

# TOPOLOGY-BASED APPROACH TO THE MODERNIZATION OF TRANSPORT AND LOGISTICS SYSTEMS WITH HYBRID ARCHITECTURE. PART 1. PROOF-OF-CONCEPT STUDY

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**Abstract:** *Industrial companies are linked with affiliated firms, suppliers and customers through the supply chains. Such chains operate within large-scale networks directly related to distribution and warehousing. In order to meet the market demands and customer new expectations, the various components of the supply chains have to be developed i.a. through implementation of the innovative vehicles, green and blue technologies. Moreover, modernization processes of transport and logistics system need to be resistant to crucial mistakes related to innovative solutions implementation in order to exclude domino effect occurrence. The authors attempt to build topology-based approach to the modernization of transport and logistics systems. It is assumed that each innovation application is the independent element-based coalition, possessing linked object structure. The results of multi-year researches demonstrate the offered approach as a useful tool to analyze innovative changes for obsolete transport and logistics system as hybrid structure. The ways of system structure transformation, as well as possible innovative effects are considered. The preliminary results have been obtained for compositions on meso-level for the case of marine propulsion modernisation. The paper is illustrated by various examples.*

**Key words:** *topology-based approach, transport and logistics system, innovative changes, component-based coalition.*

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## 1. Introduction

As a result of progressive evolution, mobility remains the key to prerequisite for prosperity of the society. Long before the industrial revolution, our civilisation had evolved due to innovative changes. Such alterations had developed from a propulsive force of wind and sail, animal power and wheel up to a coal-fired propulsive plant and steam engine, as well as later on petroleum and Diesel ones.

Therefore, transport systems transformations have taken place within more than 4000 years, beginning from scattered, uncoordinated and homogeneous (unimodal) structures, e.g. mail-coaches or sailing fleet, up to networked, coordinated and heterogeneous (hybrid) structures, hereinafter referred to TLS (*Transport and Logistics System*).

The authors examined innovations covering the period from 1715 to 2015 that were divided into three categories (Fig. 1). These categories may be named as:

1. Incremental Innovations (improvement). These innovations consist of small, yet meaningful improvements.
2. Substantial Innovations (breakthrough). There are meaningful changes that give consumers some demonstrably new features.
3. Transformational Innovations (disruptive). This kind of innovations often eliminates existing transport means or totally transforms them. Conducted researches show that transformational innovations tend to be championed by those who aren't wedded to obsolete structures (clipper, chariot, steam locomotive etc.).

After industrial revolution obsolete vehicles were eliminated and replaced by engine-based means. In XX-century the idea to integrate such vehicles within intermodal transport systems, defined as hybrid transport systems, was created (Konings et al., 2005) (Fig. 2).

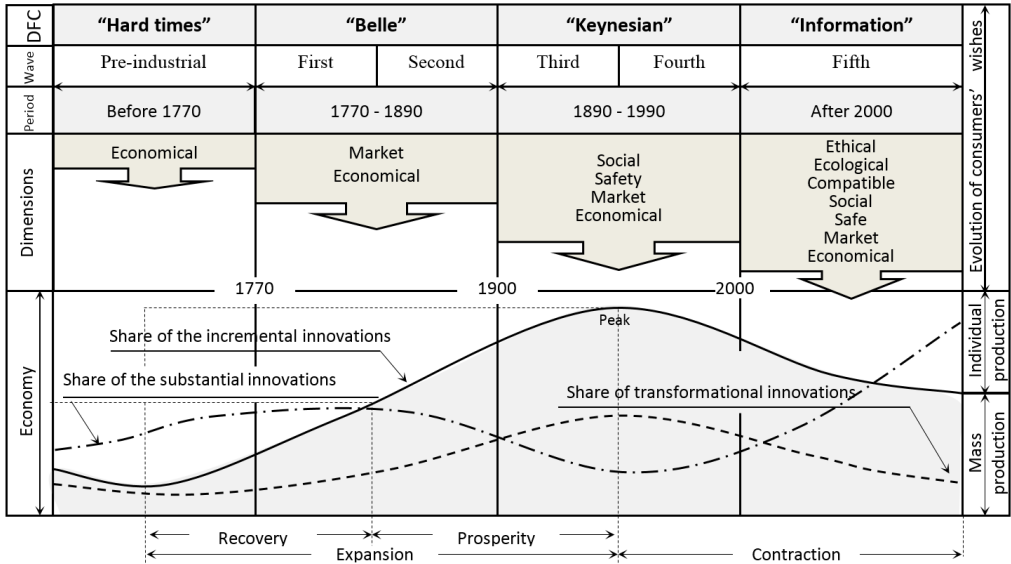


Fig. 1. Worldwide changes at Transport/Logistics innovations

Source: Authors' research on the basis of Aho et al. (2006); Bolt and van Zanden (2014); United Nations (2015)

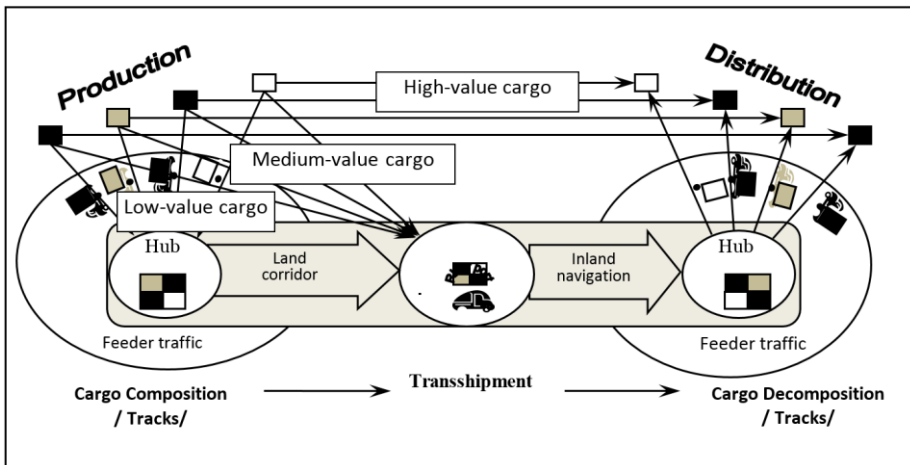


Fig. 2. An example of the intermodal Transport and Logistics System

Intermodal transport links different participants (e.g. shipper, carrier, consignee) through supply chain development (Jacyna-Golda, 2015; Kerbache and Maccregor Smith, 2004). Conducted literature analysis revealed that TLS problems were widely described in current literature (Chataway et al., 2014; Hölzl and Janger, 2011).

The drivers and sources of innovations have been examined e.g. by (Dosi et al., 2000; Chaminade et al., 2010, Schumpeter, 1950) paying particular attention to the technological and organizational companies resources. Moreover, it is known that implementation of innovation does not always have positive effects. Sometimes the rejection or the lack

of compatibility with the existing system takes place. This phenomenon generates fundamental transport or logistics problem, i.e. the need of combinatorial optimization of the TLS assembled by CSG (*Coalition Structure Generation*) techniques (Mauro et al., 2010; Rahwan et al., 2009).

Improvement of any TLS development may be based on the multi-agent approach (Chen and Cheng, 2010; Chen and Wang, 2009; Davidsson et al., 2005; Graudina and Grundspenkis, 2005; Lin, 2011, Modelewski and Siergiejczyk, 2013; Rocha et al., 2014) and object-oriented approach (Arm Badr-El-Din, 2013; Crespi et al., 2008; Juman et al., 2013). There is a number of publications examining the use of coalition structure in systems transformations (Aziz and de Keijzer, 2011; Baras, 2011; Semenov, 2006; Voice et al., 2012). Nevertheless, despite extensive research in this field there are still gaps referring to the lack of a uniform approach to TLS modernization based on the interaction of innovative and obsolete coalitions that can be considered as independent object modules.

