The Method of Modelling the Intermodal Network in Poland Using Multi-Agent Systems

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For a dozen or so years, despite a transitional financial crisis, the European Union countries have been observing a steady growth in the movement of goods by road transport. As specified by the European Commission, the share of road transport in total movement of goods (in tkm) in the European countries amounted to 76.9%[1]. Rail transport accounted for as little as 17.6%[2]. This, in combination with the increase in trade in goods, results in the fact that an increasing number of roads reach their maximum capacity and the efficient organisation of transportation processes becomes increasingly difficult or impossible [1, 3, 10]. Moreover, as the authors have observed, enterprises make attempts at fulfilling their customers' orders frequently and quickly, using mainly road transport. The consequence of such an approach is that the enterprises, while improving the processes and increasing customer satisfaction in short term, may contribute to their deterioration in long term. It should be noted that frequent and quick deliveries require more means of transportation which in turn boosts traffic congestion and deterioration of road safety. The growing congestion results in the decrease of average driving speed, which eventually extends the delivery time and thus may affect customer satisfaction and, in worst-case scenario, loss of orders [1].

1. INTRODUCTION

The European Commission has been making attempts at tackling the problem of traffic congestion growth and deteriorating road safety by presenting in its documents the strategy of transportation and logistics development. One of the first ideas published in the White Paper was to increase the share of alternatives to road transport, in particular rail transport. Also intermodal transport was stressed, meaning freight transport in which the goods are moved by various modes of transport. In the intermodal transport, the goods are moved in the same loading unit or vehicle, along the entire route from the sender to the receiver, without transshipment of goods, using various modes of transport. The vehicle may of a road or rail vehicle, barge or a vessel. This study presents an innovative approach to the development of the intermodal network in Poland. The chief assumption is to develop a solution that would eliminate the barriers hindering the development of intermodal transport and take into consideration the strong interrelations between the transport subsystem of enterprises (service recipients and providers) and the state transport system.[3]

2. THE INTERMODAL NETWORK IN POLAND

Poland, due to its geographical location, can use practically all transport modes for intermodal transport. However, in practice, intermodal transport using inland waterways does not exist.

[1] http://epp.eurostat.ec.europa.eu, data for 27 EU countries
[2] http://epp.eurostat.ec.europa.eu, data for 27 EU countries

[3] This study is a result of own research no. N N509 398536 called: The Intermodal Logistic Network in Poland - models to follow and implementation conditions" carried out in the Institute of Logistics and Warehousing in Poznañ under the supervision of prof. Leszek Mindur, PhD.

On the other hand, solutions combining maritime and road transport are applied.

Intermodal transport is handled in intermodal transport units, so called UTI (French: Unités de Transport Intermodal), which were codified by European railways. These units include: containers, swap bodies and semi-trailers. It should be added that over 98% of goods are transported in containers[4].

In the organisation of intermodal movement of goods, the efficient linear transport infrastructure and transport nodes are necessary. In the case of Poland, this should cover good quality railways and a network of container terminals allowing the transshipment of a unit between the modes of transport.

Over the last 5 years a significant 50% increase in the number of container terminals in Poland could be observed.

Figure 1 presents the location of the 30 container terminals which facilitate the transshipment of intermodal UTIs. These terminals are the property of various business entities which often have capital relations. An example of such a enterprise may be PKP Cargo S.A. and CargoSped Sp. z o.o. or PCC Port Szczecin and PTK Holding S.A. There are also undertakings of local companies.

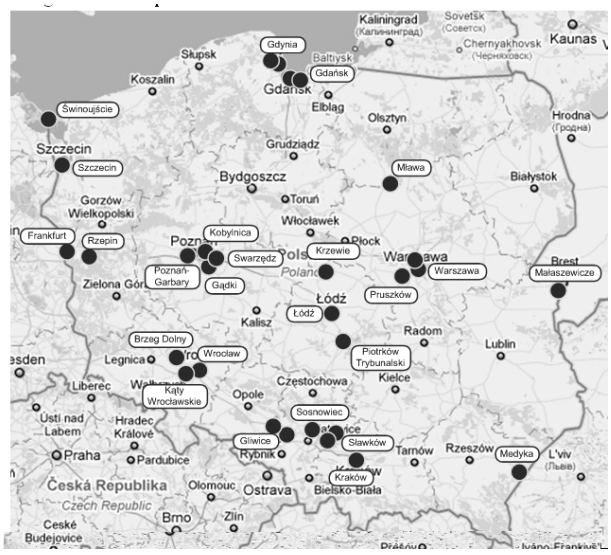

Figure 1 The network of container terminals in Poland
Source: Own study, map: http://mapy.google.pl/

