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## **INLAND WATER TRANSPORT APPLICABILITY FOR SUSTAINABLE SEA PORT HINTERLAND INFRASTRUCTURE DEVELOPMENT. KLAIPEDA SEA-PORT CASE**

**Summary.** The aim of this paper is to present an analysis of the main factors influencing negatively Klaipeda Sea Port performance and competitiveness as well as their limiting impact on the development of this transport system entity in general. This case study research is proposing some alternative solutions decreasing negative influences of comparatively declining land transport infrastructure connectivity to the Sea Port hinterland. Analysis of hinterland connectivity is based on the extended gate concept, where a series of terminals and related logistical activities are integrated into a functional single entity. The intensity of real road transport flows on the main connecting road intersections has been evaluated using digital tools with input data from the ArcGIS platform. Also, accessibility to other terminals (at the local, regional and global scale) as well as the terminal linkage to the regional transport system has been taken into account. One of the objectives of this research was to define objectively the state of traffic flow on the highway connecting Klaipeda sea-port to its hinterland because the road infrastructure was not qualitatively improved for a long period, while the average annual seaport turnover is constantly growing by 6% - 9%. Secondly, it was defined how substantially is possible to decrease the load of road traffic in case of reestablishing of an inland waterway connection between practically the same points of the transport route. Using mathematical modeling of traffic flows is proved that, road transport highway connection in/from the Klaipeda Seaport is loaded substantially and requires systemic improvement (building at least additional lanes in both directions, etc.) to promote further growth of Klaipeda sea-port capacities. The option to apply an additional inland waterway connection allows to decrease the road traffic flow up to 9 – 11% with the possible development of this option, what in its' turn also decrease the negative influence on the environment.

### **1. INTRODUCTION**

The operation of any sea port is usually considered to be efficient if its cargo flow is stable and continuously increasing and is not creating systematic problems of transportation. This case study research analyzes the circumstances that emerge because of lack of appropriate development of onshore transport junctions.

In case of planning sustainable growth of cargo flows through any kind of terminal, especially a maritime terminal or seaport, it is essential to confirm its accessibility to its market areas through an inland transport system (rail, road or barge) [9]. Taking into account the general growth of cargo flow, its comparatively undeveloped land transport infrastructure could become a serious problem causing underload and inefficiency of the terminal. Especially it is applicable for port terminals where transport connection with the hinterland is made by means of road transport. A form of hinterland connectivity is

based on the extended gate concept, where a series of terminals and the related logistics activities are integrated into a single functional entity [9]. Accessibility to other terminals (at the local, regional and global scales) as well as how well the terminal is linked to the regional transport system are important. For instance, a maritime terminal has little relevance if it is efficiently handling maritime traffic, but is poorly connected to its market areas through an inland transport system (rail, road or barge) [9].

In case of Klaipėda Sea-port terminal hinterland is also much dependent on political reasons, i.e. border policies of neighboring countries could define very different limits for it. Because the main aim is to keep the hinterland infrastructure up to date and not to use unnecessary resources, the solution for solving this problem is close monitoring of transport traffic flows and improving outdated segments of the hinterland system. In case of planning transportation, the measurement of cost prognosis can make the decision-making process rational, uncomplicated, efficient and inexpensive. The importance of the fundamental constraints mentioned above could vary because of specific circumstances (including political constraints) impacting the decision-maker. The main aim of this research is to create an efficient possibility to compare rational alternatives of transport infrastructure development, including inland water transport mean, and to compare each of the evaluated variants.

## 2. TRAFFIC FLOW ANALYSIS – APPLICABILITY OF MATHEMATICAL MODELS

When analyzing the influence of various factors on traffic flow, it is important to define clearly the properties of traffic flow and the surrounding conditions of this process.

### Traffic stream properties

Traffic stream could be characterized through motion as a function of time, as a function of distance and as a function of speed.

