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Social and Economic Analysis of the EU Road Freight Transport Fleet

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Abstract

An analysis of economic and social indicators provides a good overview of the situation of a country or region in terms of a service or an industry. These indicators can help determine development, even in a community such as the European Union, to establish rankings and take appropriate strategic decisions at the transport policy level. This study aims to analyse road freight transport's economic and social impact. The analysis of economic and social indicators for freight transport in logistics is presented. The trends in vehicle population change in the EU countries were examined, and the relationship between road freight transport and population development in the countries under study was analysed from an economic point of view. The aim was to explore the effects of transport policy measures taken in the region over the last ten years on freight transport, both economically and socially. The study found no correlation between social and freight transport indicators in the EU Member States. Whereas, there is a correlation in the economic dimension, which may raise further questions, for example, when looking in more detail at the situation of a country within the Community.

Keywords
European Union, vehicle fleet, mileage, HDI, GDP

1 Introduction

The relationship between economic growth and transport is a popular key research topic, but it also has many untapped areas. To ensure continued economic growth, it is essential to answer the question of the contribution of each financial sector to development. In addition to the economic impact, it is essential to explore exactly what the environmental impact of freight transport is and what opportunities we have for creating sustainable transport, including transport directly linked to freight transport. An important step is to map and model the present and past situation and draw conclusions. At the same time, it is essential to note that convergence always has a crucial third area, the social impact, although this is not given much attention in logistics, including freight transport. With this in mind, Figure 1 illustrates this study's defined and delimited field.

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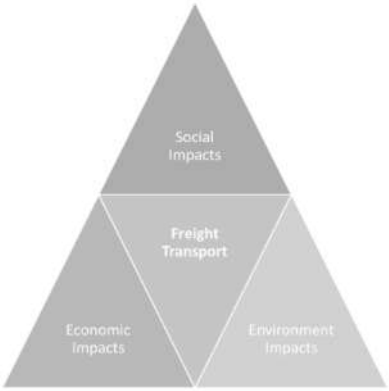

Figure 1. The research framework

The present study examined four factors to investigate the relationship between fleet size and mileage in the EU road freight transport sector by analysing the GDP (Gross Domestic Product) and HDI (Human Development Index) indicators. By examining these indicators, the extent to which each area interacts with the other was calculated, thus confirming or refuting the transport policy aspirations of the region in economic and social terms.

The HDI (Human Development Index) measures the social and economic dimensions of a country's overall performance. The HDI indicator is calculated based on life expectancy at birth in a given country, educational attainment (level of schooling: number of years of regular schooling and average number of years of education) and standard of living (gross national income per capita). The indicator has been used by the United Nations Development Programme (UNDP) to measure well-being since 1993, and the results are published annually in the Human Development Report (HDR) (UNDP, 2020). The indicators, which also provide a picture of the social situation, explain development by factors other than GDP (KSH, 2008). Figure 2 shows a map of the Human Development Index of the world's countries.

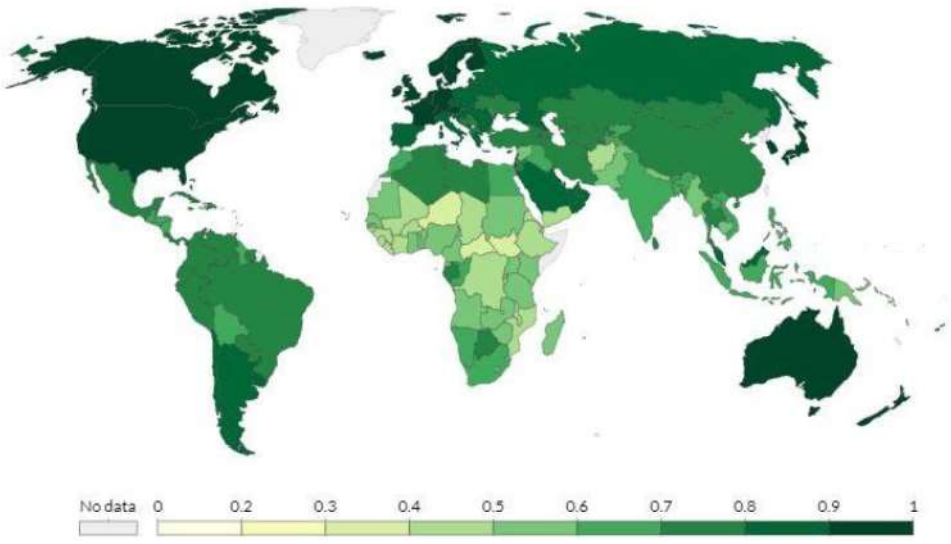

Figure 2. The World Human Development Index 2017 (Our World in Data)

Figure 2 shows that most of Europe is highly developed, while those lagging slightly behind, such as Hungary, have a high HDI. The HDI, as outlined above, can be used to draw several conclusions, for example, on the impact of other indicators. Figure 3 shows the HDI values for Europe. The map shows that almost all the countries in Europe belong to the very highly developed countries.

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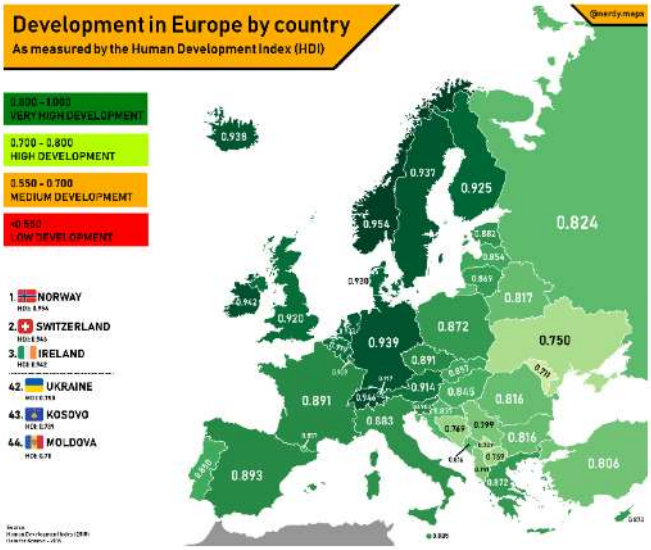

Figure 3. Human Development Index in Europe (Reddit)

Some studies have tried to get a picture by comparing HDI and other indices and indicators, using it to examine recent findings such as the Water Poverty Index (WPI) (Ladi et al., 2021), the prediction of municipal elections (Yero et al., 2021), sustainability in the area of freight transport (Kumar & Anbanandam, 2019), or the impact of the Covid 19 epidemic (Liu et al., 2020). These indicators are most useful strategically to help decision-makers set the right direction. A study carried out in 2015 already analysed the impact of logistics performance on social development. The result shows a strong relationship between the LPI (Logistics Performance Index) and the HDI, which substantiates that in the EU, the LPI strongly influences social development; logistics performance is higher in countries where social development is more advanced (Bîzoi et al., 2015).

According to preliminary estimates from the International Transport Forum (ITF) 2019 data, global GDP or a nation's gross domestic product, grew by 2.9% between 2018 and 2019, rising slower than in the previous year. GDP grew by 1.7% in most advanced economies, while in emerging and developing economies, it rose by 3.7%, slightly less than in previous years. Airfreight tonne-kilometres fell by 3.2% in 2019 due to global trade tensions. In Russia, rail freight transport is stagnant, up just 0.2%, even with a 6.3% decline in the United States. The EU is down 1.9% in this area. It is estimated that tonne-kilometres of road freight transport continued to grow by 1% in the EU and 6.3% in Russia (ITF, 2019).

The most significant research results published concerning the vehicle fleet are mainly connected to emissions, environmental challenges (Krause et al., 2020), and road safety (Pauer et al., 2019). In this context, the establishment of logistics networks and distribution systems, both from an ecological, economical and an efficient point of view, and their analysis using statistical tools (Bac & Erdem, 2021), as well as spatial statistical studies (Szabó & Sipos, 2020), are essential aspects. The fourth and last indicator chosen to characterise road freight transport is mileage, which is an excellent indicator of the performance of the EU Member States involved in road freight transport and the haulier's situation (Nowak et al., 2019).

Following a literature review and the presentation of the research framework, a general analysis of the EU vehicle fleet is presented in Sections 3 and 4, followed by a linear regression analysis of each value and the results. Section 5 concludes with a summary of the significance of the research findings.

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2. Methodology

This study aims to explore the possible relationships between HDI, GDP, vehicle fleet, and mileage at the macro level across the European Union Member States from 2018 (Figure 4).

Figure 4. Research parameters for freight transport

To this end, the vehicle fleets of the Member States were examined and analysed for each category, such as small, medium and heavy vehicles, to provide an overview of the current situation. 24 Member States participated in the analysis, partly due to geographical features (e.g. island countries) or lack of data. The collected data were analysed with descriptive statistical tools, from which a comprehensive picture of the data set can be obtained immediately. A linear regression analysis was then carried out on the values presented above to see if and to what extent there is a relationship between the values.

3. Freight transport vehicle fleet in the European Union

The European Union has a significant road freight transport performance, with almost 75% of the total volume of goods transported by road. Consequently, it is essential to look at the vehicle fleets in different countries to see what trends currently dominate the market. The vehicles involved in road freight transport can be divided into three categories according to their transport capacity: small, medium and heavy goods. The GVWR (Gross Vehicle Weight Rating) determines which category a vehicle can be placed in and how much load it can safely carry. The GVWR also defines eight subcategories (ACEA Report, 2021). Figure 5 shows the number of small trucks in the European Union between 2015 and 2019.

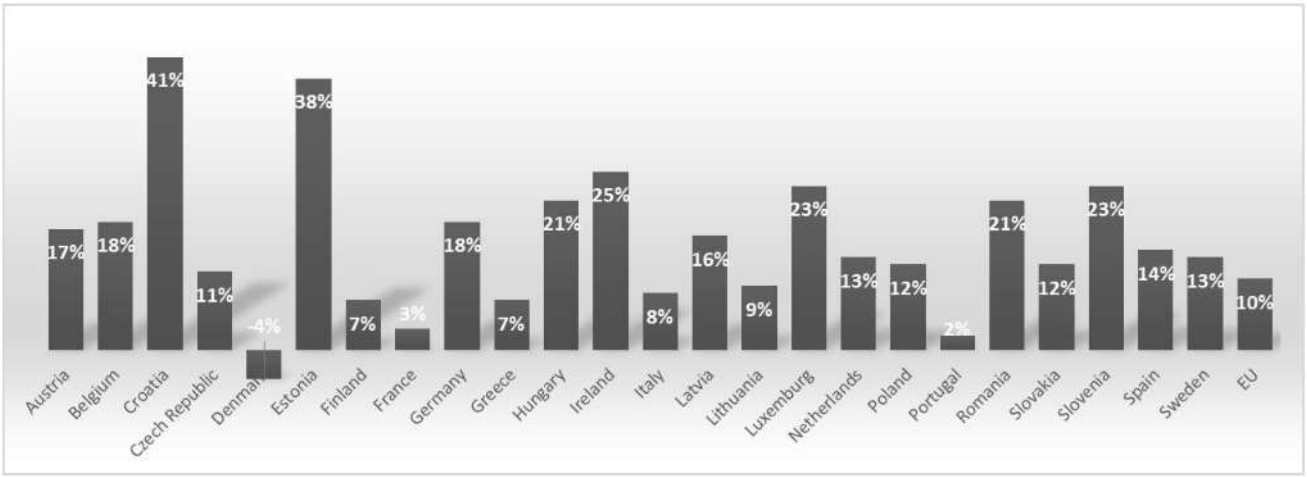

Figure 5. Change in the number of vans between 2015 and 2019 (Own editing)

As shown in Figure 4, the number of light commercial vehicles increased between 2015 and 2019 in most EU Member States, with only Denmark showing a 4% decrease. Croatia (41%) and Estonia (38%) have exceptionally high figures. Ireland follows them with 25%, then Luxembourg and Slovenia with 23%. Hungary had 388,718 light commercial vehicles in 2015, which rose to 470,454 in 2019 after a 21% increase. Overall, there is a 15–25% increase between countries. France is very far behind with 3%, Greece with 7%, Italy with 8% and Portugal with only 2%. On average, the European Union saw a 10%

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increase. France has the highest number of vans of all the countries listed, with around 6 million. Figure 6 illustrates the growth of medium and heavy goods vehicles in the European Union in 2019.

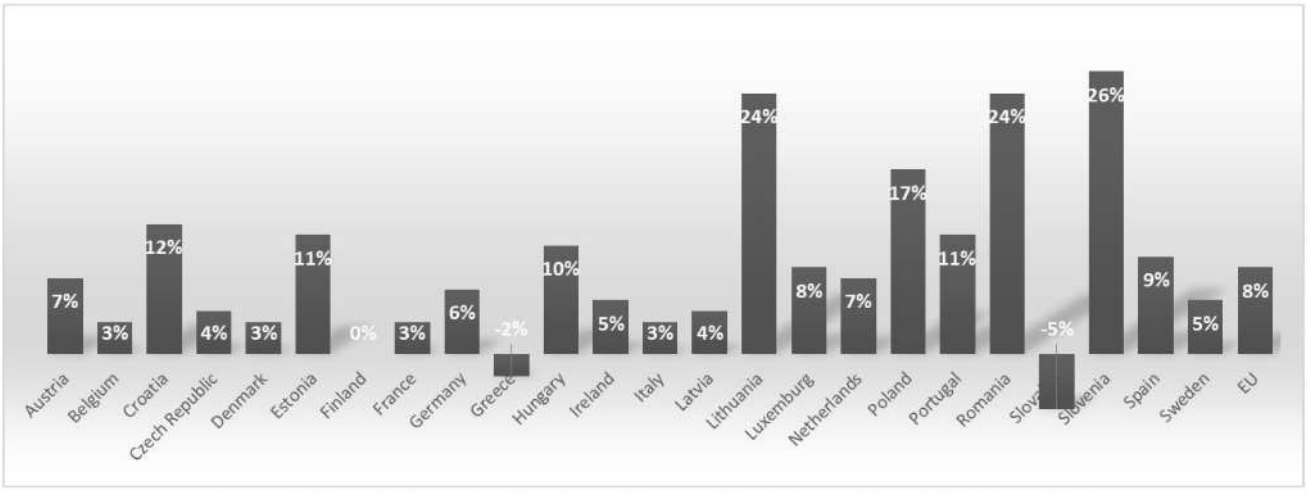

Figure 6. Change in the number of medium and heavy vehicles between 2015 and 2019 (Own editing)

In contrast to light commercial vehicles, the number of medium and heavy goods vehicles increased less in the EU. Greece saw a 2% decrease, Slovakia a 5 % decrease, and Finland stagnated. In Belgium, Denmark, France, Italy, Latvia and Denmark, a slight increase in numbers was witnessed. Slovenia had the highest growth with 26%, followed by Romania and Lithuania with 24% and Poland with 17%. For the EU, there was an 8% average increase between 2015 and 2019. The figure is 10% in Hungary, with 96,109 medium and heavy goods vehicles in 2019, compared to 87,666 in 2015.

A descriptive statistical method was used to analyse further the small, medium and heavy goods vehicles involved in freight transport. The results are presented in Table 1. The table shows that the number of elements analysed is 24 instead of 27 Member States because no such data were available for Malta, Cyprus, and Bulgaria. Consequently, further analyses were carried out for 24 Member States with 2019 data.

Table 1. Descriptive statistical results (Own editing)

	Vans	Medium and heavy vehicle
Average	1171290 pcs	259553 pcs
Standard error	320028.17	69270.62
Standard deviation	1567811.43	339355.33
Median	527772.5	95625
Mode	-	-
Minimum	38547 pcs	12300 pcs
Maximum	6029070 pcs	1150493 pcs
Sum	28110951 pcs	6229282 pcs
Sample number	24	24

The analysis shows significant differences in the number of transport vehicles between the countries studied. The average for vans is nearly 1.2 million units, and for medium and heavy goods vehicles, it is 260,000. In terms of dispersion, there is quite a significant variation in both cases.

Based on the preliminary studies and the literature review, our null hypothesis is that socio-economic development has an evident influence on the extent of freight transport. In the next section, this hypothesis is tested and will be explored to what time freight transport influences the socio-economic development if a relationship can be found.

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4. Regression analysis of the social and economic impact of freight transport

Linear regression was used to examine, among other things, the relationship between the change in a country's population and the characteristics of freight transport, such as fleet size and mileage, and was also prepared for the 24 countries previously analysed. To determine this, the HDI and mileage of the nations, expressed in million tonne-kilometres, were considered, and the relationship between the Human Development Index and the number of transport vehicles (Figures 7/a and b) was checked

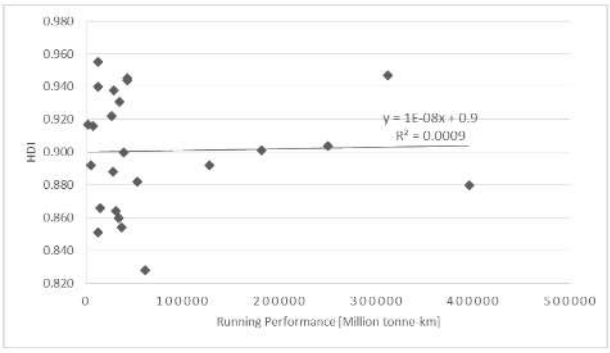

Figure 7/a. Relationship between HDI and Running Performance (Own editing)

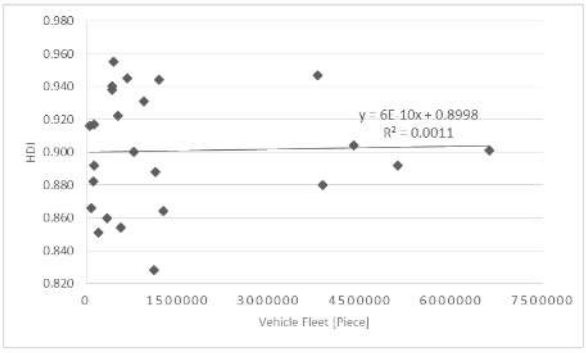

Figure 7/b. Relationship between HDI and Vehicle Fleet (Own editing)

The two graphs show no linear regression relationship for the data series under consideration. The relationship between the number of road freight vehicles and mileage is analysed below. Figure 8 clearly shows that, in this case, a correlation between the two data series can already be detected. R^2 is 0.58, which also supports the previous statement. In the present case, this value is 15.699, which means that a 1% change in the fleet of vehicles leads to a change in mileage of about 16% by 2019.

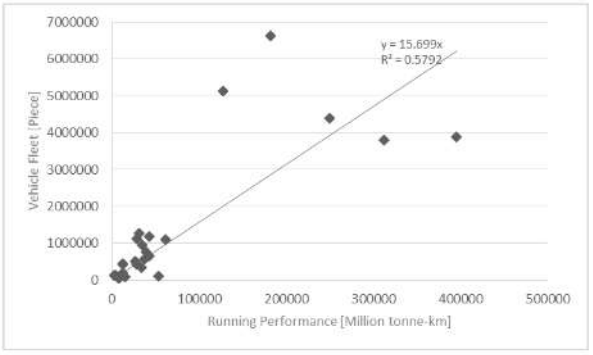

Figure 8. Relationship between number of road freight Vehicle Fleet and Running Performance (Own editing)

Figure 8 shows a direct correlation between the number of road freight vehicles and the mileage of the countries studied. This result indicates that a government, or even a company, can increase its transport performance by increasing the number of its vehicles.

