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The Analysis of Selected Factors Improving the Cargo Susceptibility to Modal Shift

Mateusz Zając

Faculty of Mechanical Engineering, Wroclaw University of Science and Technology, 50-370 Wrocław, Poland; mateusz.zajac@pwr.edu.pl

Abstract: The issue of shifting loads from road to rail is always vivid when it comes to reducing CO_2 emissions from transport. Practically not every load transported by road vehicles over a long distance can be transferred to rail. Additionally, the potential of the railway lines is limited, which means that the network is not able to accept huge amounts of loads from road transport. In the article, attention was paid to the typology of cargo susceptible to changing the means of transport. The article discusses the factors influencing the real possibility of CO_2 reduction by changing the mode of transport. The analysis and calculation example of the selected region in Poland is presented.

Keywords: intermodal transport; modal shift; rail transport utilization; CO_2 reduction; case study

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1. Introduction

There are numerous definitions of intermodal cargo transportation. It can be found in, e.g., Ref. [1] as well as in [2] or [3]. Each time these sources refer to the transportation of goods with the participation of at least two modes of transport, where the stage that initiates and finalises the transportation of cargo is carried out using road transport, and the main distance is covered using a different mode of transport. Moreover, the transport is carried out with the use of integrated loading units, most often containers.

This article refers to intermodal transportation related to the use of rail and road transport without looking for inland waterway transportation connections. It, therefore, relates to continental haulage. Intermodal cargo transportation has been developing for decades, which can be seen in the papers referred to in the article [4]. A particularly dynamic era of development is the outset of the 2000s, but in some regions, especially developing countries, it can be noticed even in times of global crises.

In the context of comparing intermodal and road transportation, for some time, it could be noted that intermodal transportation (executed by rail) and road transportation were put against each other. Both communities pointed out the weaknesses resulting from the use of lorries (emissions, road accidents, congestion) and railways (travel times too long, high prices, no timely deliveries).

In recent years, however, a change can be noticed, and an attempt to look for the elements that connect both modes of transport [5]. Factors that determine the choice of one or another means of transport or mode of transport were also reported. In the article [6], it was pointed out that the cost of transportation is still the most crucial criterion in taking this decision. However, the environmental impact is the second most important factor.

This publication uses an approach where intermodal transport is a form of cargo transportation, which should utilise the advantages of both forms of cargo transportation:

- Road transport provides for the possibility of transporting cargo in a door-to-door relationship;
- Rail transport allows for covering long distances quickly and in a manner that is more environmentally friendly than road transportation.

The ultimate goal is to reduce CO_2 emissions resulting from the haulage work; the remaining discussion is subordinated to this issue.

Some publications indicated that the transfer of the loads from road to rail transport would unarguably result in a reduction of pollution. However, the following issues should be taken into consideration:

- Not all goods hauled by road transport qualify for rail transport;
- the rail transportation infrastructure is not always (and most often) able to accept an additional transported volume due to its own limitations;
- Conditions that would guarantee the economic profitability of maintaining transshipment sites are not always available in a given region (hence the lack of such points).

The aim of the article is to demonstrate that the factors related to the structure of the hauled cargoes, the available railway infrastructure and the elements accompanying intermodal transportation allow for the calculation of the benefits resulting from the reduction of CO_2 footprint caused by the transfer of cargoes from the road to rail transportation.

The first part of the article discusses the method of estimating the parameters defining the volume of road transport, which shows an increased susceptibility to modal shift. The next part is a presentation of popular methodological approaches related to the calculation and modelling of CO_2 emissions in cargo transportation. Then, the method of calculating CO_2, taking into account the transport susceptibility of cargoes, was presented, and examples of the method's use were introduced. In the final part of the article, there is a discussion of the results and applicability of the method, together with a summary.

2. Estimation of a Modal Shift-Susceptible Volume

At present, in the EU countries, the division of freight performance between the modes of transport is quite reproducible: approx. 80% of hauled cargoes are carried out by the road, approx. 15% by rail and a few percent by inland waterways. These statistics may differ in individual countries. It depends on numerous factors, ranging from geographical location, through the past-decades infrastructural investments, the development of logistics systems, the availability of rolling stock, as well as considerations of a less technical weight, such as the transportation policy of a given country.

Attempts to estimate the volume susceptible to modal shift emerged, among others, in a paper concerning a specific region [7] or country [8].

Similarly, the structure of goods hauled in individual regions differs. Apart from the above -mentioned factors, this structure is characteristic of a given region. In areas where aggregate is mined, this type of cargo will certainly be of greater importance than in the region where the main source of the region's income is wood harvesting or tourism. Intensively urbanised regions have a different structure of the goods hauled than more rural areas. Nevertheless, all data on the hauled cargoes are recorded for statistical purposes, and each EU country reports data on transportation activities, which can be found in this publication [9].

You can find out that the ratio of the amount of the goods hauled to the GDP generated in the country in the EU-27 has remained practically unchanged over the last 10 years. However, in selected countries, this ratio is much lower (0.9 level), e.g., Switzerland, Italy, and in countries such as Croatia, Latvia or Spain, it amounts to approx. 1.1. Individual countries keep statistics on the transportation structure. It is most often carried out by the units of the relevant ministry dealing with transportation.

The breakdown of the structure of the cargoes hauled may differ from country to country. Even between road and rail transport, differences in the developed transport structure are visible; in road transportation, we have several basic cargo groups, including metal ores, food products, food, waste and recycled materials, wood and wood products, chemicals, coke, coal, prefab products, etc.

In rail transportation, the main categories of products transported are metal ores, coal and crude oil, coke and refined petroleum products, chemicals, rubber and plastics, nuclear fuel, base metals, and processed metal products.

