THE CO-EVOLUTIONARY APPROACH TO SYNTHESIS OF BIMODAL TRANSPORT SYSTEMS

Key words: co-evolution, sustainable development, bimodal transport system, innovative, environmentally friendly transport, compatibility, critical factors, safety, decision-making.

1. Introduction

Transport services market plays a key role in the world economy because transportation goods and passengers along TEN-T. Among transported cargoes the significant segment is transportations of raw materials, including power resources (oil and gas). The consumption forecast of fuel various kinds is submitted on fig.1.

![Graph showing growth comparison by fuel, world 2002/2020 (base index 2001 = 100)](image)

Source: Author’s research on basis E.A. Gibson Shipbrokers, Fearnley A.S., R.S. Platou Economic Research
In contributing to enlargement of the transport services market, as well as re-enforcing economic, social & environment cohesion, the construction of the TEN-T is a fruitful means for economic competitiveness & sustainable development Member States of the EU. It forms requirements to increase the interconnection and flexibility of national transport networks as well as the access to them. Transport by sea routes has an important role for creation of the intermodal chains in the freight/passengers TEN-T. The Commission's White Paper on transport outlines clearly the issues at stake and the decisions that need to be taken to assure the decision that need to be taken to assure the future of sustainable transport in the enlarged EU. One of the major suggestions was the need to shift transport from road to more environmentally friendly modes as maritime transport e.g. "sea motorway" development.

Today, transportation by sea routes plays the important role in the transport market of EU. According to the data of the European commission more than 90 % of export and 46 % of trade within the EU are carried out with use of maritime transport. Baltic Sea during the last some hundreds years is one of main water areas not only in Europe, but also in the world. Already in 2004/2005 number of ships entering Baltic ports has exceeded 400000 vehicles.

The Baltic Sea is one of the busiest seas in the world and both the number of ships and the quantities of cargo afloat on the Baltic are growing rapidly. Shipping traffic in the Baltic during 2000/2005 years has increased on about 25 % and in 2005 has reached 65 thousand passages of vessels. In Baltic Sea every day are in traffic on the average 2100 – 2200 vessels, including 180-200 tankers. Along with it in water area of Baltic constantly work about 1500 -2000 fishing ships. Annually by lines of Baltic Sea it is transported more than 500 – 600 mln tons of cargoes. And by forecasts to 2010 / 2012 years growth of such transportations will equal 30-40 % [1], [2]. A basis for such forecasts is constant growth of demand for suppliers of oil & petroleum products. If in 2000 their volume was equal 40 mln tons, in 2004 already 110 mln tone. By forecasts in 2006 the demand for suppliers of oil & petroleum products by tankers will grow on 3-5 %, and in 2010 will equal about 200 mln t [6].

Oil and petroleum products are dangerous cargoes. Consequences of tankers accidents can cause not only losses of a vessel and death of crew, but also ecological catastrophes. On the basis of HELCOM data in waters of Baltic Sea during 1988/2004 there were 5 crashes with tankers, which consequences were the oil spills exceeding 100 m$^3$. Moreover it is necessary taking into account, that with 2000 for 2004 the total number of tankers’ accidents on Baltic Sea was equal 29. An average of 8-9% from these accidents are resulted in some kind of pollution.

One of the most serious accidents in the Baltic marine area has occurred 2001 March 28 night by bad weather. The catastrophe happened 13 nautical miles north of Darss, in the sea lane between the north German coast and the Danish island of Falster. The tanker „Baltic Carrier” was in collision with a freighter the Cypriot-flagged “Tern” carrying a cargo of sugar from Cuba to Latvia. Nearly 2,700 tones of the oil leaked from the tanker „Baltic Carrier”, which was en route from Estonia to Gothenburg in Sweden when the accident happened. Substantial growths of tankers number are increases probability of such sea accidents.

For purpose of minimize probability of marine catastrophes in the future the Commission on a special session in 2001 after accident with the tanker „Baltic Carrier” has made the decision on development of the “Vessel Traffic Monitoring and Information System” (VTMIS) including “Automatic Identification System” (AIS) and creation of traffic separation schemes, which should be established for the whole Baltic Sea.
During the recent decades the traffic in the Baltic area has not only increased, but the nature of the traffic has also changed rapidly. But not only the number of tankers has increased but also their size has grown. At the same time, the cruises by Baltic Sea have increased tremendously, and this route is crossing the main routes of vessels transporting hazardous substances.