In the next step, the economic correlations were analysed. The relationship between the number of transport vehicles and GDP is illustrated in Figures 9/a and b.

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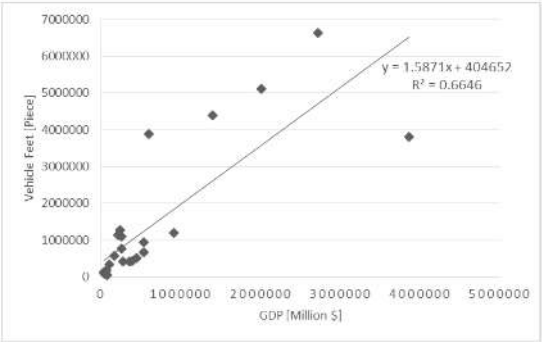

Figure 9/a. Relationship between GDP and the number of transport Vehicles (Own editing)

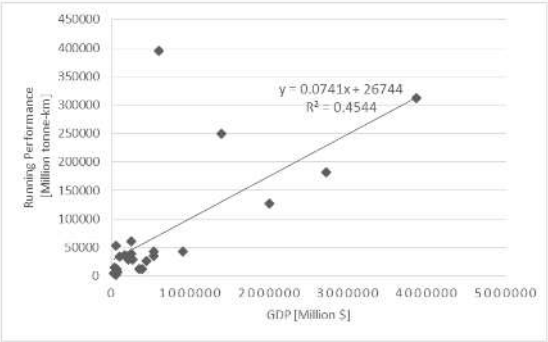

Figure 9/b. Relationship between GDP and Running Performance (Own editing)

The test between GDP and the number of goods vehicles resulted in an R^2 of 0.66, suggesting a weak positive correlation between the values and a significantly higher regression coefficient than the HDI tests. When analysing mileage and GDP, the R^2 value is 0.45, suggesting that there is also a fragile relationship between them. The other values tested are shown in Table 2.

In the analysis of fleet size and mileage, it was assumed that if the former is zero, i.e. if there is no transport vehicle, the mileage is zero. In this case, the axle section is also zero since it starts from the origin. This assumption is not valid for the other tests, so the line does not start from the origin in those cases.

The analysis of heavy goods vehicles shows that, although the Community transport policy is moving in a different direction, there has been a steady increase in the number of road transport vehicles in the EU for almost all Member States and, therefore, for the EU average. Only in very few cases has the number of road transport vehicles decreased in a given country. Consequently, it is assumed that the volumes of goods transported by road have not reduced in the recent period, but rather, as the market has required more transport vehicles, the area continues to grow. The correlations between GDP, HDI, fleet size, and mileage in 2019 have been examined in the economic and social context. Linear regression results ascend from the weakest to the most substantial relationship (Table 2).

Table 2. Results obtained by linear regression calculation

Parameters	R^2	Regression constant	Regression coefficient
Running Performance + HDI	0.0009	0.9000	$1*10^{-8}$
Vehicle Fleet + HDI	0.0011	0.8998	$6*10^{-10}$
Vehicle Fleet + Running Performance	0.5792	0	15.699
Vehicle Fleet + GDP	0.6646	404 652	$2*10^{-6}$
Running Performance + GDP	0.4545	26 744	$7*10^{-8}$

The regression coefficient is small for mileage and HDI and fleet size and HDI, showing no strong correlation between the value pairs. In contrast, the values compared to GDP are much higher, indicating a positive correlation. This yielded a surprising result, given the economic link between each value when calculating the HDI indicator, and it was previously assumed that HDI and each of the goods transport parameters were also related.

5. Conclusion

This article sought to answer the question of the relationship between economic and social indicators in a country and fleet size and mileage. This analysis was carried out for the European Union Member States based on 2019 data. From the data collected, it can be concluded that in most of the countries studied, the number of transport vehicles and the mileage increased, indicating a continuous growth in road freight transport. There is a moderately strong positive relationship between fleet size, mileage and GDP, so it can be said that these values generate each other in the direction of growth. In addition to the economic effect, freight transport performance has been compared with HDI using linear regression. No direct correlation between a country's HDI indicators and road freight transport performance has been found.

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Due to the recent pandemia, another exciting area of research could be how these same values evolved in 2020–21. A limitation of the study is that only one specific base year was examined, so it is impossible to get a fully comprehensive picture. However, the analysis of the fleet size also revealed an increasing trend, which has been present in the past and is likely to continue in the future. It is essential to highlight that current EU transport policy ambitions include the target of zero-emission devices for passenger cars, vans and heavy-duty vehicles by 2050. Consequently, continued monitoring and possible further development of research may be necessary. Overall, the results reflect the situation in the whole European region, highlighting how the Community's transport policy choices can affect the social and economic status.

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How Does Economics Approach Nature?

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Abstract

Ecological economics exists in relative isolation among the economics disciplines. This is mainly due to the difficulty which economics has in digesting the thought that the ecosystem as an entity can exist independently of human society, since the mentality of economics is based on individual utility and economic efficiency. However, the ecosystem can be integrated into the mainstream New Keynesian model, as it has been demonstrated in practice. Applying modern models, this study explores why it is difficult to change the usual approach to Nature in economics. It also examines how far the ecosystem and economics can interlock.

Keywords

Nature, economic theory, environment, climate change, model, green tax

JEL: A11, B41, C53, C78, D90, E17, O13, O44, Q50, Q54

"*[W]hen should the forest be cut for timber? [...] [W]hen the rate of growth of the forest equals the interest rate.*" (Varian, 2010: 211)

1. The puzzle

The need for environmental protection and the negative externalities affecting nature was recognized many decades ago, but nature is still one of the capital assets, while ecological economics is an isolated discipline. Although the long-term challenges and impacts of environmental damage are now included in economic modelling and forecasting, the most widely used, New Keynesian, short and medium-term growth models have not really integrated the constraint that resources are finite. Indeed, mainstream models are even less likely to reckon with the finite load capacity of the climate and the environment, as well as to recognize that environmental damage can lead to irreversible processes on a human time-scale. In the following pages, this objectified understanding of nature will be reviewed to investigate what progress has been made and potentially can be made in the integration of the ecosystem into mainstream economics.

Dasgupta (2008; 2009) demonstrates that in economics, the terms *nature* and *ecosystem* mostly refer to agriculture, mentioned as natural resources or natural capital, and are incorporated as "land" into mainstream models. Thus, in focusing on GDP, a sector like agriculture, comprising just 3-4% of total income production is not in the spotlight at all. As Cavalcanti (2010: 57) notes, even "*(e)nvironmental economics is normally considered as a branch of microeconomics. Its focus is to find correct prices for the optimum allocation of resources*." The mainstream attitudes towards nature in economics are that nature is merely a form of 'natural capital', a property and externality, while environmental protection is understood as part of a cost-benefit analysis.

In the current stage of civilization, mankind regards themselves so independent of the natural environment that it is no wonder that social science models reflecting this way of thinking are unable to treat the economy as part of the natural world. On the contrary, nature is considered to have been conquered by civilized economy. Economics defined itself as a social science, and consequently, neglects every entity that exists independently of human society, such as nature for example. Spash and Smith (2021) clearly deduce that nature in a (post-)modern understanding comprises the non-human, and particularly exists without the mankind. Thus, it can be observed as an entity beyond or besides the economy and human society. In economics, however, the economic activities which cause environmental damage as a negative externality are analyzed only from the perspective of the rest of society.

Economic models do not reflect any responsibility for nature as an independent entity as long as it is treated merely as an asset or a resource. Can nature be raised above the level of a mere production factor, subordinated to human society in a discipline which is, after all, a social science? In mainstream theories and models, nature is just one of several consumable goods and resources. This approach narrows the outlook of economists, for example, when considering the economics of global warming. Fundamentally, social sciences think in terms of costs and benefits to individuals and societies. Can a discipline of social sciences consider the natural environment as more than just a tool, which requires only renewal and sustainability, to channel it properly into production? What questions should a modern macroeconomic model set out to answer? Starting from the widely used Cobb–Douglas production function (Cobb and Douglas, 1928) based on the Solow model (Solow, 1956; Swan,1956), the basic

assumption of growth models is that economy will have a stable level of growth in the long run. How does the continuously growing global energy demand relate to such a steady state? Does it have a steady state level in reality? And what happens if the energy source turns out to be insufficient?

While the theory of economics identifies welfare as its ultimate goal, at the same time, the practice of economic policy constitutes a contest for survival between nations and national economies racing each other in growth and performance. The Cold War entailed a military rat race to finance armament from the fruits of economic growth. In such a paradigm, China aims to defeat the US in trade and production to build her global power supremacy. Despite all the criticisms that have been levelled at it, GDP growth remains the most important economic policy indicator. Obviously, the attitude of the de-growth school (Georgescu-Roegen, 1986) – which rejects economic growth – will never be a mainstream approach in the current global order. Is it possible in the New Keynesian model that the development of technology and the improvement of productivity are sufficient to reach income growth without expanding any kind of need for natural resources? The reason for this need is to avoid overburdening ecological carrying capacity. Less extensive use of land as a capital asset could contribute to the slowing of the processes of desertification and rainforest eradication. Meanwhile, reducing the demand for non-renewable energy sources could, hopefully, reduce the greenhouse effect. Nevertheless, the increase of production could also improve the quality of life without unsustainable environmental side effects if it was based on quality innovation instead of quantitative extension of machinery made from raw materials. Papers similar to Georgescu-Roegen's (1986) approach have also been published in recent years, which recommend turning the focus of economics from boosting the GDP toward production for sharing or not for sale, where welfare is sustainable without the classic consumer society characterized by frequently repetitive consumption and planned obsolescence (Bliss and Egler 2020).

2. Ecological economics in mainstream modelling

Costanza (1996) reviews how the natural world, the ecosystem and the discipline of ecology sought to be incorporated into economics during the history of economic thinking. He claims that "ecological economics views the socioeconomic system as a part of the overall ecosphere" (ibid. 980) and focuses on the activities and welfare of the human population in a fair system of allocation of resources. Cavalcanti (2010) asserts that ecological economics has targeted the feedback between social and natural systems, and the influence of the services received from the ecosystem. This is the reason why ecological economics is not very compatible with current mainstream economics, which is based on marginal utility, individual and social optimum, and efficiency seeking, where the ecosystem is part of the socioeconomic system and not opposed to it, as in the ecological approach. Although Costanza believes that the general equilibrium model could be a methodological entry into mainstream economics for the ecological discipline if 'generality' were extended to the ecosystem including human society, the wide range of General Ecosystem Models does not currently include the classic structure of General Equilibrium Model with households, firms and government. (Figure 1 and 2)

The methodological pluralism of economics means that the mathematical methodology of the New Keynesian model, which represents the mainstream in the 21st century economics, would be supplemented by methods drawn from ecological economics. In such an approach, the evolution of economic theory could be a further development of the neoclassical model. (According to Thomas Kuhn (1962)'s philosophy of science, until a fundamentally new paradigm arrives, science builds on existing theories)

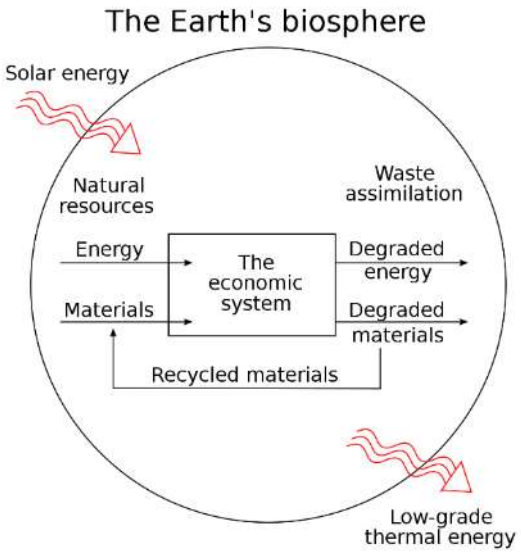

Figure 1. Ecosystem model

Source: Hammond and Winnett (2009:1216)

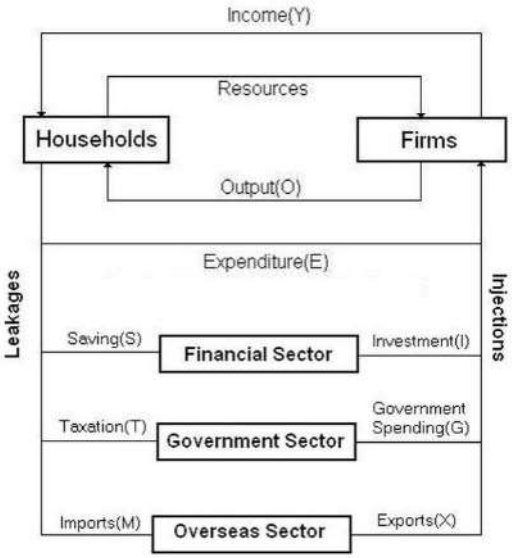

Figure 2. Five-sector model of general equilibrium

Source: Buultjens (2000:10)

If we want to understand the role of ecology in economics, Boyed (2007: 721) is worth quoting here, who considers that ecology should be used to "assess welfare losses arising from over-consumption", which originates in borrowing from future resources just for consuming in the present. Such an approach can be observed in recent economic modelling. The claim that the mainstream is not concerned at all with the destruction of the natural environment is an exaggeration. Global warming has been incorporated into both general growth models and analyses focusing on economic sub-sectors. The DICE model of Nordhaus (1992) and its modified version, Nordhaus and Yang (1996), are capable of scenario analysis about the long-term effect of climate change. These models incorporate the long-term growth impact of carbon consumption, of course in a strictly cost-benefit analysis approach. So far, however, there is a sharp distinction between the short-term forecasting model and the long-term scenario analysis model.

Modelling practices based on the CGE (Computable General Equilibrium) model have been advanced, too, regarding the global warming effects of trade policy decisions, as exemplified by Balistreri and Rutherford (2011). More information on environmental impacts and methodological options can be found in the studies by Holzer and Cottier (2015), Ecorys (2014), the House of Commons Environmental Audit Committee (2015), Frankel and Rose (2005), Holladay (2008) and the UNEP-IISD (2005). However, since ecological economics also analyzes welfare, usually treating it just like economics though in an ecosystem context, the discipline still thinks in terms of the cost-benefit understanding of use of nature and of value theories of economics (Dasgupta 2009; Pirgmaier 2021) This phenomenon strengthens the long-term focus on sustainability, but does not go beyond the mainstream view of nature as a capital asset.

Paavola and Adger (2005) and Dzeraviaha (2018) approach the integration of ecology into economics from the perspective of institutionalism to attempt to integrate ecology into the mainstream of economics. This perspective analyses environmental topics from a governance perspective, for example carbon tax or regulation. In tax matters, starting from the Pigou tax, several advanced models are ready to examine the relationship between tax impact and climate change: Kim et al. (2011), Cooper (1998), Pizer (1997), Nordhaus (2007). Meanwhile, Buchanan (1969) and Nye (2008) analyzed the tax impact on the fuel market, while Edlin and Karaca-Mandic (2006) adjust it to heterogeneous markets. Sinn (2008) outlines the green paradox, i.e. when an efficient green tax eliminates its own tax base, which is obviously unfavourable from a budgetary point of view. Edenhofer and Kalkuhl (2011) also investigate the realization of this paradox. Bossier and Bréchet (1995) examine the limited possibilities of green taxes in the context of the tax system as a whole.

Based on the Coase Theorem (Coase, 1960), some optimization models derived from microeconomics for pollution pricing take into account welfare optimization, intertemporal resource allocation, and variable discount rates (Kuik et al., 2008; Azar, 1999) Moreover, the issue of limited natural resources has already been incorporated into the labour market model (Lintz 1992) and the modified version of Porter's Competitiveness Diamond (Berg and Holtbrügge 1997).

3. Policy analysis and environmental factors

Institutional ecological economics has also penetrated into policy analysis and valuation models. Heller (2003), who confronts fiscal policy with various long-term public finance challenges, integrates the issue of climate change into fiscal policy. Jones and Keen (2009) contemplated the so-called green recovery path at the beginning of the global financial crisis in 2009, an idea that had already appeared in Bossier and Bréchet's (1995) study on how to mitigate the European employment crisis by replacing labour taxes with increasing green taxes to make labour costs more competitive. Barker (1998) developed the E3ME (energy-environment-economy model of EU) model, which specifically tests the combined effects of green taxes on energy efficiency, employment and competitiveness.

The issue of climate change has also been integrated into mainstream monetary and financial policy models. A study by the Bank of England (2015) concludes that global warming and the wrong economic policy reactions to it undermine financial stability. Companies that have suffered directly from climate damage and thus become insolvent, as well as oil companies that may have suffered from a fall in stock prices, could be among the first causes of growing instability. A working paper by Dafermos et al. (2017) examines a central bank initiative called the green QE (Quantitative Easing) program using an ecology-based macromodel. The focus of their study is on how climate change affects financial stability and price stability, and how central banks should adapt to them. Their thesis is that global warming will destroy companies' capital stock, which will spill over to a deterioration of both their profitability and liquidity. This could increase insolvency, which would ultimately erode both financial stability generally and the banking sector. Participants in the capital market might reallocate their investment portfolios in such a case if they want to manage the risk from climate change. The reaction to this will result in a decline in the value of corporate bonds and stocks. In addition, growing financial instability restricts credit growth, which would have a negative impact on green investment. In this way, efforts to mitigate climate change are weakened. For this reason, the green QE can anticipate global financial instability and support climate change mitigation. Based on the results presented by Dafermos et al. (2017), the effectiveness of a green monetary program is determined fundamentally by the elasticity of green investments in response to changes in the yields on the bonds which finance them. Murphy and Hines (2010) and Campiglio (2016) also addressed Green Quantitative Easing, concluding that monetary and financial policy should shift funding sources towards low-carbon economic activities.

4. Further interlocking of ecosystem and economics

All of the models above continue to be conceived within the framework of a cost-benefit analysis by rational decision-makers and the self-interested (selfish) individuals. However, individual selfishness may also entail that the interest of individuals is to preserve nature, either to save their own living environment or for the benefit of their descendants. Economics is a social science, thus, by definition, it is constructed from the perspective of human society. The assumption of rational thinking as a cornerstone of the *homo oeconomicus* model cannot allow human individuals' interests to override nature.

The boldest approach is imported from behavioural science into ecological economics, as exemplified by Gowdy (2007). This study places individual decisions on the foundations of neuroscience, and claims that they are driven not only by reason (rationality) but also by emotion. A human individual participates in social decisions in a given institutional and cultural environment, and does not merely take their own narrow interests into consideration. The decision theory (and game theory) model developed by Güth et al. (1982), known as the ultimatum game, argues that an explanation for human behaviour can be found in motivations which exceed the *homo oeconomicus* approach. On this basis, it is clear that the impact of financial incentives is limited when it comes to solving environmental and social problems.