Unfortunately, despite a considerable development of transport nodes in Poland, the share of intermodal transport in rail transport based on the data of Central Statistical Office, PKP Cargo and PCC Intermodal accounts for app. 2.5% - 3%. At the moment most containers from Polish seaports are transported by road (app. 80%). In 2008 four ports (Gdańsk, Gdynia, Szczecin, Świnoujście) transshipped the total of 859,183 TEUs, which is by 20% up against the total number of containers transported intermodally in Poland. Similar is the situation with transporting containers to Poland from chief European ports, such as Rotterdam, Hamburg or Bremerhaven, where in 2008 almost 650k TEUs were transported to or from Poland by road5. Hence the market is a high-potential one and the volume of intermodal transport may in foreseeable future grow up to app. 10-15%. However, further development is required, as well as upgrade of both transport nodes and linear logistic infrastructure. These changes, due to their key importance to the growth of intermodal transport, should also be a priority for national, regional and local authorities. Activities related to the removal of a number of barriers hindering the development of intermodal transport are particularly important.

The development of the intermodal transport in Poland requires that actions to eliminate the existing barriers and supporting (promoting) actions be undertaken.

The main actions to eliminate said barriers include:

Barrier: relatively low quality of railroad services

Eliminating actions:

- upgrade of the AGTC railways;
- shortening the regular travel time of trains with intermodal units;
- assuring scheduled travel times of trains;
- monitoring the connections and assuring up-to-date information on packages for customers.

Barrier: lack of price competitiveness as compared to road transport

[4] Maciej Mindur "Transport Europa – Azja". Wydawnictwo ITE-PIB, Radom-Warszawa 2009

[5] Przewozy Kontenerowe w Polsce (Container Transport in Poland), Polska Gazeta Transportowa magazine, 2009-11-26

Eliminating actions:

- flexible price and discount policy of PKP,
- state budget subsidies for operators to co-finance the costs of combined/intermodal transport;
- income tax benefit for companies using combined/intermodal transport;
- income tax benefits for terminal operators;
- exemption from the motor vehicle tax for road carriers drop-off/pick-up of loading units from and to terminals
- measures to limit the demand for long distance road transport of goods.

The fact that it is difficult to assure a significant development of the combined/intermodal transport without state aid (in particular financial assistance) has been proved in EU states, in particular those which play a leading role on the combined transport market in Europe. These states assumed, following the recommendations of the EC Commission, that this transport mode should be promoted before the competitive conditions between the road and rail transport are balanced.

Hence, in view of the authors, before the competitive conditions between the transport modes are balanced, in particular by internalising external costs of transport and harmonising the fees for using the transport infrastructure, at least strategic connections in the combined transport infrastructure should be financially supported by the state, which would result in the development of a stable transport network and reduction of transport cost in this technology as well as the adaptation of the market to such a system.

The economic instruments supporting the development of combined transport include state financial aid related to AGTC upgrade and capital investments in specialised rolling stock.

When selecting the instruments to support combined transport, one should take into consideration the factors provided for by the Act on the Regional Development Support Principles. This applies in particular to investments in linear infrastructure and transport nodes which largely comprise an element of regional policy. It is also important to strengthen the actions of local self-governments and regional authorities to create a logistics centres infrastructure with intermodal terminals connected with road and rail infrastructure.

The experiences and achievements of other countries in the development (of intermodal transport) show that an effective and consistent state transport policy is required, under long-term programmes for the development of combined/intermodal transport.

The significance and role of the programme in transport development in Poland has been discussed by many experts, thus making the Ministry of Infrastructure the initiator and supervisor of Programme's implementation. This confirms the statement that the future of combined transport in Poland will be decided by consistent implementation of the long-term Combined Transport Development Programme (Program Rozwoju Transportu Kombinowanego) with full commitment of the state.

The tasks under the Intermodal Transport Development Programme should be implemented in parallel by the Ministry of Infrastructure and all entities operating on the transport market. Concurrently, the role of the Ministry, as a state authority, should focus on:

1. implementation of instruments promoting intermodal transport
2. creation of legal bases for granting a global and comprehensive state aid for the intermodal system, i.e. the creation of conditions conducive to the development of transport in Poland and it will be up to the enterprises operating on the market whether the provided opportunities are fully put to use.