![Fig.2. World LNG demand forecast. Source: Author’s research](image)

In 2004 the whole Baltic Sea is admitted to the official status of a “Particularly Sensitive Sea Area” (PSSA) designated by IMO. A PSSA is an area which due to its ecological, economic, cultural or scientific significance and its vulnerability to international shipping activity needs special protection. PSSA status can be used to protect a variety of marine and coastal habitats as well as sea wildlife, and to improve maritime safety, to estimate of the environmental effects and threats associated with increasing maritime traffic, especially oil shipping area.

Growth of world demand for gas transportation can reach up to 350-500 mld m$^3$ in 2020 by long-term forecasts that can be developed by one of three scenarios (Fig.2). One of the reasons of such growth is aspiration of suppliers’ diversification. Now some countries have a problem of gas supplies diversification. For Poland gas also is strategic raw material in power supply. This problem is important today because gas consumption is about 13 mld m$^3$ annually. Approximately Poland imports 70 % of gas, and 65 % from Russia, and it is potentially unsafe situation. The most favorable variant is a situation at which of one source it is imported no more than 30%. Already begun construction of northern gas pipeline in a bottom of Baltic Sea, and also a forecasted rise in prices on the Russian gas prove necessity of gas port construction in Poland for power safety. Number increase of the gas ports worldwide allows forecasting stable growth of demand for shipbuilding of LNG [11]. For the nearest 10 years the quantity of such tankers can grow on 70-80% (Fig.3). All this is cause for designing bimodal transport systems (BTS) of power resources supplies on the basis of new approach with taking into account of oil & gas transport risk and interaction of functioning principles and evolution principles, reflecting, in particular, through relationship of categories “transport’s moving ability” and “transport’s innovative ability”.

![Fig.3. LNG tanker demand forecast](image)
The author proposes to BTS synthesis using the innovative multivariable co-evolutionary approach\(^1\) [20], [21]. The multivariable co-evolutionary approach is a methodology for successful introduction’s providing of innovative solutions in separate subsystem (land and maritime) of BTS. This approach can be used for the interaction analysis of innovative subsystems of BTS for raw material transportation. The offered approach embraces various aspects of compatibility and interoperability, and supposes an opportunity of modeling progressive and regressive development of BTS as whole. The most important subsystem of oil/gas transportation chain is transport by sea, therefore at synthesis of BTS on the basis of the innovative co-evolutionary approach.

2. Current state of the tankers’ market

The current state of all tankers’ market is defined by states of its segments:
- Segment of new-building tankers.
- Segment of “second-hand” tankers.

The major role is played a price level for this type’s ships.

To price level increase in shipbuilding have influences several factors [8]. The basic factors are ever-growing demand on transport services market and the pressure situation for shipbuilding industry. The important roles to state of this industry are:
- the peak set of the orders received for the Asian shipyards;
- the high prices for steel and completing equipment,
- a low dollar exchange rate in relation to the Japanese or European currency.

2.1. Segment of new-building tankers

During last 5-7 years the world market of maritime transport services is characterized by steady growth of contract prices, especially on the containerships,

\(^1\) The co-evolution – technological development of some closely associated units (elements, subsystems, technologies, etc.) when takes place the adaptation of each unit to transformation in another.
bulk ships and tankers. This growth is characterized by data of R.S. Platou, Gibson, Poten & Partners and other companies; periodical “MER” and ”Naval architect”. Statistical dates about contract prices for the tankers’ fleet shown in Table.1.

Table 1

<table>
<thead>
<tr>
<th>Year</th>
<th>Classes</th>
<th>VLCC</th>
<th>Suezmax</th>
<th>Aframax</th>
<th>MR* product tanker</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>VLCC</td>
<td>70±3.1</td>
<td>45±2.5</td>
<td>35±2.2</td>
<td>26±1.5</td>
</tr>
<tr>
<td>2002</td>
<td>Suezmax</td>
<td>65±2.7</td>
<td>43±2.4</td>
<td>32±2.1</td>
<td>25±1.4</td>
</tr>
<tr>
<td>2003</td>
<td>Aframax</td>
<td>77±3.3</td>
<td>53±2.8</td>
<td>43±2.4</td>
<td>31±1.7</td>
</tr>
<tr>
<td>2004</td>
<td>MR* product tanker</td>
<td>110±3.2</td>
<td>70±2.9</td>
<td>60±2.5</td>
<td>40±2.0</td>
</tr>
<tr>
<td>2005</td>
<td>45 000 DWT</td>
<td>125±3.5</td>
<td>74±3.0</td>
<td>64±2.5</td>
<td>43±2.1</td>
</tr>
<tr>
<td>2006**</td>
<td>30 000 DWT</td>
<td>127±3.0</td>
<td>76±3.1</td>
<td>65±2.5</td>
<td>44±2.2</td>
</tr>
</tbody>
</table>