Gowdy (2017: 642) concludes that a minimum proportion of people (a threshold) is needed to address certain problems such as climate change, who are willing to work together to take any action to manage the problem at all. However, the masses are only willing to cooperate if non-cooperating rule breakers (free-riders) can clearly be punished. Furthermore, it is very important for human individuals to be willing to work primarily with those who are considered to be "hive minded". This is the behavioural challenge in global warming: the whole human race needs to feel that every other person on the Earth belongs to the same group as them from an environmental perspective to be able to begin a strong and effective cooperation within the global society and community.

Further interlocking of the ecosystem model and the New Keynesian model is hindered by a crucial difference in their fundamental approaches to the relationship between economy and nature. The ecosystem model of ecological economics regards economy as a subset of the ecosystem, which participates in the flow of resources, energy and waste. In contrast, the mainstream economics model considers the economy to be an overall set which includes nature as one of the subsets in the circulation of factors and income. This fundamental conflict is not irresoluble, however. The model of a circular economy opened up the possibility for economists to extend the current general equilibrium open economy models towards new perspectives of optimization. The *homo*

oeconomicus approach has been undergoing a gradual revision in economics since microfunded macroeconomics and behavioural economics started to spread in applied economics. In parallel, environmental constraints and necessities have forced human society to reform its way of thinking about individualism, interest, optimum and environment. Just as a social science adjusts its models to be able to understand society as completely as possible, this slow change in social behaviour must be reflected in mainstream models as well. The circular economy model, behavioural economics and the evolving social attitude together can provide an opportunity for a possible future outcome, where the overall set is the ecosystem and the economy is a subset in a mainstream general equilibrium model of economics.

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Identifying the main categories of key performance indicators for nature-based solutions

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Abstract

As the number of people living in urban areas is firmly increasing, more innovative solutions are needed to tackle the accompanying effects of climate change there, such as heatwaves, stormwater concerns or pollution. As these projects are continually developed and their effects are yet to be fully tapped, there is a lack of a coherent monitoring system. This study presents a systematic and comprehensive overview of three of the most recent studies of Sari et al. (2021), Connop (2020) and Elagiry et al. (2019), which list key-performance indicators (KPIs) for nature-based solutions. These indicators are grouped into six major categories, which are further divided into sub-categories. The results of the paper highlight the importance of a general and widely implementable monitoring tool system which is scalable and localizable for different urban settings, making it possible for individual nature-based projects as well as complex urban ecological systems to be well-monitored.

Keywords

Nature-based Solutions (NBSs), Sustainability, Key Performance Indicators (KPIs), Monitoring Tools, Indicator Assessment

1. Introduction

What makes a city liveable is argued by many. One might highlight the level of infrastructure or the proximity of services and opportunities. Jaszczak et al. (2020) argue that the level of liveability is determined by nature itself around us, as it has a positive effect on human well-being. Jaszczak et al. (2020) and da Costa and Kállay (2020) emphasized the importance of nature in urban areas by pointing out the social awareness of nature in urban areas and the beneficial impacts of green areas on the health and overall well-being of individuals. It is highlighted that the global pandemic created a sense of need for the expression of our "biophilic" behaviours (Jaszczak et al., 2020; Tomasso et al., 2021), which can only be fulfilled with the presence of nature and ecological diversity around us. Hence, the arising social recognition of environmental connectedness has given us a unique opportunity to have the willingness for bringing nature back to our everyday urban experiences.

It is projected that the total population living in cities will steeply increase and will reach 68% by 2050. This trend is significant, as in 1950 only 30% of the global population was located in urban areas (United Nations, 2018). Since urbanization is inevitable, and several effects are emerging as well as intensifying; local, urban solutions are needed for addressing these issues.

As with all parts of the globe, the continual urbanization in European cities has led to the increasing number of climate change-induced stress effects, including intensifying heatwaves or concrete jungle effects; the escalating noise, light, or air pollution; flood and stormwater effects. All in all, the cities in the continent are getting more exposed to the severe effects of climate change (Fűr and Csete, 2010; Szabó et al., 2018). These effects have both short- and long-term consequences on human well-being, leading to temporary or acute health issues (da Costa and Kállay, 2020), permanent mental state degradation or induced stress experiences for locals. Due these effects, not only human well-being is put at risk, but also the level of food, water and energy security, driving to a potential disruption of the economic structure of cities (Faivre et al., 2017). Holistic, systemic approaches are needed that are not tackling these issues with only one solution, but rather apply a cognitive sustainability approach: utilizing the biological and artificial systems with technological solutions to create a more comprehensive web of tools (Zöldy et al., 2022).

Dorst et al. (2019) states that so called nature-based solutions (NBSs) have the potential to incorporate several disciplines and aspects of urban adaptation processes together, enabling a more holistic, systematic approach. This interdisciplinary and multipartite toolset would allow policymakers to realize and communicate the role and position of nature in urban systems.

To be able to implement impactful and sustainable policy measures and regionally suitable and effective green solutions, monitoring results are needed from already executed projects. And evidently, in order to get monitoring results, suitable monitoring processes are required.

Raymond et al. (2017) discussed that the assessments conducted for monitoring purposes only focus on one single area of green urban solutions. A similar conclusion was arrived at with respect to decision making approaches by Zöldy et al. (2022), as they pointed out the lack of holistic, hence cognitive aspects being implemented in urban decision-making processes. Frameworks and monitoring processes have been mainly looking at one of the fields of biodiversity, ecosystem services or other green solutions. As nature-based solutions are such interwoven projects, proper monitoring tools are required in order to allow a cross-sectorial analysis of their impacts instead of a single-sighted managing process. Such broad tools exhibit a complex, intersected system dynamics that requires intricate and detail-oriented monitoring and evaluating processes as well.

In their 2018 study, Macháč et al. argued that adaptation measures have difficulties in terms of implementation, as there is not enough knowledge in the topic; and as a result, these measures have a blocking effect on proper monitoring practices for the implemented projects.

As a uniform but still flexible monitoring system for nature-based solutions is required, based on a comprehensive review of the literature, this paper presents a hierarchical system of key performance indicators (KPIs) that are used to monitor nature-based solutions according to three influential studies: Sari et al. (2021), Connop (2020) and Elagiry et al. (2019). The system described here could be used as a starting point for the creation of an internationally accepted monitoring system. Section 2 reviews the relevant literature on the basic concept of nature-based solutions, the role of green areas in cities, and the parameters of nature-based solutions. Section 3 showcases the importance of indices in monitoring processes of green solutions as well as presents the author's work on the main categories of KPIs for NBSs with the mentioning of possible limitations. The suggested system of KPIs is presented in a table in the Appendix.

2. Literature review

The literature review section of the article discusses the different definitions of NBSs with special focus on the similarities of different approaches, then the role of green areas in cities will be showcased including the sustainability dimensions of NBSs, followed by the short literature review for the different parameters of NBSs.

2.1 Nature-based solutions

It has been discussed lately whether rapidly growing urban areas can adopt to the severe effects of climate change. Numerous policies, city planning approaches, engineering solutions, and green methodologies have been introduced in order help adaptation measures (Szalmáné Csete and Buzási, 2020; Szlávik and Csete, 2005). One such approach is that of the so-called nature-based solutions.

The concept emerged in the last decade, when adaptation practices started to shift from a predominantly engineering-oriented approach to more environmental-based solutions (Cohen-Shacham et al., 2016). It was realized that the increasing number and intensity of urban exposure to climate change effects are not adequately addressable with only technological solutions; rather a better, more complex system is needed to tackle these. A concept emerged that allowed the services provided by nature to do this job. Hence the term "nature-based solutions" was born. As this notion is considerably new, there is no internationally accepted definition, framework, or categorization of the term. Therefore, a comprehensive literature review on the concept is presented in order to provide a broader view on the topic.

The European Commission's (2015) agenda on NBSs lists multiple objectives that can be associated with the green urban solution toolset. The most obvious one is climate change mitigation and adaptation development; additionally, the positive effects of NBSs on risk management and resilience enhancing were highlighted, as well as the development of sustainable urbanization procedures; and lastly, the restoration of degraded ecosystems. Many other sources emphasize the importance of NBSs: Dushkova and Haase (2020) discuss that NBSs have been created to provide an ecosystem services approach inside urban planning strategies and implementations, to completely join in the environmental dimension to socio-economic urban structures, as well as to address current societal challenges in urban areas. Faivre et al. (2017) emphasize the importance of NBSs for urban development as a tool for innovation and encourage the urgent inclusion of these practices for both policymakers as well as practitioners. According to Dorst et al. (2019), NBSs offer a toolkit that has the capability of uniting different disciplines and aspects into a general overview within the concept of urban greening, allowing researchers and policymakers to address climate change challenges in a more effective way. Bush and Doyon (2019) state that NBSs are key elements of resilient urban planning, without which cities would not be able to face the climate challenges. By proposing an integrated system of planning NBSs for urban resilience, they urge the mainstreaming of ecosystem services used in urban planning.

What are the opportunities NBSs can bring to the table that other similar practices, such as green technologies, ecosystem-based adaptation practices or green infrastructure solutions cannot? Dorst et al. (2019) concluded that this is the multifunctionality and the ability to provide solutions to more complex issues due to the broader interpretability of the term "nature-based". In general terms, NBSs are such green solution toolsets that offer societal, economic, and environmental benefits in any setting, including urban areas, rural spaces, or agricultural lands.

NBSs are mostly implemented for the adaptation practices to the effects of climate change in urban areas, although an increasing number of sources suggest a rather expansive interpretation. The European Environment Agency (2021) concluded that NBSs are – along with climate change adaptation tools –also risk reduction instruments, allowing urban areas to reduce their disaster threat exposures. Several studies (for example Almassy et al., 2018; Bush and Doyon, 2019; Cohen-Shacham et al., 2016, 2019; da Rocha et al., 2017; Dorst et al., 2019; European Environment Agency, 2021; Giachino et al., 2021; Kabisch et al., 2017; Katsou et al., 2020; Mendes et al., 2020; Seddon et al., 2020; and van den Bosch and Sang, 2017) emphasize the multidisciplinarity and the complex systemic tool trait of NBSs; labelling the term to be an umbrella concept.

While other papers discuss NBSs as tools for urban adaptation, it should be noted that the European Environment Agency (2021) interprets NBSs as an umbrella term, thus all other climate change adaptation and disaster risk reduction practices are considered to be a sub-category under NBSs (Poyraz and Csete, 2021).

2.2 Role of green areas in urban settings

The European Commission's Horizon 2020 expert group on "Nature-Based Solutions and Re-Naturing Cities" (2015) argues that NBSs are key aspects in bringing sustainability into urban development, as they enhance economic, social, and environmental development simultaneously *(Table 1)*.

Table 1: Sustainability aspects of NBSs services in urban areas.
Source: Author's table based on data retrieved from Cohen-Shacham et al. (2016), De Vries et al. (2003), Dushkova and Haase (2020), European Commission (2015), and Keniger et al. (2013).

Economy	Business opportunities
	Decrease resource dependencies
	Knowledge-shift
Social	Food and water security
	Disaster risk mitigations
	Health improvements
	Socio-economic development
	Relaxation or therapeutic areas
	Sports activities
	Positive experiences in nature
Environment	Adaptation to urban pollution challenges (air, noise, light)
	Heatwave mitigation
	Water management issues
	Ecosystem-services

As for economic aspects, more and more market players realize the importance of climate change adaptation practices. Consequently, as the awareness of companies and other actors of industries is growing, the interest of the public is rising as well. These shifts in knowledge can lead to policy changing initiatives and a global will to take action. On a less apparent note, economic development is expected from NBS projects in the form of business opportunities, as well as allowing a decrease in the resource dependencies of industries in urban areas (European Commission, 2015).

According to Cohen-Shacham et al. (2016), social challenges that can be addressed by NBSs including adaptation to climate change effects are food and water security, mitigation of disaster risks, and socio-economic development. Furthermore, De Vries et al. (2003) and da Costa and Kállay (2020) add human health improvement here as well. Other social benefits may include creating hospitable areas for relaxation and for therapeutic purposes (Keniger et al., 2013), for active leisure time activities, or increasing the positive experience associated with such an area of the local communities (Dushkova and Haase, 2020).

The beneficiary effects of NBSs on environmental development are straightforward, although they are not fully discovered in their entirety. The adaptive ability of cities to the urban effects of climate change is significant: these urban effects may include air, noise, and light pollution; sudden and severe heatwaves; or stormwater management issues. Alongside with adaptation practices, NBSs provide valuable settings for different ecosystem services. As it has been discussed above, NBSs and ecosystem services are closely interconnected, resulting in an overlapping group of tools.

2.3. Parameters of nature-based solutions

There is an absence of literature related to the operational transparency of NBSs (Cohen-Shacham et al., 2016), which results in the lack of reliability as well as applicational deficiencies of the newly emerging implementation practices. As Cohen-Shacham et al. (2016) have found, the overall goal, the definition, and the principles of NBSs are concepts are already in existence in the literature, although there is a significant absence of operational parameters for such projects on a global level. Lapintie (2021) highlighted the need for embeddedness of such practices into urban planning systems as well as policy making practices, in order to achieve systemic change.

The lack of operational parameters results in different implementation methods, a lack of inconsistency of monitoring tools, as well as no standardized indicator utilization for evaluation and examining.

In their more recent study, Cohen-Shacham et al. (2019) found that NBS implementations and frameworks offer higher levels of solutions than other methodologies, as NBSs assimilate with strategies and measures, making it possible to tackle the challenges. The essence of NBSs is the integration with other nature services (Cohen-Shacham et al., 2019), allowing a more comprehensive range of addressed issues. By merging numerous different concepts, a higher implementational impact may be achieved through the improved allocation and scaling-up of NBS projects.

3. Results and discussion

The domain of NBSs is increasing worldwide, making the concept more accepted and considered in urban planning processes, as it does not only provide environmental and ecological benefits, but also significant social and economic advantages (Oen, 2019). On the other hand, there are numerous shortcomings of the concept of NBSs, as it is still in its rudimentary form. Kabisch et al. (2016) suggest a stricter monitoring of implemented projects in order to produce so called evidence-based NBSs projects in the future. This would result in a more impactful, possibly socio-economically more beneficial outcome of schemes. Alongside with monitoring, the broader inclusion of stakeholders is advised by the research team, in order to make NBSs more adaptable for the complex and administration-heavy governance systems worldwide. Furthermore, Kabisch et al. (2016) highlighted the inclusion of social justice aspects into the transdisciplinary concept of NBSs, making it more inclusive and transparent for social benefits.

Meerow (2019), Chrysoulakis et al. (2021, 2018 and 2015), Ludlow et al. (2016), Spencer and Coye (1988) and a constantly increasing number of other scholars have been searching for proper monitoring tools for NBSs projects, with little to no comprehensive solution for the tool. As there are various tools in terms of focus scales (regional or specific), they might work proficiently for individual solutions, while they are not suitable at the European nor global scale. It would be negligent to assume that there is one monitoring tool that fits for all, although a broadly accepted, globally adaptable, and most importantly, scalable monitoring tool is essential.

Besides monitoring, the lack of citizen involvement is alarming. Lorencová et al. (2021) concluded that the lack of awareness of locals as well as the absence of institutional frameworks also raise significant obstacles against climate change adaptation practices in urban areas. They have found that the cooperation of researchers, NGOs and governmental agencies have a major effect on realizing and sustaining these projects. Hence, a broader spectrum of communication about NBSs is needed, including scientific publications, social media announcements, public awareness campaigns, civil society goals, or governmental communication.

Similarly to Lorencová et al. (2021), the European Environment Agency (2021) also highlights the importance of stakeholder involvement in the designing, implementing, and monitoring processes of any NBSs, stating that this approach is the key to raise awareness and to tackle possible disagreements amongst players.

3.1. Data evaluation

The data collected by the Naturvation Project (Almassy et al., 2018) shows that the V4 countries (Poland, Slovakia, Czech Republic, and Hungary) show a lack of monitoring of these implemented NBSs projects. Only 64 out of 111 projects implemented in these 4 countries have reported in-situ monitoring activity. Investigating the data it became quite evident that there are barely any number of monitoring processes for these NBSs projects. This is an enormous inadequacy of these developments, as the lack of these practices results in projects being implemented with possibly no positive impact or even the further estrangement of the ecosystems and their benefits to urban areas.

As mentioned above, it is not only an adverse practice for the lack of data provided, but mainly for the fact that these monitoring practices would enable projects to be more impactful and resourceful, and possibly more economic, as data would be available about the cost benefits of the implemented NBSs projects. The return rates of these projects could be lowered as possible impacts are more accurately pre-measurable with initial data from previous monitoring practices. For

this reason, the investigation of present monitoring tools was required. It was found that one of the reasons for the lack of monitoring frameworks in action is the absence of proper indicators. In their 2017 article, Buzási and Csete have highlighted the importance of an indicator-based monitoring system in order to find impactful solutions for urban effects of climate change and to ensure the decision makers, to confidently consider green developments in urban planning.

3.2. Key Performance Indicator approaches

In order to be able to determine the most important aspects of the monitoring toolsets, the KPIs of NBSs need to be defined. KPIs are such tools that allow a rather practical approach towards measuring performance. Warren (2011) discusses them as a "type of language" that allows effective measurements of practices and their effects to their surroundings. In order to provide the most up to date KPI approaches, three publications are going to be presented, published in 2019, 2020, and 2021, respectively. Later in this study, an assessment and possible KPI list will be presented based on the findings of the three studies.

Within the Nature4Cities Project, Sari et al. (2021) and his colleagues investigated the key performance indicators of NBSs and urban climate challenges. They grouped the different indices into five main pools of indicators: climate, environment, resources, social, and economy. They utilized the so-called RACER method: this abbreviation stands for the necessary traits of functioning indices: Relevant, Accepted, Credible, Easy, and Robust. Through this system, Sari et al. (2021) created a list of multi-thematic and multi-scale indicators (UPIs) for urban performance evaluation and monitoring, out of which the KPIs have been selected.

The main goal of Connop (2020) was to create a comprehensive list of KPIs for NBS monitoring in cities. They identified 93 indicators, out of which they have highlighted 17 of them being the most fundamental or impactful ones. Hence only these highlighted 17 indices were included in this investigation. With direct focus on the positive effects of NBSs, they created subgroups for economic, social, ecological and wellbeing benefits. Their study further investigated the locality of the analysed cities, taking a general path and implementing it on scalable and localized level for each city's needs and peculiarity.

Elagiry and their team has created the so called GREENPASS tools, which enable the user to assess the effects of NBS projects. These tools also aid planning processes, as they can be used to measure current and possible impacts on a given urban area, by comparing them before and after the green projects (Elagiry et al., 2019). They have collected 28 KPIs that are used to evaluate the performance of aforementioned areas by dividing them into 6 main categories of climate, water, air, biodiversity, energy, and cost.

