The study has been carried out in order to estimate the profitability of container transport by barges on the Oder River – bypassing places where multilayer transport is impossible with the use of other means of transport (including road transport). This system, presented in the project entitled “Combined transport as a basis for effective carriage of containers by Oder Waterway in the presence of its limited capacity” has been submitted to the National Science Centre as part of Applied Research Programme with the No ... and also presented in the paper (1).

The following have been assumed as the fundamental parameters describing the system of combined transport:

a) the entire length of the transport river way \( L_o \) (e.g. distance from Gliwice to Świnoujście),
b) the percentage \( p \) of the land transport \( L_L \) in the entire length \( L_o \):
\[
p = \frac{L_L}{L_o}
\]  
(1)
c) number of transhipments \( n \), each including a transhipment from a barge to another means of bypass transport and vice versa, along with necessary interoperational storage
d) the number of container layers \( w \) transported by water.

The preliminary profitability assessment has been based on the comparison between the cost \( K_o \) of the transport of one container in the combined system on the entire route of the inland waterway and the cost of transport of one container using waterway only on the entire length in the one-layer system.

The assumed system of reference is therefore the transport of one layer of containers on the entire route of the Oder Waterway (ODW; e.g. Gliwice-Świnoujście, i.e. 744 km). This is due to the fact that such transport is deemed possible by the current state of the ODW.

The cost of transport of one container (TEU) per one kilometre of the inland water transport has been assumed as the basic parameter. The following ratio has been accepted for the analysis as a comparative parameter:
\[
\Psi = \frac{K_o}{K_1}
\]  
(2)
where:
\( K_1 \) – cost of transport on the ODW of one container in one-layer system per 1 km of the river way,
\( K_o \) – cost of transport of one container in the combined \( w \)-layered system per 1 km of the river way

The cost of the combined transport consists of the following:
\[
K_o = K_1 \cdot p + K_w(1-p) + K_L + K_p
\]  
(3)
Where:
\( K_w \) – cost of transport only by waterway of one container in the \( w \)-layered system per 1 km of the river way, assuming that transport cost does not depend on the extent to which the barge is loaded.
\[
K_w = \frac{1}{w} K_1
\]  
(4)
\( K_L \) – the unit cost (per 1 km of the overland route) of land transport of one container per 1 km of the river way,
\( K_p \) – cost of transhipments of one container from a barge to land vehicle/train and vice versa, along with necessary interoperational storage, per 1 km of the river way:
\[
\Psi_E = \frac{K_L}{K_1}
\]
Assuming as the limit (e.g. the ratio of the railroad transport cost to the cost of water transport in one layer), one may calculate the limit of the percentage of the land transport $p_E$ with a given number $n$ of transhipments with the criterion that:

$$\Psi \leq \Psi_E$$

(5)

In order for the combined transport to be profitable, one must assume that the percentage of the land transport shall be lower than the limit

$$p = \eta \cdot p_E \quad \eta \leq 1$$

(6)

The profit of transporting one container by combined transport in comparison with land transport:

$$Z_0 = K_L - K_0 = K_1(\Psi_L - \Psi)$$

(7)

One may then determine a profit ratio as the percentage of the cost of river transport of one container in one layer:

$$z_1 = \frac{Z_0}{K_1} = \Psi_L - \Psi$$

(8)

The results of calculations presented below have been obtained after the following figures were estimated:

1. The cost of inland water transport of one container of the average weight of 16 t in one layer (assuming 20 containers per layer) amounts to $K_1 = PLN\ 512/\ L_o$
2. The cost of transport of one container by railroad: $K_L = PLN\ 2.5/\ km/\ L_o$
3. The cost of transhipment of one container: $P = PLN\ 400/\ L_o$
4. The duration of break caused by the transhipment of upper layers of containers: $T_p = 24$ hours

Picture 1 presents charts showing the limit value of the percentage of the land transport in the entire transport route depending on the number of transhipments. In order for combined transport to be profitable, i.e. meet the condition (5), one should assume $p$ values over the curve. Negative figures point to the scope of inadmissible parameters. The chart proves that with 2 layers of containers up to 8 transshipments are possible in order to achieve minimum profit. The chart in picture 2 presents the connection between the profit ratio and the number of transhipments calculated for $\eta = 0.66$. Two general variants have been analysed: G1 – the land transport of all containers (no river transport on sections under Class III), G2 – the land transport of containers over the first layer and the river transport of the one remaining level on sections under Class III.

The advantage of the G2 variant is clear, as well as the significance of the number of transhipments.
The transport capacity has significant effect on the overall economical effect. Combined transport is faster than river transport as part of the way “p” is covered with the speed of land transport \( v_L \). At the same time the multilayer water transport must be adapted to the transport capacity of the land transport, e.g. in multi-carriage trains. The principle of combining may be here the adaptation of the delivery time to the transhipment and reception place without storage, taking into account the lock capacity. The result will be transport capacity higher than that of water transport in one layer. Such a state will multiply the profit from combining water transport in a few layers with fast, multi-carriage railroad transport, in comparison with the one shown in picture 2. The dependence of the equivalent velocity for the entire land and water route on the component velocities is set out by the following equation:

\[
\delta \gamma \frac{v_w}{1 - p(1 - \gamma) + n \cdot \delta}
\]

where:

\( \gamma = \frac{v_w}{v_L} \) – ratio of water transport velocity to land transport velocity

\( \delta = \frac{T_p}{T_w} \) – ratio of the duration of the storage break to the time of water transport on the entire route.