This would considerably strengthen the role of the Ministry of Infrastructure in the process of strategic planning of transport development thus creating a chance to integrate various modes of transport and to develop intermodal transport under the integrated transport system in Poland.

Barrier: technical

Different track gauges in Europe.

- Various traction power supply voltages in individual EU states.
- Unfavourable rates for access to rail infrastructure for intermodal operators (in

2009 the rate, in line with the intermodal tariff, amounted to PLN 5.44 per km, and in 2010 it was as much as PLN 12.32 per km).

On the other hand, supporting (promoting) actions include:

- setting up combined/intermodal networks in Poland, supported out of public aid, as the first stage of building a modern logistics and transport infrastructure;
- building logistics centres and upgrade of intermodal terminals located in seaports and in the AGTC railway network;
- assuring the harmonisation and standardisation of intermodal loading units;
- development of intermodal transport to/from Scandinavia;
- commissioning and development of regular container line along the E-WE-E line using the Trans-Siberian Railway.

Concurrently, the operators on the combined transport market should focus on making the offer of this transport mode more attractive, e.g. by means of:

- assuring the regular passage of trains with intermodal loading units in line with the timetable and with travel time competitive to road transport;
- reduction of service time of intermodal units at terminals;
- ongoing monitoring of all lines using IT systems;
- assuring more effective marketing and promotion of combined transport;
- steady cooperation with local and regional authorities in developing the intermodal terminals infrastructure and logistics centres.

Based on their analysis, the authors have concluded that there is a multifaceted research issue consisting in the lack of a coherent method of developing the intermodal network in Poland. This method should include strong relations between transport subsystems of transport users, transport service providers and the transport system of the country or a region they operate in. In addition, this method should be consistent with the concept of sustainable development, i.e. taking into account the economic, environmental and social factors.

The method developed by the authors should allow the coordinated actions aimed at the development of intermodal network and elimination of identified barriers. These actions, as the research has shown, are at the moment being carried out individually by various business entities and public administration. Thus, the basic concept underlying the developed method is the coordination of individual actions and indication of the meeting point between entities.

The authors, analysing the methods to solve thus formulated research problem, concluded that the devised solution to develop intermodal network in Poland should, in its assumption, relate to multi-agent systems. These systems assume coordinated actions to solve a specific problem using cooperating agents (holons), in this case entities connected with intermodal transport in Poland [8, pp. 251-252; 9, pp. 39]. The following section presents a detailed description of multi-agent systems and the rationale for their application.

3. MULTI-AGENT SYSTEMS

By analysing the needs of individual entities involved in the development and organisation of intermodal transport in Poland and strong relationships between them, the authors assumed that the said entities, both public and private, should function as a holonic organisation. This gives a possibility to take an innovative approach to the implementation of business processes by creating open, reconfigurable organisations which share the common aim of accurate emulation of market and business environment changeability [2120, pp. 538-550]. Holonic organisations are small, decentralised, partially independent entities which are focused on key competences only [9, p. 38]. An example of a holonic organisation is presented in figure 2.

The basic elements of a holonic organisation are holons, i.e. cooperating nodes responsible for gathering, processing, storing and sharing information or physical objects. A holon (also called “agent”) may be a stand-alone entity or a part of a group of holons with a holarchy or a multi-agent system [8, pp. 251-252; 9, p.39]. The

idea behind a multi-agent system is a coordinated action aiming at solving a specific problem by cooperating agents (holons). Agents may include major or specialised participants, e.g. an agent searching the best offers, negotiating agent, verifying agent etc. [[8], pp. 251-252; [9], p. 39].

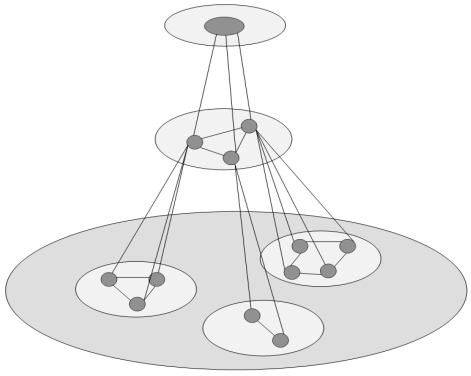

Fig. 1 A graphic representation of a holonic organisation
Source: Own study based on [9, p. 39].