The article aims to demonstrate the topological approach to analyze innovative changes for obsolete TLS as hybrid system.

## 2. The levels of modernization process

The TLS modernization has never been the simple and easy process. According to O. Levander (Rolls-Royce): *“It has never been more difficult to know what’s the right investment decision to make when selecting a new vessel. The answer is flexibility – the ‘future-proof’ ship”* (Low-cost, 2017). Nowadays, the TLS development stage is leading to the substitution of obsolete and polluting technologies by modern and ecological ones, as well as mobility improvement through its inner openness to innovative changes. Therefore, the design of such systems should be based on risk management of each component, coalition and a whole composition, as well as inclusion of modernisation process in the context of maximising efficiency and minimising disturbances.

For that reason, all TLSs can be divided into two groups:

**A Group: so-called COTLSs (*Closed TLSs*).** Each system is a closed structure, if it isn’t connected with defined environment (Hubka and Eder, 1988). According to the system approach, the closed system is isolated form of compositions, which must be developed as high-reliable construction. Such

systems should have higher assurance factor and survival rate. They stand out by scarcity of evolutionary mechanisms, and consequently are ill-adapted to any transformations. The striking examples are the subsea oil and gas pipelines, as well as the TLPs (Tension Leg Platforms) transformed from the jack-up drilling rigs.

**B Group: so-called OTLSs (*Opened TLSs*).** Each system is an opened multi-element structure, if it is connected with environment by at least one input or/and output. The feasibility of the OTLS transformations depends on a degree of such system worsens, structural complexity and modernisation tasks.

The OTLS improvement can be carried out at micro-, meso- and mega-level of TLS hierarchy. Let’s consider these levels closely.

**1) The micro-level:** describes transport systems at low aggregation levels and refers to the functioning elements of systems and is, therefore, a valuable assessment instrument for innovative analysis, see e.g. Semenov (2008). An engine is the classic example of the component-based coalition embedded into any kind of engine-based vehicle. Its improvement implies modification of one or several components, including the camshaft, the crank shaft, the flywheel, cylinders, pistons, etc., as well as a principle of their interactions. An assembly of such components can be formed in different ways. As a result various MAGI (*Micro-Areas of Geometrical Incompatibility*) are generated (Bhalla et al., 2014). Any innovative micro-level transformations have the tendency to complicate the engineering systems drastically, increasing the risk of costly human errors occurrence. This fact stimulates the reduction of total number of obsolete coalitions within such compositions, raising its reliability and usability. One of the representative examples is the innovative solution developed by Bosch Corp. uniting the few components within coalition *“Combined Active and Passive Safety”* (Bosch, 2017).

**2) The meso-level** is wedged between the macro- and the micro-levels. Therefore, the meso-level describes the transport system from an intermediate aggregation level, and this type of analysis acknowledges the mutual coherence of actors’ groups (Schenk et al., 2007). A vehicle is a good example of the next OTLS ordered level.

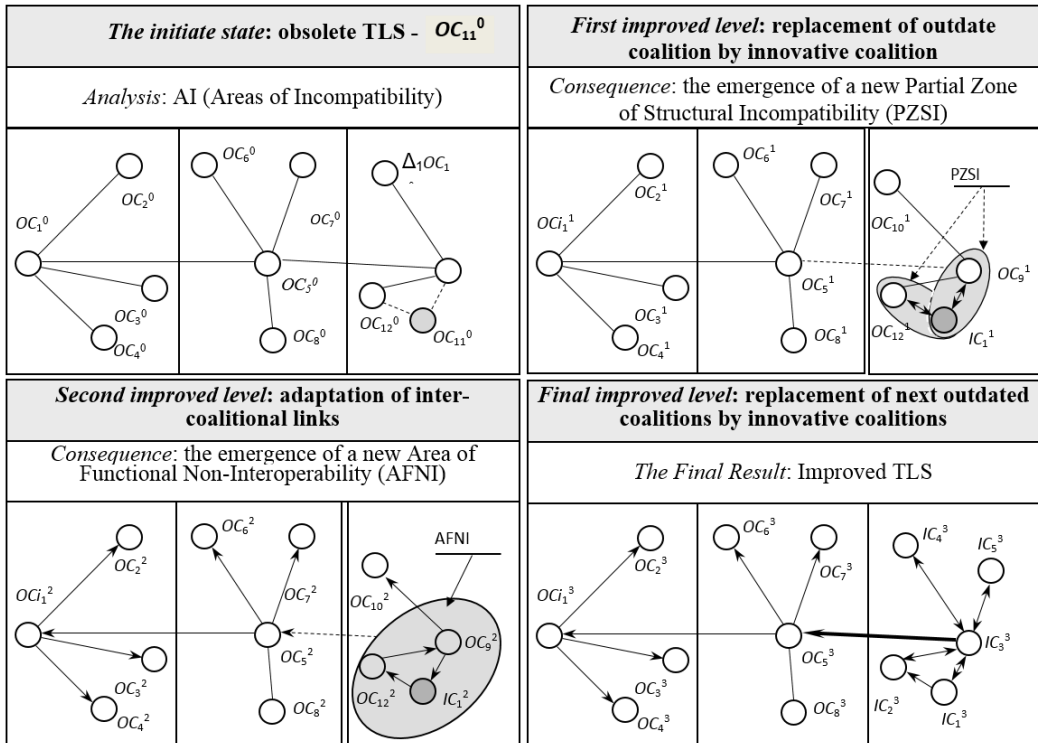


Fig. 3. The stages of outdated TLS modernization, where OC – outdated coalition, IC – innovative coalition

Improvement of the vehicle implies modification of various coalitions (subsystems), i.a.:

- safety subsystems including anti-lock braking subsystem,
- subsystems preventing roll-overs and skids,
- a ship hull, an power-plant, an engine, a propulsion devices etc.

Consequently, assemblies of aforesaid coalitions can be formed in different ways (Fig.3) and as a result, MAGI could generate PZSI (*Partial Zones of Structural Incompatibility*). Moreover, the upgrade within single coalition, as a rule, leads to corresponding alterations in other coalitions. For example, invention of a hybrid engine demanded a reconfiguration of car bodies, and usage of transverse under floor installation of car engine. In addition, consumers are heterogeneous in their needs, opportunities, and wishes. In conclusion, each transport system is struggling with various AFNI (*Areas of Functional Non-Interoperability*).

To escape from these difficulties, the managers developed and implemented novelties under imperative motto “the preferences declared by the majority of customers should be above all“. As a rule, it is converged with aspiration of persistent reduction of the vehicles prices and services expenses. Unfortunately, often enough the satisfaction of such wishes can be achieved only by a refrain from innovative transformations and, as a result, application of outdated solutions, e.g. usage of petrol engines in car production. Also the contrary situation may take place, when the clients’ wishes concern an environmental protection, reliability, safety or comfort. Managers should take into account that the AI (*Areas of Incompatibility*), both functional and structural, can arise in each case.

The striking example of described case concerns unsuccessful decisions taken during the design of several VLCCs (*Very Large Crude Carriers*) decks. The critical imitation of helicopters landing space and the limited opportunity of emergency crew

escape took place. However, history shows that formation of AI does not finish the progress. The development of the sailing fleet contains enlightening examples of cut-and-try method.

Furthermore, rapid growth of the European economy and reinforcement of trade relations in both South and North America within XVI-XVII centuries resulted in the need for drastic reduction of the transportation time. This problem had been solved owing to transformations of sailing equipment, including permanent changes of ship's hull forms, localisations and a quantity of sails and, consequently, number of sail masts.