In 2020, in road transportation, similarly as in previous years, "metal ores and other mining and quarrying products" make up the largest group of products transported in terms of tonnage, constituting 25.0% of the total tonnage. The most important product groups are "other non-metallic mineral products" and "food, beverages and tobacco", each constituting 12.2% of the total, and "agricultural, forestry and fish products" (9.5%).

However, the susceptibility of cargoes to modal shift is conditioned on their character. Palletised cargoes, due to the ease of loading operations, are the best solution in this respect and the cargo group they represent does not matter. It is worth noting that goods transported on pallets accounted for nearly half of road freight transportation in the EU in terms of tonne-kilometres (44.6% in 2019 and 45.6% in 2020). The second most common type of cargo was solid cargo in bulk, accounting for one -fifth of the total (20.3% in 2019 and 19.9% in 2020). The countries with the highest share of goods on pallets were Romania (74.2% in 2019 and 73.0% in 2020), Bulgaria (64.4% in 2020) and Slovakia (61.4% in 2020). The lowest share of palletised loads occurred in Cyprus (8.1% in 2020), Finland (26.7% in 2020) and Belgium (29.1% in 2020).

In the statistics provided by Eurosat, a preliminary division into the transportation of up to 300 km and above has already been made, suggesting right from the start that we will not be able to take certain loads into account for modal shift. In 2020 this type of transportation in the EU-27 amounted to almost 37% of tkm.

Therefore, if we assume that palletised cargoes are in their entirety susceptible to the change of the mode of transport from road to intermodal (45.6%), then considering that 63% of cargoes are transported over a distance of over 300 km, this shall mean that 28.7% of road-transported cargoes shows a high susceptibility to shifting the mode of transport.

As previously indicated, each region is quite specific in this regard. Here, Eurostat statistics formed the main basis for this, as this is a widely recognised source. However, having access to regional or national data would allow a better understanding of the potential (and needs) in different areas of Europe.

The most useful in this respect are studies, such as surveys, source-target surveys or cordon studies. As part of this type of study, we can determine the origin-destination matrix, the origin of the vehicle, as well as the travel time and speed between points and the parking time. In addition, the use of cordon studies is characterised by an incomparably larger sample than surveys, which are still quite often used to determine the origin-destination matrix. In addition, in terms of surveys, they do not interfere with traffic – no need to stop vehicles from conducting surveys and do not contain errors caused by false responses of the questioned.

Most often, transit surveys are carried out as round-the-clock surveys, with a distinction of the generic structure being made. Unfortunately, this structure applies only to the vehicle type and not to the form of the cargo, both in transit and local (regional) traffic studies. On the other hand, carrying out surveys – interviews for a long time on the roads of the region or even the city is close to impossible.

This shall mean that when determining the volume transported via road, we can only speak about its susceptibility with a great level of uncertainty based on the values declared by the entities performing such transportation activities. An element that supports this estimation is the determination of the relationship between the relation of GDP and transportation operations in a given country and region.

Cyclical studies of traffic can serve as a reference point and be used to adjust the resulting estimates.

Estimation of the Capacity to Increase the Volume of Cargoes in Rail Transportation

The second element that has to be taken into account while determining the potential to reduce CO_2 generated by transportation as a result of transferring a portion of cargoes from road transport to intermodal transport is determining the capability to launch successive trains hauling the container cargoes, that is in relation to the capacity of the railway system.

In this article, the problem is approached from two directions: differentiating capacity at the section level and at the regional or country level.

In the literature, capacity is defined as a measure of the ability of a given number of vehicles to travel along a given railway line with a fixed timetable [10].

In the article [11], the authors provide two definitions of capacity: theoretical and practical. The theoretical capacity is described as the maximum number of trains that can travel through the considered component of the railway system under ideal conditions, often assuming full homogeneity of the traffic structure. On the other hand, the practical capacity is the maximum number of trains that can travel through the studied component of the railway system but with a reasonable level of reliability (but without including this level in the definition). The capacity is similarly defined in relation to road traffic—as the largest number of objects that can travel through the road cross-section under certain road and traffic conditions [12]. According to most definitions, capacity refers to the maximum number of objects. However, it is dependent on traffic conditions, including the generic and directional traffic structure.

In general, terms, increasing the capacity of a section consists in calculating the current occupancy and recalculating the possibility that a train with specific traffic parameters (type, weight, length, etc.) travels along a given section. If this new train does fall into conflict with already assigned other trains, then it can travel along the railway section.

Apart from the issues of access to infrastructure related to the access to railway tracks and their harmonious use, an attempt to respond to random loading of the railway line was presented in the article [13].

Then, this topic, supplemented by the introduction of random disturbances, was developed further and included in the article [14].

A method has been proposed that allows the calculation of the buffer times adjusted to the events occurring in the railway system. The calculations performed showed the calculated punctuality of trains at the level of 90% and the delay not exceeding 2.5 min at the level of 95%. The method allows the use of data already collected in the system to allocate the time reserves concerning operational experience where needed, contributing to the reduction of power loss.

The connection between the issue of energy consumption and capacity on a railway route is contained in the article [15]. On the other hand, Ref. [16] presented a method of influencing the global demand for electricity by designing timetables in a manner that gives consideration to this aspect. The authors recognise that there is still room for further development of the algorithm in order to further improve the method. They also note that the proposed algorithm provides timetables in such a form that it is easier to build cyclical timetables.