* Medium Range; ** First quarter

Source: On basis E.A. Gibson Shipbrokers, Fearnley A.S., R.S. Platou Economic Research

The market demand for oil tankers, LNG and LPG, has increasing at the highest level, because large vessels provide for large volumes of oil/gas transportation on several routes [10], [23], [24], [25]. During 1999/2002 years the VLCC (about 300,000 DWT) within the cost $62 - 73 mln and in 2006 cost of the tanker has grown up to $130 mln by data R.S. Platou. Trends of the new tankers prices’ change are submitted in Fig. 4 by data for last 7 years.

Fig. 4. Trends of the new-building tankers prices’ change (on basis by data R.S. Platou Economic Research)

2.2. Segment of “Second hand” tankers

There is a close relation between prices dynamics for new-building and “second-hand” vessels. This can be illustrated by the diagram below (Fig.5). It shows the prices change for Aframax class by brokers’ company Poten & Partners. As is seen in the diagram, the both graphic curves changed synchronously and, starting from 2003, came close to each other and became almost equal in late 2004/2005.
The rapidly increasing prices for “second-hand” tankers also continue to put all new records, reaching a historical maximum. “Second-hand” tankers cost sometimes became more, than contract price for the new-building tankers of same class. For the last year it became already widespread tendency. Among the second hand tankers of various classes even more old vessels have become expensive. For example, a Suezmax aged 20 years has increased in price 2.4 times: its cost rose up to $20.0 mln against $8.3 mln in early 2003, while a ten-years old Suezmax tanker has risen in price 2.9 times, and a 5-year old one 2.2 times.

2.3. Long-term plan for tankers’ market

The situation at tankers’ markets can change in the nearest future under the influence of both demand and supply. The demand for transport capacities is determined by macroeconomic factors, and the future development of world economy does inspire optimism. Though in the December, 2004 year the world volume of new building tankers orders has exceeded 85 mln. DWT (Fig. 6).

According the report “On the Perspectives of World Economy”, published by the International Monetary Fund in April 2005, predicts that the economy growth rates for most industrial countries will slow down in 2006, compared to the 2004. These are not good news for marine trade or the related charter markets. High prices for fuel cannot help, negatively affecting the economies of importing states. Preliminary estimates indicate an increase in seaborne oil trade of between 3 and 4 percent from 2004 to 2005 and a slight reduction in average transport distance. There seems to have been an increase in waiting time in ports and straits compared with the year before, leading to a decline in the productivity of the fleet. Preliminary estimates show an overall growth to 5 percent in tankers’ tonnage demand from 2004 to 2005.

One of the last innovative projects for transportation of gas by the sea was the Coselle project (2003), sponsored by Shell, Chevron, Mobil, BHP, Marathon, McDermott, Conoco and BG, and encouraged others to enter the CNG (Compressed Natural Gas) arena with their own designs. In addition to EnerSea, these include Knutsen OAS with its Pressurized Natural Gas (PNG) carriers, TransCanada with its Gas Transport Modules (GTM) and Composite Reinforced Pressure Vessels (CRPV) and Trans Ocean Gas with its composite pressure vessels for CNG transportation.
Assumption 1. For many ship-owners the new-building tankers’ high price has become a difficult financial barrier and they have to refrain from placing new orders and postpone modernization of the fleet for power resources transportation, expecting a price reduction or purchase of the “second-hand” ships.

3. Bimodal transport as organizational systems

Bimodal transport is two interacting functional system (railway and maritime, usually) and various technical subsystems, which are functionally related to each other by means of an organizational subsystem for the purpose of customers’ need satisfaction and has the specific relations with the environment. Define of maritime system as functional system consisting from technical and organizational subsystems.

*Functional system* is a collection of nodes (ports) and links (waterways), resources and procedures united and regulated by interaction or interdependence to accomplish a set of specific functions (oil/gas transportation, loading etc).

*Technical subsystem* is a combination of two or more interrelated equipment (hull, engine etc.) arranged in a functional package (tankers, LNG, LPG) to perform an operational function.

