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Comparative Assessment of Effectiveness of Transport Facilities

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Abstract: Over the centuries of human civilization, the development of transport has had significant impact on progress. This influence was particularly evident in the development of water, railway, and air transportation. The method of assessing the quality of transport can be a very significant stimulus to progress.

The authors propose a transport efficiency criterion as a product of efficiency factor by the productivity of transport facilities. This criterion can be determined based on the terms of reference (TOR) or technical specifications (TS). The article presents the comparative efficiency of different modes of transportation.

zndex Terms: aircraft, assessment, criterion,diesel-electric locomotives, effectiveness, efficiency factor, life cycle, performance, ships.

I. INTRODUCTION

For many centuries, the main types of water transportation were boats, rafts, and galleys driven by oars. The first sailing ships appeared several thousand years ago. The most notable development of sailing ships was in the first half of the second Millennium AD. Intense use of the sailing fleet continued until the mid-19th century when ships emerged. The creation and use of the sailing fleet gave a significant impetus to the development of civilization. The planet Earth was practically mastered. Due to navigation, cartography, navigation instrument-making, accurate determination of time, measures of length and weight have developed. Within a few centuries, there was noticeable progress in philosophy, mathematics, chemistry, medicine, natural science, the concept of the universe, etc. Shipping has had huge impact on the growth of productive forces and industry. Certainly, one can say that around the same period there was an intense change of formations. Mankind has moved from a slave system to feudalism and capitalism. And exactly this transition marked a leap in the development of civilization. Nevertheless, there is no direct evidence of the validity of the primary nature of these factors. The apogee of the sailing fleet development falls on the 18th and early 19th century. In the 18th century, the steam engine was invented, and in the 19th century, the sailing fleet was replaced by steamers, i.e. steam-driven ships. By the end of the 19th century, it became obvious that the age of the sailing fleet was over. Steamers began to be used in passenger and cargo transportation, as well as for military purposes. The question arises as to why there was so intense change. After all, the sailing fleet had a huge advantage, since it did not require an external source of energy. Its efficiency factor was almost equal to 100%, whereas that of the steam engine barely reached 30%. It means that the transition to steam traction was not due to efficiency, but something else, namely performance. Steamers delivered cargo regardless of the weather and in a shorter time. Revolution in surface transport occurred almost simultaneously with the revolution in maritime transport. The horse-drawn transport was replaced by steam-powered railway transport.

It is important to understand why this happened. Obviously, the qualities of transport means, which were essential for future development, were changed. Apparently, this was not an efficiency factor, because in both cases efficiency was deteriorated.

One may assume that this key factor was performance. For any transport facility, costs are certainly important, but the main thing is the delivery of cargo and passengers within a short time. It is these qualities that ensured the transition to steam traction, both at sea and on land. Probably, in the subsequent development of transport, this quality should be taken into account along with the efficiency factor.

II. METHODS

A. General description

The most well-known methods of transport facilities' evaluation include the cost of transportation [1], [2], cost of the life cycle [3]-[5], operating efficiency [6], [7], and others. The disadvantage of such assessments is that they can be used only for a specific type of transport facility operating under specific conditions.

B. Algorithm to determine the effectiveness of transport facility

In contrast to the suggestions of authors [1]-[7], it is proposed to take the product of the efficiency factor on performance as a criterion to assess the autonomous transport facility [8], [9]:

$$W = \eta \cdot \Pi \Rightarrow \max;$$

where ŋ is the efficiency factor, as a ratio of the work performed to the amount of energy consumed:

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$$\eta = \frac{A}{H_u \cdot B_F};$$

where A is the work done by the transport facility, J; B_F is the energy (fuel) consumed, kg/h; H_u is the lower calorific value of fuel, J/kg; P is the performance of the transport facility as performed work A, divided by the time of its execution T; T is the time corresponding to the performed work A, hour.

Then the criterion can be written as:

$$W = \frac{A^2}{H_u \cdot B_T \cdot T} \Rightarrow max$$

When talking about electrified transport facility, the criterion can be written as:

$$W = \frac{A^2 \cdot \eta_э}{E \cdot T} \Rightarrow max;$$

where E is the consumed electrical energy kWh; η_e is the efficiency factor of the energy production E.

While comparing different types of electrified transport facilities, it is not important to know where from and at what price energy is purchased. When comparing electrified and autonomous transport, difficulties arise in determining the efficiency factor when generating electric energy, as well as losses during its delivery. In this article, these modes of transport are not compared. Below is assessed the comparative efficiency of transport facilities and their development over time based on the proposed criterion.