The development of existing routes also has an impact on increasing capacity. Ref. [17] is a good example of this. The article [18] presents the method of implementing a virtual rail coupling by extending the standard set of ERTMS operation modes by concept verification and a sample numerical analysis. Virtual Coupling enables extremely short travels and, thus, greater track capacity. Relevant mathematical models and control algorithms adapted from the automotive industry can be used to prove the effectiveness of cooperative control strategies in referential feedback scenarios and even in degraded scenarios such as emergency braking.

In the article [19], it was noted that the main advantage of introducing ETCS systems is the impact on increasing the capacity of railway lines. Depending on the level of application of the ETCS system, the maximum capacity of the line is estimated at 20 trains per hour (level 1) or 24 trains per hour (level 2).

The publication [20] refers broadly to various aspects related to the development of infrastructure that should be implemented to increase the competitiveness of rail transportation and the capability to let through more trains. However, the ultimate goal of the discussion is to increase the length of the drafts of cars on routes in various European countries, which is supposed to result in an increase in the transportation volume of the railway.

In general, the institutions responsible for the supervision of the railway infrastructure make estimates of the possibility of increasing the number of trains. It is estimated that the rail system may increase its capacity by 30 to 40% in the years to come, thanks to a combination of activities related to the extension of the length of the draft of cars and the implementation of higher levels of infrastructure management.

In the context of the transportation capacity of the railway increasing, the discussion—depending on the needs and context—is conducted at a very detailed level, where the starting point is to estimate the load on individual sections and take into account various random factors, as well as the current division into passenger and freight transportation. Another approach in consideration of capacity is to rely on calculations simulating rail traffic and introduce, e.g., state-of-the-art control systems that enable to increase of the travelling speed of the train.

3. Methods of Calculating CO_2

In the literature and praxis, it is possible to find numerous methods for calculating (allocating) CO_2 to mobility. In addition to analytical methods, simulation methods may be identified. In article [21], it was noted that in real life, companies struggling with CO_2 attribution tend to use simple cost calculation formulas and ad-hoc schemes based on indicators representing costs such as weight, distance or revenue-based indicators. There seems to be no consistent and simple calculation method that would be a great tool for many entities.

In a publication [22], it was noted that almost all greenhouse gas emissions from freight transportation are related to energy. The most accurate way to calculate these emissions is, therefore, the recording of energy consumption. So the easiest way would be to collect fuel invoices related to a given vehicle or by registering an actual mileage and estimating fuel consumption against average fuel consumption reports.

Publication [23] shows that a good method to calculate gas emissions is to multiply the energy consumption ratio by the volume of fuel consumed over a specific distance, taking the extent of vehicle load level into consideration. This method of calculating CO_2 includes the distinction between the type of fuel used. However, in the event that the transport is executed to several points within a single trip, then this method may become not entirely dependable. It also does not take into consideration the driving situation or the driver's behaviour, or the traffic scenarios.

Guajardo and Rönnqvist identify over 40 analytical methods in their paper [24]. They provided a closer look at the proportional method, which is relatively easy to calculate. For example, many publications have attempted to attribute CO_2 costs to mobility by utilising the travelling salesman algorithm, e.g., [25,26].

Another approach is to use the vehicle routing problem in assigning CO_2 emissions to transportation operations. It was used, among others, in [27–29]. *The latter* examines the issue of the cost and allocation of emissions of the logistics system. Road transportation was considered to be the largest contributor to global greenhouse gas emissions and, consequently, to global warming.

If we assume that the attempts to calculate CO_2 emissions are based primarily on energy consumption, then the approach that presents a very detailed approach to the issue of calculating vehicle emissions within the logistics system is [30].

Whereas, concerning railway vehicles, we can learn about the method of energy consumption modelling in the article [31], where, similarly to before, the starting point was the theory of vehicle motion and the computations assigned to it. In the literature, much attention is also paid to the modelling of CO_2 emissions in transportation. In article [32], the division of methods used for this purpose has been prepared, putting particular emphasis on road transportation. The following were listed in the article:

- Modelling through microsimulation;
- behavioural models;
- agent models;

- system dynamics;
- technical and economic models.

In micro-simulation modelling has the assumption that fuel (energy) consumption is constant. Acceleration, braking, driving dynamics, etc., do not matter. In the behavioural approach, the results obtained are considered to be closer to life-like values [33,34].

Agent-based modelling was presented in [35]. In this article, barriers to adopting energy efficiency by households and identified four individual clusters: structural, economic, behavioural and social barriers were identified. The presented modelling method relates to the policy linked to emissivity in such a way that it also takes it into account in the operational process.

The advantage of agent-based modelling is that it recognises the behavioural dynamics in the transport system, similar to behavioural models. In addition, it can help to identify more precisely the behaviour and motivations related to the trip.

The system dynamics is yet another approach. The publication uses this approach to modelling CO_2 emissions in the road sector. The model is unique in its capability of modelling the effect of political measures with unlimited numerical values (e.g., the subsidy rate for the purchase of a vehicle powered by alternative fuels) [36].

Similarly, the publication [37] highlights the relationship between the modal division of transportation and its impact on the emission of pollutants in a transregional view.

System dynamics has also found its use in modelling specific phenomena. In the paper [38], it was acknowledged that road transportation has its own specific aspects. Therefore it requires the use of emission-related indicators suitable for a specific application.

Technical and economic models are presented in the article [39]. Fourteen different cost models of pipeline transport and related CO_2 emissions were compared. In the case of this form of transportation, there are great uncertainties related to the costs of CO_2. It has been noted that specific features related to the execution of the pipeline (e.g., thickness, fluctuating prices of steel and the effects of contamination are often excluded) when calculating the CO_2 footprint.