*Organizational subsystem* is a collection of personnel, rules, guidelines and methods organized to accomplish a set of management functions for the purpose of the tankers’ (LNG, LPG) fleet’s success operations.

Sustainable development of bimodal transport system of oil/gas supplies is possible only with stable market demand. Among other conditions for favorable development of this transport mode are:

- Compatibility of its interacting subsystems;
- Harmonization of activity with environment on the principles of fair compensation for adverse effects;
- Rationalization of economic and legal mechanisms regulating the relations between the Member States of the EU;
• Compatibility with other transport modes providing feeder services;
• Enhancing the efficiency of management systems for the continual monitoring of navigation and vessels (tankers, LNG, LPG) quality control;
• Absolute priority is actions for the prevention and minimization of emergency consequences;
• Implementation of the innovative transformations into shipbuilding and the oil/gas transport technologies;
• An effective professional training and workshops are for steersmen, mechanics;
• Combination of tanker’s safety control are according ISM Code with self-control of steersmen, mechanics etc.

None of the listed conditions is new, being to some extent implemented in one or other field of maritime transport. And yet attaining overall consistency by logical, collaborative and balanced implementation appears problematic. This requires mechanism to prevent or settle conflicts of interests between the community and ship-owners, government agencies and shipping companies, oil pollution and environment etc. This problem has been considered in some papers [2], [5], [14], and [26]. The analysis of these researches has allowed drawing the conclusion that exists three main categories of conflict which need specific solutions:

*Multi-level or vertical* conflicts occur between the different institutional levels, namely between the EU and the national level, between the national and the regional/local level as well as between the EU and the regional/local level.

*Cross-sectoral or horizontal* conflicts arise between shipowner and community at the same institutional level. They are often conflicts between different policies, for instance between environmental policy, tankers’ shipbuilding and transport policy.

*Cross-border* conflicts often occur because of different national (planning) systems with different standards or because of language problems. A great part of cross-border conflicts can be traced back to cultural factors.

The EU economy has the great potential for transport network is important factor for its growth as today as well tomorrow. Under condition the feasibility of an international legal instrument bimodal transport systems have chances for quick enlargement. Rising TEN-T potential allows:

− diversity and serviceability of the transport systems (*should satisfy customers*);
− reduction of the delivery times & haulage tariffs (*should satisfy consignors/consignees*);
− profitability of the innovative transformations (*should satisfy investors*);
− efficiency of the management techniques (*should satisfy decision-makers, e.g. authorities, ship-owners*).

**Assumption 2.** Main goals to organization of power resources transportation are:

− organization stable and quality service of oil/gas flows;
− free consignors from superfluous transport risk;
− minimization of negative influences to environment;
− elimination possible “bottlenecks”;
− preparation of conditions for transport networks’ innovative transformations e.g. implantation intermodal cargo-carrying. [21]
4. Basis of bimodal systems’ synthesis

BTS for oil and gas transportation should be rather cheap and efficient, reliable, safety, environmental friendly and real competitive alternative to land transport or pipelines. For such transport systems including maritime transport mode are recommended [15], [18]:

− to define functional goals;
− to form input information data base;
− to identify the critical factors;
− to assess of risk to oil & gas transport;
− to select of the fruitful synthesis method.

4.1. Defining of functional goals for bimodal systems

The main goals of BTS synthesis are:

• Attracting attention to increase of transport system competitiveness, cost-benefit efficiency and support of economic vitality of The European Union as whole
• Increase the accessibility, mobility and interoperability for bimodal system.
• Improve quality of community life thanks to protecting environment, enlargement of recreation areas, preservation of landscapes, etc.
• Intensify the integration and connectivity of infrastructural nodes
• Expansion of transport system’s functions and liability for delivery.
• Strengthen of stability for transport system and its adaptability to:
  − external factors’ influences, including political, legal and social barriers etc.
  − internal factors’ influences including: loss reliability, crew’s errors etc.

For an estimation of conformity the designed BTS to goals is recommended to create data bases, which are submitted in Table 2.