These transformations caused the increase in the ship's centre of KG (*Gravity above Keel*), and loss of static and dynamic stability of sailing ships, causing negative effects, i.a:

- sailing ships had to take aboard of huge quantity of the solid ballast,
- necessity to increase a crew size and as a result to expand the amount of supplies (fresh water and foods) on ships that reduced cargo capacity.

However, growing demand for freight caused upsizing of sailing ships, both the number of sail masts and crews increased aiming to support the transportation capacity. Similar changes took place until the end of the XIX century, giving the chance for steamships fleet development (Fig. 4).

Today shipping industry has become a key component of the world's economy. Over 90% of global trade is carried by sea. The world fleet of sea-going merchant ships reaches over 104,000 ships. As a result, such problems as ship CO<sub>2</sub> emissions and sulphur emissions occur (Table 1). From 2015, ships operating in SECA (*Sulphur Emissions Control Areas*) have to use fuels with 0.1% or less

sulphur content. This sulphur regulation put pressure on ship owners and operators forcing them to invest in cleaner fuels and green technology, as well as ships innovations. For that reason, during the last decade an increasing focus on emissions reduction for new and existing ships had been observed. Therefore, ship-owners optimise the form of ship hulls, fit equipment for emission reduction, install new propellers and tune engines.

Table 1. Outcome-oriented goals for modern fleet of merchant ships

Outcome-oriented goals	Description
Market development	Improve the competitive advantage for shipping companies through implementation of green technologies
Health protection	Reduce premature deaths from exposure to particulate emissions *
Climate preservation	Reduce per-capita CO <sub>2</sub> emissions from ferries and merchant ships
Technological improvement	Improve shipping sustainability through usage of good practices and innovative solutions
Law compliance	Meeting the SECA requirements**
Profitability ensuring	The ability to finance ongoing operations and future fleet growth

\* WHO reports: in 2012 around 7 mln people died as a result of air pollution (one in eight of total global deaths).  
 \*\* Sulphur Oxides, International Maritime Organization, 2014, retrieved 4 May 2014.

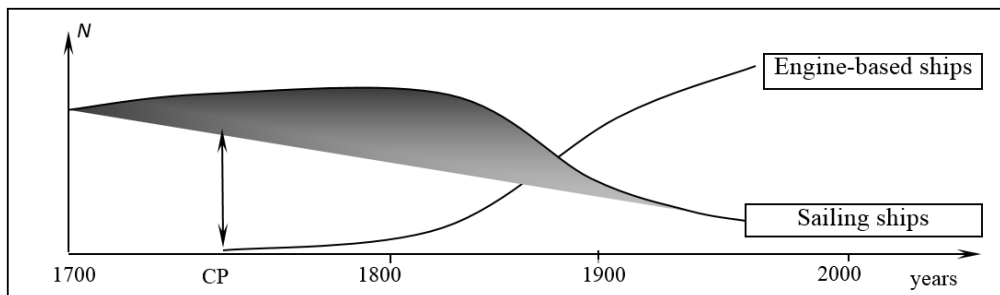


Fig. 4. The global fleet development: Engine-Based vs. Sailing Fleet  
*N-the number of worldwide ships, CP-Critical Point in civilization development (the "Belle" Epoch - Fig. 1)*

This situation influences on production of emission-efficient ships using new solutions, such as exhaust gas cleaning (scrubbers) systems or ships adapted for the LNG fuel. Coming new solutions include the combination of three different technologies: water injection, SCR (*Selective Catalytic Reduction*), as well as EGR (*Exhaust Gas Recirculation*). The EGR technology is fairly straightforward in on-land applications, while recycling exhaust gases from marine fuel back into an engine causes different challenges.

**3) The macro level** relies on a very aggregate view of transport systems and determines modernisation processes at meso- and micro-levels and considers systems as hybrid structures. Therefore, each harbour is the representative example of the OTLS at the macro level because consists of the multi-coalition composition, which includes (Fig. 5):

- unmovable components, including road/railway networks, storage warehouses,
- mobile components, i.a. the portal cranes, wheel loaders.

Seaports modernisation faces the number of possible complications, dealing with regulations changes,

technological incompatibility with simultaneous widening of services spectrum etc. Therefore, each unfortunate modernisation can cause significant expenditure and even investment fiasco.

### 3. The modernization process

#### 3.1. Core assumptions and tasks

Existing TLS are characterised both by a wide variety of structures (from opened to fully closed complexes), and different purposes. Therefore, we'll introduce a few conditions for modernization and development of OTLS. The major conditions are as follows:

- a phased transformation process is based on unified procedures;
- an irreversible transformation process that once started modernization cannot be stopped;
- a progressive transformation process is not only inevitable but desirable;
- a risky transformation process creates on-target, as well as off-target effects;
- a transformation process changes the obsolete system into a modernity state;
- a pushed transformation process builds chance for obsolete system (Fig. 6).