In Ref. [40], the presented technical and economic analysis assessed the decarbonisation process of some major industrial processes that involve fossil fuels in a rational manner.

The article [32] presents the heuristic method for the identification of changes in the balance of CO_2 emissions resulting from the diversification of transportation supply. The work utilised a simulation tool, which allows us to compare the current situation in a given transportation space and compare it with probable alternative variants. A broader understanding of energy consumption was proposed by including in the calculations the share of emissions generated by the entire manufacturing process of the materials under consideration, from the extraction of raw materials to their disposal. A similar subject matter was included in the article [41].

4. Allocation Methods

The previous chapter focused on the methods for calculating or forecasting CO_2 emissions resulting from transportation operations. The literature also includes the indicated estimates of CO_2 emissions related to transportation activities. In this section, an attempt has been made to introduce a more general approach that answers questions regarding the reduction of emissivity of a group of vehicles. An interesting paper on this subject is [42].

This paper presents a number of different types of cooperative models between players within the logistics chain, and the goal of the cooperation is to reduce the emissions of pollutants. The author focuses primarily on showing examples of cooperation within the logistics chain and the use of shared options for transporting cargo in road traffic.

Particularly interesting in the context of this study is the article [43]. In the first part of the article, the authors performed calculations that, similarly to previously, were based on the use of shared resources of road transportation companies and the reduction of emissions by 11 to 18%. However, the further parts show that cooperation between different modes of transport can bring savings in CO_2 emissions at the level of up to 50 to 53%.

In calculations of this type, the starting point is the assumption of the average level of emissions of pollutants. Initial calculations are made based on the scheduled experiment. However, after obtaining the basic data, further considerations utilise the average value.

When it comes to attributing the CO_2 emission value, such attempts have been noticed for many years. The publication [44] indicates that there are models for calculating or allocating CO_2 emissions at the macroscopic and microscopic levels. On the other hand, the average value of carbon dioxide emissions is provided by the German railway (DB AG) in its own publications. They amount to 41 g/tkm for rail freight transport and 207 g/tkm for road transport. It is worth noting that this publication dates from 2003. Institutions dealing with transportation issues periodically publish updates on these values. In 2020, the European institution CER, in its publication [45], indicated that CO_2 emissions from the transportation of goods by rail amount to 24 g/tkm and by road to 136.9 g/tkm. However, as presented in the previous chapter, the value of these emissions will be different for vehicles representing various stages of technological development, dissimilar to different terrain conditions, driving styles, and infrastructure. These values should be approached in a general way. However, these are interesting and beneficial when calculating the emission values for a larger transportation space, region, country, etc., like in [46].

Method for Analysis of the Potential for Reduction of Cargo Transportation and CO_2 Emissions

Further in the article, the method will be presented that enables the determination of the reduction of CO_2 emissions resulting from the transportation of goods by transferring cargoes from road to intermodal transportation utilising the railway system. The general method is presented in Figure 1.

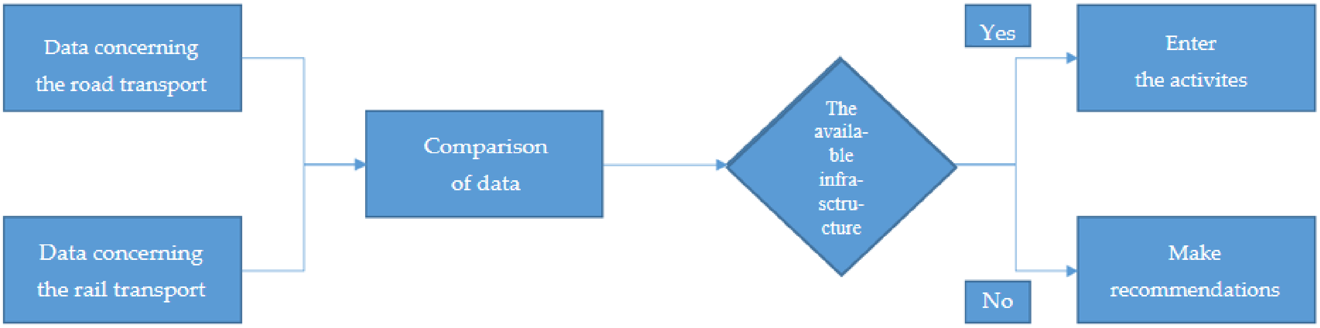

Figure 1. The general method of analysing is taking advantage of the potential of road and rail transportation.

It is based on a comparison of the volume of cargo hauled by road and exhibits the potential for transfer to intermodal transport as well as the possibilities resulting from the additional burden of railway routes.

Step 1. Determining the possibilities of relocating cargoes from road transportation.

First of all, it is necessary to determine how many cargoes are potentially ready using transportation other than the road. Ideally, this type of data was collected in the studied region, and these are ready to be used. The analysis is then based on historical data. However, as indicated earlier, carrying out such types of studies in a continuous manner is close to impossible. The current state of the art does not allow for the collection of this type of data in realtime.

However, if historical data is not directly available, rough calculations and estimated values can be used. One of the ways is to estimate these values by basing them on the GDP and haulage performance in the country and the region. This way, it is possible to determine what haulage work, in proportion to the entire country, was performed in the studied area. However, it should be noted that not every type of transportation activity connected with the carriage of goods is equally susceptible to being transferred to another mode of transport. As part of intermodal transportation, highly processed products are the ones the most often transported, e.g., electronic devices and components used in the automotive industry. As indicated earlier, practically all palletised loads have the potential to be transported via intermodal transport. Bulk products are usually not considered goods suitable for intermodal transport. Consequently, it is important at this stage to determine what proportion of the goods can potentially be transferred to rail transport based on the transport structure. The procedure for this part of the model is provided in Figure 2.