3.3. Key Performance Indicators

In order to fully investigate the differences and similarities between the indices presented in the three studies, the following five steps were taken: (1) data collection; (2) comparison of all indices; (3) categorization of indices; (4) sub-categorization of indices; (5) assessment of the availability and quality of indices. Appendix A shows the list of KPIs taken from the three sources, categorized and clustered by the author. 6 main categories (NBSs; land-use and habitats; pollution and emissions; social; economy; and other) and 20 sub-categories were created (Table 2).

The number of indices listed are quite different in the three sources: Sari et al. (2021) uses 52, Connop (2020) listed 93 (out of which 17 has been used), while Elagiry et al. (2019) collected 28 of them. It needs to be stated that the number of indices does not necessarily correlate with the quality of them: either too few or too many can be problematic.

Table 2: Main and sub-categories of key performance indicator assessment by author.

NBSs	Blue spaces Blue-green spaces Green spaces
Land-use and habitats	Shannon index and ecosystem Land-use
Pollution and emissions	GHG Air quality and temperature Heat Energy Noise Light Waste
Social	Health Society Accessibility
Economy	Infrastructure Costs

Other	Environment Social Economy

As mentioned previously, one of the main tasks was to categorize the indices into comprehensible core and sub-categories. As a result of the categorization, six major groupings were set up by categorizing same and/or nearly essentially same indices by the three studies into one category. As an example, for the *Pollution and emissions* main category, under the GHG (greenhouse gases) sub-category came the indices *CO_2 annual carbon sequestration* by Sari et al. (2021), *CO_2 emissions reduced*, *Carbon sequestration rate by tree species*, *Carbon storage/carbon sequestration in vegetation/soil*, *CO_2 emissions reduced* by Connop (2020), and *CO_2 storage score* by Elagiry et al. (2019). The first three categories *(NBSs*, *Land-use and habitats*, and *Pollution and emissions)* are considered to be the environmental core groups, followed by the *Social* and *Economic* categories. Lastly, there is a category for indices that could not be listed elsewhere.

The first category is *NBSs*, which includes the KPIs that are directly connected to the implemented projects themselves. A total of 46 indices were classified here with further sub-divisions of Blue spaces, Green spaces, and the combination of them: Blue-green spaces. The most important similarities in the indices in the Blue spaces group of the *NBSs* category are the consideration of water availability in urban areas, especially water scarcity and the demand thereof. The Blue-green spaces sub-category has only been considered by Connop (2020), highlighting the importance of the interconnectedness of the two systems. They have considered the importance of connectivity of these areas, and the cultural and recreational value they offer.

The next core category is the *Land-use and habitats*, in which two sub-categories are listed: the Shannon Index and ecosystem, and Land-use. Although all the three of the investigated sources consider the Shannon Index, only two of them (Sari et al., 2021; and Elagiry et al., 2019) name it directly, while Connop (2020) itemizes the main elements of it. It is notable also that Connop is the only author to mention the role of pollinators, as they have introduced two indices dealing with this phenomenon. The sub-category of Land-use contains no indices by Elagiry et al. (2019), and only 2 by Sari et al. (2021). Connop (2020), on the other hand, listed 14 of them, focusing on land-use trends, food production, brownfield regeneration practices and urban sprawl patterns.

The third major category of the environmental scope – *Pollution and emissions* – is rather segmented, it is further divided into 7 groups. The sub-category of GHG includes indices from all 3 of the publications, each focusing on CO_2 sequestration. Air quality and temperature is the largest sub-category, including 23 elements, although the only common index included is air temperature. The other sub-categories include heat, energy, noise, light, and waste related indices. The latter 2 are only considered by 1 publications, respectively, where light pollution is highlighted only by Connop (2020), and waste management is included exclusively by Sari et al. (2021).

The *Social* category of the indices was divided into 3 groups: Health, Society, and Accessibility. The former 2 is only included by Sari et al. (2021), who laid great importance on society by the listing of 7 indices here, while others listed none. As discussed previously in the paper, also Kabisch et al. (2016) highlighted the importance of such considerations into NBS implementation approaches. The sub-category of accessibility includes KPIs by both Sari et al. (2021) and Connop (2020), highlighting the importance of the availability of NBSs for everyone.

The group of *Economic* indicators is divided into 2 parts: Infrastructure and Costs. The former category includes KPIs exclusively by Connop (2020), which is due to their great interest in accessibility indices. On the other hand, Costs include only indices from Sari et al. (2021) and Elagiry et al. (2019), with special focus on the investment and maintenance costs, as well as the effects of NBSs on pricing in the related areas.

The last category comprises indices that could not be grouped elsewhere. A similar sub-divisional approach was conducted here as well, with the category having the 3 elements of sustainability: Environment, Social, and Economy. The first sub-group includes indices like albedo or radiation (with only Sari et al. (2021) not utilizing them), the Social category contains KPIs like responsibility or adaptive comfort, while the Economy group discusses indices like leapfrog development index or sustainable practices index.

As with all scientific assessments, inaccuracies, misinterpretations present in the processes are inevitable. That is why it is crucial to highlight the possibilities of such "practices". 3 main biases or potential limitations have been collected to provide a better understanding of the dynamics of the system: bias within the indicators collected, limits of data readiness, and finally, the vicinity aspects of indices assessed.

As for the bias across indices, Sari et al. (2021) claimed that it is challenging to find adequate and all-including indices as (1) the field of NBSs is a wide-ranging toolset with numerous different actors; and (2) this field of science is a relatively new, still emerging discipline with many variables being formulated in the upcoming times. These indices need to be comprehensive, same-level, and inclusive. Hence, deeper research needs to be conducted in the field. It was also argued that the stakeholders might interpret the importance of various indicators differently, which leads to varying lists of KPIs. The diverse group of actors, stakeholders and experts need to be able to come to a comprehensive, similar conclusion for a KPI list in order to gain relevant and impactful insights from the monitoring processes.

Concerning data availability, Buzási and Csete (2017) have concluded that in order to utilize the adequate KPIs, multiple characteristics need to be met by the indices. One of these qualities is the availability of data for the given index. It is crucial to utilize indices whose data is either accessible or easily measurable, since their introduction of new data measurements can deter different stakeholders, such as monitoring bodies or policymakers from project implementations.

On the topic of the locality of indices, Farkas et al. (2017) found that indices provided on an international level have great biases across implementations, as indices required for monitoring procedures need to be differentiated regionally due to the territorial differences in different areas. This finding – although it is considerable – is not suitable for real-life measures, as most monitoring bodies do not have the capacity to use individualized indices for each and every project. Furthermore, this would result in an incomprehensive set of data across project monitoring.

4. Conclusion

This study found that the nature-based solution (NBS) toolset is widely considered as an umbrella term by the researchers. It is an interdisciplinary, sustainability-oriented multilateral methodology for urban mitigation, adaptation and disaster risks decreasing measures related to climate change. A comprehensive literature review was conducted to highlight the various characteristics of NBSs, resulting in an overview of the different approaches and interpretations.

It was found that one of the reasons why no proper monitoring solution is globally available is the lack of a comprehensive group of KPIs for NBS monitoring. Three of the most recent articles were investigated to find the similarities and differences between the KPI lists in them. 6 main categories as well as 19 sub-categories were created by the author.

To understand the reality of the NBS implementation and monitoring processes as well as the proper attributes of impactful KPIs, a list of possible limitations was compiled in order to ensure the proper and comprehensive evaluation of data. KPIs related to NBSs can play a pivotal role in urban decision-making processes, enhancing cognitive sustainability in local systems.

As for further research, the list of monitoring tools available for NBS monitoring needs a comprehensive, systemic study. These tools are available and impactful: implementors, researchers, municipalities, NGOs, or residents can utilize them to evaluate the impacts of implemented NBSs, enabling them to carry out more impactful projects in the future, resulting in resourceful adaptation or mitigation tools against the severe effects of climate change.

In addition to the comprehensive research on monitoring tools, further research is needed for the assessment of KPIs. An exploratory data analysis is suggested, for which cluster analysis is highly recommended.

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**Anonymous version. **

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Appendix

Appendix A. KPIs for nature-based solutions monitoring processes created by the author.

Based on data retrieved from Sari et al. (2021), Connop (2020) and Elagiry et al. (2019).

		Sari et al. (2021)				Connop (2020)				Elagiry et al. (2019)			
NBSs	Blue spaces					Blue space areas							
		Water scarcity				Drinking water (surface/ground)	Reduction of drought risk	Water expiration index	Water consumption	Water demand (GI/TCS)	Water demand (GI)	Cost water demand GI/m^2	
		Stormwater quality				Reduction of stormwater treated in public sewerage system (economic benefit)	Water quality	Groundwater quality	Increase greywater and rainwater reuse				
		Total rainfall volume	Peak flow variation			Flood peak reduction/delay	Flood damage (economic)	Rainfall storage/absorption capacity of NBS	Increase groundwater availability	Water storage	Cost invest GI/water storage		
						Increase evapotranspiration				Evapotranspiration			
		Soil biological activity	Soil classification factor	Water detention time		Soil sealing				Sealing Grade	Run-off score		
NBSs	Blue-green spaces					Connectivity of urban green and blue spaces (struct. and funct.)	Cultural value of blue-green spaces	Recreational value of blue-green space					
	Green spaces	Connectivity of green spaces	Urban Green Space Proportion			% of buildings with NBS adaptation	Green space areas	Public green space distribution		Green space			

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		Sari et al. (2021)				Connop (2020)				Elagiry et al. (2019)			
		Normalized Difference Vegetation Index				Community garden area / child capita and in a defined distance	Community garden area / capita and in a defined distance						
						Urban tree health	Urban forest pattern	Total monetary value of urban forests		Leaf area			
Land-use and habitats	Shannon Index and ecosystem	Shannon Diversity Index of Habitats				Index of habitat types	Habitats restored	Targeted habitats		Shannon Index			
						Species diversity	Number of nature species	Species under nature conservation designation					
						Ecological connectivity	Ecological connectivity (eco. connectivity index)						
						Change in ecosystem service provision	% of protected areas (ecologically and/or culturally sensitive	Mapping ecosystem services and spatial - temporal biodiversity legacies	Supporting/increasing biodiversity conservation				
						Increase in pollinators (abundance of pollinators)	Increase in pollinators (habitat)						
Land-use and habitats	Land-use	Biotope Area Factor				Land-use intensity	Land-use mix	Proportion of landscape not in intensive	Land-use change and greenspace configuration				

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		Sari et al. (2021)				Connop (2020)				Elagiry et al. (2019)			
								management					
		Per capita food production variability				Reduction in pesticide use	Local food production	Use of organic fertilizers	Cultivated crops				
						Fragmentation	Ratio of open spaces to build form						
						Brownfield use	Reclamation of contaminated land						
						Population density	Urban sprawl						
Pollution and emissions	GHG	CO_2 annual carbon sequestration				CO_2 emissions reduced	Carbon sequestration rate by tree species	Carbon storage/carbon sequestration in vegetation/soil	CO_2 emissions reduced	CO_2 storage score			
		Avoided GHG emissions				NOx emissions							
Pollution and emissions	Air quality and temperature					Fine particulate matter emissions	Atmospheric pollutant flux	Pollutant fluxes/m^2/year					
		Exceedance of air quality limit value - Local scale				Share of emissions (air pollutants) captured/sequestered by vegetation	Value of air pollution reduction	Annual amount of pollutants captured by vegetation	O_2 production by vegetation				

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		Sari et al. (2021)				Connop (2020)				Elagiry et al. (2019)			
		Common air quality index	Air quality indicators - short term health effects	Air quality indicators: long-term health effects		Air quality change	Air quality index						
		Air temperature	Physiological equivalent temperature	Thermal Comfort score (outdoor)		Air temperature change				Thermal comfort score	Thermal load score	Thermal storage score	Thermal Performance
						Temperature increase / wind shelter				Wind field			
Pollution and emissions	Heat	Heat induced mortality				Tree shade for local heat change				Cost invest GI/Red. Cooling. Degree Hours Building	Cooling Degree Hours Building	Shading Area Factor	Night-time Cooling
	Energy	Energy security	Buildings energy needs	Cumulative energy demand		Air temperature - Energy demand	Energy savings						
	Noise	Day-evening night noise level	Effects of night noise on health			Noise pollution reduction	Noise mitigation by vegetation						
	Light					Light levels at night							
						Increase portion of sky visible from the ground							
	Waste	Specific waste generation	Construction and demolition waste										
		Efficiency of valorisation as a result of recycling process	Material Circulatory Index	Raw material efficiency									

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		Sari et al. (2021)				Connop (2020)				Elagiry et al. (2019)			
Social	Health	Perceived health	Quality of life										
		Number of deaths and missing people											
	Society	Social capital											
		Procedural justice	Segregation index	Percentage of gender violence	Percentage of victimization								
		Recognition	Distributional justice										
	Accessibility	Accessibility				Accessibility of green spaces	Community accessibility	Access to public amenities					
Economy	Infrastructure					Quality of public transport	Length of bike route network	Access to vehicle sharing	Citizen access to public transport				
						Area for pedestrians	Road density	Land devoted to roads	Inundation risk for critical urban infrastructures (probability - economic)				
Economy	Costs	Adjusted Net Saving								Cost invest GI/m^2	Cost invest GI	Cost invest GI/TCS	
										Cost maintenance GI	Cost maintenance GI/m^2		

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		Sari et al. (2021)			Connop (2020)				Elagiry et al. (2019)			
		Housing Pricing Index	Domestic Property Insurance Claims	Gross Value Added in the local Environmental Good and Services sector								
Other	Env.				Albedo				Albedo			
									Radiation			
	Soc.	Responsibility	Capabilities	Adaptive comfort (indoor)	Introduction							
	Additional Indices	Sustainable Practices Index			Climate resilience strategy	Linearity development index	Leapfrog development index					

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Sustainable Human Resource Management Practices Impacting Employer Branding

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Abstract
Business seeks a long-term competitive advantage to make money and stay afloat as the market grows more competitive. Human resource management is essential for gaining a competitive advantage. Companies that embrace sustainable Human Resource Management (HRM) practices have a distinct employer brand, but how an organisation's culture plays its role indirectly in employer value proposition is scarcely studied. This paper discusses academic literature on employer branding factors by sustainable human resource management, and helps to take a holistic perspective of the present state of global acceptance of HRM.

Keywords
Human Resource Management, Employer branding, Sustainable HRM

1. Introduction

In today's competitive market, companies must publicize their employer brands if they intend to attract new employees and keep their current employees happy and productive. Highly qualified and talented personnel are in higher demand in knowledge-based economies, because they may provide a long-term competitive advantage (Moroko and Uncles, 2008). The labour market is transitioning from a sellers' to a buyers' market, especially for highly skilled persons, because more high-value employment is available than eligible job searchers (Tumasjan et al., 2020). It is a challenge for human resource management (HRM) to sustain the organization's competitive edge over time by retaining highly qualified and motivated employees, as it is generally difficult to find and keep suitable candidates in organisations. Employee retention and productivity are critical components of long-term human resource management (Mohsen and Sarbuland, 2020)

The sustainability argument appears to be a possible answer to this problem. Other variables, such as resource regeneration and development, are considered in Sustainable HRM and sustaining a competitive advantage (Ehnert, 2009). Sustainable HRM is a solution for those businesses that wish to promote themselves as responsible employers and who offer a desirable workplace to prospective and present employees. Employer branding influences a person's desire to work for a given company, as it addresses characteristics such as culture, personality, and look. While culture shapes how employees act; personality and image shape how customers perceive a company. According to Backhaus and Tikoo (2004), building employer brands both inside and outside the organisation provides a more engaging working environment. In the 1990s, Ambler and Barrow (1996) invented the term *employer brand* (Backhaus, 2016; Theurer et al., 2018; Vatsa, 2016). Employer branding has become an important concept of the business world since then. An employer's brand is a collection of activities to recruit and retain new and existing employees (Ahmad et al., 2020). As a result, maintaining the company's public image is vital. Every company's productivity and capability are essential success elements. However, organisations face a tremendous challenge in attracting and retaining top-tier personnel in today's competitive environment. In such a situation, employer branding, which also tackles the scarcity of qualified workers, is the most effective technique for attracting and retaining top talent.

HRM is used to identify and keep the most outstanding individuals, regardless of the firm's size. Building your company's brand, is a very effective strategy for acquiring new employees. HRM impacts employee branding and organizational culture. It is critical to understand what employer branding is and how it affects job experience and commitment. Employee engagement has been studied for a long time. The importance of branding for both products and organisations has now been

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recognized by academics and practitioners alike. As branding strategy is still a relatively new concept, it is vital to investigate the concept deeper.

2. Theoretical background

In order to improve the corporate reputation and attractiveness to potential employees, Ahmad et al. (2020) claim that organisations tend to incorporate sustainability (primarily ecological and social aspects) into their branding and communication policies. This concept appears in previous corporate branding literature as well. Long-term HRM studies investigate whether the social component improves employer appeal (a significant consideration for job candidates) (Albinger and Freeman, 2000; Backhaus and Tikoo, 2004; Greening and Turban, 2000). As for Sustainable HRM, Tanwar and Kumar (2019) examine the importance of employer branding for all HR practices. According to these principles, resource-based theory, signalling theory, social identity theory, and person-organisation fit theory are all relevant theories. These are going to be discussed in detail below.

2.1. Resource-based Theory

One of the most important and frequently stated points of view, the resource-based view (RBV), has evolved with the advent of management theory. The central claim of RVB is that a corporation must acquire and hold valuable, rare, inimitable, and non-substitutable (VRIN) resources and capabilities, as well as have an organisation in place to absorb and utilise such resources in order to achieve sustainable competitive advantage (Barney, 1991). The RBV's basic premise, according to Grant et al. (2008), is appealing, simple to understand, and practical to teach since it has immediate face validity.

2.2. Signaling Theory

According to this theory, all of a firm's activities are considered as signals that the company sends out. During the hiring process, job candidates want organisations to share their characteristics as employers. When seeking a job, this information might assist potential employees in forming opinions about the working environment (Celani and Singh, 2011; Greening and Turban, 2000). Maintaining the company's HRM brand may assist in competing in the labour market by making the company more appealing to potential employees. The company gives future employees the ability to interpret the message of a substance-oriented employer by communicating Sustainable HRM. As a result, the company's reputation as an appealing place to work will improve. If Sustainable HRM is applied, an employer's competitive advantage will last longer.

2.3. Social Identity Theory

According to social identity theory, a person's self-perception is influenced by their involvement in various social organisations (Ashforth and Mael, 1989). Furthermore, employees' perceptions of themselves are affected by a company's image and reputation (Greening and Turban, 2000). Employees who can make comparisons between their company and less appealing companies may have a better self-image. As a result, having a favourable opinion of a firm might help people develop positive thoughts about themselves (Ashforth and Mael, 1989; Backhaus and Tikoo, 2004; Lievens et al., 2007; Mael and Ashforth, 1992), as employees may make cross-company comparisons based on the employer brand, affecting their self-perception. Sustainable HRM should be part of an organisation's employer brand, since it adds value to employees and helps them establish a healthy self-concept. This type of integration should also help businesses stand out from the crowd, boosting employee morale even further. To attract and retain top people, a company's employer brand must represent its dedication to long-term HRM. As a result, the company has a long-term competitive advantage.