Motion as a function of time: if  $x(t)$  is supposed to be the vehicle trajectory, then:

$$x(t) = x_0 + \int v(s) ds; \quad v(t) = v_0 + \int a(s) ds; \quad a(t) = a_0 + \int j(s) ds, \quad (1)$$

where all the variables with the subscript "0" are given initial conditions at time  $t_0$ .

### Motion as a function of distance:

In some applications, it is convenient to take distance as the independent variable.

A vehicle trajectory is represented by  $t(x)$ , the inverse function of  $x(t)$ .

If  $v(x)$  is given, then  $t(x)$  can be derived as:

$$t(x) = t_0 + \int_{x_0}^x \frac{dx}{v(x)}; \quad t(x) = t_0; \quad (2)$$

If  $a(x)$  is given, then  $v(x)$  can be derived using the chain rule:  $\frac{dv}{dx} \frac{dx}{dt} = v'(x) v(x)$ . (3)

Hence

$$v(x) = \sqrt{v_0^2 + 2 \int_{x_0}^x a(x) dx}; \quad (4)$$

### Motion as a function of speed:

Vehicle kinematics models give the "desired acceleration"  $\mathbf{a} = \mathbf{a}(\mathbf{v})$  that the driver imposes on the vehicle when traveling at a speed  $\mathbf{v}(\mathbf{t})$  at time  $\mathbf{t}$  under free-flow conditions. A desired acceleration model captures both driver behavior and the physical limitations imposed by roadway geometry on the engine [1].

### Traffic stream properties

Traffic flow is generally constrained along a one-dimensional pathway (e.g. a travel lane). A time–space diagram shows graphically the flow of vehicles along a pathway over time. Time is displayed along the horizontal axis and distance is shown along the vertical axis. Traffic flow in a time–space diagram is represented by the individual trajectory lines of individual vehicles. Vehicles following each other along a given travel lane will have parallel trajectories, and trajectories will cross when one vehicle passes another. Time–space diagrams are useful tools for displaying and analyzing the traffic flow characteristics of a given roadway segment over time (e.g. analyzing traffic flow congestion) [2].

There are three main variables to visualize a traffic stream: speed ( $v$ ), density (indicated as  $k$ , the number of vehicles per unit of space) and flow (indicated as  $q$ , the number of vehicles per unit of time).

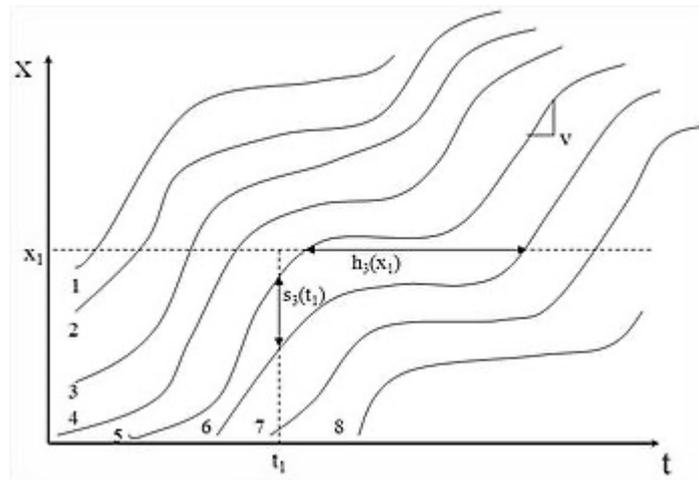


Fig. 1. Time–Space diagram

**Speed**

Speed is the distance covered per unit time, but one cannot track the speed of every vehicle; therefore, in practice, average speed is measured by sampling vehicles in a given area over a period of time. Two definitions of average speed are identified: "time mean speed" and "space mean speed".