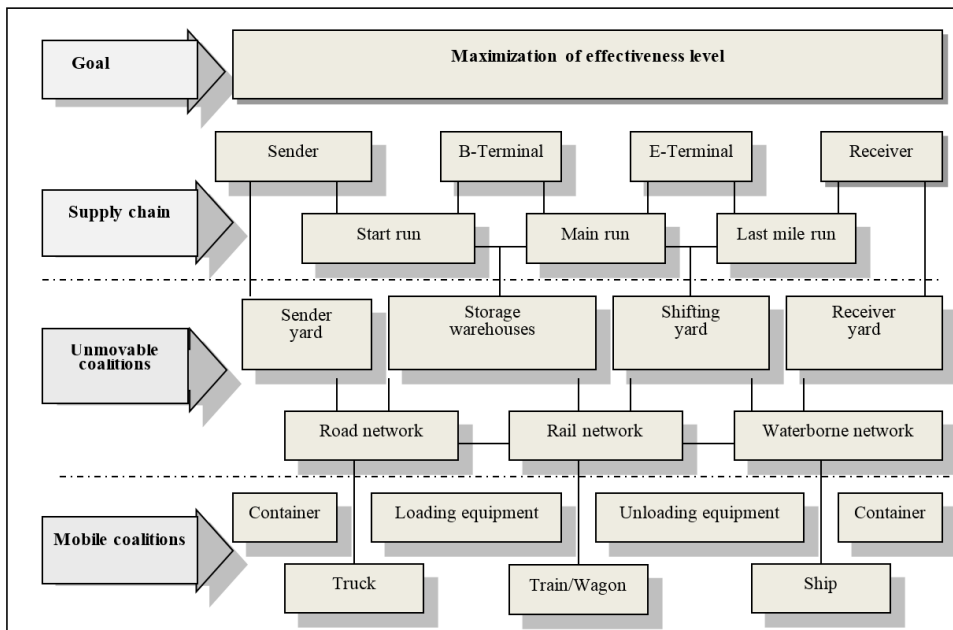


Fig. 5. The seaport as the Hybrid OTLS

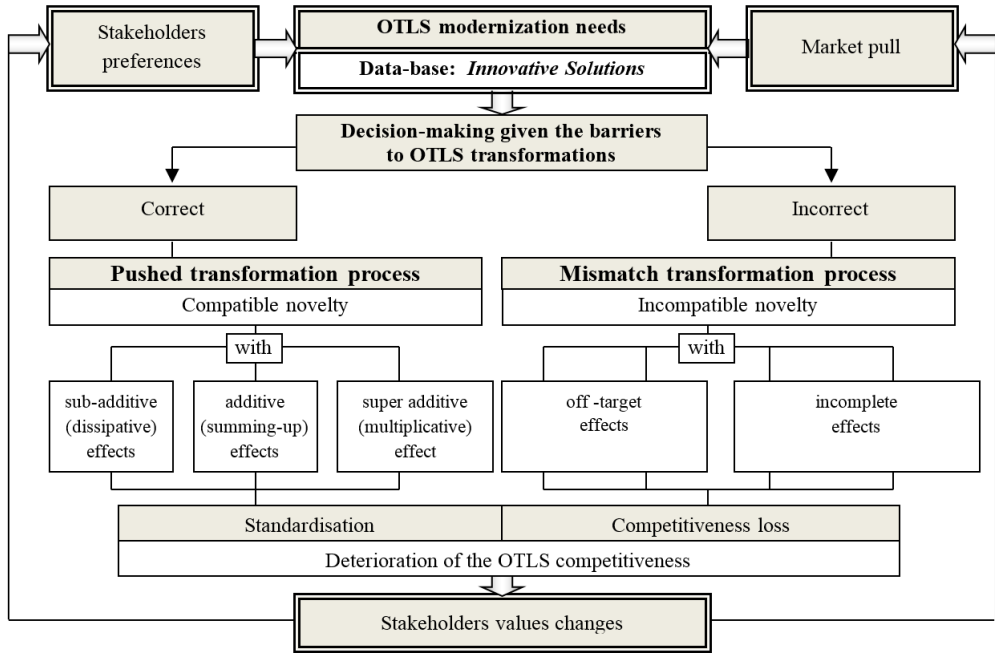


Fig. 6. Conceptual innovative sequence of the OTLS transformation

The presented approach should help to reduce modernization risk or destruction threats for renovated system as a result of the imprudent innovative decisions.

Consequently, the process of modernising each TLS begins with the development of a concept, core assumptions and general goals that forms innovative investment decisions. Setting of clearly defined goals will help to create the basic procedures.

### 3.2. The modernization principles

The OTLS modernization processes are based on two rules. First, each OTLS should be assembled by CSG techniques and connected together in order to carry out the set functions. Second, the achieved results must be assessed step-by-step. These two rules support correct decision-making based on two basic principles:

*Principle 1.* Innovation-based components introduced into the OTLS should interact with standard-based components embedded into that system earlier. If the resulting composition is non-interoperable, then the new component should be excluded, because the target OTLS cannot continue

to exist under the formed conditions, or all components should be co-evolved and, as a result, mutually adapted within the system.

*Principle 2.* If the OTLS is under transformation then all phenomena that occur within the technical system should have requirements changed and as a result, the composition of this OTLS will be modified.

Regarding continuous market changes, OTLS almost constantly is under one of the so-called transitive conditions, described by critical parameters of SC (*Structural Compatibility*) and FI (*Functional Interoperability*). Moreover, the larger the variety of topological compositions is allowable for system structure which is in transitive condition, the more likely the target system is able to adapt to external impacts.

Following the above-mentioned argumentation, the authors propose the five-steps procedure of converting a renewal task into improved transport structure:

*Step 1.* Identification of OTLS modernization problem. Obsolete elements are labeled, as well as possible solutions are identified.

*Step 2.* Identification of relations between the OTLS elements. Both direct and indirect interactions, as well as binary operations for heterogeneous coalitions selection are indicated.

*Step 3.* OTLS hierarchy development, i.e. the OTLS elements composition order. Authors suggest using algebraic topology for innovative coalitions integration into the OTLS structure.

*Step 4.* Innovative elements implementation. Improvement process combines step-by-step analysis of SC & FC between innovative and obsolete coalitions with accepted or non-accepted changes within the OTSL structure.

*Step 5.* Approval of the strategy of large-scale commercialization for the upgraded OTSL. This step finishes the procedure and isn't considered in presented paper.

The idea of using the topology as an optimization tool for structural analysis of the artificial systems has been proposed by Kost B. (Kost, 1995). On the other hand, Levin M. (Levin, 2015) has explored the concept of upgraded system structure constructed from previously selected elements. According to mentioned publications, the topology of each OTLS can be described as the skeletal diagram shown in Fig.7

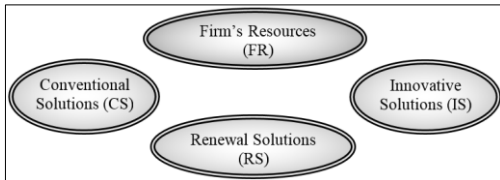


Fig. 7. Basic coalitions of the typical OTLS with uncertain connection state

The topology of each hybrid system is defined on a fixed planar grid with few-components. In our case, OTLS, as multilayer structure, is made from separate coalitions of engineering solutions. Such solutions are grouped into CS (*Conventional Solutions*), IS (*Innovative Solutions*) and RS (*Renewal Solutions*). Considering the OTLS as a hybrid system, we are dealing with the complex problem, because:

- modernisation process is performed on multilayered structure (Fig. 8),
- the success of modernisation process depends on designer's knowledge and skills.

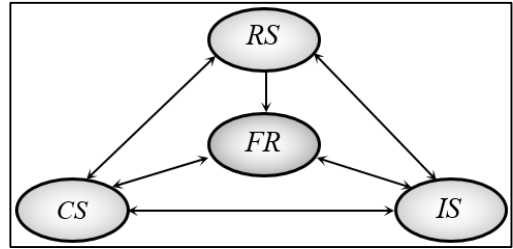


Fig. 8. Basic coalitions of the typical OTLS with certain connection state

Regarding this problems the following situations for OTLS modernization can take place:

- 1) **Absolutely uncertain situations** when the designer doesn't possess any information about desired innovation. In this case, CS is replaced by RS. Such solutions are called *BF (Braking Factors)*, and consequently increase the regressive trends in the OTLS development. The *BF* elimination is possible due to the strengthening of the modernising strategies and best transport practices implementation.
- 2) **Partial uncertain situation** when the designer possesses only partial information about desired innovation. However, final solutions are connected with the high risk and depend on top-management decisions and available assets.
- 3) **Certain situation** when the designer has complete and reliable information about desired innovation, as well as diffusion of the desired innovation has stable behavior.

### 3.3. The topological approach to meso-level modernization

Let's assume that typical OTLS is a hypothetical construct that represents a multi-layer complex and consists from conventional component-based coalitions achieving a particular obsolete level. The actual demands imposed by transport and logistics tasks during their performance may be modified by many factors (e.g., the increasing competition, new legal norms, various technical defects, client's wishes) that require the system modernization. Such changes the most commonly appear on the OTLS meso-level. Let's particularize the above-mentioned steps of the OTLS modernization on chosen structure example (Fig. 9):



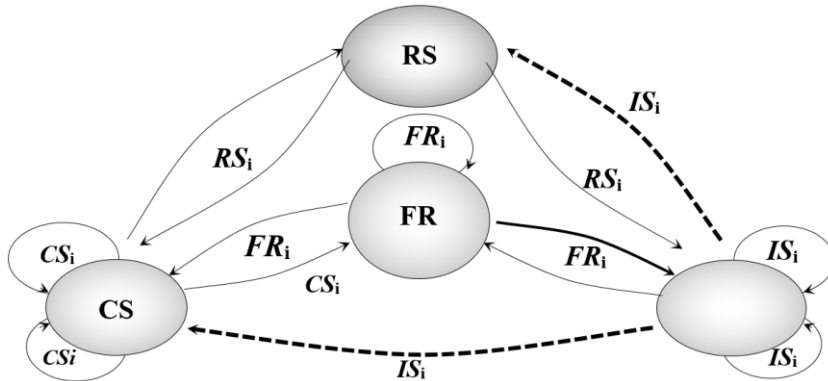


Fig. 9. The topological diagram of typical ways for OTLS modernization

**Step 1.** Identification of outdated elements and modernization/adaptation activities. The following actions between basic coalitions can be recognized:

A. The CS – coalition:

- Link  $CS_1$  – labeling obsolete components;
- Link  $CS_2$  – marking interrelated components;
- Link  $CS_3$  – evolving standardization norms;
- Link  $CS_4$  – reconditioning conventional solutions.