2.4. Person–organisation Fit Theory

To achieve congruence or the best possible fit, job seekers should match their personal qualities and values with the firm's culture and identity, which explains the effect of Sustainable HRM on the employer brand (Cable and DeRue, 2002; Cable and Judge, 1996). Those who believe their personality suits the organisation's culture are more likely to look for work. Employees are concerned about safeguarding their resources (such as their employability or health). If Sustainable HRM is adopted, a company's culture can assist future and current employees identify with the organisation. According to a Corporate Social Performance (CSP) study, employees who value these intangible but meaningful benefits are more likely to value a good people–organisation fit (Albinger and Freeman, 2000).

3. Discussion

3.1 Sustainable HRM practices and employer branding

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Employer branding was established in the 1990s by Ambler and Barrow (1996), who defined it as a package of benefits gained from work, including functional, economic, and psychological benefits. At least two fields of study are involved in employer branding: human resources management and marketing, both influenced by their everyday activities (Kashive et al., 2020). However, global polls have demonstrated a clear link between employer branding and strategic management during the current (COVID pandemia 2020) crisis. According to academics, employer branding has its roots in management concepts such as *psychological contract* and *customer relationship management* (Barrow et al., 2007; Beaumont and Graeme, 2003; John and Raj, 2020).

Employer branding is becoming a more critical concern for businesses these days. Employers' ability to attract, hire and retain qualified employees is becoming increasingly crucial for the company's long-term success (Backhaus and Tikoo, 2004). A competent employer will successfully promote their attributes both inside and outside the organisation to project a positive picture of the workplace (Foster et al., 2010; Mosley, 2007). These objectives can only be achieved if employer branding is viewed as a critical component of HR management and the company's broader business strategy (Foster et al., 2010; Mosley, 2007). Companies can recruit and keep excellent personnel while paying them less than competitors if they have a stronger employer brand. The company benefits from increased earnings when revenues fluctuate less, and personnel are happier (Jackson, 2012). When the thoughts of a large number of employees are positive and confirmed, an organisation's image is boosted (for example, during talks on Internet networks). This draws more potential employees who want to contribute to the company's productivity and innovation. Strong employer brands have socio-psychological advantages, such as improved employee engagement and performance. As a result, they form a solid working relationship with their boss and feel like a valued member of the team. As the importance of a knowledge-based economy grows, so does the necessity for a robust corporate culture (Jackson, 2012; Oleksa-Marewska, 2020).

Finally, the firm's employer brand image reflects the present and potential employees' perceptions; therefore, an employee perspective must be considered while positioning an employer brand. Instead of relying on the supply from labour markets, Sustainable HRM proposes that businesses ensure the long-term supply and 'reproduction' of their human resources (App et al., 2012). Employees regard this as an investment in the company's human resource base, which benefits both present and future workers (Cooke et al., 2020). As a result, the organisation's attractiveness to potential employees improves. Thus, implementing Sustainable HRM into the employer brand could be a way to recruit top personnel (App et al., 2012). HRM enhances an organisation's ability to attract and retain outstanding employees, offering it a competitive advantage in the long run.

3.2. Sustainable HRM practices and organizational culture

Organisational culture refers to "a framework of values, beliefs, attitudes, norms, employee behaviour, and expectations shared by the organisation's members". Organisational culture has been shown to significantly impact performance, particularly efficiency and effectiveness (Nongo and Ikyanyon, 2012). This means that if a company develops the right culture, it will be successful. They assert that organisational culture impacts employee commitment, and employee commitment is inversely proportional to the strength of the organisation's cultural commitment (Nongo and Ikyanyon, 2012; Park et al., 2020). A company's culture, which includes the physical working environment, organisational structure, size, and work approach, plays a significant role in employer branding (Gaddam, 2008). Organisational culture, in other words, is what makes an organisation who it is.

The success or failure of an organisation is primarily determined by its culture. The employer brand has the power to influence the company's culture when imagining it as an appealing place to work. Because cultural dimensions such as organisational values, heroes, rites, and cultural networks all contribute to and influence employer branding, the employer branding process can change these dimensions. Semnani and Fard (2014) discovered a strong link between organisational culture and employee commitment. Corporate culture implies an employee's willingness to provide extra support for the brand and the company. Through employer branding, employees internalise the desired brand image and are motivated to project it to customers and other organisations (Miles and Mangold, 2005; Sharma and Raghuvanshi, 2021). Employer branding can change the way employees in the organisation think, feel, and react to customers and the brand, as long as the culture is defined as a "collective programming of the mind" that reinforces "patterned ways of thinking" that "think, feel," and "react"(Akuratiya, 2017; Barrow and Mosley, 2011). Intangible employer brand characteristics like culture are far more

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difficult for competitors to copy than operational components (Barrow and Mosley, 2011). The more closely an organisation's culture matches its desired employer brand, the more committed its employees are.

4. Results and limitations

Employer branding was first introduced into business literature in the 1990s due to the "war for talent" (Backhaus and Tikoo, 2004). According to a growing body of literature, the increased interest in employer branding results from local and global economies and demographic changes. As a result, companies increasingly recognise the value of attracting and retaining top-tier employees (Mosley, 2007). According to Backhaus and Tikoo (2004), employer branding aims to promote the desirable aspects of a company's workplace internally and externally to attract new hires and retain current ones.

Future research can be done to explore challenges that might arise. Finally, as information technology is evolving, businesses face rapid changes in internet marketing strategies, and this research is time-sensitive. There might be new barriers that can effect sustainable HRM in technology adoption; therefore, a research framework is needed that should keep highlighting technology adoption barriers for Sustainable HRM and employer branding.

5. Conclusion - organizational culture and employee branding

According to some experts, employee branding both reinforces and affects organisational culture. According to a People Energy Corporation study on the internal marketing effort, employees buy into the new company culture and align their behaviours with what is expected as the branding campaign progresses (Papasolomou and Melanthiou, 2012). As a result, cultural norms emerge based on the company's expectations (Vasantha, 2018). According to a Chinese market study by Xia and Yang, employer brands meet employees' spiritual and material needs, and as a result, they give back with improved motivation (Xia and Yang, 2010). Several studies have discovered a link between employer brand and employee attitudes, such as organisational identity (Hoppe, 2018), satisfaction, and commitment (Edwards, 2017; Schlager et al., 2011).

Similarly, having a well-known employer brand allows an employer to acquire top people for less money. For example, a strong employer brand can save a company 26% on labour costs. For firms with employer brands, the average allowed wage level is 859 euros, whereas, for organisations without an employer brand, the standard permitted income level is 1164 euros (Kucherov and Samokish, 2016).

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Implementation of COVID-19 measures in railway operation in the Slovak Republic

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Abstract

Rail transport has a crucial role to play not only in the EU's strategy for a sustainable transport sector, but also in terms of economic and social cohesion. It contributes significantly to the mix of transport modes in the EU, while providing clean mobility and a high degree of efficiency. Following the outbreak of the COVID-19 pandemic, the volume of passenger and freight rail transport has fallen sharply due to constraints and lower demand for transport. Several players in the rail market had to close down. Rail operators had to face a sharp decline in transport services. In 2020, the demand for passenger transport was significantly lower than in the previous year. Thus, railway undertakings were not able to pay the charges for access to the railway infrastructure during the emergency caused by the COVID-19 pandemic. Infrastructure managers had the opportunity to temporarily reduce, waive or defer these charges. The negative economic consequences of the COVID-19 pandemic could reduce or significantly endanger their financial viability for market stakeholders. Reducing charges for access to railway infrastructure is just one of the few measures that will help railway undertakings to function better. The paper focuses on the analysis of the impact of the pandemic and the implemented measures on the passenger rail sector in the Slovak Republic and on the development of rail passenger and freight transport during the pandemic. It summarizes the proposed measures against the spread of the COVID-19 pandemic in rail transport in Slovakia.

Keywords

Measures in railway transport, pandemic COVID-19, railway transport market, railway transport

1 Introduction

Since the beginning of 2020, the COVID-19 pandemic had a major impact on rail transport in the EU. The slowdown in the spread of the COVID-19 pandemic has been achieved by reducing the mobility of the population. Travel within the country and abroad and the transfer of a large proportion of the population to work were limited (Poltimäe et al., 2022). The reduction in mobility has an impact on passenger transport performance. The number of national rail passengers fell by as much as 90% during the first wave of the pandemic compared to the previous year. Several operators, especially new carriers, had to close down, while rail freight operators reported a dramatic drop in volumes as many sectors slowed or even stopped production as a result of the pandemic

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On 7 October 2020, the European Parliament and the Council adopted Regulation (EU) 2020/1429 laying down measures for a sustainable rail market in view of the occurrence of COVID-19. The aim of the Regulation was to enable rail stakeholders to better manage the financial implications of the COVID-19 pandemic and to respond to their urgent liquidity needs by reducing, waiving or deferring charges for the minimum access package and for access to infrastructure connecting service facilities. These support measures covered fees payable throughout the reference period provided from 1 March 2020 to 31 December 2020. The scope of application has been limited to this timeframe to ensure that the measures are applied only for as long as necessary (European Union, 2020).

The second wave of the autumn 2020 pandemic has forced many countries to take further restrictive measures regarding population mobility. The outbreak of the third wave of the pandemic prevented a rapid recovery in rail transport, especially for passenger rail services (Gkiotsalitis and Cats, 2021). In October and November 2020, Member States introduced new mobility restrictions, which they only partially and gradually lifted in 2021. The number of passengers has not yet returned to pre-pandemic levels, and the time to return to pre-pandemic levels may be longer than expected, especially in the case of commercial passenger transport (Huang et al., 2020). The impact of the pandemic on the transport sector, therefore, remains significant. The arrival of a new extremely contagious variant of COVID-19, omicron in the autumn of 2021 with still unknown properties compared to previous variants raised concerns about the fourth wave of the pandemic and more stringent measures to prevent the spread of the disease (Mogaji et al., 2022).In an effort to help the railway sector cope with the ongoing pandemic, the EU extended the possibility for Member States to reduce, waive or defer railway infrastructure charges until 30 June 2022. The measure was first introduced in October 2020, and the aim is to reduce the financial burden on railway undertakings during the COVID-19 pandemic (Tirachini and Cats, 2020).

The aim of the proposed research is to analyze measures for limiting mobility during a pandemic and their impact on transport from the point of view of a sustainable transport system, based on the cooperation of researchers from the field of sectoral and cross-sectional economics and the field of transport. Subsequently, innovative approaches to ensure the usability of public transport in time of pandemic measures, which will contribute to the safety of passengers and maintain the attractiveness of transport connections with a focus on rail transport as a main transport system, are explored.

2 Impacts of the pandemic COVID-19 on the railway sector

The effects of the measures introduced during the COVID-19 pandemic, which are related to transport, were addressed in his research by Zhang et al. (2021). These authors developed a case study focused on the development of COVID-19 transport policy in six developed countries. They describe the effectiveness of 418 policy measures based on the PASS approach (P: prepare — protect – provide; A: avoid – adapt; S: change – share; S: replace – stop) and examine it using 27 indicators. The authors reveal the dynamic relationships between policy-making, factors and consequences. The case study attempts to provide scientifically based evidence for proposing more effective COVID-19 policy measures in the transport sector. Meanwhile, Ding & Zhang (2021) developed a case study focusing on the dynamic relationships between temporary behavioral changes caused by the COVID-19 pandemic and subjective assessments of policy-making. They conducted a nationwide online survey in Japan to assess changes in population behavior during the COVID-19 pandemic. They reveal the effects of risk perception in the use of public transport during a pandemic.

Xin, et al (2021) evaluated the effects of COVID-19 on urban rail transport using the synthetic control method in their research. The authors try to estimate the impact of COVID-19 on the daily number of passengers in urban rail transport (URT) using the Synthetic Control Method (SCM). Six variables are selected as predictors, out of which four variables unaffected by the pandemic are employed. A total of 22 cities from Asia, Europe, and the US with varying timelines of the pandemic outbreak are examined in this study. The effect of COVID-19 on the URT ridership in 11 cities in Asia is investigated using the difference between their observed ridership reduction and the potential ridership generated by the other 11 cities. Two traditional methods (causal impact analysis and straightforward analysis) are employed to illustrate the usefulness of the SCM.

Many researchers and organizations have investigated and reported on the negative impacts of COVID-19 on various aspects of public transportation. Most notably, many cities around the globe have experienced major reductions in public transit demand as a result of the substantially reduced economic activities. Work at home and online business became the new norm after the outbreak of COVID-19, contributing to reductions in passenger demand in the range of 80% – 95% (Vickerman, 2021). Modal preferences by commuters were also impacted by the pandemic. For essential out-of-home activities, it was observed that commuters preferred the private car, cycling, and walking over public transit. On the supply-

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side, many transportation agencies have cut service levels to reduce costs and meet government restrictions on service hours (Wang and Noland, 2021). Such reductions have consequently contributed to further decline in public transit ridership.

It is thus obvious that the COVID-19 pandemic has adversely affected public transit ridership, both directly and indirectly. On the one hand, fewer people were commuting to work and school. Those who commuted were less likely to use public transit due to the perceived health risks while travelling (Tan and Ma, 2020). On the other hand, the restrictions enforced by governments and transit agencies have limited the public transport service levels, contributing to further decline in transit ridership. The study by Marra et al. (2022) observes how the pandemic affected travel behaviour of public transport users, focusing on route choice and recurrent trips. They conducted a travel survey based on GPS tracking during the first pandemic wave. They analyse how the pandemic affected users, in terms of travel distance, mode share and location during the day. They specifically focus on recurrent trips, commuting and non-commuting, observing how mode and route changed between the two different periods.

The impact of the COVID-19 pandemic on rail transport in the EU was assessed by the Council of the Union in a report of 21 December 2021 (European Union, 2020). The performance occurred in the same way as in the Slovak Republic in April 2020, when performance in passenger transport decreased by 40.6%. The number of trains running on the network also declined, but by September, the segment of trains running in the public interest had recovered, reaching 2019 levels. The number of trains running on commercial lines did not recover until after the second wave broke out. The impact of the COVID-19 pandemic on rail passenger transport cannot be fully assessed as the pandemic situation still persists. What is certain, however, is that the negative economic impact on transport is significant. A decrease in the volume of performance of commercially motivated carriers and the associated financial problems may result in a reduction in the level of quality of services provided, due to lower competition between carriers.

The consequences of the first wave of the pandemic were exacerbated by the onset of the second wave in autumn 2020, when measures to reduce population mobility were reintroduced (European Union, 2020). Due to the exit ban in 2020 and reduced demand for train transport, the Railway Company of Slovakia (ZSSK) on 7 March, on the basis of instructions from the Ministry of Transport and Construction of the Slovak Republic, began to optimize the supply of train traffic from the first changes to the train schedule. Of the 34.4 million train kilometers planned for 2021; 917,000 train kilometers were lost. Traffic in the vicinity of Bratislava was temporarily limited, where even after the reduction, the hourly train cycle remained in the area of suburban transport, which was concentrated in the rush hour at a thirty-minute interval between trains. This meant a sufficient and high-quality transport offer due to reduced demand. Railway transport (8 trains) was permanently stopped on the Bánovce nad Ondavou – Veľké Kapušany line section due to long-term public disinterest. The reduction in the scope of transport services is the result of an agreement between the ZSSK and the Ministry of Transport and Construction of the Slovak Republic. The aim was to optimize train supply and public transport expenditure so that the impact of the reduction on the public was minimal due to reduced demand (Mašek et al., 2018; Dedík et al., 2019; Šipuš and Abramović, 2017).

In connection with the declaration of an emergency situation in the Slovak Republic, international train traffic with all neighboring states was temporarily stopped, and the operation of IC trains was also suspended. The operation of all customer centers, and of ticket office of selected points of sale was also interrupted, the sale of national reservations was temporarily suspended, and the ordering of restaurant, sleeping car and coachette and car carrier wagons was also limited. These measures negatively affected the management of the ZSSK, and the consequences of the COVID-19 pandemic were also felt in 2021 and later (Ľupták and Pecman, 2021).

2.1 Development of transport performance in railway passenger transport in the Slovak Republic

As a regulatory body, the Transport Authority monitors competition on the railway market in the territory of the Slovak Republic. Monitoring the development of the railway market is an important tool for obtaining up-to-date information on individual segments of the railway market and analyzing it (Daniš et al., 2019). This analysis is focused on the comparison of performances in passenger transport, passenger kilometers, and revenues (Torok, 2017; Gaal et al., 2015). The data and information presented in this article are taken from the analyses and documents of the infrastructure manager and from the information available from railway undertakings at the end of 2020, focusing on the monitored indicators of the impact of the pandemic during 2020 (Slovak Republic, 2020).

The COVID-19 pandemic crisis had a major impact on the supply, demand and economic performance of rail transport. The largest impact was recorded in the second quarter of 2020, from April to June. Passenger transport was more affected

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than freight transport, with international transport falling by an average of 85% in the second quarter of 2020, domestic transport falling by 18%, while freight transport fell by 14% in the second quarter of 2020. The reduction in rail transport in the first months of the crisis was a direct consequence of the public authorities' response to the COVID-19 crisis (restrictions on passenger mobility) as well as the impact of the global economic slowdown, which generally led to a reduction in transport demand (Slovak Republic, 2020). The number of passenger trains within the public service operated in the network in the period from January to September 2021 is comparable to the number for the same period in 2019, while in 2020 it was by 7.8% compared to 2019 lower. However, the number of commercial passenger trains between January and September 2021 was still 21.5% lower than in the same period in 2019, which means that compared to the same period in 2020, when it was 23.3% lower compared to 2019, there has been no recovery. The number of freight trains operating on the network was still 2.5% lower than in the corresponding period in 2019. Similar trends can also be observed when expressing the volume of traffic in train kilometers. From January to September 2021, the volume of passenger transport within public services expressed in number of trains was 5.2% lower compared to the same period in 2019. In 2021, commercial passenger transport services expressed in number of trains remained lower by 25.6% than in the same in 2019, which is in line with the (low) level already reached in 2020 (Slovak Republic, 2020). The development of transport performance during this period is shown in Figure 1.

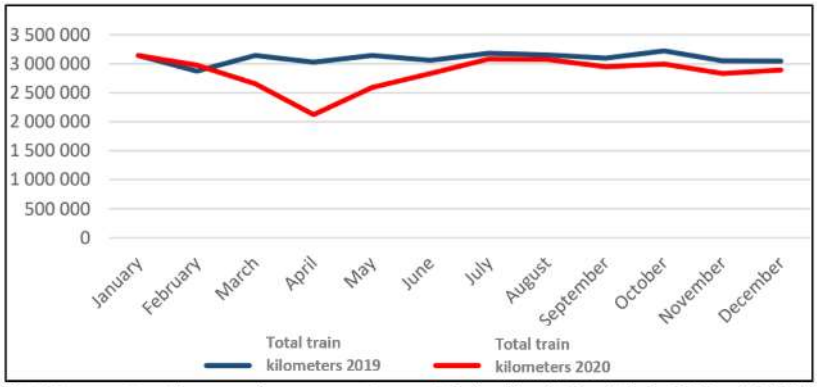

Figure 1. Comparison of total transport performance in passenger transport in the Slovak Republic in 2019 and 2020 (Slovak Republic, 2020).