"Time mean speed" is measured at a reference point on the roadway over a period of time. In practice, it is measured by the use of loop detectors. Loop detectors, when spread over a reference area, can identify each vehicle and can track its speed. However, the average speed measurements obtained from this method are not accurate because instantaneous speeds averaged over several vehicles do not account for the difference in travel time for the vehicles that are traveling at different speeds over the same distance.

$$V_t = \left(\frac{1}{m}\right) \sum_{i=1}^m V_i \tag{5}$$

where *m* represents the number of vehicles passing the fixed point and *V<sub>i</sub>* is the speed of the *i*-th vehicle.

"Space mean speed" is measured over the whole roadway segment. Consecutive pictures or video of a roadway segment track the speed of individual vehicles, and then the average speed is calculated. It is considered more accurate than the time mean speed. The data for calculating of space mean may be taken from satellite pictures, a camera or both. In our case, the ArcGIS tool has been applied and

$$V_t = \left(\frac{1}{n}\right) \sum_{i=1}^{n-1} \frac{1}{V_i} \tag{6}$$

where *n* represents the number of vehicles passing the roadway segment.

The "space mean speed" is thus the harmonic mean of the speeds.

The time mean speed is never less than the space mean speed:

$$V_t = V_s + \frac{\rho 2s}{V_s} \tag{7}$$

where  $\rho 2s$  is the variance of the space mean speed.

In a time–space diagram, the instantaneous velocity,  $v = dx/dt$ , of a vehicle is equal to the slope along the vehicle’s trajectory. The average velocity of a vehicle is equal to the slope of the line connecting the trajectory endpoints where a vehicle enters and leaves the roadway segment. The vertical separation (distance) between parallel trajectories is the vehicle spacing (*s*) between a leading and the following vehicle. Similarly, the horizontal separation (time) represents the vehicle headway (*h*). A time–space diagram is useful for relating headway and spacing to traffic flow and density, respectively.

**Density**

Density (*k*) is defined as the number of vehicles per unit length of the roadway. In traffic flow, the two most important densities are the critical density (*k<sub>c</sub>*) and jam density (*k<sub>j</sub>*). The maximum density achievable under free flow is *k<sub>c</sub>*, while *k<sub>j</sub>* is the maximum density achieved under congestion. In general, jam density is seven times the critical density. The inverse of density is spacing (*s*), which is the center-to-center distance between two vehicles [10].