When assessing various transport facilities, it is necessary to select the type of work A taken to assess their energy effectiveness. At first glance, it would be appropriate to take the energy generated by the power plant of an autonomous transport facility. To determine the efficiency factor, this approach is quite acceptable. But what about the transport facility's performance? What kind of work should be taken as a basis for its definition? In order for this work to have commonality for different modes of transport, it is necessary to take work common for all means of transport. For freight transport, ton-kilometer based work is well suited. However, there are some nuances. In railway transport, it is accustomed considering the gross ton-kilometer work that is, taking into account the movement of the tare mass of wagons. In maritime transport, this concept corresponds to the movement of the ship along with the cargo related to the distance, although it is customary to estimate the transported cargo at a given distance (in net ton-kilometers). But to assess a certain transport facility itself in both cases, it is advisable to evaluate the work performed in gross ton-kilometers.

Choosing the dimension of work in passenger traffic is much easier. Here, all modes of transport are assessed based on passenger kilometers that are quite suitable.

The proposed criterion allows calculating its maximum possible value based on the performance specifications of the transport facility. During operation, the criterion value will be less than the maximum, since the maximum power and the designed speed are not always used. The criterion calculated based on the operational data will show the extent, to which operating conditions correspond to the parameters set for the given transport facility.

III. RESULTS AND DISCUSSION

Consider the proposed criterion for some selected transport facilities, calculated based on their technical characteristics:

Diesel-electric locomotives

Performance specifications of diesel-electric locomotives are given in the rules of traction calculations [10]. The following technical data are available for any locomotive:

F_g – long-term mode thrust force, kN;

V_d – the speed at the continuous rating, km/h;

B_F – fuel consumption in long-term mode at a given fuel calorific value H_u, kg/h.

For limiting grade usually given as 9‰, one can calculate the estimated weight of the train according to [10]:

$$W`_0 = 17.2 + 0.044 \cdot V + 0.0026 \cdot V^3$$

$$W``_0 = 5.2 + (34.2 + 0.732 \cdot V + 0.022 \cdot V^2) \cdot g_0$$

at g_0>6 tons.

$$Q = \frac{F_{cr} - (w`_0 + i_p \cdot g) \cdot P}{w``_0 + i_p \cdot g},$$

where $w`_0$ and $w``_0$ are the specific tracking resistances of the locomotive and railway cars on the continuous welded rail.

Determine the maximum possible operation work of the locomotive for one hour and the criterion value:

$$A_p = Q_p \cdot V_p, \text{ tkm gross}$$

$$W = \frac{A_p^2}{B_T \cdot H_u \cdot T}, \text{ (tkm)}^2\text{/kJ·h}$$

Thus, for single unit TE3 diesel-electric locomotive we have:

The long-term mode thrust force, kN: 186.4

The speed at the continuous rating, km/h: 20

Fuel consumption, kg/h: 340

The estimated weight of the train at a slope of 9‰, t:340

Work in gross ton-kilometers per hour:

A=1574·20=31480 tkm.g.

The value of the criterion is as follows:

$W = \frac{A^2}{(B \cdot H_u \cdot T)} = \frac{31480^2}{340 \cdot 42700 \cdot 1} = 68.26$ (tkm. g.)^2/kJ.

Performance specifications and the criterion for some locomotives are given in Table I.

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Table I. Performance specifications and criterion of locomotives in freight traffic

Locomotive	Production year	The speed at the continuous rating, km/h	Fuel consumption Kg/h	Train weight at i=9‰ (unit engine), t	Criterion, tkm^2/kJ	Relative criterion
TE3	1953	20	340	1,574	68.2	1.0
TE10	1962	24.6	478.7	2,089	129.4	1.9
TE116	1971	24.7	461.2	2,102	136.9	2.007
TE25K^{2M}	2018	28.35	654.5	2,846	233	3.41

Performance specifications and criterion of locomotives in passenger traffic are given in Table II.

Table II. Performance specifications and criterion of locomotives in passenger traffic

Locomotive	Production year	The speed at the continuous rating, km/h	Number of passengers	Fuel consumption, kg/h	Criterion, (pass.km)^2/kJ	Relative criterion
TEP 60	1964	50	800	510	7.35	1.0
TEP 70BS	2001	60	800	624	18	2.45

The proposed criterion allows assessing the change in the efficiency of the transport facility over time due to technological progress. For example, the effectiveness of the locomotive 2TE25K^{2M} is 3.41 times higher than that of a diesel locomotive TE3. The efficiency of TEP 70BS diesel locomotive produced in 2001 is 2.45 times higher than that of TEP 60 locomotive of 1964. The proposed criterion can be used to assess different modes of transport. Below are the performance indicators of water and air transport modes.