In passenger transport, performances were significantly affected by the pandemic, which resulted from the restriction of passenger transport trains: it was introduced on 14 March 2020 by changing the schedule of public transport, the so-called Saturday timetable. The highest decrease in output was recorded in April 2020. Output (train kilometers) in the given month decreased by 37.60% compared to 2019. The most significant decrease in train was recorded in international transport due to restrictions, even disruption, of international rail transport. Figure 2 shows the change in total transport performance in rail passenger transport.

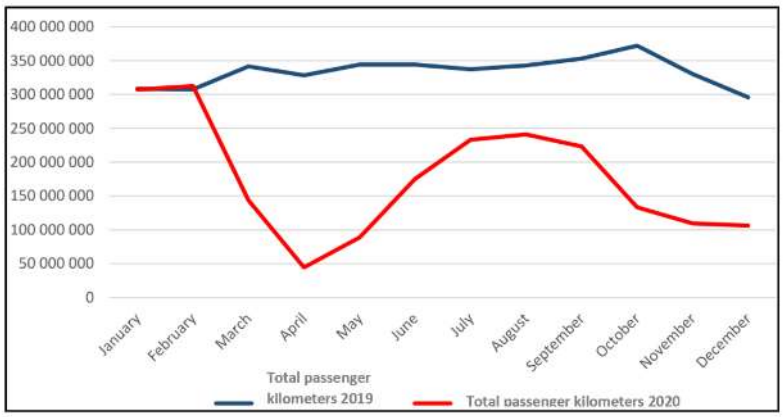

Figure 2. Comparison of transport performance in passenger transport in 2019 and 2020 (Slovak Republic, 2020).

Performance in passenger-kilometers in rail transport also shows that the most significant decrease was recorded in April 2020. The loss of performance measured in passenger kilometers is a direct consequence of a significant reduction in the number of passengers in passenger transport in the period considered. Overall, passenger transport performance in 2020 in

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the above indicator decreased by as much as 47.10% compared to the previous year 2019. The development of the number of passengers carried in domestic transport is shown in Figure 3.

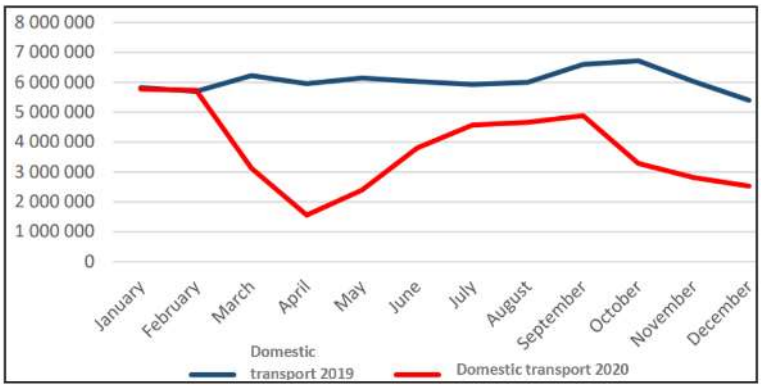

Figure 3. Development of number of passengers carried in domestic rail passenger transport in the Slovak Republic. (Slovak Republic, 2020)

During the first wave of the pandemic, passenger transport saw significant declines in the number of passengers transported in national and international transport. The number of transported persons in domestic transport decreased by 60.90% compared to 2019 and in international transport by 67.32%. The negative value in April represents the return of the fare. The development of the number of transported persons in international transport is shown in Figure 4.

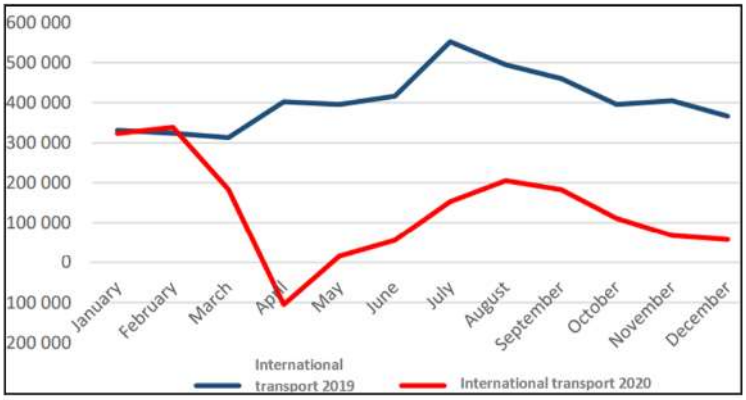

Figure 4. Development of number of passengers carried in international transport. (Slovak Republic, 2020)

The COVID-19 pandemic affected the management of the ZSSK in 2021. In January and February 2021, compared to 2020 (January and February 2020 were not yet marked by a pandemic), it transported 7.9 million passengers less (-65.24%), which corresponds to a shortfall in revenues from passenger transport in the amount of 9.2 million € (-71.24%). The shortfall in transport revenues in 2021 was at the level of 50% of the original plans, and expenditures rose for measures to eliminate the impact of coronavirus on the health of employees (ZSSK, 2020). Given the current situation in the economy and the continuing epidemiological situation, it can be assumed that its impact on the overall performance of rail transport will continue. The Transport Authority continuously monitors the individual indicators that will serve as the basis for further evaluation of the railway market and will prepare further reports on the impact of COVID-19 in the future (Slovak Republic, 2020).

2.2 Impacts of COVID-19 measures on a selected railway line in the Slovak Republic

The COVID-19 pandemic crisis had a major impact on the supply, demand and economic performance of rail transport. The largest impact was recorded in the second quarter of 2020, from April to June. Passenger transport was more affected than freight transport, with international transport falling by an average of 85% in the second quarter of 2020, domestic transport falling by 18%, while freight transport fell by 14% in the second quarter of 2020. The reduction in rail transport in the first months of the crisis was a direct consequence of the public authorities' response to the COVID-19 crisis (restrictions on passenger mobility) as well as the impact of the global economic slowdown, which generally led to a reduction in transport demand (Slovak Republic, 2020). The number of passenger trains within the public service operated in the network in the

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period from January to September 2021 is comparable to the number for the same period in 2019, while in 2020 it was by 7.8% compared to 2019 lower. However, the number of commercial passenger trains between January and September 2021 was still 21.5% lower than in the same period in 2019, which means that compared to the same period in 2020, when it was 23.3% lower in compared to 2019, there has been no recovery.

For the purposes of this article, the Bratislava–Košice railway line was chosen as an example. The largest year-on-year decline was recorded in April 2020 at -88.24% and in May (-76.63%). After these two critical months, transport performance began to rise again. Figure 5 shows the development of traffic performance on the Bratislava–Košice line in the years 2018–2020.

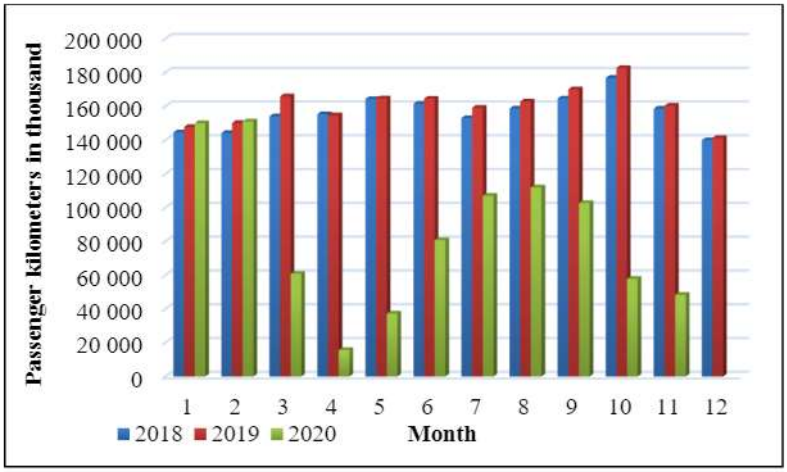

Figure 5. Development of transport performance on Bratislava–Košice line (Source: authors according to data from ZSSK)

In the Figure 5, we can observe transport performance on the Bratislava–Košice line in years 2018–2020. The data show the increasing popularity of long-distance rail transport during 2019 and the first months of 2020. Regular monthly services range between 140 million during less popular months up to 180 million during October 2019. Figure 6 shows year-on-year change in transport performance on the Bratislava–Košice line in 2020, compared to the corresponding data in 2019.

Figure 6. Year-on-year relative change in transport performance on the Bratislava–Košice line in 2020 (Source: authors according to data from Železničná spoločnosť Slovensko - ZSSK)

During the first months of 2020, the trend of steady growth in transport performance continued. With the arrival of the pandemic in March, we can again observe a two-thirds drop in performance, reaching an absolute bottom in April 2020. The renewed trend is the same as the return trend, but transport performance remained 33% to 31% lower during the summer months than in 2019, with passenger numbers only 25 to 22% lower. The reason for the lower performance may be the above-mentioned trend of longer trips during the summer, for example by students from Bratislava back to the east. As colleges remained closed during the first half of 2020, students traveling the entire length of the semester remained at home and transport performance was higher.

3 Identification of COVID-19 measures implemented in railway operation

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The spread of the COVID-19 crisis seriously affected rail carriers due to a significant reduction in demand for rail transport services. Some carriers faced significant liquidity problems, large losses and, in extreme cases, the risk of bankruptcy. As a result of these adverse changes, Regulation (EU) No 182/2011 of the European Parliament and of the Council 2020/1429 of 7 October 2020 was issued, laying down measures for a sustainable railway market with regard to the spread of COVID-19 (Haspra, 2021). All the measures below have been defined for national rail passenger services.

3.1 Measures of EU for a sustainable rail market

Regulation no. 2020/1429 addresses the issue that many railway businesses in the context of this emergency may not always be able to pay infrastructure access charges (or the cost of using the track). One of the tools to mitigate the negative economic impact on passenger or freight transport should be to allow these charges to be reduced, waived or deferred. According to Point 3 Article 31 of Directive 2012/34/EU of the European Parliament and of the Council, infrastructure access charges shall be set at the cost that is directly incurred as a result of operating the train service than the costs incurred in operating the rail service. However, in order to mitigate the impact of the COVID-19 crisis, Member States should be able to allow infrastructure managers to reduce, waive or defer such charges in a transparent, objective and non-discriminatory manner over a defined reference period (Kębłowski et al., 2022). In a similar way, the issue of surcharges should be addressed, and infrastructure managers should be able to assess the market segment's ability to bear this burden in times of crisis, or to reduce, waive or postpone these surcharges. Similarly, Article 36 of Directive 2012/34/EU provides for a capacity reservation fee scheme which is intended to provide an incentive for efficient capacity utilization. The spread of the pandemic in terms of restricting population movements caused serious disruption to rail transport, which in turn caused widespread disruption of train paths, leading to temporarily lower capacity utilization. Even in this case, infrastructure managers should have a relevant option not to collect these charges during the specified reference period (Haspra, 2021).

3.2 Measures of Slovak infrastructure manager ŽSR

The measures implemented by the infrastructure manager to slow down the spread of the COVID-19 virus, which have been analyzed since 2020, are arranged chronologically. For passengers, the measures are identical to those used in all ŽSR spheres of public life during the 2020 to 2021 pandemic, namely "cleaning and disinfection of railway station areas, in particular, the surfaces touched by people (door controls, handles, handrails, armrests, tables and the like).

ŽSR regularly informs the public about the possibilities and ways of preventing the transmission of the disease during public transport. This education is carried out through information technology and leaflets in the station premises. For employees who come into close contact with passengers during their work, ŽSR will provide personal protective equipment and hand sanitizers (ŽSR, 2020).

ŽSR also plans to create premises for the shutdown of trains or their wagons for the needs of an unexpected shutdown. Employees coming into possible close contact with the traveling public on the platforms, for example dispatchers, shall be equipped to perform their activities with protective masks, protective gloves and hand disinfectants, the distribution of which to the affected workplaces is regularly carried out (ŽSR, 2020).

ŽSR tightened measures in the fight against the COVID-19 pandemic by suspending the sale of tickets by employees at 67 stations in the Slovak Republic. These are stations where the sale does not take place through the ZSSK, the sale has so far been mediated by ŽSR employees on the basis of contracts (ŽSR, 2020). Those interested in traveling by train from the above stations are still advised to purchase tickets electronically. The infrastructure manager has enabled the employees, who are allowed to do so by the nature of the activities performed, to work from home. Also in workplaces, where the conditions and nature of work allow it, the number of employees present was reduced as part of the change (ŽSR, 2020). Another change is characterized by a return to the timetable before the beginning of the pandemic situation, respectively by adjusting it to the current pandemic situation.

3.3 Measures of the railway carrier ZSSK

Based on the decision of the Government of the Slovak Republic, travel by long-distance trains (IC and express trains) was allowed until further notice, only in the "OTP" mode (vaccination – testing – overcoming). These are passengers with a complete vaccination, passengers with a valid test or those who have already had Covid. In all ZSSK train connections, passengers had to be protected by a mask, so it was mandatory to have a covered nose and mouth during the entire transport period according to measures (ZSSK, 2020).

ZSSK has also introduced a series of measures required of passengers, concerning masks, distance, hands (see Figure 7):

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- Mask – covered mouth and nose;
- Distance – keep a distance of at least 2 meters from unknown people;
- Hands – frequent and thorough disinfection or hand washing.

Figure 7. Pictogram of valid measures for passengers in ZSSK trains at the time of the pandemic COVID-19. (ZSSK, 2020)

Since the beginning of the pandemic, the ZSSK has ensured, to the maximum extent possible, that trains meet the highest hygienic and safety standards. The individual measures taken in coordination with the public authorities and in accordance with the guidelines of the Chief Hygienist were a guarantee that train travel remained safe even in difficult times. With the introduction of new disinfection and increased hygiene measures in the vehicle areas, including air conditioning, as well as other key measures, passengers could travel by train comfortably, safely and responsibly (ZSSK, 2020).

Based on the statement of the Minister of the ZSSK and in accordance with the guidelines of the Chief Hygienist, measures were introduced in all passing trains (ZSSK, 2020):

- daily check of air conditioning functionality,
- 9-12 times per hour fresh air from outside,
- monthly filter change,
- disinfection at least once a day beyond routine cleaning,
- twice a week polymer disinfection with an effectiveness of 6-7 days,
- increased protection of personnel in operation.

At least once a day, surfaces were disinfected beyond the usual cleaning (in addition to toilets, these surfaces included handles, buttons, waste bins, etc.), twice a week the vehicles were disinfected with polymer with an efficiency of 6-7 days. The personnel also provided 9-12 times per hour air exchange for fresh thanks to air conditioning. At the same time, according to the technical possibilities of individual trains, some regular trains of the IC, Ex, R, RR and Os categories, which were expected to be of greater interest to the traveling public, were also strengthened. It was recommended to book tickets and seats well in advance. Their purchase was possible not only at the ZSSK cash registers, but also conveniently via the ZSSK e-shop or the *Ideme vlakom* mobile application, or as an SMS ticket. To achieve maximum safety, protective equipment for train staff was also provided (ZSSK, 2020).

The company has also introduced a series of temporary measures related to off-train services (ZSSK, 2020):

- closure of all customer centers,
- closure of the reservation center,
- closure of selected points of sale,
- stopping the transport of consignments marked COURIER,
- suspension of the admission of luggage to the depository,
- ban on sending and handing over found items on the train.

Passengers were allowed to reimburse the full amount of tickets and seats purchased after the introduction of these measures from March 2020. From December 2021 until the revocation of the ZSSK, traffic was limited by more than 350 trains. Restaurant wagons were not used on national trains during the pandemic period. Passengers had the opportunity to take To Go food or order it from their place via the *Najedzsavovlaku.sk* application (ZSSK, 2020).

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4 Proposal of systematic measures against the spread of COVID-19 in railway operations

The proposed measures against the spread of COVID-19 can also be regarded as operational-organizational measures. We methodically divided them into direct measures and indirect measures. These measures are characterized by not requiring high investments and they are not significantly demanding to implement. The proposed direct measures are shown in Figure 8.

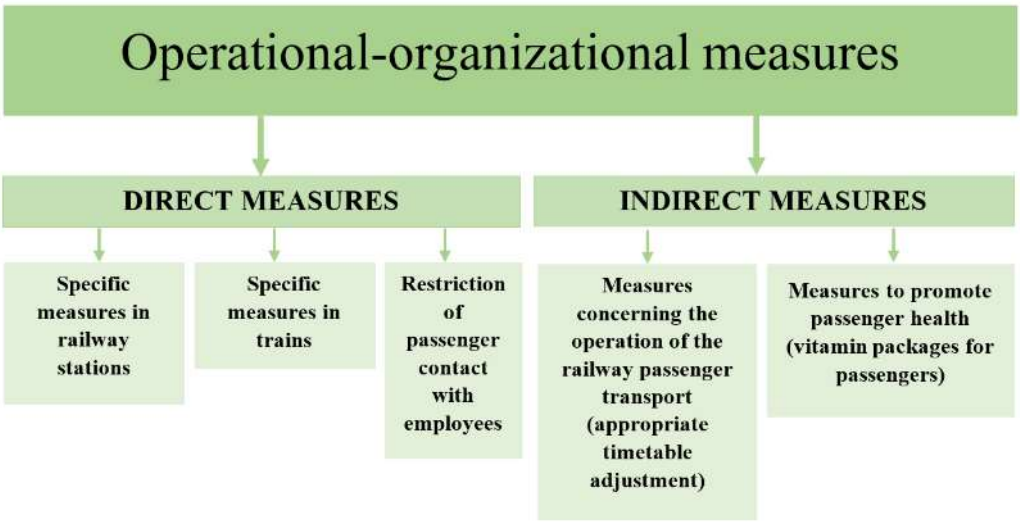

Figure 8 Proposal of Operation – organizational direct and indirect measures (Source: authors)

Direct measures can be divided into specific ones in railway stations, trains and the restriction of passenger contact with employees. Indirect measures included measures concerning the operation of the railway passenger transport and measures to promote passenger health.

4.1 Special free vitamin packages for passengers

As several studies in the field of virology have shown, the regular use of the right vitamin composition has a significant effect on the body protection increasing against infections, including SARS 2-Covid-19. Taking vitamins significantly alleviates disease, relieves certain difficulties and accelerates recovery. Thus the company planned to offer passengers free packages, including:

- Vitamin C 250 mg,
- Vitamin D3 2000iu – 30 tablets,
- Selenium, Zinc Forte – 30 tablets,
- 200 ml hand sanitizer,
- disposable mask (10 pcs/FFP2 type respirators 5 pcs).