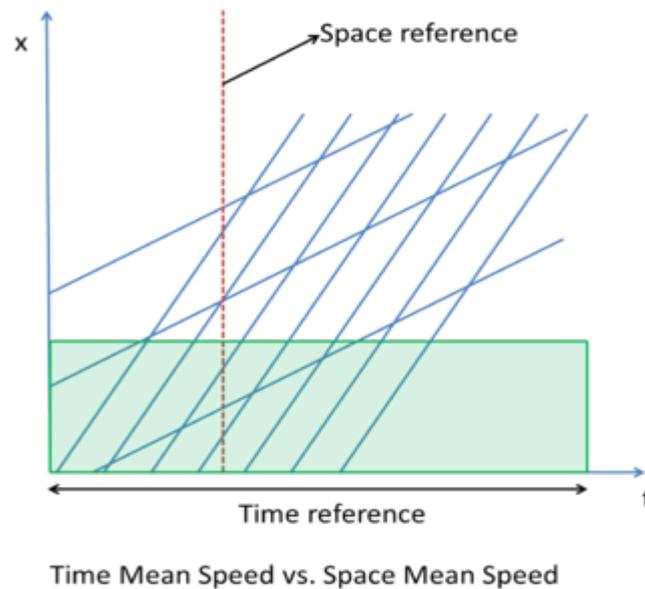


Fig. 2. Space Mean and Time Mean speed

Following the statements described above and taking into account the real conditions of our case, it is possible to describe the mathematical model of traffic flow. For a road with 2 lanes and a desired speed of 100 km/h and a safe interval of 50 m between cars, there are 40 cars on each 1 km of road. During 1 minute, they move about 1.6 km, where there are  $40 \times 1.6 = 64$  cars passing the cross section in 1 minute. Therefore, the normal flow is 64 cars per minute. Suppose now that it is required to pass more cars, for example, 80. If we pack them on this road, there should be less distance, let us say 40 meters. For this distance, safe driving would imply not a speed of 100 km/h, but let us say only 70 km/h. Thus, an increase of spatial density by 25% implies a reduction of speed by 30%; hence, in the end, the flow declines. This also leads to a traffic jam. In fact, it starts when we deviate just slightly from the optimal flow  $F^*$  designed for a road,  $F^* = \max F = \max [v/d(v)]$ , where  $v$  is the speed and  $d$  is the safe distance, depending on the speed.

If the flow  $F < F^*$ , there is no congestion, and it starts from  $F > F^*$ .

Traffic congestion occurs when the actual capacity (the number of vehicles on the road) reaches up to design or theoretically calculated capacity, and this reduces the speed of traffic, and thus vehicles piling up on the road [6].

**An example illustrating the operation of a digital model:**

There are two-lane road linking two nodes (a - b) and design capacity (E) = 1000 vehicles / hour, and calculates the volume of traffic it was actual capacity (Q) 1100 vehicle / hour.

The level of service =  $(Q / E) = 1100/1000 = 1.1$

The service is divided into 6 levels:

A = less than 0.6

B = 0.6 - 0.7

W = 0.7 - 0.8

D = 0.8 - 0.9

E = 0.9 - 1.0

P = Greater than 1.

The best of these levels is the first and the worst is the latter.

It is important to stress the fact that for the highway Klaipėda-Kaunas, regularly the service coefficient is between 0.5 and 0.6. Thus, taking into account that cargo flow growth through Klaipėda Sea-port is 6 -8% annually, it is evident that the situation requires immediate strategic decisions to be made in this case.

**Restrictions on the physical characteristics of the road** - in this group, two criteria are foreseen to be related to pavement and physical road surface quality assessment.

**Influence of road section coverage on cargo transportation speed ( $K_d$ )** - this criterion is intended to compare the advantages of the route in different modes of transport. In the case of automobile route assessment, two alternatives to road segment criteria are distinguished: asphalt or gravel. These options allow us to evaluate the speed of cargo movement on the route. In case of the absence of a road section tends to evaluate the possibility of constructing a new road or looking for alternatives.

$$K_d = \frac{1}{v_{vid}} \in (lab), la = [0, \dots, n], b = [0, \dots, n]; \quad (8)$$

where  $K_d$  is the numeric meaning of pavement characteristics;  $la$  is the asphalt pavement length of the route in kilometers;

In the case of an inland waterway, this criterion has two extremes: fulfills the criteria or the route is inappropriate.

**Physical quality of road pavement affecting on general speed of transport flow** - this criterion makes it possible to assess the suitability of road pavement for cargo transportation and the need for one or the other actions required to ensure the quality of the road.

In the case of inland waterways, this criterion has four alternatives, i.e., the quality required, the necessary cleaning of the section required for the removal of the stone in the section under consideration or the required depth of the section. The last three alternatives to this criterion are to be evaluated only if the development of the stretch is only required for an OHC carrier. The nominal depth and quality of the route ensuring the movement of vessels is guaranteed by the Inland Waterways Authority.

$$K_F = \frac{c+e+g}{d} \in \begin{cases} c, & c = [0, \dots, n] \\ e, & e = [0, \dots, n] ; \\ g, & g = [0, \dots, n] \end{cases} \quad (9)$$

where  $c$  is the estimation of road construction and rehabilitation costs;  $e$  is the estimation of road construction and rehabilitation time;  $g$  is the need of further works, expressed in financial terms; and  $d$  is the possible financial loss.