The transport capacity of the system is in proportion to the number of layers \( w \). The ratio of increasing transport capacity by using \( w \) layers in comparison to the one-layer transport may therefore be described as:

\[
\beta = \frac{v_z}{v_w} \cdot w = \frac{w}{1 - p(1 - \gamma) + n \cdot \delta}
\]

A demonstration of transport capacity ratio dependence on the main system parameters is presented in picture 3. As one can see, even with a low (a few per cent) share of land transport and six transhipments, one may increase transport capacity as much as 50% in comparison to one-layer transport.

Profit per unit (per one container) obtained in combined transport with the equivalent velocity (9) in comparison to the land transport, as the percentage of the cost of one-layer river transport:

\[
z = \beta \cdot z_1
\]
In practice, the frequency of deliveries is of great importance and it depends not only on the transport velocity but mainly on the logistics. Intermodal transport rises in Poland to the level of 6-8 trains per week. The combined water and land transport will be limited by the times of lockage and transhipments as well as waiting at the locks and in transhipment points. While it is not limited as much by timetables and the access to transport way, it is obstructed by navigation conditions. It is predicted that the frequency of deliveries of about 30-40 barges per week in the navigational season will be possible to achieve. With a similar figure (40 containers) per one delivery in the land and combined transport one may reinforce the profit.

![Pic. 3. Transport capacity ratio](image)

In order to assess possible profits for the buyer of services, two examples of using the proposed system have been analysed:

**Variant 1: Gliwice-Świnoujście route**
- Now – 3-layer transport (60 containers) to Brzeg Dolny (including bypassing 3 bridges), unloading upper layers and bypass to Kostrzyn, loading upper layers and transport to Świnoujście
- After the 1st stage of modernisation – 3-layer transport (60 containers) to Bytom Odrzański (including bypassing 3 bridges), unloading upper layers and bypass to Kostrzyn, loading upper layers and transport to Świnoujście.

**Variant 2: Gliwice-Hamburg route**
- Now – 3-layer transport (60 containers) to Brzeg Dolny (including bypassing 3 bridges), unloading upper layers and bypass to Kostrzyn, loading upper layers and transport to Hamburg
- After the 1st stage of modernisation – 3-layer transport (60 containers) to Bytom Odrzański (including bypassing 3 bridges), unloading upper layers and bypass to Kostrzyn, loading upper layers and transport to Hamburg.

The results of the analysis are presented in table 1. They justify the opinion that it is possible to lower the cost of transporting one container in this system twofold compared to railroad transport.
Tab. 1. The results of the analysis

<table>
<thead>
<tr>
<th>Example</th>
<th>Layer w</th>
<th>Transhipments n</th>
<th>Land transport %</th>
<th>Profit ratio zł</th>
<th>β</th>
<th>Individual profit z %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variant IA: \ Gliwice – Świnoujście Now</td>
<td>3</td>
<td>4</td>
<td>40</td>
<td>36</td>
<td>26</td>
<td>2.1</td>
</tr>
<tr>
<td>Variant IB: \ Gliwice – Świnoujście after stage I of modernisation</td>
<td>3</td>
<td>4</td>
<td>40</td>
<td>21</td>
<td>54</td>
<td>1.9</td>
</tr>
<tr>
<td>Variant IIA</td>
<td>3</td>
<td>4</td>
<td>40</td>
<td>29</td>
<td>39</td>
<td>2.0</td>
</tr>
<tr>
<td>Variant IIB \ Gliwice – Hamburg after stage I of modernisation</td>
<td>3</td>
<td>4</td>
<td>40</td>
<td>17</td>
<td>62</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Summary

The first, tentative attempts at economic evaluation point to the fact that there are organisational and terrain combinations which lead to establishing a certain percentage of the use of relief roads and the number of transhipments for the whole length of the route (Oder Waterway + sections of European roads), which indicates a possibility to achieve a positive economic effect. This effect will be a cheaper transport of multi-layer containers by bypasses rather than by direct railroad transport.

To confirm or to deny this thesis is one of the tasks of a short-term research project. Such a project, under the title of “Combined transport as a basis for effective carriage of containers by Oder Waterway in the presence of its limited capacity” has been submitted with the National Science Centre as part of Applied Research Programme. This project is part of European strategy for the development of the transport of goods [3] and takes into consideration recommendations for the analyses of economic effectiveness [4].

Abstract

The article presents an analysis of the effect of main parameters of the river and land system of container transport on its economic effectiveness. Those parameters are: the number of layers of containers on a barge, percentage of the land transport in the entire route, number and time of transhipments and speed relations. Relationships between those parameters have been established together with the principles of their selection, assuming the main criterion to be gaining profit by using combined transport in comparison with land transport. Examples of combined transport have been presented on the Gliwice – Świnoujście and Gliwice – Hamburg routes, including progress in modernizing the Middle Oder.

REFERENCES