B. The IS – coalition:

- Link  $IS_1$  – testing before implementation;
- Link  $IS_2$  – evolving structural & functional effects;
- Link  $IS_3$  – marking PZSI (*Zone of Structural Incompatibility*);
- Link  $IS_4$  – marking AFNI (*Area of Functional Non-Interoperability*);
- Link  $IS_5$  – elimination of the detected incomplete effects.

C. The RS – coalition:

- Link  $RS_1$  – renovating obsolete components;
- Link  $RS_2$  – renewing database of innovative solutions;
- Link  $RS_3$  – changing of operation mode.

D. The FR (*Firm's Resources*):

- Link  $FR_1$  – improving adaptation techniques;
- Link  $FR_2$  – permanent control of capital & operating expenditures;
- Link  $FR_3$  – decision-making support.

**Step 2.** Identification of coalitions relations within the OTLS.

Each OTLS could be defined as orderly set coalitions and relationships between them. Then

typical OTLS will be described as multilayered topological structure (Fig. 9), which contains:

- three pairs of the inter-coalitions relationships:

$$(CS_i - RS_i); (FR_i - CS_i); (IS_i - FR_i); \quad (1)$$

- three pairs of the self-oriented relationships:

$$(CS_i); (FR_i); (IS_i); \quad (2)$$

- two pairs of the single-oriented relationships namely  $IS_i$  links.

Usually, the modernisation process is realised via three techniques:

1) Firstly, the technique for creating future-oriented OTLS through the replacing conventional solutions by innovative solutions. This replace is possible as:

1.1) Direct change of conventional solutions by innovative solutions:

$$FR_i + IS_i = OTLS_{i+1} \quad (3)$$

1.2) Indirect change of conservative solutions by new solutions ( $IS$  to  $RS$  and  $RS$  to  $CS$ ):

$$FR_i + IS_i + RS_i = OTLS_{i+1} \quad (4)$$

2) Secondly, the technique for creating modern OTLS through the replacing conventional solutions by renewal solutions:

$$FR_i + CS_i + RS_i = OTLS_{i+1} \quad (5)$$

3) Finally, the technique for increasing number of conventional solutions through innovative and renewal standardisation:

$$FR_i + RS_i = CS_{i+1} \quad (6)$$

To conclude, decision-maker determinates two groups of modernization procedures:

- the procedures of evolutionary process, mapped as:

$$FR_i + IS_i + OTLS_i = OTLS_{i+1} \quad (7)$$

- the procedures of co-evolutionary process, mapped as:

$$(IS_i - FR_i) + (RS_i - FR_i) + (RS_i - IS_i) = OTLS_{i+1} \quad (8)$$

**Step 3.** The hierarchy of the upgrading process.

Let's create topological sequence for the possible transformations within the OTLS. For that purpose we use the skeleton diagram (Fig. 9) and apply modernization procedure assuming that this system is upgraded at the component level only. Firstly, such procedures are used for each coalition separately, and secondly - for inter-coalition relations.

**Step 4.** Innovative elements implementation.

We should consider each vertex of our framework through the sequence of elementary processes describing implementation of innovative elements, under condition of authentic cohesion of the target OTLS (shown in Figure 10).

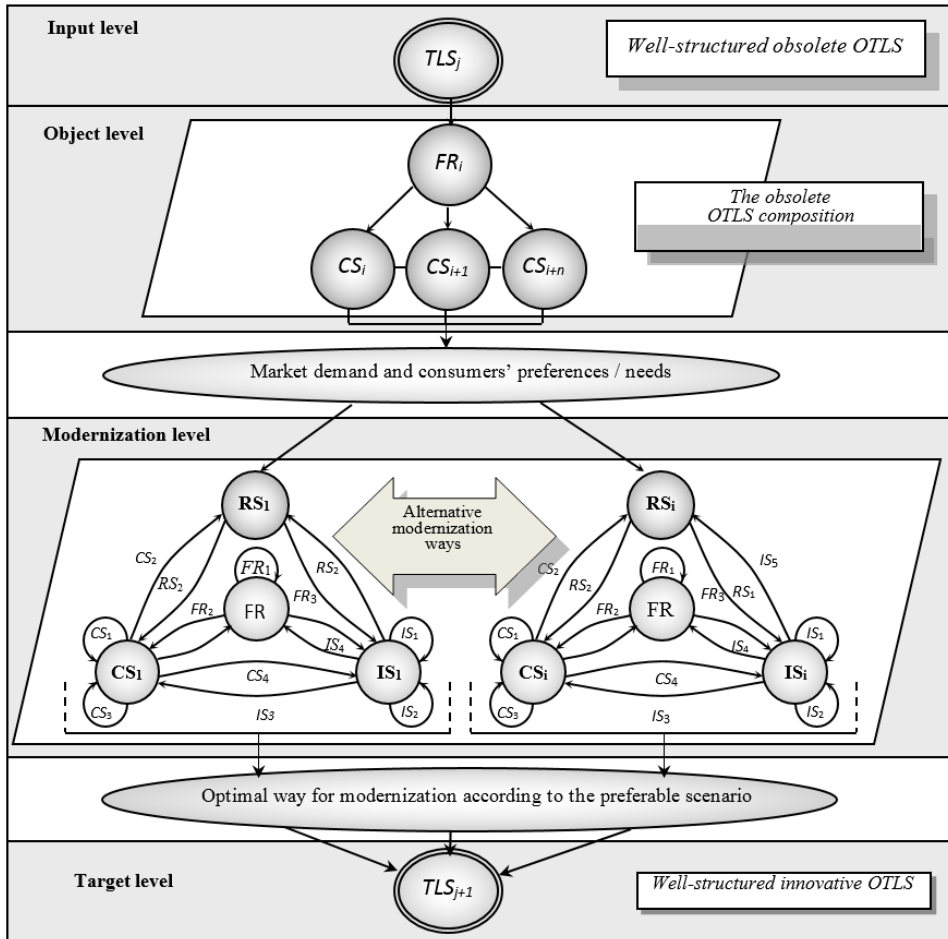


Fig. 10. The conceptual framework for the OTLS modernization sequence

#### 4. Proof - of - Concept study

The studies conducted by authors were divided into three related tasks:

- 1) Establishment of the state-of-the-art in the extent of SECA requirements;
- 2) Assessment of success factors, barriers and transferability effects of innovative solutions;
- 3) Development of the approach to integrate standard and innovative components within the obsolete MPSs (*Marine Propulsion Systems*) under condition of cohesion.

##### 4.1. Explored innovative solutions

Let's consider innovative solutions implementation in shipping industry in viewpoint of modernisation of marine propulsion, cleaner fuels and green technology introduction. There are many factors affecting choice of the suitable ship emissions reduction method, which include ship type, power rating, economic issues, adaptability, and compliance with the current and future emission regulations. The authors have studied the basic ones (Table 2).

##### 4.2. Explored barriers to innovative solutions

In order to foster innovation competition dynamics and attenuate systemic failures, it is important to identify the multiplicity of barriers faced by future-oriented companies. According to several authors (Løvdal and Neumann, 2011; Semenov, 2008) barriers for maritime business innovation are identified within the multidimensional framework along the five groups of causes, namely technological, financial, legal, market and management specifics. Furthermore, most of identified barriers emerge or tend to aggravations between shipping and shipbuilding industries. The results of conducted research are shown in Table 3. The research revealed that:

- technological barriers represent the most numerous group (26.6%);
  - financial barriers form the second largest group (25.2%);
  - the least onerous barriers are legal barriers (4.8%).
- On the other hand:
- fuel-related technology is easy to implement in shipping operations (15.6%);
  - maximum level of complication in new technology implementation regards the dual fuel engine technology (31.9%).

