. Dust is deposited on leaves and reduces the intensity of photosynthesis, breathing and sweating processes. Plants do not grow normally and agricultural output is low. The effect on forests is less visible. High concentrations of dust in the air occur for a limited period of time.

Other effects induced by the application of intervention strategies are related to the production of noise related to the technological process of rehabilitation of the degraded sectors. The high noise level during the execution of the road work can cause behavioral changes in the interspecies relationships. A disturbance of the predator-prey balance ultimately results in population changes, behavioral changes in mating rituals, reproduction, migration etc. Additionally, noise may affect the hearing capacity of some species and the altered natural sound background may mask the presence of predators, call for mating, and the communication with other members of the same species. However, it should be noted that in the literature (studies of the American Environmental Protection Agency), such changes generally occur at a noise level higher than 90 decibels and the noise level on the site does not exceed 75 decibels. The intense circulation of construction equipment at the work stations, the operation of asphalt and concrete cement plants, the storage of materials and fuels, the deviation and temporary restriction of road traffic, etc. will constitute temporary sources of discomfort for the population living or working in the studied area. The impact is mainly caused by the already mentioned sources of air pollutants and the additional noise induced by the machines in operation. Consumption of non-renewable lithographic resources represents another significant impact associated with rehabilitation work. This impact can be mitigated by applying road recycling processes by milling the existing material and incorporating it into the mass of a new asphalt mixture. The benefits associated with this operation are the use of smaller quantities of natural aggregates, fillers and bituminous binders, and implicitly the reduction of the environmental impact of the exploitation and processing of aggregates in quarries and ballasts.

6. The Influence of Traffic Flow and its Impact on the Environment

The continuous increase of vehicle fleet along with the development of road transport networks has a wide range of negative ecological impacts. As a response, the current development of road transport promotes a growing interest for sustainable and eco-friendly transportation worldwide. In correlation with traffic pollution, one can notice the exponential increase of the greenhouse gas effect and fuel consumption (Condurat *et al.*, 2016). Therefore, providing specific strategies necessary for the improvement of road network sustainability based on the road pavement condition is essential. Statistics on the consequences of transport development highlight the connection with climate change, high levels of pollution and depletion of lithographic resources. In this context, it is necessary to make changes, take adequate measures and focus on low carbon mobility and reduced energy consumption as fundamental features for a sustainable future and competitive urban areas. According to PIARC Report (PIARC, 2015) the energy consumption associated with road transport results mostly from vehicle traffic and less from pavement construction (Condurat, 2016). The pollution effects resulted from road traffic are extensive, due to a significant number of factors like atmospheric conditions, topographical and climatic conditions, traffic congestion, type of used fuel, age and poor maintenance of vehicles. The consequences include exhaust emissions discharged in the atmosphere, fuel leakage to the road surface, dust and noise pollution resulted from vehicles and accidental spillage of toxic chemicals in the event of road accidents. These externalities, expressed in CO_2 emissions, ecosystem fragmentation and release of particulate matter into the atmosphere (PM10) (Borken, 2003), resulted from road traffic, are currently considered the most pressing problems facing humanity. These are accompanied by soil sealing, due to permanent cover with an artificial impermeable material of the ground surface, noise pollution, NO_x and ozone levels (Borken, 2003). Exhaust emissions discharged into the atmosphere, in addition to affecting air quality, population health and ecosystems equilibrium; contribute also to intensification of global warming. The process of fossil fuels combustion in engines provides the necessary mechanical energy to start and move the vehicles but in the same time, it creates a mixture of harmful gases and particles which are released into the atmosphere. The air pollution caused by traffic has negative effects also on the built environment. Metal corrosion and deterioration of coatings, lime, mortar and construction elements through the action of acidic deposits of NO_x,

SO_2 and particulate matter represent some of the current challenges. Complementary, soil contamination with chemical compounds from transport activities contributes to soil erosion, as the pollutants lead to the destruction of existing vegetation and soil organisms. Vehicle manufacture itself is an important source of pollution for the environment. The production of vehicles and component parts contributes enormously to the increase in pollution by eliminating toxic chemical agents in the manufacturing process that can affect the soil, vegetation, water and the atmosphere as well as the habitats in the area. The pollutants with the most significant impact (Institute for Local Self – Reliance, 1997) are the solvents used for cleaning, painting and finishing parts, carbon monoxide, suspended particles, volatile organic compounds, mercury, lead, etc.,

7. Conclusions

In the first part of the paper the main environmental indicators and their corresponding chains of causality – production of noise and vibration, accidents, air pollution, soil and water pollution, impact on the land, non-renewable resources use and greenhouse effect and their negative impacts on the environment – have been discussed and investigated.

Finally, the negative influence of the road pavement condition, expressed in terms of roughness, various distresses, and the intensity of traffic flow have been assessed. Based on these evaluations, in Part Two specific classes of impact will be defined and recommended.

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EVALUAREA IMPACTULUI ECOLOGIC AL STĂRII THNICE A DRUMURILOR ŞI A INTENSITĂŢII FLUXULUI TRAFICULUI RUTIER

Abordare teoretică. Indicatori de mediu. Lanţuri de cauzalitate (I)

(Rezumat)

În prima parte a lucrării, Partea întâi, după descrierea principalilor indicatori de mediu şi a diferitelor lanţuri de cauzalitate luate în considerare pentru evaluarea impactului ecologic negativ al drumurilor, se prezintă influența stării tehnice asupra mediului înconjurător pe baza degradărilor din structura rutieră, rugozității stratului de rulare, precum şi pe baza intensității traficului rutier. Pe baza cercetării teoretice efectuate în prima parte, în cea de-a doua parte a lucrării au fost concepute şi propuse clase de impact ecologic specifice.