<table>
<thead>
<tr>
<th>Database №</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Comparison by fuel. Current state and dynamics for last 5 years</td>
</tr>
<tr>
<td>II</td>
<td>World power resources. Demand forecast.</td>
</tr>
<tr>
<td>III</td>
<td>Tanker’s (LNG &amp; LPG) fleet forecast.</td>
</tr>
<tr>
<td>IV</td>
<td>Cost structure of bimodal transport system including contract prices for new-building (second-hand) tankers</td>
</tr>
<tr>
<td>V</td>
<td>The risk structure for bimodal transport systems</td>
</tr>
<tr>
<td>VI</td>
<td>Basics transport innovations (maritime, railway etc.)</td>
</tr>
<tr>
<td>VII</td>
<td>Best practice in intermodal strategies</td>
</tr>
</tbody>
</table>

Source: Author’s research

4.2. Critical factors identification for bimodal transport designing

At designing of bimodal systems the author proposes to use co-evolutionary approach with taking into account the critical factors instead of the logistical suppositions (Table 3).
In traditional statement:

Logistical supposition: Maximal profit by extensiveness way

Co-evolutional approach: Maximal competitiveness by innovative way.

Give preferences for:

- Quality vs. Quantity
- Safety & Security vs. Speed
- Interoperability vs. Capacity, etc.

In modern statement:

In special cases to listed principles add the principle of interaction compatibility for separate subsystems of BTS. For example we have task to design “maritime – railway” system. At all efficiency of the logistical approach, it possesses one essential fault as does not take into account influence of innovative changes which can take place in separate subsystem (Fig.7).

![Fig.7. BTS with using the traditional technologies](Source: Author’s research)

Not consideration of such changes as a rule becomes the cause of additional barriers generation, including technical, technological, and functional [12], [19]. For example is a hypothetical situation when large investments into the innovative project of productivity increase of loading works can become the reason of standing idle of the new equipment because delivery of a cargo in previous a subsystem will be late owing to use of old, traditional technology (Fig.8).

![Fig.8. BTS design not taking into account separate innovative modification](Source: Author’s research)

From this simplified example follows, that implantation of innovative technologies in one subsystem will lead to expected result only in case of implementation of corresponding innovative changes in other subsystems of this BTS.
In other words, innovative development of BTS should occur simultaneously in all subsystems i.e., on basis of co-evolutional approach (Fig. 9).

![Diagram showing co-evolutional approach]

Fig.9. Co-evolutional approach. BTS design taking into account innovative modifications. Source: Author’s research

Prove necessity of the co-evolutionary approach’s use to an efficiency estimation of the innovative projects implantation, using analysis results of statistical information about accident rate of tanker fleet in Baltic Sea during 1994 – 2004 (Table 4.) On a safety level of maritime transport, including transportation of oil and gas by tanker fleet have influence two groups of the causes:
- The internal causes, including technical failures.
- The external causes, including human factor.

The analysis we shall carry out on the basis of accidents statistics’ comparison for:
- single hull tankers designing in accordance with critical factor “maximal profit”.
- double hull tankers designing in accordance with critical factor “maximal safety vs. transport speed”.

### Table 4

<table>
<thead>
<tr>
<th>Causes:</th>
<th>Internal causes</th>
<th>External causes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single hull</td>
<td>Double hull</td>
</tr>
<tr>
<td>Years:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1994 - 1999</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>2000 - 2004</td>
<td>8</td>
<td>1</td>
</tr>
</tbody>
</table>

Innovative projects of tankers with the double hull have begun will take root at the end of 90th years of the last century, gradually superseding in fleet’s structure single hull tankers, which age reached 20 and more years [9]. Marked dynamics is well illustrated by the data of the table, showing that according to the accident rate factor by the internal causes during 1994-1999 took place one tanker accident having

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2 The double hull tankers requirement was adopted in 1992, following the “Erika” catastrophe.
innovative double hull and 6 tankers failures having single hull. During next five-year period took place one tanker accident having innovative double hull and 8 tankers failures having single hull. That is the relative increase of accident rate for obsolescent tankers each 5 years average from 25 – 30 %.

Consider the external causes of the tankers accidents on Baltic Sea. From the information of Table 4 follows that during 1994-1999 took place 7 tankers accidents having innovative double hull and 2 tankers failures having single hull. It is possible to draw from this ratio a following conclusion: during the considered period single hull tankers which traditionally used in maritime transport, had considerably the best compatibility with ambient systems e.g. with port infrastructure, systems of navigation and the communications, etc., than innovative double hull tankers.

It is necessary to note that during the subsequent period 2000 – 2004 took place on the one hand, drastic growth of tankers accidents, and on the other hand, number of tankers failures having single hull was approximately equal to number of tankers failures having double hull (25 accidents - single hull tankers; 26 accidents – double hull tankers). In author’s opinion, the indicated tendency has two reasons. Firstly, introduction of separation schemes for traffic of tankers’ with dangerous goods and permanent monitoring over vessel were not carried out. Other reason is the innovative changes introduced in one subsystem of BTS (e.g. double hull tankers) that at the beginning has resulted to incompatibility between innovative vessels and traditional elements of the feeder transport system. On account of process complexity it is recommended to form BTS, including maritime transport, taking into account the following principles too:

The first principle. Obligatory observance of the consumers’ requirements to basic transportation conditions.