Table 2. Chosen examples of innovative solutions

No	Innovative solution	Characteristics
1	Fuel-related technology: <i>Selective catalytic reduction (SCR)</i>	SCR is a simple, cost-effective NOx reduction solution. The technology uses a simple chemical reaction to neutralise the NOx in the exhaust. Consequently, a NOx limit of less than 0.5 g/kWh can easily be achieved. The investment costs are between 15 and 70 EUR per kW engine power. It depends on engine size and the number of engines per ship. The running costs are mainly driven by the cost for the urea solution. In general, running and maintenance costs are between 5 and 7 EUR per MWh engine power.
2	Engine tuning technology: <i>Fuel-efficient engines (FEE)</i>	FEE technologies implementation can help ship engines potentially reduce emissions by 40%. Such vessel should be equipped with latest energy efficient technologies: an exhaust gas by-pass system, a ballast water treatment system, an electronically-controlled engine that can reduce NOx emissions.
3	Exhaust cleaning technology: <i>Scrubbers (ECT)</i>	A scrubber is a system that uses seawater and chemicals to remove sulphur from engine exhaust gas. The scrubber uses a chemical reaction to neutralize the SOx present in the exhaust gas. The price for installing a scrubber on a ship typically ranges from EUR 1 million to EUR 5 million per ship, depending on the size of the vessel. SWECO AB* estimates the market for scrubbers and stated that 350 ships have adopted the technology by January 2015. Scrubbers can be included in new ships or retrofitted into existing vessels.
4	In-engine technology: <i>Dual fuel engine (DFE)</i>	Another option for shipping companies trying to reduce their sulphur emissions would be to opt for low-sulphur fuel. Low-sulphur fuels are typically marine fuels with a sulphur content that is much lower than heavy fuel oil, which has a sulphur content up to 4.5%. Therefore, the use of low-sulphur fuel is the best solution as it requires limited initial investment costs.

\*SWECO AB (originally "Swedish Consultants") is one of the larger European engineering consulting companies, active in the fields of construction, architecture, and environmental engineering.

Source: *Andreasen and Mayer (2007); Chryssakis et al. (2014); IACCSEA, (2012); Lamas et al. (2013); Seddiek and Elgohary (2014).*

Table 3. Barriers to meet SECA requirements

Barriers	Causes	Innovation types (%)				Total (%)
		SCR	ECT	FEE	DFE	
Technological barriers	<ul style="list-style-type: none"> <li>•Structural incompatibilities,</li> <li>•Functional non- interoperability,</li> <li>•The lack of experience,</li> <li>•Producing incompatibilities.</li> </ul>	5.5	6.1	6.9	8.1	<b>26.6</b>
Financial barriers	<ul style="list-style-type: none"> <li>•The lack of financial access,</li> <li>•Poor financial background,</li> <li>•High cost of renovated propulsion system.</li> </ul>	2.3	6.8	7.8	8.3	<b>25.2</b>
Legal barriers	<ul style="list-style-type: none"> <li>•The lack of patents portfolio,</li> <li>•Prohibitive legislations,</li> <li>•Strong licensure laws etc.</li> </ul>	1.7	0.6	1.1	1.4	<b>4.8</b>
Market barriers	<ul style="list-style-type: none"> <li>•Opposition of competitors,</li> <li>•Limited market capacity,</li> <li>•The lack of demand, etc.</li> </ul>	3.3	5.2	6.4	7.6	<b>22.5</b>
Management barriers	<ul style="list-style-type: none"> <li>• The incorrect forecast,</li> <li>• The lack of ambitions,</li> <li>• The resistance to changes,</li> <li>•The lack of skilled human resources.</li> </ul>	2.8	4.2	7.4	6.5	<b>20.9</b>
<b>Total</b>		<b>15.6</b>	<b>22.9</b>	<b>29.6</b>	<b>31.9</b>	<b>100</b>

Source: Authors research on the basis: Godfrey (2008); Hölzl and Janger (2011); Roithmayr (2000); Semenov (2008)

#### 4.3. Methodological base for the assessment of innovative solutions compatibility

In order to assess possible effects of two element-based coalitions connection, we propose to determine the three levels of innovative solutions compatibility (Table 4). The interaction of coalitions was investigated distinguishing:

- 1) Highly compatible coalitions, where two standard coalitions are considered and their interaction contributes to increase of the conventional OTLS efficiency.
- 2) Coalitions interaction that affects the need of radical changes in the OTLS structure. In this case the standard and innovative coalitions are connected. Heterogeneity of coalitions structure causes insufficient capability of OTLS, therefore structural changes should be made.
- 3) Incompatible coalitions, where two incoherent coalitions interaction is analyzed.

Each of mentioned group of innovative solutions used in modernisation of MPS was analyzed in detail and the relationships between particular element-based coalitions were investigated.

#### 4.4. The early-stage results

Conducting the research on coalitions fitting the authors received introductory results. The topological approach was used to analyze the retrofitting of MPSs. The space of simulation results was broken down by four subspaces shown in Fig. 11, wherein:

- two subspaces (matched as 2, in Fig.11) are covered by ZSI (*Zone of Structural Incompatibility*), where so-called incomplete effects of retrofitting process are located;
- one subspace (matched as 1, in Fig.11) is covered by ZFC (*Zone of Full Compatibility*), where on-target effects of retrofitting process are set;
- one subspace (matched as 3, in Fig.11) is covered by AFNI (*Area of Functional Non-Interoperability*), where off-target effects of retrofitting process take place.

Analyzing the research results (Fig. 11) it can be stated that each modernisation iteration have different innovative effects. On-target effects are achieved within ZFC of coalitions fitting, while off-target effects are specific for AFNI.

Table 4. Domains describing the levels of innovative solutions compatibility

Graphical illustration	Comment
	<p>1. <i>Task</i>: two coalitions connection                  2. <i>Nomenclature</i>:  <math>\phi_1(t)</math> = potential of the 1-st coalition,  <math>\phi_2(t)</math> = potential of the 2-nd coalition,  <math>\Sigma\phi_{1,2}</math> = innovative ship potential,  <math>\alpha</math> = compatibility level,  <math>\beta</math> = incompatibility level</p>
<p>1. High compatibility level of the two coalitions</p>	
	<p>1. <i>Modernization stage</i>:                  Implementation and connection of two compatible coalitions                  2. <i>Evaluation</i>:  <math>\beta = 0</math>                  3. <i>Conclusion</i>:                  On-target effect</p>
<p>2. Partial compatibility level - PZSI (<i>Partial Zone of Structural Incompatibility</i>)</p>	
	<p>1. <i>Modernization stage</i>:                  Implementation of innovative coalition connected with standard coalition                  2. <i>Evaluation</i>:  <math>\beta &gt; \alpha</math>                  3. <i>Conclusion</i>:                  Incomplete effect</p>
<p>3. Incompatibility level - AFNI (<i>Area of Functional Non-Interoperability</i>)</p>	
	<p>1. <i>Modernization stage</i>:                  Implementation of innovative coalition connected with standard coalition                  2. <i>Evaluation</i>:  <math>\alpha = 0</math>                  3. <i>Conclusion</i>:                  Off-target effect</p>

Figure 11 presents one of the tested sequences of the modernisation process for the obsolete MPSs. The conducted research in this subject area revealed incompatible innovative and standard coalitions, where 18% of structural compatibility and 12% of functional interoperability were indicated.