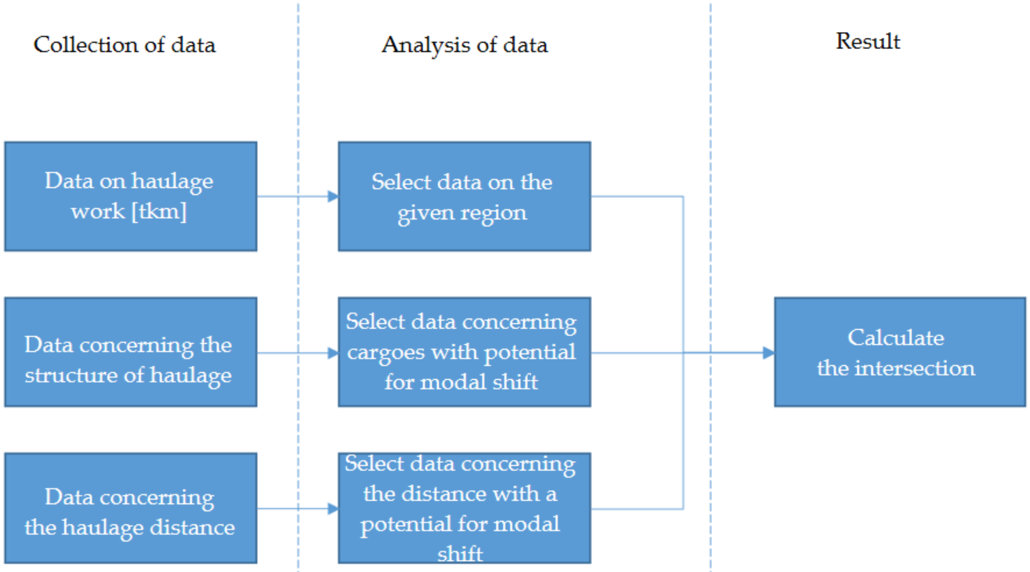

Figure 2. Plan of data preparation for the calculation of modal shift-susceptible cargoes.

Step 2. Determining the potential of rail (intermodal) transport.

At this point, the considerations could be met with the statement that cargoes listed in road transport as potentially suitable for modal shifts should be simply transferred to rail transport. However, rail transport has its intrinsic limitations, which shall mean that it is possible to accept only a portion of the cargo from the road, which may result from, e.g., insufficient access to infrastructure. Determination of the potential may be carried out by determining the level of occupancy of the routes on which trains with cargoes transferred from road transportation could travel. It is a straightforward task should this type of information be collected in the region. However, if there is no such data, then, as in the previous case, data should be used that will allow estimating the unused potential. Such data may include, for example, information on haulage work and the region's GDP, as well as data on the occupancy of railway routes. The precise determination of the unused potential of the railway route is quite a complex component of the equation. This study is based on expert knowledge. Detailed calculations should include information on the route previously used, the exact parameters of the trains to be run, and the policy on sharing the railway line between passenger and freight carriers. The case also concerns the available infrastructure, its condition, and planned repair works.

The procedure for determining the unused railway potential is shown in Figure 3.

The next step is to calculate the difference: how many of the potentially modal shift-susceptible cargoes can the railway accept? This way, it is possible to determine what haulage work might be shifted to rail transport. When we multiply this result with the difference in CO_2 emissions by different modes of transport, we get the result informing us about the potential of emission reductions linked to shifting cargoes to intermodal transport.

The issue is developed further by comparing the obtained values with the potential resulting from the rolling stock available. The experiences of intermodal terminals and railway carriers indicate a great need to introduce further flatbed cars for the haulage of containers. However, if it turns out that the number of available cars is greater than the potential resulting from the infrastructure, further calculations utilise the latter value. In this case, a comparison (listing) of the weight transported by road that can be shifted to intermodal transport and the average gross load of the container can be used. Taking into consideration the capacity of cars calculated in TEU, the number of cars needed to fulfil the needs can be determined. This number, in turn, divided by the number of wagons in the draft of cars and the number of days, will determine whether the availability of cars is sufficient.

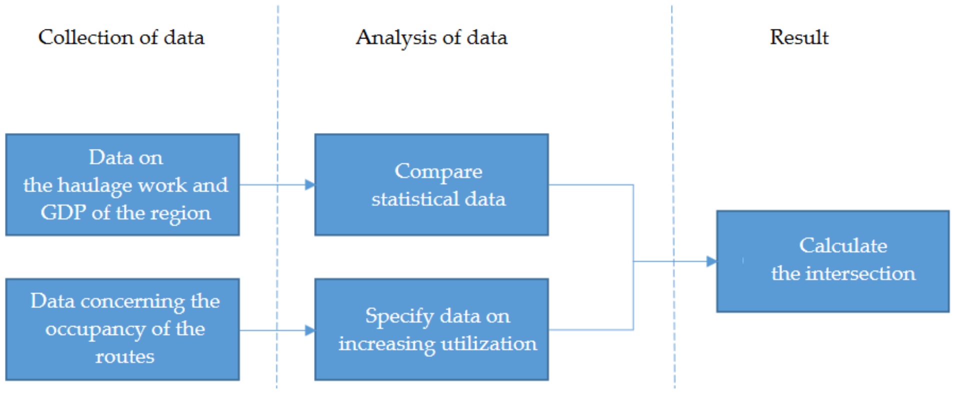

Figure 3. Plan for the preparation of data for the calculation of railway transport potential.