The second principle. Optimization of employment, forms and quality of consignors’ service are basic determinants at decision-making.

The third principle. Maximal flexibility and throughput of BTS as a condition of its stability.

The fourth principle. Minimization of expenses at multipurpose use of BTS.

The fifth principle. Preservation of natural resources, including ground and surface waters as lead indicators of environment; public health etc.

The sixth principle. Maximization of the transport safety (taking into account rule ALARP – As Low As Reasonability Practicable) including creation and application of innovative technologies for the continuous monitoring of transport process [17].

The seventh principle. Improvement of interoperability intra- bimodal systems. Its success depends from thorough interability. Interoperability is called the ability of national, regional and global transport networks to provide efficient operations and services across national, technical, geographical, legislative, organizational and socio-economic barriers.

The four major dimensions of thorough interoperability are:

− Technical interoperability;
− Organizational interoperability;
− Economical interoperability;
− Juridical interoperability.
Fig. 10. Oil & Gas Transportation Risks. Source: Author’s research

*Technical interoperability exists* if there is strong functional correlation between BTS subsystems through productive and compatible technologies.

*Organizational interoperability exists* if different actors of the transport market are willing and able to co-operate to provide transport services for end-users.

*Economical interoperability exists* if barriers for capital flows between different actors of the transport market are eliminated through cost-benefit approach.

*Juridical interoperability exists* if barriers to rules compatibility, such as national anti-trust laws differing from EU Directives, are removed or harmonized.

Not performance of interoperability conditions is connected to high probability of various risks appearance that introduces essential information uncertainty into the designing process of BTS (Fig. 10). Investigate this problem.

### 4.3 Risk estimation of the oil and gas transportation

The success of new transport technology in the raw materials sector depends mainly on the willingness or ability of decision-makers to implantation of this technology. Information regarding the innovative technology tends to be available and frequently the limiting factors are economical, ecological or technical. Although the market uses traditional ways for diffusion of the information, the consumers will not
come close to the innovative technology if promotion effort is not made in direct contact with the decision-makers.

The achievement of designing depends from knowledge’s degree of decision-makers [3], [13], [17]. The information uncertainty level is higher, than they are further from the novelty source (the so-called “effect of deep uncertainty”). Generally this level is determined by properties of “value”, “obsolescence” and “dissipation” of the design information which we represent as Y-information. Next we shall consider these properties by the example of decision-maker’s knowledge.

**Information value.** Value of the information is basic parameter forming at the knowledge level of decision-makers. It is characterized by utility, from the point of view of their knowledge, availability, timeliness, completeness and reliability. Let be primary:

− uncertainty of the decision-makers about \( i \)-vehicle was measured \( U_i^\nu \);
− decision-making risk about BTS project, including innovative \( i \)-vehicle amounted \( R(U_i^\nu) \).

Let, that at the expiration of the period \( \Delta t \), the decision-maker has received the additional ITI\(^3\) - ITI, which has lowered his uncertainty up to \( U_{\Delta t} \). Then:

− information uncertainty of the decision-maker will decrease up to \([U_i^\nu - U_{\Delta t}]\) level.
− the risk’s reduction of decision-making about the BTS project is equal:

\[
R(U_i^\nu) - R(U_i^\nu - U_{\Delta t}) = \Delta R_i^\nu
\]

This holds for all “\( i \)”.

Consequently, the quantity \( \Delta R_i^\nu \) reflects the approximation’s degree of the decision-maker to the virtuous decision about refusal / implantation of innovative \( i \)-vehicle.

**Information’s obsolescence.** All volume of the ITI accessible to the decision-maker consists of quickly obsolescent and slowly obsolescent data. For example, quickly obsolescent data it is the information about number of the shipping companies introducing novelty or the economic benefits achieved after introduction of an innovation. Slowly obsolescent data it is the ITI e.g. (technical, operational or cost-benefit, etc. characteristics of the TI\(^4\)).