These packages will be provided to passengers upon fulfillment of at least one of the following conditions, but not more than once a month:

- after traveling 300 km,
- for daily commuting by train to any distance (in the range of at least 15 calendar days per month).

4.2 Modification and disinfection of common areas in wagons and stations

The interior of the vehicle must ensure the health safety of the vehicle. This means influencing the bacterial, viral and fungal microflora to make the environment as safe to humans as possible. Bacteria and viruses enter the air through the breathing, talking, but especially coughing and sneezing of passengers. Bacteria and viruses may also attach to the wall surface:

- if they can find a source of nutrients there,
- they may multiply there if the material does not affect them adversely,
- may be directly destroyed by the material from which the vehicle is constructed.

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In order to ensure health safety, the third mentioned option is optimal, the surfaces of the means of transport must be adapted to be able to directly destroy bacteria and viruses. Other effective measures must also be provided that can eradicate these microorganisms quickly and effectively.

4.3 Restriction passengers' contact with employees

It is strongly recommended to apply measures to passenger transport processes that limit passenger contact with carriers' employees. It is primarily a matter of limiting this contact both at railway stations and on trains.

Measures at railway stations

These measures consist of limiting passengers' contact with cashiers at personal cash registers, which should be kept to a minimum in this case. This will motivate passengers to buy tickets online (via the internet or via a mobile application), which will also be more advantageous for users, as they will not have to wait in lines at the cash desks at train stations, but they can comfortably arrive at the station just before the train leaves.

Another measure could be the introduction of turnstiles in the interior of railway stations, underpasses or platforms. These turnstiles would be located in reserved places and each passenger would have to go through them and would only be released after reading a valid travel document. In the case of the introduction of turnstiles, regular checks of travel documents by train drivers would not have to be carried out on trains, a random check by inspectors would be sufficient. It would also be appropriate to consider the installation of special devices that would be able to measure the body temperature of passengers before boarding the train, or identify other symptoms of COVID-19 or the possible degree of infectivity of the passenger to their surroundings. These operations could also be carried out at railway stations in the area before entering the underpasses or platforms, or before entering the station building by means of a special device (something similar to walk-trhough metal detectors at airports). Each passenger would pass through such a device, and this device would immediately measure his body temperature, or other indicators of his health and, based on the results, he would then be admitted to the platform and onto the train. An alternative solution could be to install a sanitizer dispenser with body temperature measuring facilities.

Measures in trains

Contact with the train staff should be limited for passengers, which will also be due to the lack of train drivers in the ZSSK. The control of travel documents may take place on the train in such a way that an automatic QR code reader of travel documents will be placed in each wagon above each seat, while the passenger will scan his travel document before taking a specific seat. After the travel document has been scanned, a green light will illuminate above the place. If a valid travel document is scanned but in the wrong place, the light will turn yellow, and if no travel document is scanned, the light will turn red. However, this progressive system can only be introduced in the case of trains with mandatory seat reservation. Subsequent checks will be carried out by an auditor or other authorized employee, and only in the case of such passengers, whose control indicator over their seat will not turn green. This measure could serve as an alternative to the introduction of turnstiles at stations.

4.4 Introduction of mandatory seats and limitation of the capacity of individual train connections

If certain measures are put in place to help reduce the mobility of citizens, and thus a reduction in passenger frequencies can be considered, it will also be possible to reduce the capacity of individual trains. This measure could also only be implemented if mandatory train seats are introduced. This measure can be applied especially in long-distance transport, as in regional transport it is significantly more complicated. However, capacity constraints could also take into account the groups in which the passengers travel (whether the passenger is alone, a couple, or a family or a larger group). Based on this, compartments could be reserved for families or groups of people. The implementation of most of the above proposed measures will have a major impact on employment in the rail passenger transport sector. As a significant reduction is considered, or absolute abolition of regular ticket inspectors and personal cashiers, it will be necessary for these people to find an alternative job. They could find application, for example, as special inspectors on trains, checking only those passengers who did not read their travel document correctly (their indicator light would not turn green), and they could also help to disinfect trains and stations and to check passengers when crossing the turnstile, or the body temperature measuring device. They could also work as operators who could assist in the electronic sale of travel documents and also in organizing the distribution of vitamin packages for passengers.

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Another group of measures could concern construction and renovation processes (see Figure 9). These measures are technologically, temporally and financially more demanding.

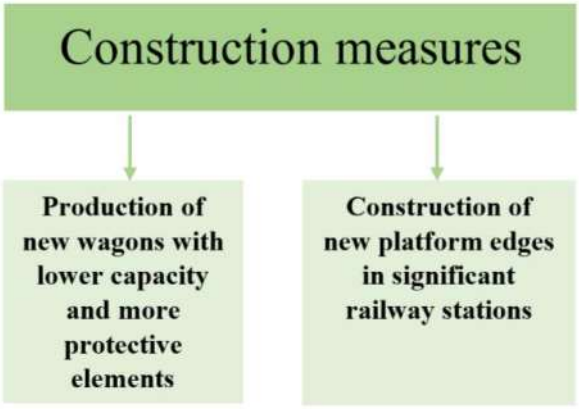

Figure 9 Proposal of construction and reconstruction measures (Source: authors)

The proposal of construction and reconstruction measurements contains production of new wagons with lower capacity and more protective elements and reconstruction of new platform edges in significant railway stations.

5 Conclusion

During the first wave of the pandemic, rail transport in Slovakia suffered a significant drop in transport performance. With the declaration of the global pandemic and a state of emergency in the Slovak Republic in March 2020, an average drop in performance on all routes by 61% was observed. The sharp decline in output continued until April, when it stopped at an average of 87%, compared to the previous yearBefore the pandemic, the positive trends in rail transport in the Slovak Republic had been evident for several years. The number of passengers grew every year before 2020, and it can be assumed that after the end of the pandemic, the growth trend will resume. Functioning railway connections within the Slovak Republic offer a suitable alternative to the individual automobile transport for transfer between regional cities. There is a presumption that with the resurgence of cars on the roads, potential passengers will find their way back to rail transport. The EU's efforts to reduce emissions through the financing of greener modes of transport provided by rail can also contribute to long-term positive developments. With the gradual reconstruction of lines from sources partially provided by the European Union, the competitiveness of train transport in Slovakia may increase.

The negative effects of the pandemic are more of a short-term threat to rail transport. Weakened passenger confidence in the sterility of trains and stations is unlikely to persist for more than half a year after the end of the pandemic. The transfer of passengers to the individual automobile transport, combined with the effort to avoid human contact, will no longer be an attractive option with a large number of cars returning to the roads and opening up the economy. Regular contact with people at work and leisure is overshadowed by the fear of contact with unknown passengers during the train journey. The biggest threat to the smooth development of railway transport in the Slovak Republic is the shortage of financial resources caused by more than an annual decrease in passengers. The national carrier ZSSK has an almost monopoly position on the railway transport market within the Slovak Republic. For this reason, the losses caused by the pandemic could be covered by a state subsidy. However, it is not clear whether the Slovak government will be prepared to spend sufficient funds to cover the losses incurred.

Acknowledgement

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Coincidence of pressure pulsations with excitation of mechanical vibrations of hydraulic system components. An experimental study

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Abstract

This paper discusses certain excitations that affect the components of hydraulic systems composed of pipes and valves. The negative effects of low-frequency noise and vibration on humans are also pointed out. Particular attention is given to the effect of pulsatile flow on the structure of hydraulic components. Pressure pulsations in a hydraulic system are shown to generate and transmit mechanical vibrations across a wide spectrum of frequencies, and the negative consequences of this phenomenon are pointed out. Based on the latest generation of proportional directional control valves, a special stand was built to generate pressure pulsations over a wide frequency range (up to 350 Hz). Amplitude-frequency spectra of mechanical vibrations and pressure pulsations were used instead of time courses in the considerations. The paper concludes that effort must be made to reduce the amplitudes of pressure pulsations in hydraulic systems, particularly in the low-frequency spectrum.

Keywords
vibrations, pressure pulsation, hydraulic systems, signals coincidence

1 Introduction

A particular property of hydraulic systems is that their operation depends on ambient conditions and the instantaneous values of flow rate and pressure. An operating hydraulic component, e.g. a directional or pressure control valve, is constantly subjected to complex excitations of various origins, including external vibrations coming from the ground, flow rate pulsation and pressure pulsation. It bears noting that any excitation applied at any point of the hydraulic system is transferred to the components of that system through viscous or elastic components. Meanwhile, the effects of this phenomenon depend on the location affected by the excitation, its amplitude and frequency, the physical properties of the components transferring these excitations, and the configuration of the hydraulic system.

Those elements of a hydraulic system whose essential part is a control component in the form of a spool, ball, cone, plate, etc. are subjected to variable loads resulting from changes in operating parameters: the flow rate of the medium, pressure caused by inconsistent positive displacement pump efficiency, and variable external load (Stryczek, 2014). These loads are frequently stochastic and may be harmonic in specific cases. Generally speaking,

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excitations affecting hydraulic valves can be divided into intentional and interferential groups. Intentional excitations include signals controlling the operation of valves forming part of a control or regulation system (Glanowski, 2001; Tomasiak, 2001). Excitations that interfere with the operation of valves include vibrations affecting the valve (Kollek et al., 2008; Stosiak, 2006). The issue of the impact of these excitations on the operation of the valve control component applies to all hydraulic systems operating in real conditions, and, in particular, those subject to increased requirements as to the manufacture of precision elements and response to control signals. Due to the above, a significant impact of external signals on the operation of modern proportional elements or hydraulic microvalves is to be expected, as interferential excitation forces in these components may be of the same size as the controlling forces, leading to many detrimental effects that include stability loss, lack of positional precision, sealing damage, and increased noise generation (Kollek et al., 2010). At present, there is a strong tendency for proportional control technologies to be developed in various types of hydraulic components (Jesionek et al., 2004b; Tomasiak, 2001), replacing the previously used conventional components and opening up new possibilities with regard to time of response to control signals (Cichoń and Stosiak, 2011) and bandwidth frequency, and completely new opportunities for performing pre-programmed work cycles, reducing dynamic surplus and mitigating transitional states (Kudźma and Stosiak, 2013; Bury et al., 2022). Modern medical devices and industrial robots are equipped with proportional components such as proportional directional valves, proportional overflow valves, electrohydraulic boosters, and increasingly commonly, hydraulic microvalves (Jesionek et al., 2004a; Kollek (ed.), 2011).

Irrespective of how they are generated, the mechanical vibrations of hydraulic system components affect the human body. An initial analysis of the impact of vibration on humans may be performed after determining the scope of resonant vibrations of the human body treated as a multibody system. Figure 1 shows frequencies of normal mode vibrations of certain organs in the human body (Engel and Zawieska, 2010). Numerous experiments demonstrate that the nervous system and the circulatory system are the parts of the body that are most sensitive to vibrations.

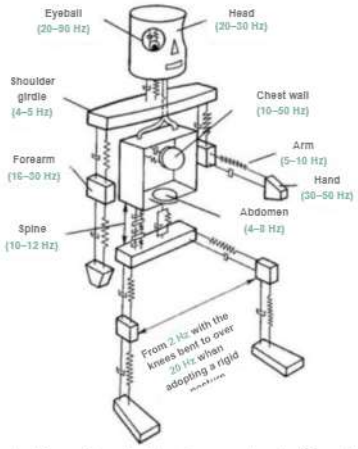

Figure 1 Simplified diagram of the elastic system in the human body (Engel and Zawieska, 2010: p168).

Through mechanoreceptors in the skin, vibrations transfer specific information to the central nervous system, causing reflexive reactions of the entire body. Long-term exposure to mechanical vibrations causes irreversible changes in various organs and systems. These changes can be divided into (Engel and Zawieska, 2010):

- acute changes that occur during exposure and for a short time afterwards; they involve specific changes in the behaviour of the entire body seen as a mechanical system;
- chronic changes that occur as a result of long-term exposure to intense vibrations.

The maximum exposure limits of the human body are often exceeded, causing a disorder known as vibration syndrome (Fig. 2) (Engel and Zawieska, 2010).

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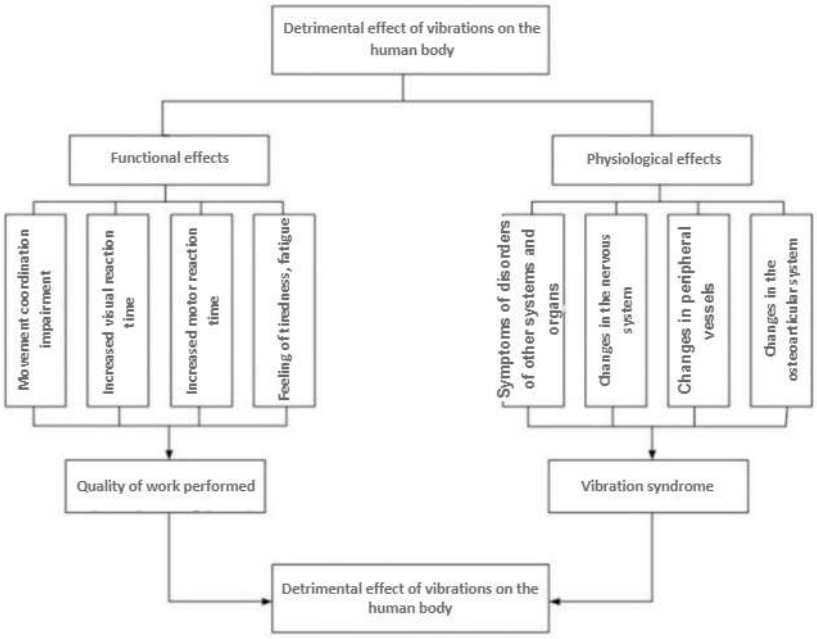

Figure 2 Effect of vibrations on the human body (Engel and Zawieska, 2010: 173).

The harmful effect of vibrations on machines and devices is determined by measuring the amplitude of the effective speed of vibrations in the place where the machine or device is installed and comparing it against the permissible values, shown in Table 1. For class II–V sensitivity, the permissible amplitude is compared against the maximum vibration value present in a given direction, whereas for class I sensitivity, it is compared against the modulus of the velocity vector $v_{dop} = \sqrt{v_x^2 + v_y^2 + v_z^2}$, where v_x, v_y, v_z are the components of the velocity vector in the *x, y, z* directions.

Table 1. Classes of sensitivity to external mechanical vibrations for groups of machines and devices according to (PN-ISO 9612:2004).

Sensitivity class	Sensitivity description	Name of machine or device group	permissible velocity $v_{dop} \times 10^{-3}$ [m/s]
I	high sensitivity	devices used to balance and adjust instruments, microscopes, interferometers and other precision tools, computers, precision machining tools	0.1
II	moderate sensitivity	cog and bearing sanders; precision milling machines and lathes	1
III	low sensitivity	regular milling machines and lathes, power drills, sanders, textile weaving and printing machines	3
IV	nearly no sensitivity	motors, mortisers, sewing machines, metal and wood machining tools, presses, cutters	6
V	no sensitivity	fans, crushers, mills, agitators, vibration tables and sieves, screening machines, hammers	> 6

Table 1 shows that all sensitivity classes include groups of machines equipped with hydraulic components and systems. Class I machines are expected to be particularly susceptible to mechanical vibrations, and these include precision instruments and machine tools equipped with hydrotronic and microhydraulic components which are subject to increased requirements with regard to, for example, precision and repeatability of operation (Stosiak et al., 2020).

The mechanical vibrations of machines and system components also generate noise in a wide spectrum of frequencies. Low-frequency vibrations and noise, called infrasounds, have a particularly adverse effect on the human body; see Table 2.

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Table 2. List of pathological symptoms caused by the impact of infrasounds on the human body (Chaban et al., 2021; Tonin et al., 2016; Gužas and Viršilas, 2009; Stosiak, 2015): f – frequency, L_m – acoustic pressure level, t_{exp} – time of exposition, N – number of appearances.

f [Hz]	L_m [dB]	t_{exp} [s]		Symptoms
2–15	105			Increased visual response time in 50% of subjects, balance disorders in 10%
1–2	150			Change of threshold of hearing, feeling of eardrum displacement
2–15	110–120		7	Reaction time increased by 4%
3–15	115	1800		Symptoms similar to alcohol abuse
10	135	900	6	Sensation of internal organs vibrating, feeling of eardrum membrane vibrations, pain in the middle ear, increased pulse, increased arterial pressure, quickened breath by 4 or more breaths per minute, change of threshold of hearing by 15–20 dB during testing and by 8–10 dB immediately after the end of the test
7	90	2100	30	Reduced blood pressure, reduced heart rate, heart murmurs in half of subjects
2–22	119–144	180	30	Change of threshold of hearing by 10 dB in 30% of subjects
1–100	154	24–120		Vertigo, headache and dizziness, dyspnea, tingling in the ears, trismus

The above considerations lead to the conclusion that vibrations of machine and device components result in clearly adverse effects, which include:

- incorrect operation of the machine (including the irregular operation of hydraulic receivers, generation of pressure pulsations resulting from the excitation of vibrations of control components in hydraulic valves);
- reduced durability of the machine or device;
- harmful effect of vibrations (Chenxiao and Xushe, 2012) on the surroundings (humans, hydraulic valves, other machines, devices and processes);
- noise emissions (particularly low-frequency noise) (Hubballi and Sondur, 2017).

The analysis of vibration and or acoustic diagnostic signals can provide information about phenomena and processes in machines. The machines are often equipped with hydrostatic systems whose main source of noise is the working positive displacement pump or maximum valve. In this case, a diagnostic acoustic signal is used to detect the presence of cavitation in the suction port of the positive displacement pump or in the maximum valve (Kollek et al., 2007). The main objective of this paper is to demonstrate the coincidence of pulsatile fluid flow with mechanical vibrations of hydrostatic system components. The paper focuses on the excitation of mechanical vibrations of selected elements of hydrostatic systems by pulsatile flow of working fluid. It was pointed out that the phenomenon of excitation of mechanical vibrations of hydraulic micropipes and bodies of hydraulic valves occurs. The author's own test stands, measuring instruments used and examples of experimental results are presented. Finally, the presented results are discussed.

2. Pulsating fluid flow and vibrations. A theoretical background.

The coincidence of mechanical vibrations and pressure pulsations in hydraulic systems can be approached in two ways. The first approach relates to the vibrations of the hydraulic system components that are caused by a pulsating flow (e.g. vibrations of pipes and valves), while the other approach relates to pressure pulsation arising due to the vibrations of the hydraulic system components, and in particular, of valve control components (e.g. directional valve spools or relief valve discs).

Variable fluid pressure in a hydraulic system may be caused by factors such as the pulsating efficiency of the working fluid, resulting from the kinematics of operation of displacement components in the pump. The instantaneous capacity of an external gear pump can be represented as (Stryczek, 2014, p66):

$$Q = \frac{b_z \cdot \omega_l}{2} \cdot \left[r_{w1}^2 + \frac{r_{t1}}{r_{t2}} \cdot r_{w2}^2 - r_{t1} \cdot (r_{t1} + r_{t2}) - \left(1 + \frac{r_{t1}}{r_{t2}}\right) \cdot u^2 \right] \tag{1}$$

where,

b_z – width of the wheels, ω_l – angular velocity of the gear, r_w – radius of the apex wheel, r_t – radius of the rolling wheel, u – momentary distance of the point of contact of the teeth, moving along the line of the buttress, from the mesh pole, r_z – radius of the base wheel, φ_z – angle of rotation of the gears.