From the formal point of view, this research was based on the RA-MAS system (Reasoning About Multi-Agent Systems) the purpose of which is to formalise systems composed of many dispersed and concurrent processes [9]. The RA-MAS system, as a multimodal logic, is based on temporal, epistemic and algorithmic logic. The following modal operators are used [9]:

E - "calculation exists",

X – "in the next calculation state",

G – "in all calculation states",

U – "as long as".

The said operators are parameterised by agent sets. Such an approach also gives an opportunity to specify and analyse the cooperation between various agent groups in the intermodal network (the same multi-agent system or various multi-agent systems) on the basis of a single formal system.

The modality set adopted by the authors makes it possible to describe such local state of agents as knowledge, belief, goal and method. In addition, the metalanguage adopted in the research includes operators describing the dynamics of the agents' actions. The *possible* (A, a) formula means that agent A may perform action a. Formula $\diamondsuit Z\ \alpha$ means that after performing the set of actions *Z*, condition α may be true and formula *ER*β α assures that if all members of β group perform their actions, condition α may be true.

From the point of view of creating an intermodal network, it is extremely important to identify conflicts or barriers limiting its operation and development. To that end the *conf*(Z) formula has been applied, which means that actions composing set Z are in conflict.

The RA-MAS system facilitates clear description of conflicts, which is of particular significance when developing intermodal network (dispersed system). Owing to the application of the said logic, it is possible to identify and describe conflicts and eventually develop solutions.

A conflict may be represented by the following formula:

$\neg ER\{A_1, A_2\} true \rightarrow (possible\ (A_1, a)\ \square\ possible\ (A_2, b) \rightarrow conf\ (\{a,b\}))$,

which presents a situation in which agents A_1, A_2 cannot perform their tasks a and b simultaneously as they are conflicting. The next section presents in detail the concept underlying the method of developing the intermodal logistics network in Poland, based on the multi-agent systems specified above.

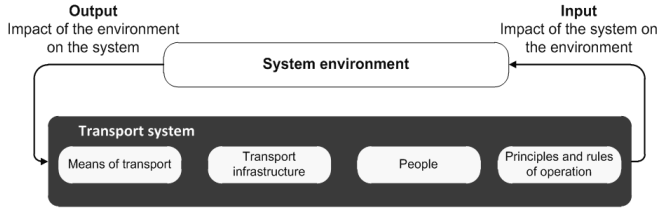

Fig. 2 Transport system and its environment
Source: Own study

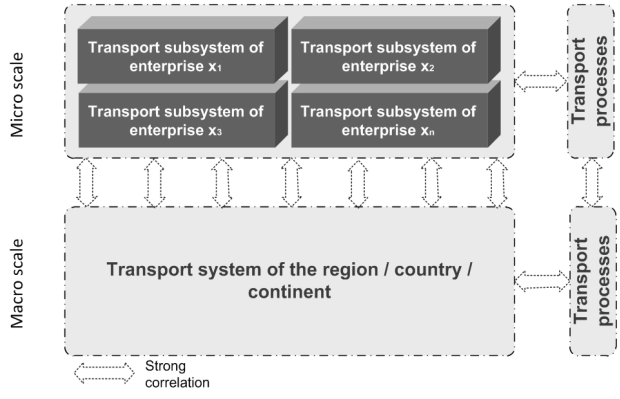

Fig. 3 Dependencies between micro and macro scale transport systems
Source: Own study

4. THE CONCEPT UNDERLYING THE METHOD OF DEVELOPING THE INTERMODAL LOGISTICS NETWORK IN POLAND

The method, in line with the adopted assumptions, relates to multi-agent systems. In the case of the said method, agents are enterprises using transport services, transport service providers and transport process coordinators. It is also worth stating that the intermodal logistics network constitutes an element of a transport system which may be defined as a set made of means transport, point and linear transport infrastructure, people responsible for the operation of the transport system as well as the principles and rules of operation. They are responsible for movement of people and goods from starting points (dispatch points), through potential transshipment points to destination points (reception points). The principles of operation include the principles of traffic movement organisation [[12], p. 12; [13], p. 517; [18], p. 11]. Fig. 3 presents the transport system and its environment.

Hence, having in mind the elements of the transport system, the authors have defined also the additional agent groups responsible for the operation of the transport infrastructure and its principles and rules.