Let the decision-maker is in a situation “A”, which is characterized by on-line receipt of the data about BTS parameters and its ITI uncertainty is equal \( U_i^o \). Risk of vicious decision is equal \( R(U_i^o) \) in this situation. On the other hand, the situation “B” is possible too, in which the decision-maker does not receive the new ITI during time \( \Delta t \), and his uncertainty increases on \( U_{\Delta t} \), and risk’s increase of the vicious decision is equal:

\[
R(U_i^o + U_{\Delta t}) - R(U_i^o) = \Delta R_i^o
\]

This holds for all “\( i \)”.

Hence, quantity \( \Delta R_i^o \) is the risk’s measure of obsolescent ITI. If the decision-maker receives the information:

\(^3\) ITI – Information about Transport’s Innovation
\(^4\) TI – Transport Innovation (e.g. CNG, CRPV, GTM)
− in regular – determined pattern, [describe as $R(U_{\alpha}) \to 0$], i.e. BTS designing is support by actual ITI constantly, and process of its obsolescence does not influence probability of vicious decisions;
− in irregular - stochastic pattern, [describe as $R(U_{\alpha}) \gg R(U_{\alpha}^*)$], i.e. BTS designing isn’t support by actual ITI constantly, it negatively influences rationality of the decision-making.

Information’s dissipation. As a rule, the ITI is dissipated on the time period, and it non-liner created by set interacting designers. It is necessary to take into account the fact of interaction of such sources also, when the ITI in process of verification passes from one source in another. At the same time if:
− the larger level of the information verity, the longer dissipation period;
− the larger scale of information’s dissipation, the presence’s larger probability of false information sources.

Let the decision-maker is in a situation “A”, which is characterized by on-line receipt of the firsthand information from the limited number of sources. Decision-maker’s information uncertainty is equal $d_{iU}$. Risk of vicious decision is equal $d_{iU R}$. On the other hand, the situation “B” is possible too, in which the decision-maker receives the ITI from numerous sources, including secondary, tertiary, etc. The part from these sources is not free from a false ITI $f_{iU}$. Then, risk’s increase of the vicious decision about refusal / introduction of TI amount:

$$R_i^d \left( U_i^d + \sum_{n=1}^{m} U_n^d \right) - R(U_i^d) = \Delta R_i^d$$

(3)

Where:

$n$ – sources’ set probably containing a false ITI; $n = 1 \div m$

Hence, quantity $\Delta R_i^d$ is the risk’s measure of dissipated information.

Assumption 3. The information’s properties marked above demand the new approach to decision-making during BTS designing.

5. Co-evolutionary approach to bimodal chains designing

5.1. Conceptual design stage

At conceptual design stage of BTS probably application of the expert approach to an estimation of its functional efficiency [4], [7], [16]. For realization of this approach we shall accept two suppositions:

1. Probabilities of the disadvantage/profit in each of links of a bimodal transport chain do not depend on similar probabilities in the previous links of a chain
2. Distribution probabilities of the disadvantage/profit are smooth convex – concave functions
At such assumptions the disadvantage risk of power resources transportation by BTS can be estimated using the following equation:

\[ R_d = \sum_{i=1}^{k} \left[ P_p^c \times V_p^c - P_d^c \times V_d^c \right] \]

Where:
- \( R_d \) - disadvantage risk of BTS project;
- \( P_d, P_p \) - probabilities of the disadvantage/profit for power resources transportation by BTS, accordingly;
- \( V_d, V_p \) - value of the disadvantage/profit for power resources transportation by BTS, accordingly;
- \( c \) - number of bimodal chain links, \( c = 1 + K \)

Graphic representation of the disadvantage risk’s estimation for power resources transportation by BTS on the basis expert approach is submitted on Fig. 11.

### 5.2. Research design stage

At a research design stage of BTS the great importance takes decision of the problem for the bimodal chains’ management. Investigate this problem.

Let transport process by BTS can be considered as chain \( C \), including \( z \)-intermodal links. Such chain can be presented as the matrix block of the directed action. By square matrix \( M_j \) call a matrix of ties between \( C_i \) links of the intermodal chain. The matrix \( M_j \) is the set of rectangular blocks \( M_{a\beta} \), each of which will be a matrix of ties for the corresponding links.
As the following condition holds $\alpha \neq \beta$ for each block $M_{\alpha\beta}$, then its diagonal blocks will be equal to zero:

$$M_i = \begin{pmatrix}
0 & M_{12}(y_{12}) & \cdots & M_{1z}(y_{1z}) \\
M_{21}(y_{21}) & 0 & \cdots & M_{2z}(y_{2z}) \\
\vdots & \vdots & \ddots & \vdots \\
M_{z1}(y_{z1}) & M_{z2}(y_{z2}) & \cdots & 0
\end{pmatrix}.$$

(5)

If ties between the matrix blocks are realized so, that the state of each link of intermodal chain $C_i$ (with the exception of last link $C_z$) is defined only by a state of the previous link, then takes place the directive management method of the intermodal chains. This approach to BTS synthesis is graphically submitted in Fig. 12.