5. Calculations as per Method Using a Region as an Example

The next section of the article will include an example of the calculation of CO_2 reduction as a result of shifting loads from domestic roads to rail (intermodal) transportation. The example is based on the Zielona Góra Voivodeship in Poland, a region located at the intersection of two European transportation corridors.

The calculations made below are of a general nature; the basis for the analysis is data collected from distributed sources [47]. The analysis is carried out with the assumption that road transport of goods is entirely carried out by typical diesel -powered vehicles. This is a simple assumption as there is currently no information available on freight data delivered with electric or alternative fuel vehicles. The type of fuel can affect carbon dioxide emissions, which - especially in the case of electric vehicles, significantly reduce the emissivity advantage of intermodal transport. Nevertheless, at the time of writing the article, data on this subject were not recorded in Poland.

Calculations of the potential of loads ready to change the means of transport were made on the basis of information on total transport in the country. Then, the volume of transport in the region in question was estimated. On this basis, after identifying cargo susceptible to modal shift, the possibility of absorbing road traffic was calculated depending on the increase in the potential of rail transport.

5.1. Basic Data

The Lubuskie Voivodeship is located in the western part of Poland and borders the Federal Republic of Germany from the west and the Western Pomeranian, Greater Poland and Lower Silesia voivodeships.

The value of GDP per capita of the Lubuskie voivodeship in the years 2015–2020 was constantly growing, but the percentage share in relation to the GDP of the country fluctuated within the range of 2.1–2.2%.

Haulage of cargo by road in Poland in 2020 amounted to 461,582 Mtkm (2,331,758 kT), 90% of which is commercial transportation. Domestic transport amounted to 123,819 Mtkm, and international transport to 231,107 Mtkm. The remainder is cabotage haulage or transit.

In the haulage outside the Polish voivodeships, 381,864 M tkm of cargo was hauled by road, i.e., almost 82% of the transported cargo. From national statistics, it can be further read that 57% of cargo in domestic transport was hauled over a distance of 150–499 km, and 12% for more than 500 km, being in total 69% of cargoes in both ranges. Therefore, in further discussions, it was assumed that 69% to 82% of cargo is transported over distances that allow for intermodal transport. Concerning the region being discussed, the share of road transport in this region in relation to the total haulage work in Poland amounted to 2.8%. As can be seen, it is slightly higher than the share in the realised national GDP share.

In the further part, data on the structure of cargoes were reviewed, so an attempt was made to determine the susceptibility of cargoes to a shift in the mode of transport. Table 1 shows the structure of road haulage in Poland in 2020.

Table 1. The structure of road haulage in Poland in 2020.

Groups of Goods	Tonnes	Tonne-Kilometres	Average Distance Travelled by 1 Tonne of Goods in Kilometres	Susceptibility to Modal Shift
	In Thousand	In Millions		Yes/No
Total	**1,172,964**	**123,819**	**106**	
Agricultural and other products	87,233	10,677	122	N
Hard and brown coal; petroleum and natural gas	22,273	3217	144	N
Metal ores and other mining and quarrying products	345,834	17,399	50	N
Food, beverages and tobacco	134,632	22,534	167	N
Textiles and clothing products	1766	283	160	Y
Wood, wood products and cork products (excluding furniture)	56,659	8697	153	N
Coke and refined petroleum products	44,293	3633	82	N
Chemicals, chemical products	41,324	7686	186	N
Other non-metallic mineral products	158,500	16,200	102	N
remaining construction materials	96,756	8876	92	N
Base metals; finished metal products, except plant and equipment	41,807	7361	176	Y
Plant and equipment nowhere else classified	14,477	2085	144	Y
Transportation equipment	18,020	2042	113	Y
Furniture; other products nowhere else classified	13,847	2346	169	N
Secondary raw materials; municipal waste and remaining waste	108,910	5750	53	N
Equipment and materials used in the transportation of goods	17,639	2924	166	Y
Other goods not elsewhere classified	65,751	10,985	167	Y

The systematisation of information on cargoes susceptible to a modal shift in terms of the country and region is presented in Table 2. As can be read, taking into account the groups of goods within the hauled cargoes, approximately 21% of the cargoes are susceptible to a shift in the mode of transport. If this information is combined with the previously shown distances for which the cargoes are hauled (69% to 82% are hauled over a distance greater than 150 km), then the common part of both sets turns out that the estimated share of cargoes susceptible to rail (intermodal) transportation in the Polish region discussed ranges from 15 to 18%.

Table 2. Distribution of cargoes susceptible to a modal shift in Poland.

	Thou. Tonnes	Mtkm
Total domestically	1,172,965	123,819
Susceptible domestic (product)	159,460	25,680
Susceptible domestic (distance) 69–82%	809,345–961,831	85,435–101,531
Joint part (15–18%)	175,944–211,133	18,572–22,287
Total Lubuskie Voivodeship	32,843.02	3466.93
Susceptible Lubuskie Voivodeship (product–21%)	4464.88	719.04
Lubuskie Voivodeship (69–82% distance)	22,661–26,931	2392.18–2842.88
Joint part (15–18%)	4926.45–5911.75	520–624

If we refer to the Lubuskie Voivodeship, as previously mentioned, the share of the transport carried out there in total domestic transport amounts to 2.8%. Hence, in further analyses, it was assumed that approx. 2392.18 to 2842.88 executed using road transport might be moved from the rail (intermodal) transport.

5.2. Analysis of the Possibility of Increasing the Transportation Volume in Lubuskie Voivodeship

When preparing data for analysis, attention should be paid that not all information on the railway infrastructure or the haulage work carried out is made available. Therefore, preparing data for analysis requires mining the data and combining numbers while making assumptions.