The research results were also grouped into six categories determined by various factors, e.g. kinds of innovative activities and expected effects, compatibility of innovative and outdated coalitions, etc. (Fig.12).

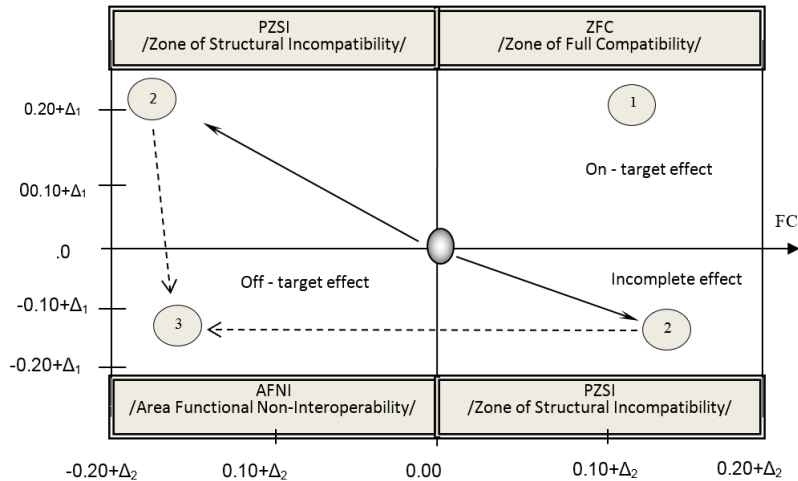


Fig. 11. The subspaces of innovative effects (research fragment)

Each of the selected solutions for modernisation of marine propulsion should be based on relevant and actual information about goals and different advantages/disadvantages of particular solutions (Tables 1 and 2).

#### 4.5. Results of compatibility and interoperability analysis

The compatibility analysis is required to assess the feasibility of using the competing innovative coalitions. Specific details of the implementation options regarding innovative marine propulsion systems are currently not validated. Therefore, our research considers only compatibility of the innovative and outdated coalitions.

The overall study addresses two aspects of current MPSs. In introduction part, SCR, FEE, ECT and DFE are considered. The first aspect relates to current MPSs as obsolete and aims to define the appropriate spectrum of perspective innovation solutions. The second one considers the current MPSs as interferers and aims to evaluate the impact of innovative coalition to current coalitions within MPSs.

The criteria identified in this paper are based on the current expected operating conditions of the new MPSs, including protection and susceptibility criteria for the maritime industry modernization. They regard such issues as i.a. emission limits for sulphur content (no more than 0.10% from 1<sup>st</sup> January 2015, against the limit of 1.00% until

31 December 2014), as well as expectations of the structural and functional parameters.

New MPS must be tuned to tolerate interference from other ship systems to operate in different sea conditions. Such systems should have compliance at levels exceeding the 99.9% for functional parameters, and 100% for the structural parameters. In order to choose the best upgraded solution the following steps may be used:

1) The objectivities choice and analysis. It should be based on the 2030 Agenda for Sustainable Development (introduced by the United Nations in September 2015 (IMO, 2016)), i.a. the goal 9 to “build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation”. The objectivities spectrum should include:

- *structural compatibility* - coincides with the objective of the structure integrity;
- *functional interoperability* - coincides with the ability of few coalitions to operate effectively and efficiently together;
- *capital expenditure* - coincides with costs to acquire or upgrade productive assets;
- *operational expenditure* - coincides with lifecycle cost;
- *maintenance cost* - the costs associated with keeping propulsion system in good condition by regularly checking it and repairing it when necessary.

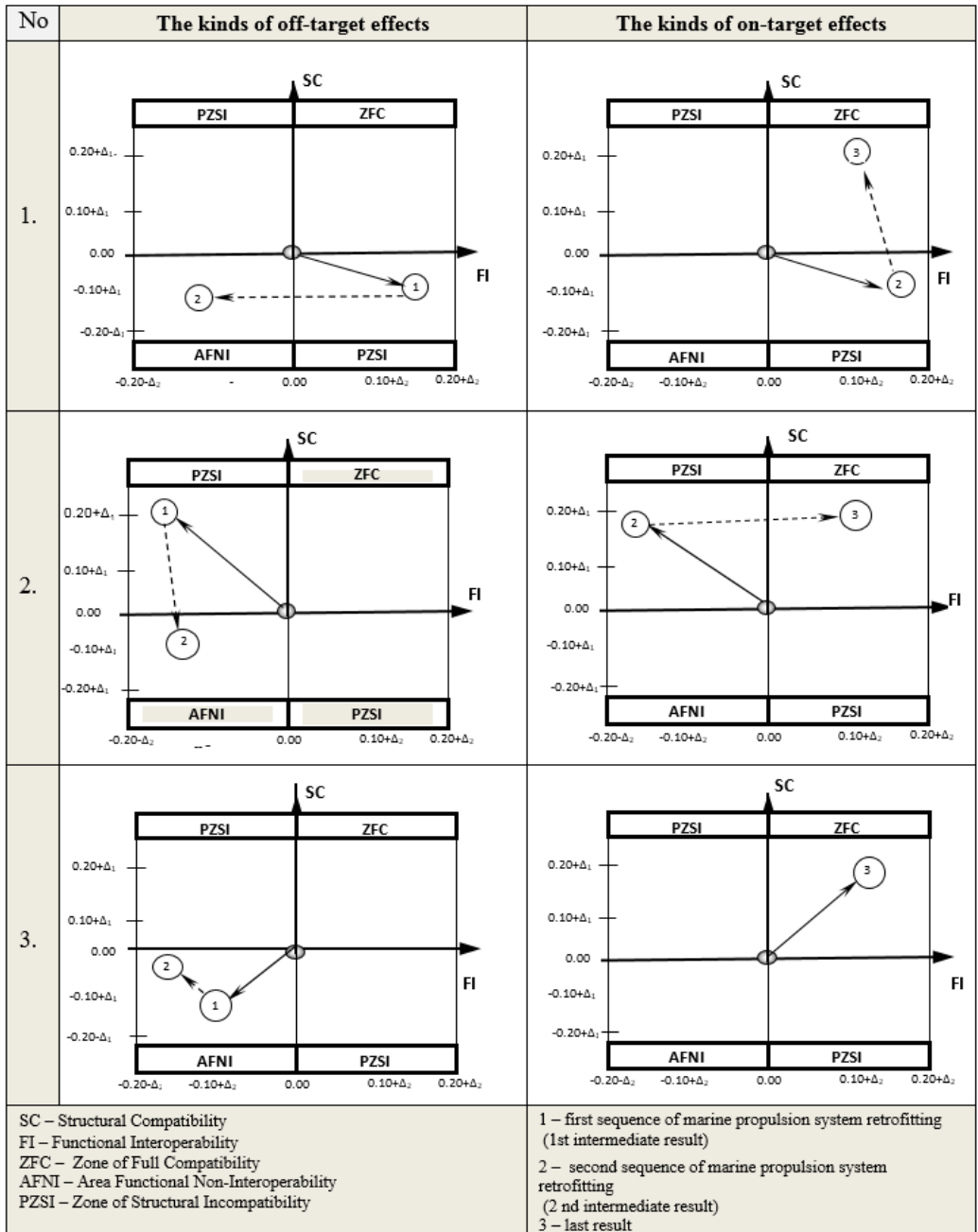


Fig. 12. Possible variants of predicted and unforeseen effects of innovative solutions implementation

2) Realization of two-step upgrading and assessment procedures:

- Using the set of six categories proposed earlier (Fig. 12) to analyse the possible modernisation situations. We propose to assess the upgrade effectiveness of modernisation according to structural compatibility and functional interoperability.
- To carry out next phase of upgrading and assessment of the MPS modernization according to selected measures, including “*Capital*

*expenditure*”, “*Operational expenditure*”, “*Maintenance cost*”.