![Fig.12. Simple sequential schema of BTS synthesis. Source: Author’s research](image1)

In the management theory this method is called a sequential method. On the structural matrix scheme it is represented as open-loop chain of the connected consecutive blocks. From practice of management by transport systems it is known, that use of a sequential method is low effective and, as a rule, is accompanied by high transport risk.

The proof is simple. Taking into account substituting real values of components, we get relatively low values of effective realization probability for transport tasks by intermodal chain.

![Fig.13. Sequential schema of BTS synthesis with feed-back. Source: Author’s research](image2)

Therefore more effective is other approach to management of the intermodal chains, namely a situational management method. Realization of such method assumes connection by information ties of outputs of last link $C_z$ with inputs of the first link $C_1$. The considered approach to BTS synthesis is shown on Fig. 13.

Assumption 4. Bimodal transport is often presented as main solution to reduce delay problem but it does not seduce transport companies. Diffusion of innovative transport technologies and demonstration of its commercial benefits are important actions to decision-making. Therefore, takes place the permanent competition between approaches to the modification of the transport services market by other means, namely improving competitiveness of the bimodal transport, or for example, increasing its reliability and raising personal professionalism.
6. **Concluding remarks**

Baltic Sea has rather shallow depths. With the purpose of shipping traffic safety on its waters is required precautionary measures for reduction in a risk level of extreme situations. Taking it into consideration, there is obligatory an activization of Poland participation in the Baltic initiatives. For this purpose development of the concrete measures plan directed on increase of traffic safety of vessels, and on improvement of various services activity coordination can be very important at extreme situations on Baltic Sea and in port water areas.

Such measures should be developed on the basis of innovative approaches to a safety on all links of a transport chain, including: new overload technologies in ports, innovative solutions to reliability of sea vessels and decrease in probability for environmental pollution.

Development of such measures is very actual, taking into account that by the optimistic scenarios soon on Baltic coast should be constructed the Polish gas port. That substantially will increase intensity of shipping traffic by the Polish waters of Baltic Sea.

Diversification of gas sources is very actually to Poland. Gas transportation by bimodal systems is implying synthesis of modal chain having several links. All this is cause for designing chains of oil/gas supplies with taking into account of transport risk on the basis of the innovative multivariable co-evolutionary approach.

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**Reference**


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Abstract

In presented paper, shown that transport services market have a key role in the world economy. It forms requirements to increase the interconnection and flexibility of transport systems. Transport by sea routes has an important role for creation of the bimodal chains meant for raw materials transport. Co-evolutional approach to designing transport systems with taking into account both the various functional risks and the long-term evolution is offered. This approach embraces various aspects of compatibility and interoperability assessments, as well supposes an opportunity of modeling progressive development and regressive trends of the transport systems as whole. Special attention devote to designing of the bimodal systems assigned for oil/gas transport.

Współ-ewolucyjne podejście do syntezy bimodalnych systemów transportowych

Streszczenie

Prezentowany artykuł opiera się na oczywistym stwierdzeniu, że rynek usług transportowych odgrywa kluczową rolę w rozwoju światowej gospodarki. Z tego stwierdzenia wynikają wymagania zarówno do wzrostu elastyczności, jak i poleczenia kompatybilności między różnymi gałęziami transportu. Pośród tych gałęzi transport morski odgrywa najważniejszą rolę w kreowaniu bimodalnych łańcuchów do przewozów takich płynnych ładunków, jak ropa naftowa oraz gaz skroplony. Zaproponowano współ-ewolucyjne podejście do projektowania systemów transportowych. Takie podejście jest zorientowane na prognozowanie długoterminowego rozwoju systemu transportu z uwzględnieniem różnego rodzaju ryzyk, w tym ryzyka funkcjonalnego, różnych aspektów kompatybilności i interoperabilności, daje możliwość modelowania progresywnych i regresywnych trendów w ewolucji systemów transportowych jako całości. Szczególną uwagę poświęcono projektowaniu systemów bimodalnych przeznaczonych do transportu surowców energetycznych zarówno drogą lądową jak i morską.