In general, the flow pulsation of a positive displacement pump is described by the flow irregularity coefficient δ (Stryczek, 2014: 71):

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(2) $$\delta = \frac{Q_{max} - Q_{min}}{Q_{av}}$$

where,

Q_{max}, Q_{min} – maximum and minimum flow rate respectively, Q_{av} – mean flow rate.

The pulsating efficiency of the pump creates periodically variable pressure values in the hydraulic system, in the form of a harmonic function. The frequency of this pressure pulsation corresponds to the pulsation of efficiency (Kudźma et al., 2014). It also causes mechanical vibrations, arising in hydraulic pipes and bodies of hydraulic valves.

Fluid flowing in a tube can cause flexural vibrations if a certain velocity value is exceeded, resulting in a loss of stability of the tube. The value of the velocity at which this occurs is usually called the *critical velocity of flow*. The critical velocity depends on the boundary conditions adopted, i.e. the way the tube is supported. The description of the flexural vibrations of a hydraulic tube with a flowing fluid assumes treating the tube as a Bernoulli–Euler beam. Therefore, the dynamic equilibrium of an elementary tube section d_x, on which forces and corresponding moments act, must be considered. Without going into the details of the analytical considerations, the final form of the mathematical relation describing the flexural vibrations of the microtube caused by the pulsating fluid flow can be presented (Gryboś, 2005: 54) as follows.

(3) $$EJ\frac{\partial^4 w}{\partial x^4} - \frac{\partial}{\partial x}\left[(S - pA)\frac{\partial w}{\partial x}\right] + b\frac{\partial w}{\partial t} + m_c\frac{D^2 w}{Dt^2} + m_r\frac{\partial^2 w}{\partial t^2} + (m_c + m_r)g\cos\alpha = 0$$

where,

m_r –mass of a tube section of unit length;

m_c –mass of a stream section of unit length;

$w_{(x,t)}$ –tube deflection in the section with coordinate x and time t;

S – external tensile force;

p – pressure inside the tube;

A – surface area of the tube;

b – coefficient of external resistance of the medium in which the tube is located.

The value *(S-pA)* depends on the pressure p and on the type of ties limiting the conductor's freedom of axial displacement.

The deflection function of the tube which is to satisfy the above equation should consist of two terms: one corresponding to the static deflection w_s, which is the result of the weight of the tube and the fluid, and the dynamic deflection w_d. It can be formulated as follows:

(4) $$w(x,t) = w_s(x,t) + w_d(x,t)$$

In order to obtain the final solution of the above equations, treating the pipe as a Bernoulli–Euler beam, it is necessary to formulate the boundary conditions – the way the tube is supported. Obtaining a more accurate description requires taking into account wave phenomena in the tube and flow during non-stationary processes, and the tube must be treated as a Timoshenko beam. This leads to partial differential equations of the hyperbolic type, which will not be presented further in this paper, as the focus here is on the experimental research aspect.

3. Methods and experimental setup.

Experiments have been carried out to verify the excitation of vibrations by pulsating fluid flow. The experiments used a steel hydraulic microtube with an internal diameter of 4 mm, an external diameter of 6 mm, a length of 194 cm, and a circular cross-section. The tube was supported at both ends. A diagram of the hydraulic system with

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measurement points marked is illustrated in Fig. 3. Measured parameters included pressure pulsation in the tested microhydraulic system (points p_1 and p_2) and mechanical vibrations of the tube in two mutually perpendicular directions *X* and *Z* (points a_1 and a_2). The experimental system featured an external meshing gear micropump with a unit efficiency of 0.8 cm^3/rotation, powered by an electric motor with a speed of 1,380 rpm. The value of static pressure in the system was measured using a throttle microvalve.

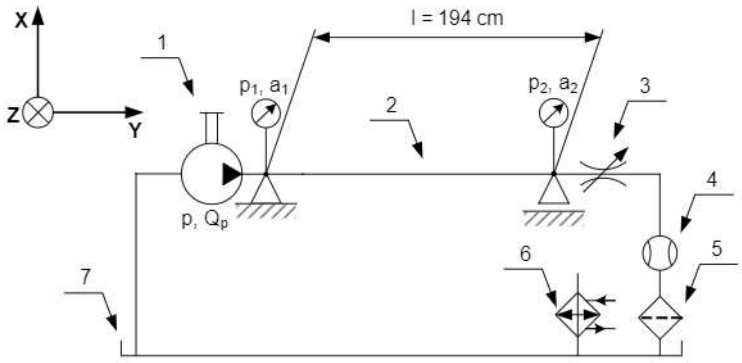

Figure 3. Diagram of the experimental system: p_1 – piezoelectric pump pressure pulsation sensor, a_1 – 3-axis accelerometer, p_2 – piezoelectric throttle valve pressure pulsation sensor, a_2 – 1-axis accelerometer, a_3 – 3-axis accelerometer, 1 – micropump, q_p = 0.8 cm^3/rotation, 2 – hydraulic microtube, internal diameter 4 mm, 3 – adjustable hydraulic microvalve, 4 – flow meter, 5 – hydraulic oil filter, 6 – hydraulic oil cooler, 7 – hydraulic oil tank.

Figure 4 shows the detailed locations of measurement sensors in the system.

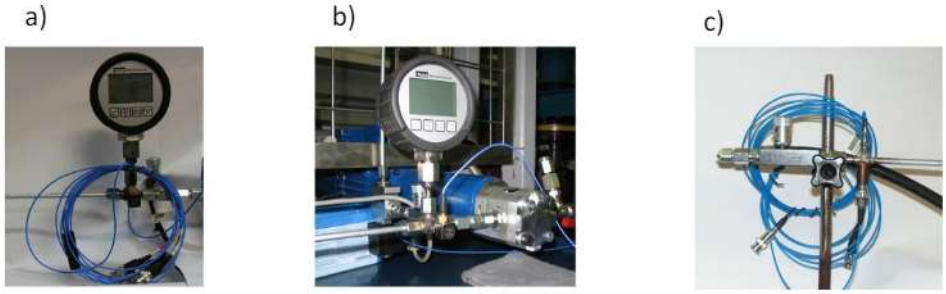

Figure 4. Point of measurement for the acceleration of mechanical vibrations of the hydraulic microtube and pressure pulsation in the microhydraulic system: a), b) at the micropump, c) at the throttle microvalve

The acceleration of mechanical vibrations was measured using Piezotronics accelerometers: point a_1 – 3-axis ICP accelerometer, point a_2 – 3-axis miniature ICP accelerometer; pressure pulsation was measured using ICP 105C23 miniature piezoelectric pressure sensors.

The excitation of mechanical vibrations caused by pulsating flow was also verified using a specially designed test stand, with a latest-generation DFPlus single-stage proportional directional valve as its major component. The test stand enabled the generation of pressure pulsation with frequencies up to 350 Hz (the limit frequency of the DFPlus directional valve). A diagram of the test stand hydraulic system is shown in Figure 5.

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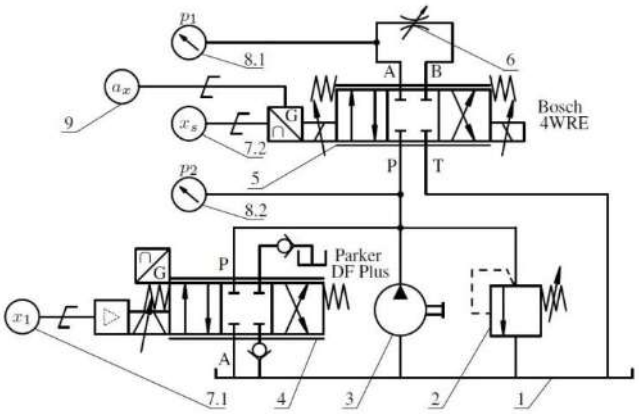

Figure 5. Diagram of the test stand hydraulic system used to test the impact of pressure pulsation on a hydraulic valve: 1 – oil tank, 2 – safety valve, 3 – displacement pump, 4 – DFPlus proportional directional valve (pulsation exciter), 5 – tested valve: a single-stage proportional directional valve, symbol 4WRE, 6 – adjustable throttle valve, 7.1, 7.2 – directional valve spool position sensors, 8.1, 8.2 – pressure sensors, 9 – accelerometer.

The following parameters were measured and recorded: DFPlus directional valve control signal waveform, DFPlus directional valve spool displacement, pressure changes upstream and downstream of the tested 4WRE directional valve, acceleration of vibrations of the body of the tested 4WRE directional valve, displacement of the spool of the tested 4WRE directional valve. A diagram of the control, measurement and data acquisition system is shown in Figure 6.

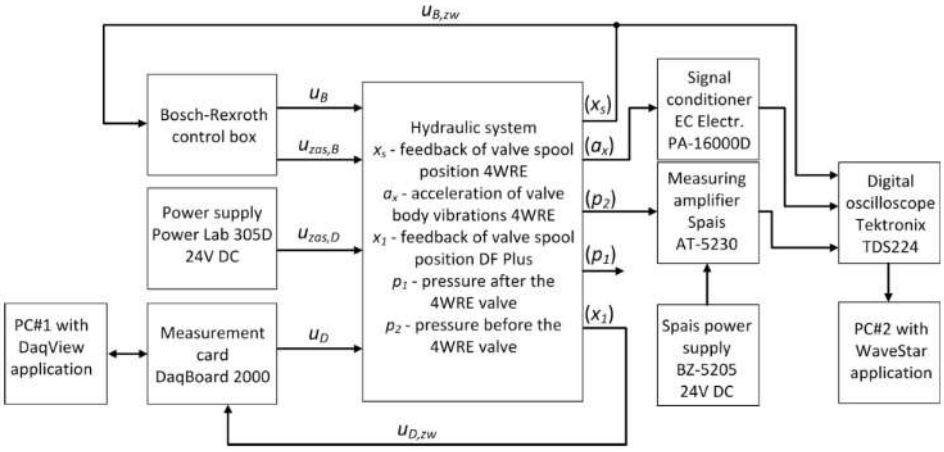

Figure 6. Diagram of the control, measurement and data acquisition system in the pressure pulsation generation test stand.

The software used with the test stand enabled the generation of changes in the control signal of the DFPlus valve over a required time. The procedure for controlling the valve using the software referred to above is described in detail in references (Herok et al., 2014) and (Kudźma, 2012). The harmonic signal used had a set frequency f and amplitude s_0, and a fixed zero offset value s_{01} of the form: $s = s_{01} + s_0 \cdot sin(2 \cdot \pi \cdot f \cdot t)$. The test results that indicate the excitation of mechanical vibrations of the body of the hydraulic directional valve as a result of pressure pulsation are shown in Figures 8 and 9, with the following parameters of the control signal: s_{01} = 5 V, s_0 = 4 V. The modular design of the test stand enables replacement of the 4WRE directional valve (item 5, Fig. 5) with a different hydraulic valve.

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4. Results and discussion

The test stands shown in Figures 3 and 5 allowed results to be obtained, examples of which are shown in Figures 7, 8 and 9. The results of the test carried out on the test bench of Figure 3, in the form of an amplitude and frequency spectrum of pressure pulsation and vibrations of the microtube, horizontally and perpendicular to the axis of the tube, are shown in Figure 7.

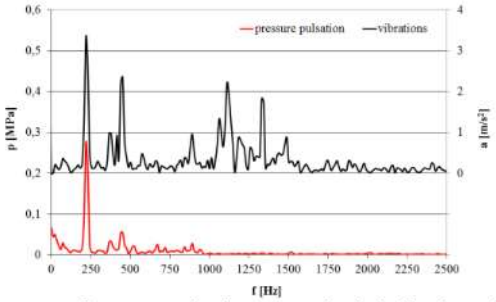

Figure 7. Amplitude and frequency spectrum of pressure pulsation and mechanical vibrations of the hydraulic tube; p_{ir} = 5 MPa, Q = 1.83×10^{-5} m^3/s (1.1 dm^3/min).

Harmonic constituents of mechanical vibrations corresponding to pressure pulsation can be seen in the spectrum shown in Figure 7 – the pressure pulsation of the fluid flow generated mechanical vibrations in the hydraulic tube. The frequency value of the thus generated first constituent of the excitation spectrum (pressure pulsation) may be calculated using the following formula:

$$f_1 = \frac{n \cdot z}{60} = \frac{1380 \cdot 10}{60} = 230 \text{ Hz} \quad (5)$$

where,

n – angular speed of the pump shaft [rpm],

z – number of teeth [–].

Figures 8 and 9 show the horizontal vibrations of the 4WRE directional valve body along the axis of movement of the directional valve spool. These results were obtained on a test stand, the hydraulic diagram of which is shown in Figure 5.

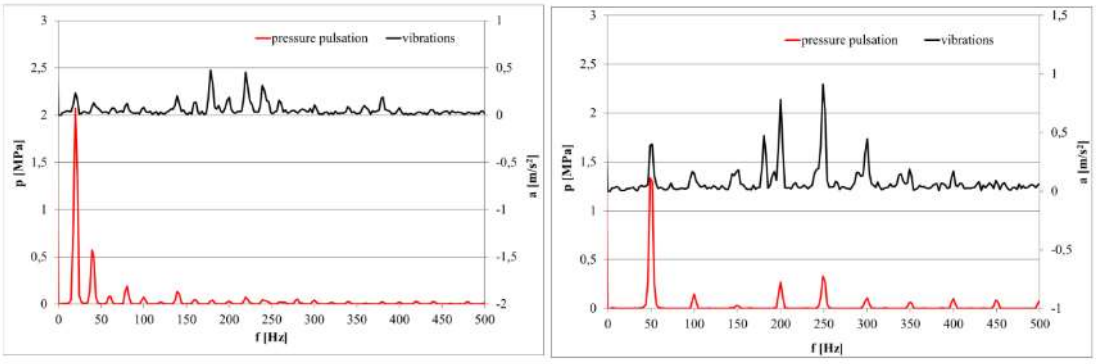

Figure 8. Amplitude and frequency spectra of pressure pulsation and excited mechanical vibrations of the body of the 4WRE directional valve: a) frequency of DFPlus directional valve control signal f = 20 Hz, b) frequency of DFPlus directional valve control signal f = 50 Hz, c) frequency of DFPlus directional valve control signal DFPlus f = 70 Hz, d) frequency of DFPlus directional valve control signal DFPlus f = 90 Hz; p_{ir} = 2.5 MPa, Q = 1.083×10^{-4} m^3/s (6.5 dm^3/min).

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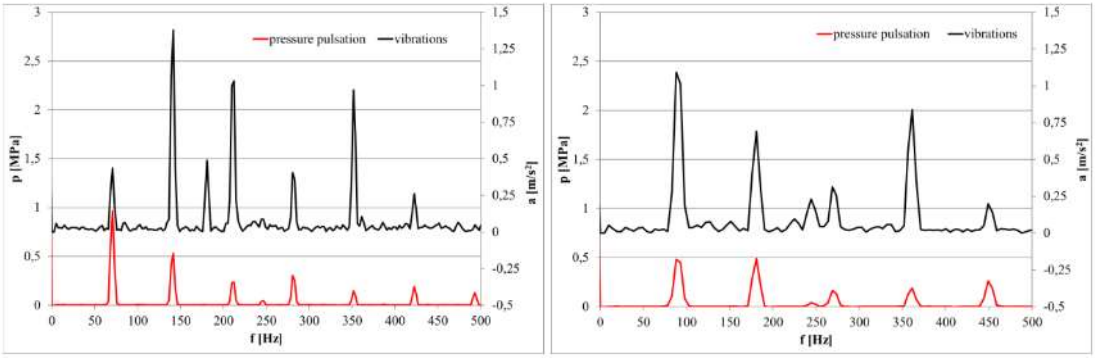

Figure 9. Amplitude and frequency spectra of pressure pulsation and excited mechanical vibrations of the body of the 4WRE directional valve: c) frequency of DFPlus directional valve control signal DFPlus f = 70 Hz, d) frequency of DFPlus directional valve control signal DFPlus f = 90 Hz; p_{is} = 2.5 MPa, Q = 1.083×10^{-4} m^3/s (6.5 dm^3/min).

The results shown in Figures 8 and 9 indicate the spectrum of pressure pulsation upstream of the tested 4WRE directional valve at point 8.2 in Figure 5, and the acceleration of vibrations of the body of the directional valve at point 9 along the spool axis. The results confirm that a correlation exists between pressure pulsation in a hydraulic system and the vibrations of valves forming part of the system.

3 Conclusions

Both our own research and literature reports indicate that machines equipped with hydraulic systems generate mechanical vibrations with broad frequency spectra and significant amplitudes. These vibrations affect the human body and, in particular, the components of hydraulic systems. Furthermore, mechanical vibrations may disrupt the normal operation of these components. An analysis of the results of tests involving exciting flexural vibrations of microtubes and vibrations of the body of the 4WRE directional valve indicates coincidence between the constituents of the pressure pulsation spectrum (excitation) and the constituents of acceleration of mechanical vibrations (system response), which results in the generation of mechanical vibrations at frequencies corresponding to the frequency of pressure pulsation in the tested system. For the results of directional valve body vibration tests presented in the study, the highest amplitudes of the first vibration constituent were observed for a pressure pulsation frequency of 90 Hz. Significantly higher constituents are evident in the spectra of vibrations of the valve body (180 Hz, 360 Hz). With an increase in the frequency of pressure pulsation generated by the DFPlus directional valve, its amplitude falls, while the amplitudes of the 4WRE directional valve body vibrations increase. This may indicate that the excitation frequency approaches one of the frequencies of normal mode vibrations of the 4WRE directional valve, treated as a two-body system. In Figures 8 and 9 we can also observe components of the vibration spectrum with frequencies below 100 Hz, which are particularly dangerous vibration frequencies for humans (as shown in Figure 1). Low-frequency vibrations are poorly attenuated by matter and propagate over long distances. It is therefore important to eliminate them at their source, i.e. using active methods.

Although the paper presents considerations for machines and equipment equipped with hydraulic systems, the scope of conclusions is not limited to this class of machines. Adverse effects of vibrations and noise on the environment (including human beings) may have different sources but identical effects. For example, in road passenger transport vehicles, vibrations and noise transmitted into the vehicle interior are caused by, among other things, unevenness of the ground, unbalance of rotating parts, inaccuracy of assembly, clearances, aerodynamic resistance of the medium, etc. In the analysis of the effects of such excitations, frequency ranges, signal amplitudes, place of application of the excitation, transmission paths and exposure times are important. Consequently, modern machinery or equipment must not only meet the new requirements with regard to efficiency and energy saving, but also with regard to the emission of harmful signals into the environment. Such an approach will meet the requirements for sustainable development of new machine designs.

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