3) Choice of the best upgraded solution.

The intermediate results based on the simulation tests of the structural compatibility and functional interoperability of MPSs after implementation of innovative solutions are given in Fig. 13. Assessment of the upgrade effectiveness of modernisation according to structural compatibility and functional interoperability give us only intermediate results.

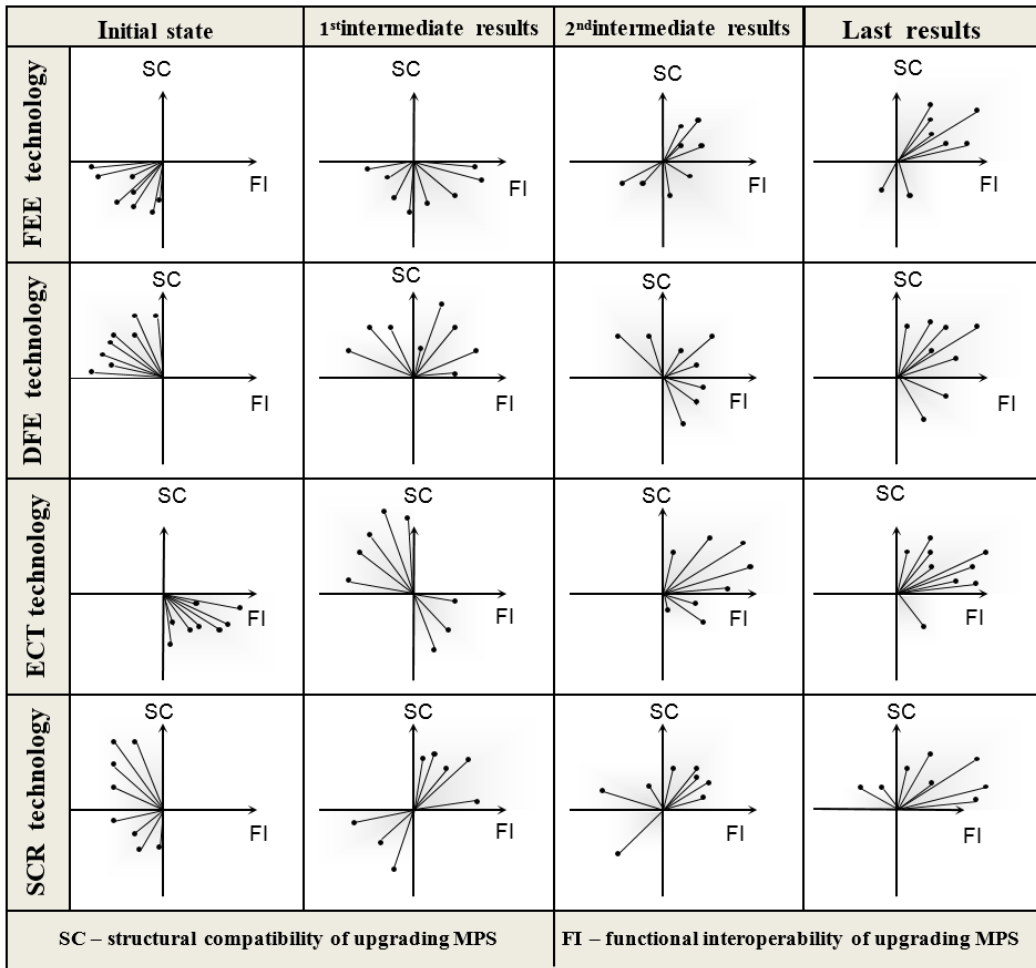


Fig. 13. Boxplots intermediate results of first step modernization for marine propulsion system



Below there are the results of the comparative analysis of four investigated innovative solutions according to selected financial measures. The calculations were carried out in accordance with Ventura M. (2017), where the following three measures were investigated:

1) Capital expenditure:

$$C_m = 1.6 \times \left(\frac{P_B}{100}\right)^{0.82} \times m_M + CF_M \text{ [USD]} \quad (9)$$

where:

$P_B$  – propulsive power (MCR) [kW],  
 $m_M$  – unit cost of the machinery [USD /kW],  
 $CF_M$  – installation and alignment cost of the machinery [USD].

2) Maintenance & repair cost:

$$C_{M\&R} = k_1 \times C_0 + k_2 \times P_{MCR}^{0.66} \text{ [USD/year]} \quad (10)$$

where:

$C_0$  – cost of the ship [USD],  
 $P_{MCR}$  – propulsive power [hp],  
 $k_1, k_2$  – coefficients that depend of the type of propulsion plant ( $k_1 = 0,0035$ ;  $k_2 = 125$ ).

3) Operational expenditure:

$$C_{SUP} = k_1 \times N + k_2 (Lpp \times B \times T)^{0.25} + k_3 \times P_{MCR}^{0.7} \text{ [USD/year]} \quad (11)$$

with:

$Lpp \times B \times T$  – cubic number [m<sup>3</sup>],  
 $P_{MCR}$  – propulsive power [hp],  
 $N$  – crew number [persons],  
 $k_3 = 150$  (steam turbine),  
 $k_3 = 250$  (diesel engine, 4 stroke),  
 $k_3 = 200$  (diesel engine, 2 stroke),

$k_2 = 4,000$  (freight ship),  
 $k_2 = 5,000$  (tanker),  
 $k_1 = 3,500$ .

The results of comparative analysis as three vertical bar charts are given on Fig.14.

### 5. Summary and Outlook

Innovation activity has become a key factor for gaining competitive advantages on the transportation and logistics market. Transport industry developed and is developing a wide range of innovative concepts to make transport systems more efficient and competitive. Such activities are focused on management of thematically connected innovative projects.

The authors studied a wide range of innovative solutions for cleaner inland and short sea shipping including fuel-related technology, engine tuning technology, exhaust cleaning technology and dual fuel engine. Research was based on expert groups interviews, as well as desk research of good practice examples. During the research it was found that desirable and undesirable retrofitting effects take place and despite of significant advancement there are numerous barriers for the large-scale implementation of achieved innovative solutions.

Explored aspects are dealing with structural and functional compatibilities required to be successful in ships' modernisation to meet SECA requirements now and in the future. The results show that fuel-related technology and water scrubber systems installed on-board ships are the good methods from the environmental viewpoint. Application of one of them depends on some conditions such as i.a. required emission reduction percentage.

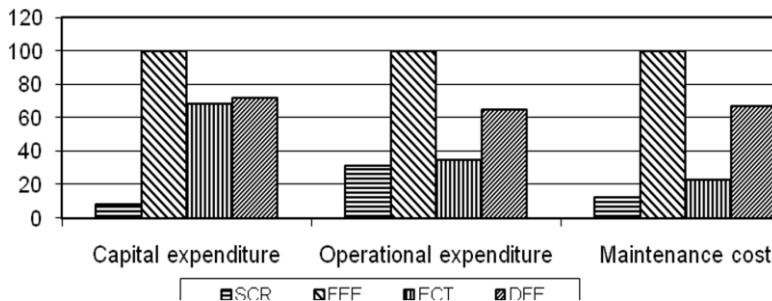


Fig. 14. Comparative profile analysis of evaluated results

Source: Authors research on the basis based on the information contained in the tables 2 and 3.

In authors' option, the dual fuel engine is very competitive technology in long-term perspective when the alternative fuels will be convenient from the market point of view and financial issues.

Achieved results shown that the application of the topological-oriented approach for analysis of the OTLS modernization process is correct. The obtained conclusions are preliminary and will be a subject to further research.

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