The Information available on the length of railway lines and haulage work in Poland is the starting point. According to the report by Statistics Poland (formerly the Central Statistical Office), there were 19,422 km of railway lines in operation in 2020, of which 12,149 km were electrified. The report further states that the haulage work amounted to 86 Mtkm. However, the statistics placed in the report of the Office of Rail Transport are different. This body is a regulator of the railway market in Poland and also deals with drawing up official reports. The report [summarising the transportation activities in 2020 showed the hauled 223.2 M tonnes of cargo and the haulage work of 52,200 M tkm.

Since statistics on haulage work in individual voivodeships are not made available, it was assumed that the haulage work carried out via rail transport in Poland is distributed evenly among all regions. In the Lubuskie Voivodeship, 927 km of railway lines are operated, and of this 337 km of electrified lines, that is 4.8% and 2.8% of the domestic railway lines, respectively. Referring to the existing proportion, it is further assumed that 2491.47 M tkm of cargo was transported by rail in Lubuskie Voivodeship. It is curious that in 2019 the highest growth in terms of percentage was recorded in the following groups:

- furniture, other finished products—52.2%;
- food products, beverages and tobacco products—24.3%;
- machines, devices, electrical and electronic equipment—21.5%;
- and transportation equipment—16.7%.

Unfortunately, little more can be said using only data on the haulage work at the national level. However, it is possible to analyse the railway transport inherent potential by analysing the availability of railway lines and collecting information on the intensity of the railway system within the region.

The railway transport infrastructure of the region in question is analysed in the context of the core and comprehensive TEN-T network already present in the Lubuskie Voivodeship. The TEN-T core network in the Lubuskie Voivodeship consists of the following:

- section of the A2 motorway (a component of the TEN-T North Sea-Baltic corridor),
- section of the S3 expressway (a component of the TEN-T Baltic-Adriatic corridor),
- section of No. 3 railway line, i.e., the international E 20 trunk highway (element of the TEN-T North Sea-Baltic corridor),
- section of No. 351 railway line, i.e., the international E 59 trunk line (a component of the TEN-T Baltic-Adriatic corridor).

The TEN-T comprehensive network in the Lubuskie Voivodeship consists of the following:

- A section of the DK18 dual national carriageway, which in the future will be retrofitted to motorway standard (A18),
- a section of the trunk railway line No. 273.

As included in the publication [45], Lubuskie Voivodeship, on a countrywide scale, belongs to areas with a relatively low volume of passenger train traffic. In 2010, almost all sections of the network had an average volume not exceeding 40 trains a day. Only in one region, the indicator was in the range of 40 to 80 trains.

In freight traffic, the voivodeship plays mainly a transit role. In 2010, traffic on the corridor lines (E 20, E 59 and C-E 59) and lines No. 203 and 358 were characterised by a volume of 15–45 trains a day, with the most intensive traffic (30–45) along the Odra River. The analysis of changes in freight train traffic volume in the period 2000–2010 shows decreasing effectiveness of the C-E 59 trunk line in terms of capacity as a result of decapitalisation. However, the average drop from 5 to 25 trains per day recorded there does not mean that it is losing its importance as a freight corridor. Simultaneously, an increase in the role of the E 20 line is evident, with an average increase in volume from 2.5–10 trains, including more visibly on the Rzepin–Frankfurt an der Oder border section.

The condition of the infrastructure is synchronised to the ETCS 1 level, and the main lines are planned to be retrofitted to a higher control level by 2030.

Therefore, it can be assumed, based on the data collected, that the existing system is capable of accepting new drafts of cars. However, the calculation can be of general nature, and more accurate results may be obtained by utilising detailed statistics.

For calculation purposes, it was assumed that the haulage work in the region amounted to 2491.47 M tkm, and it could accept more cargo. As mentioned previously, in 2020 in Poland, the average hauled volume amounted to 223 Mt of cargo, and for 40 years, the largest annual cargo haulage amounted to 282 Mt, i.e., approx. 17% more. As these results were achieved even without the implementation of the state-of-the-art rail traffic control systems, it was assumed that the potential of freight traffic is an additional 23% of the volume performed currently.

6. Analysis of the Results

In the previous part, an analysis of the available information on the haulage work performed in road and rail transportation in the selected region was carried out. Concerning road transportation, the transport structure was analysed, and a determination has been made of the size of cargoes that have the potential to be shifted to rail transport. An analysis of the potential of rail transportation was also carried out, taking into consideration the number of hauled cargoes and the capacity of the track system from a macro point of view. The results of the analysis are presented cumulatively in Table 3.

Table 3. Cumulative information resulting from the comparison of the susceptibility of cargoes to modal shift and the railway potential in the selected region.

Name	Unit	Min Value	Max Value
Number of cargoes in road transport–modal shift potential per annum	Mtkm	0.520	0.624
Railway transport potential per annum	Mtkm	0.548	0.548
Number of haulage work shifted per annum	Mtkm	520	548
CO_2 emission in road transportation *	g/tkm	138	138
CO_2 emission in rail transportation *	g/tkm	24	24
Reduction in CO_2 emissions per annum	Ton	59,280	62,472

* data are taken from [30].

Figure 4 shows a graph showing the possibility of rail transportation absorbing road traffic depending on the increase in rail transportation potential. As shown in the case at hand, the railway accepts the whole of modal shift-susceptible railway transportation until the railway reaches a fully loaded network state. Further reduction of CO_2 emissions is limited. Then, methods and means should be found to further reduce the demand for road traffic.