The developed method also defines roles taken on by the participants (agents), dependencies between them and the cooperating companies and the region they operate in. Also strong relations between the micro scale (enterprises) and the macro scale (region) have been included.

Fig. 4 presents the concept underlying the method of developing an intermodal network in Poland using multi-agent systems.

The cooperating entities share information online, using dedicated digital platforms.

In the developed method, the authors have defined five groups of agents who perform dedicated roles (fig. 4):

Transport users – companies dealing with manufacturing and/or sales. Transport is not their core business and is only subsidiary in performance of main goals. These companies may have own means of transportation or cooperate with transport service providers. As transport users they generate transport orders. Contracts for transport are concluded between users and transport service providers.

Transport service providers – enterprises whose core business is the provision of freight forwarding, transport and logistics services. Their task is to satisfy common transport needs of cooperating companies, i.e. transport users, using one or more modes of transport. The transport service providers may represent one or more modes of transport.

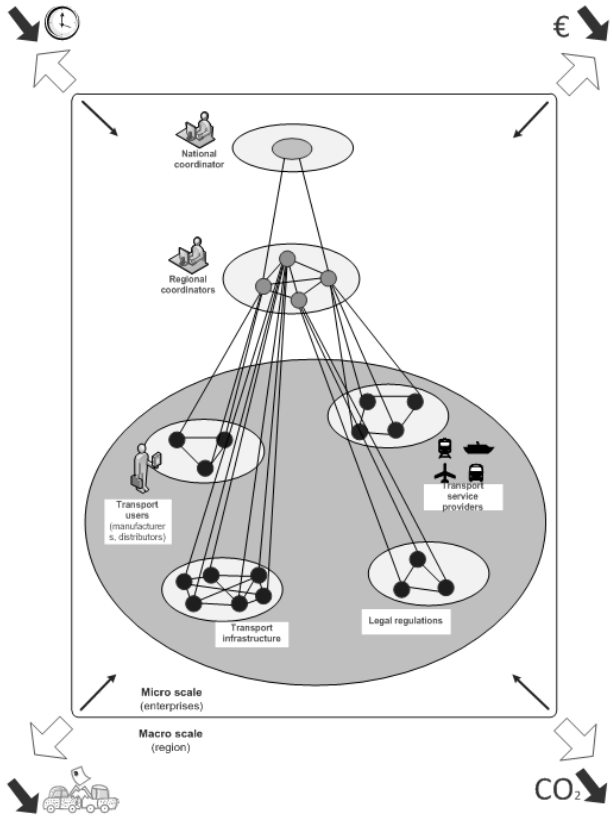

Fig. 4 The Method of Modelling the Intermodal Network in Poland Using Multi-Agent Systems

Source: Own study

Transport infrastructure – has a direct impact on the movement of goods using one or more modes of transport. Transport infrastructure may be divided into **linear infrastructure and transport nodes**, i.e. two main links – terminals allowing the loading units to change the mode of transport and transport routes which connect them. **Linear infrastructure** in rail transport, used for intermodal movement of goods, is made of railroads, i.e. rail tracks as well as equipment and structures absorbing dynamic load resulting from the movement of rolling stock, assuring the

security and direction of vehicles. Railroads, similarly to roadways, are classified in line with specific criteria, e.g. one, two or multi-lane roads, arterial roads, primary and secondary, public and private [6, p. 47].

Transport nodes in this mode are points where the intermodal transport is handled and include a network of goods stations and transshipment points which may be classified depending on their size or specialisation, e.g. junction and intermediate stations, container stations (also referred to as container terminals), stations used for local, national and international traffic service. Larger stations are equipped with material handling equipment installed along the public access tracks, storage yard, possibly a warehouse, operating equipment. Many shippers, e.g. mines or steelworks, have their own loading and unloading points, located at their site sidings [18, p. 59-50].

Transport infrastructure also includes **modern IT tools** allowing fast and online data exchange. [6]

Legal regulations – from the point of view of intermodal transport development, the regulations pertaining to the organisation of intermodal transport itself and affecting the development of intermodal network in Poland are important.

In the first group of regulations, the key regulations are those related to the price for access to the linear railway infrastructure defined in the tariff determined by PKP PLK S.A.

The other group of legal regulations pertains to the development of intermodal network in Poland. This information should be included in proper planning documents (land and environmental conditions, land use plans, local planning frameworks etc.) These regulations should be followed by specific decisions related e.g. to the development of transport nodes or the linear transport infrastructure.