The performance specifications and the proposed criterion for ships in cargo traffic are shown in Table III.

Table III. The performance specifications and the criterion of cargo ships

Ship type	Production year	Tonnage, t	Speed, Km/h	Fuel consumption, kg/h	Criterion, tkm^2/kJ	Relative criterion
Volzhski Bulk Transport Vessel	1981	5,020	20	371	683	1.0
VF Tanker 16	2013	7,030	19	504	829	1.21
Batilus Tanker	1976	663,000	16	49,000	57,413	69.2

Performance specifications and the criterion of ships in passenger traffic are presented in Tables IV and V.

Table IV. Performance specifications and criteria for certain passenger vessels

Passenger vessel type	Capacity (Passengers)	Speed, Km/h	Fuel consumption, kg/h	Criterion, (pass.km)^2/kJ	Relative criterion
Pushkin	198	41.4	278	1.93	1.0
Meteor	100	77	338	3.38	1.75
Skimming boat A 45-2	150	70	496.8	5.19	2.69

Table V. Performance specifications and criteria for some passenger ocean-going ships

Ocean-going ship	Capacity (Passengers)	Speed, Km/h	Fuel consumption, kg/h	Energy efficiency indicator (pass.km)^2/kJ	Relative value
Titanic	2,439	41.4	610 t of coal per day	5.6	1
Queen Elizabeth	2,760	56	21,000 kg/h	26.7	4.76
Oasis of the Seas	6,400	40.7	19,400 kg/h	81.9	14.36

The performance of some air-transport facilities in freight and passenger traffic is presented in Tables VI and VII.

Table VI. Performance specifications and the criterion of cargo aircrafts

Aircraft type	Average weight in flight, t	Velocity, km/h	Fuel consumption at cruising mode, kg/h	Criterion, tkm^2/kJ	Relative criterion
IL 76	185	800	9,000	57	1.0
Ruslan	325	800	10,600	149.35	2.62

Performance specifications and the criterion of some passenger aircrafts are shown in Table VII.

Table VII. Performance specifications and the criterion of passenger aircrafts

Aircraft type	Capacity (passengers)	Cruise speed, km/h	Fuel consumption at cruising mode, kg/h	Energy efficiency indicator $(pass.km)^2/kJ$	Relative value
Tu-104	50	800	12,800	6.58	1.16
Il-62	168	850	15,000	30.8	5.43
Il-96	300	870	17,000	93.8	16.6
Tu-144	300	2,300	38,500	289	51.1
A 380	853	900	20,500	673	118.7

Certainly, the presented data are illustrative, though still allow giving a comparative assessment of the effectiveness of individual modes of transport. Tables VIII and IX provide such assessment for freight and passenger modes of transport.

Table VIII. Performance specifications and the criterion of transport facilities in freight traffic

Transport mode	Cargo weight, t	Speed, km/h	Fuel consumption, Kg/h	Criterion, tkm^2/kJ	Relative criterion
Aircraft	185	800	9,000	57	1.0
Locomotive	2,846	28.35	654.5	233	4.08
Motorship	7,030	19	504	829	15.5

Table IX. Performance specifications and the criterion of transport facilities in passenger traffic

Transport mode	Number of passengers	Speed, km/h	Fuel consumption, Kg/h	Criterion, $(pass.\ km)^2/kJ$	Relative criterion
Locomotive	800	60	624	18	1.0
Motorship	6,400	40.7	19,400	81.9	4.55
Aircraft	853	900	20,500	673	37.4

IV. CONCLUSION

From the given data it follows that sea (water) transport is characterized by the greatest efficiency in the cargo traffic. In passenger traffic, air transport has the best performance indicators. Railway transport in both traffic modes occupies an intermediate position. The authors have considered the criterion for certain types of transport facilities. The conclusions are based only on the performance specifications of transport facilities and are not related to the results of their operation. In order to obtain operating characteristics, it is necessary to obtain data on the operation of the transport facility reflecting its performance and fuel consumption at specific testing areas. The operation results are influenced not only by the designed performance specifications, but also by a number of factors, such as the operation schedule, the actual load, changes in operating modes, weather conditions, and other circumstances related to the operation, which affect the performance and fuel consumption of the transport facility. To a large extent, based on the operation results, one will get the assessment of the utilization efficiency of performance specifications laid down in the design of the particular transport facility.

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