In absolute values, in the case discussed, the minimum specified minimum haulage work performed by road transport with modal shift potential is 0.52 M tkm, and the maximum value is 0.624 M tkm. As the demonstrated potential for increasing the capacity of rail transportation was estimated at the level of 0.548 M tkm (an increase of potential by 23%), it is clear that in the case of assigning more haulage work to be transferred to rail, this mode of transport should look for ways of dealing with bottlenecks. One of them is, of course, the implementation of railway traffic control systems that allows for an increase in the speed of trains and increase the capacity of railway routes.

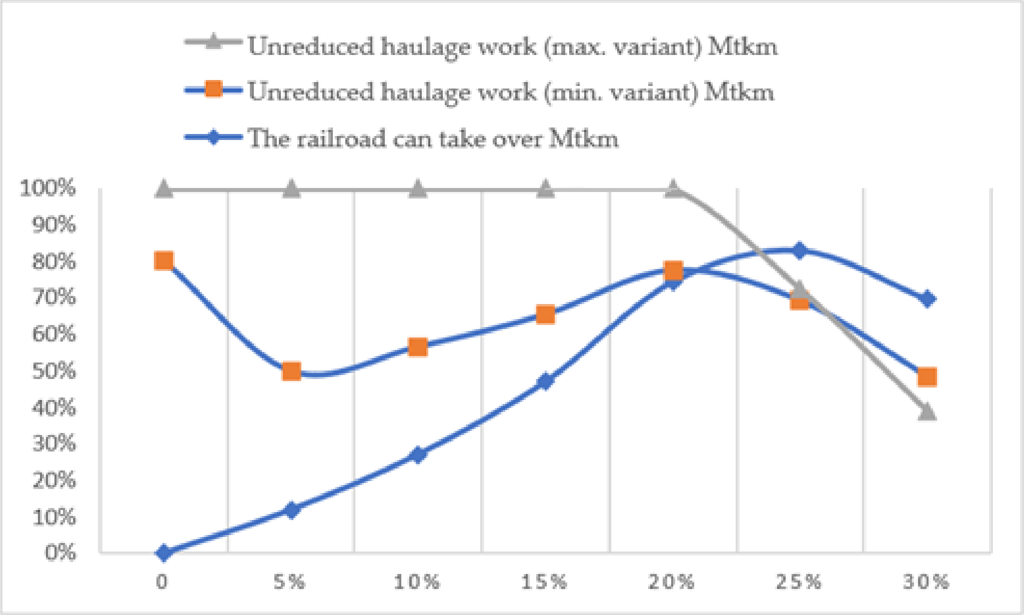

Figure 4. Analysis of the absorption of the goods hauled in road transport by rail.

Getting back to the input data presented in Table 3, it was assumed that the CO_2 emission in rail transport is 24 g/tkm. However, as specified in the previous chapter, it is a value dependent on numerous factors, e.g., the nature of the terrain or the share of renewable energy in total production in a given country or region. The efficiency of reducing CO_2 emissions may also depend on the use of energy from train braking. Table 4 shows the results illustrating the reduction of CO_2 emissions for an example (discussed) region, should the emissions of rail traffic be different than assumed in the previous calculations.

Table 4. Emissivity reduced by an increase in the utilisation of the railway line [t CO_2].

	Increasing the Utilization of Railway Lines						
Emission of rail transportation	0%	5%	10%	15%	20%	25%	30%
Emission 15 g/tkm	0	0.0153	0.0306	0.0460	0.0613	0.0766	0.0919
Emission 18 g/tkm	0	0.0149	0.0299	0.0448	0.0598	0.0747	0.0897
Emission 21 g/tkm	0	0.0146	0.0291	0.0437	0.0583	0.0729	0.0874
Emission 24 g/tkm	0	0.0142	0.0284	0.0426	0.0568	0.0710	0.0852
Emission 30 g/tkm	0	0.0138	0.0277	0.0415	0.0553	0.0691	0.0830

As expected, the greener means of transport results in a greater reduction in emissions of pollutants. However, when comparing the results for the least emitting vehicle and twice as much polluting one, the difference in the achieved results is not twofold. The progress in the reduction of the emissivity amounts to 0.0003 t CO_2 at the simultaneous increase in the utilisation of rail traffic by 1%. So while it is possible to increase rail traffic without getting into investments, the arising opportunities should be utilised.

7. Conclusions

Despite the existence of many analytical and simulation methods, there is no practical method nowadays to accurately calculate CO_2 emissions on a macro scale (e.g., for regions and countries). It would be possible if every vehicle, both in road and rail traffic, collected information on energy consumption in cargo transportation (as well as during any other activity) on an ongoing (online) basis. However, despite the fully operational bulk data collection systems, this kind of activity today seems rather unlikely (for example, for legal reasons). Today, no method of calculating CO_2 emissions for transportation on a micro-scale has any practical use for such calculations done on the macro-scale. Estimation of CO_2 emissions and indication of possible benefits for society should be an incentive for action aimed at improving the air condition, and the overall results achieved should not make anyone falter to act.

The presented approach is used for calculations based on previously collected statistical data in their heterogeneous form. Although the calculation method itself looks simple, serious attention should be paid to gathering the necessary and diverse comparative data to estimate the input parameters for the calculations. Wider disclosure by carriers, infrastructure supervisors and units supervising rail operations of information on the capacity of the section and its utilisation or about the haulage work performed and the remaining potential (in various variants of drafts of cars) could encourage a more profound discussion on how to best use the unused potential and move towards activities that can fulfil this aspiration.

In the calculations presented in this publication, it is worth considering the introduction of coefficients correcting CO_2 emissions due to various factors, e.g., the lay of the land. This actually shall mean carrying out micro-scale measurements and translating them into calculations at the macro view level.

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