Coordinator – coordinates the actions of individual agent groups, takes into account their needs, and performs micro and macro-scaled analyses. One of the key tasks of the coordinator is to pinpoint the needs for changes in the organisation of the transport system in the region, i.e. changes regarding transport infrastructure or legal regulations.

The developed method distinguishes between regional coordinators and a national coordinator. Local coordinators who know the specific nature of individual regions may develop the intermodal network more effectively. The key role of the national coordinator, on the other hand, is to gather information from regional coordinators and undertake actions that may have a favourable impact on intermodal transport nationwide. The example of that may be the joint drawing up of pricelist for the access to the linear railway infrastructure for intermodal carriers.

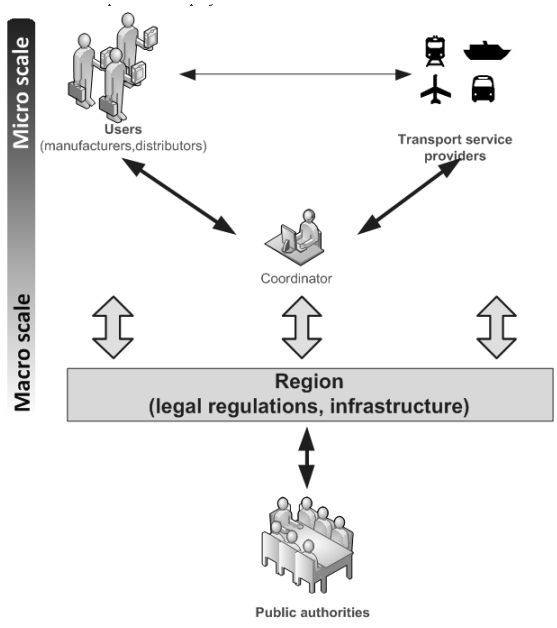

Fig. 5 Dependencies between the agents
Source: Own study

The coordinator's actions should be impartial and in line with the sustainable development concept, which means that they should include the economic, environmental and social aspects. To that end it is necessary for the coordinator to have due legal authority in order to act effectively. The said authority should be defined in the national strategy for the development of intermodal transport. The national coordinator should operate at the appropriate unit of the Ministry of Infrastructure, and the positions of regional

[6] The application of multi-agent systems may include not only the modelling of intermodal network and its impact on the development of intermodal transport, but also any other barriers limiting the growth of this transport technology.

coordinators should be created at transport departments of the Offices of the Marshal.

It is also worth mentioning that the operations of each group have a direct influence on the transport system in the region they operate in and on the development of intermodal transport. The role of the coordinator is to have a dialogue with individual groups of agents. Surely the dialogue and decisions made will be supported by proper quantitative and qualitative algorithms also developed under the project.

The said quantitative and qualitative algorithms support the works of the coordinator on the regional and national levels. Their main task is to identify the point of contact between individual agent groups, indicate which group should implement the changes and what the said changes should pertain to. Figure 6 presents one of the algorithms developed for transport users. It helps determine whether it is possible to use intermodal transport by a specific enterprise, and if not, what the reasons are and how they can be eliminated.

The algorithm presented in figure 6 shows whether the company may use intermodal transport to satisfy its transport demand. The data showed in circles refer to further algorithms which are aimed at determining the reasons for the state of affairs (e.g. insufficient data on the electronic platform). On that basis the regional coordinator may propose specific actions to model the intermodal logistics network.

5. SUMMARY

To properly model the intermodal network in Poland, an adequate organisation of cooperation between the links of the intermodal transport chains is required. In one of the most commonly encountered variants, railways share their operating systems and the combined transport enterprises purchase transport services from railways and draw up market offers resulting from the needs of dispatchers, road carriers or freight forwarders. The intermodal transport operators organise and supervise only terminal-to-terminal railway transport and the said intermodal transport enterprises offer comprehensive logistics services. The intermodal transport terminals are handled by railway enterprises, operators and private companies. Road carriers and freight forwarders sell transport services and organise short distance transport from the sender to the terminal or vice versa. It demonstrates the complexity of the processes and how many connections there are to coordinate. In addition, the development of intermodal transport is also affected by current legal regulations, as well as the transport nodes and linear transport infrastructure.