**Weight of freight to be transported** - this criterion is important for assessing modalities of all types of freight transportation, but it has the least impact on inland waterway transport. This criterion creates the connection between the possibilities of using stevedoring tools, the speed of cargo transportation and route selection.

$$K_{sv} \frac{(t_{kr} \times d) + k}{d} \in \begin{cases} t_{kr}, & t_{kr} = [0, \dots, n] \\ k, & k = [0, \dots, n] \end{cases} \quad (10)$$

**The intensity of traditional traffic in the road section under consideration** - this criterion has three alternatives common to all modes of transport in question and, at the same time, aims to assess the social consequences of transport of large loads and heavy loads.

**The effect of seasonality on the possibility of transporting goods** - this criterion assesses the seasonality of the mode of transport.

**Route flexibility in case of unforeseen disturbances** - this criterion evaluates the mode of transport's ability to change the route of the freight in the event of unplanned disturbances.

### 3. DEFINITION OF REAL CAPABILITIES OF WATER TRANSPORT INFRASTRUCTURE

In our case, an inland waterway alternative is supposed to be extremely important because of a few reasons: first, the direction of the waterway is considerably coinciding with the direction of the main transport corridor of the port hinterland; second, application of inland waterway transport is very much important from the perspective of transport sustainability and environment protection. The  $CO_2$  emissions and other negative factors caused by extensive use of road transport could be substantially decreased. Quantitative evaluation of the factors mentioned above is supposed to be a separate part of this research in the near future. Unfortunately, on the other hand, the inland water infrastructure in Lithuania is quite poorly developed because of lack of understanding of the importance of this means of transport and has been ignored by political management of the country. Nevertheless, according to our calculations, it is realistic to apply this means for transportation on a smaller scale at the moment, but it is

possible to implement necessary improvements in quite a short time. For example, river barges are still used on the river Nemunas, which are able to carry up to 36 units of 20' containers at one time. The waterway is acceptable for this kind of transportation even now. Also, the above-mentioned means would be very efficient in transporting timber wood loads, which are a substantial part of road transport cargo flows going to the Klaipeda Seaport terminals.

The modern river port in Kaunas has been recently built and is being used efficiently for such kind of transportation. According to the calculations made by the authors, a fully laden inland water transportation complex can discharge full traffic flow from 8 to 11% in total. This alternative could be instrumental in solving further hinterland traffic infrastructure development problems.

#### **4. TRANSPORT POLICY MEANS PROMOTING INLAND WATER TRANSPORT INTEGRATION**

There are a few mental obstacles to the introduction of a successful inland water transport mode in the country. For a long time, this option has been ignored among transport specialists because of strong subsidizing of other means as a result of the distorted transport policy in the soviet era. This resulted in an undeveloped infrastructure, outdated equipment and not very attractive perspectives for specialists, working in this field.

Fortunately, the main attributes of this mean of transport still exist and could be usefully applied. Therefore, the ministry of transport, according to preliminary calculations and policy priorities, could issue regulations introducing additional charges for certain sorts of cargoes transported by road, e.g., road container, timber wood transportation, etc. through road sections, important for seaport terminals, as well as financing necessary inland waterway infrastructure developments. This would attract successful business investments in the inland water transport field and would create preconditions for the necessary development of this means of transport.

#### **5. CONCLUSIONS**

5.1. According to the measurements completed in this case study research, it has been found that Klaipeda Sea-port transport connections, especially road transport connections, with its hinterland are substantially loaded, and could become a serious obstacle for future port development and growth of cargo flows.

5.2. As a solution to this problem, two parallel alternatives, according to computer modelling, have been defined: systematic improvement of existing highway connections by building additional lanes in each direction and the use of inland water transport for cargo transportation along the East–West transport corridor, using all existing infrastructure, and developing quantity and quality of this transport.

5.3. For the successful implementation of the proposed alternatives, it is important to introduce legislative taxation procedures, regulating balanced use of road, railway and inland water transport means, increasing the sustainability of the whole transport system in the country.

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