To sum up, it may be concluded that the approach suggested by the authors, consisting in the use of multi-agent system for modelling the intermodal network in Poland, facilitates the coordination of actions carried out by enterprises defined herein. In addition, the developed methodology indicates the actions that should be undertaken in each agent group to increase the application of modes alternative to road transport. It is worth stressing once more, that one of the key factors in modelling the intermodal network in Poland is the role of public authorities. It is the state that should actively participate in the creation of effective linear infrastructure and transport nodes, supporting both the transport of passengers and goods and undertake actions aimed at elimination of barriers specified herein.

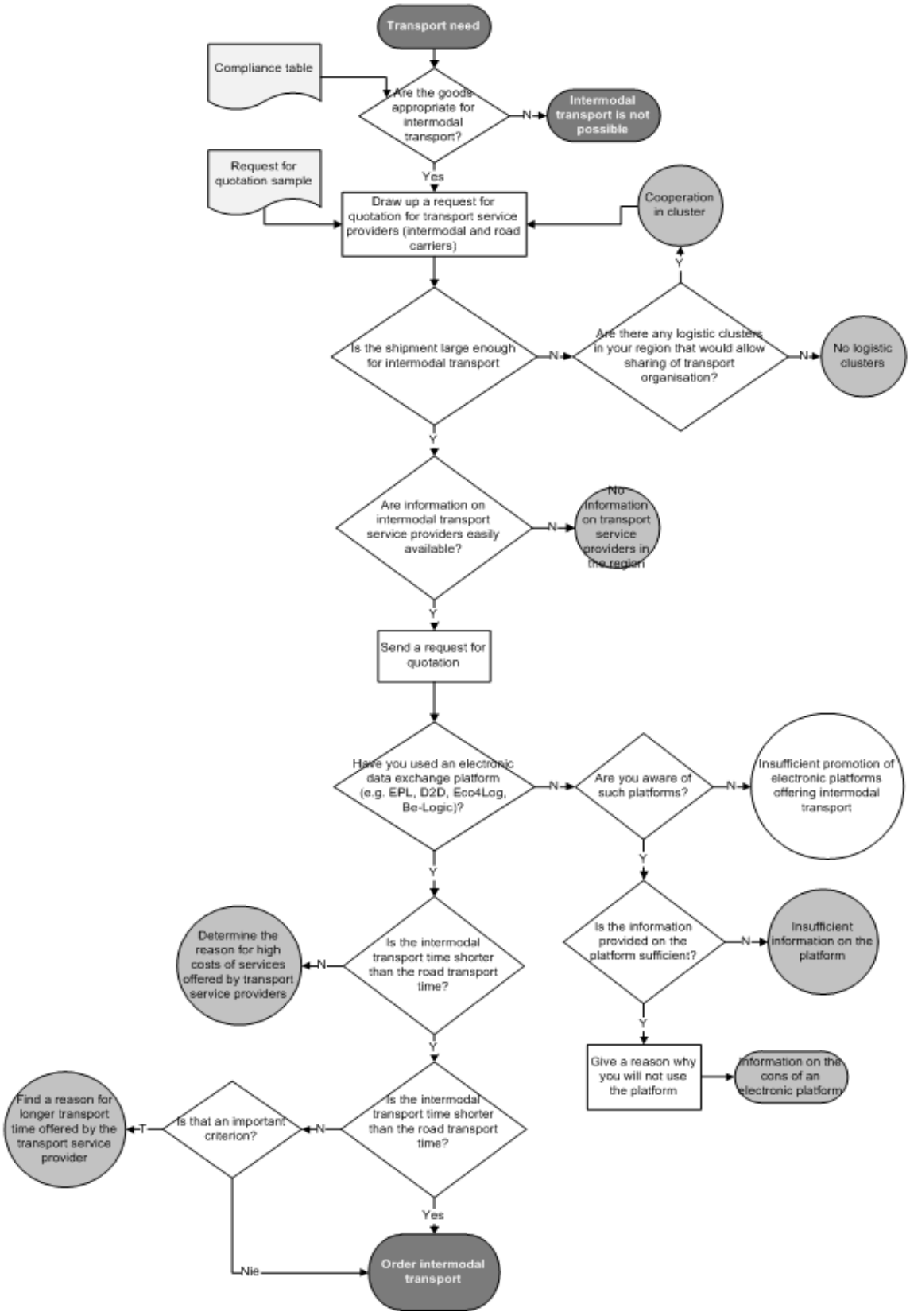

Fig. 6. Algorithm presenting the opportunities of using intermodal transport by a transport user

Source: Own study

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