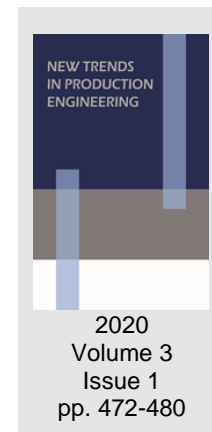


# POTENTIAL FOR TUNNEL TECHNOLOGY IN THE DEVELOPMENT OF HYPERLOOP VACUUM RAIL

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## INTRODUCTION

Vacuum rail (Hyperloop) is a concept of new means of transport that allows for the transport of people or loads at high-speed with minimum energy consumption. In order to implement these assumptions, a system was proposed, which consists of a capsule moving inside the tube, in which the air pressure is reduced to a very low value in relation to atmospheric pressure. As a result, the air resistance inside the tube is relatively very low, which allows the capsule to reach very high-speed, with limited energy consumption. Numerous studies and analyses show that vacuum rail can become one of the means of transport in the next decade (van Goeverden et al., 2018; Błażejczyk and Różycka, 2018; Fajczak-Kowalska and Kowalska, 2018; Mielczarek and Foljanty, 2019; Zhou, 2018). This technology is an interesting alternative to other means of transport, especially for journeys between 100 and 500 km, which makes it particularly interesting for Poland and other countries in the region. However, it should be noted that the vacuum rail infrastructure is practically non-existent at present. Only short experimental sections are available. The paper presents an assessment of the possibilities for development and implementation of vacuum rail technology in Poland. Special attention was paid to the challenges related to the construction of new technical infrastructure. On the basis of conducted routing simulations it was shown that in order to fully exploit the potential of vacuum rail, it will be necessary to build infrastructure using tunnel and bridge construction.

## VACUUM RAIL INFRASTRUCTURE

The simplest solution, so far performed as a test track, is a tube supported on uniformly distributed supports (Fig. 1). In real conditions such a construction is possible only on a few fragments of a potential route in Poland. Population density, the location of towns and villages, as well as the dispersed nature of buildings and the conditions resulting from legal regulations, e.g. environmental protection, will cause that vacuum rail route will not be straightforward.

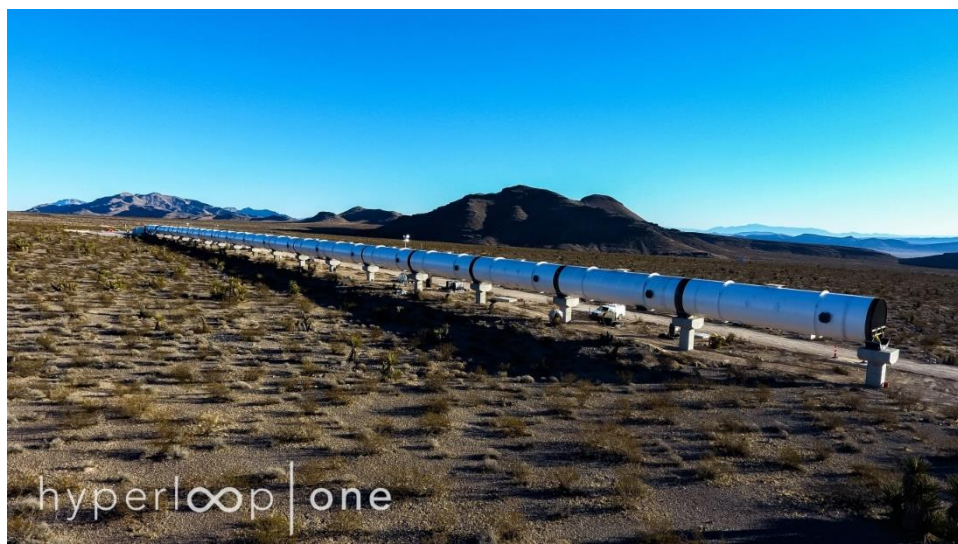


Fig. 1 DevLoop

Source: Photo: HyperLoop One

Moreover, the main obstacle for running a vacuum rail route is the terrain. Therefore, in order to fully exploit the potential of vacuum rail, it will be necessary to build a new infrastructure, alternating in tunnels and on flyovers. The course of vacuum rail route should be characterized by the minimum possible longitudinal slope and maximum length of bends. Elimination of the longitudinal slope of route is possible by means of different height of the vacuum rail support structure. In case of the occurrence of longitudinal slope of the route greater than 6% it will be necessary to use tunnels (Hyperloop Alpha, 2013).

### **TUNNEL CONSTRUCTION**

The use of tunnel construction in case of vacuum rail requires solving a number of problems from different scientific fields. Apart from geomechanical, geotechnical and constructional problems, it is necessary to take into account economic, ecological and technological conditions of vacuum rail. Due to the high costs of underground structures and the need to solve technically complex problems, their implementation should be preceded by study and design works:

- economic analysis validating the implementation of underground structures,
- site recognition in the field of geological structure, hydrogeological and geotechnical conditions,
- analysis of threats to underground structures and threats to the environment from this building,
- studies on the shape and implementation of underground buildings.
- development of designs for tunneling technology in various geological conditions and taking into account the limitations of shaping technical and organizational conditions.

Only multi-variant pre-solutions can lead to an optimal selection of economically advantageous design and technical solutions.

Using modern technology, an underground structure can be constructed under virtually any conditions, but it is also very expensive. For this reason, it is

important to consider the cost-effectiveness of a particular substructure when choosing a particular technology. The possibility of using mining methods of tunneling with the use of explosives or machines (e.g. excavators, roadheaders) was selected. These methods are suitable for deep and large cross-sectional structures made in mountain masses or in sufficiently stable ground masses. The possibility of using TBM drilling machines was verified. On the basis of conducted geological structure recognition and hydrogeological conditions in selected urban agglomerations, the use of closed mechanized full-cross section shields (TBM) for tunneling was analysed. TBMs are used in the construction of underground communication systems in aquifers and weak rocks, especially where small overburden requires immediate ground support, minimization of land subsidence, protection of overground buildings and underground infrastructure, elimination of communication disturbances. Tunnel shields do not replace other tunneling methods, but they are a technically and economically viable alternative to these methods over long distances, where high progress is expected and where there are high requirements for surface protection. The possibility of using open-pit methods was selected for the construction of railway stations. The open-pit methods generally consist in a wide or narrow-space excavation, in which a casing of classic and simple construction is carried out, and then the excavation along with the casing is filled with soil. They are usually performed for shallow underground structures.

The depth of tunnel location depends on the natural obstacles on the selected route of vacuum rail and the requirements for the maximum longitudinal slope of the route and its minimum curve lengths. In case of a tunnel under the bottom of a river, local terrain depressions, it is necessary to determine individually the smallest distance of a tunnel from obstacles for given geological conditions. Additional factors affecting the depth of tunnel are the zones of increased stress in the rock mass, zones of faults, local folds, cracked zones, rock rubble, zones of significant water infiltration, sandwaters or rocks strongly swelling under the influence of water. In urbanized areas, where stations will be located, the depth of tunnel depends on the existing underground infrastructure. It is planned to build a tunnel at a shallow depth of 20 to 50 m. The depth and type of tunnels should be considered depending on the characteristics of specific implementation.

The shape and dimensions of tunnel depend primarily on its purpose, location, requirements for use and the casing used (required durability, tightness of the casing, resistance to temperature and chemical aggression). The shape and dimensions of tunnels dedicated to the vacuum rail system should be selected in such a way as to maximally reduce the costs of tunneling and construction of casing and subsequent maintenance. The target shape of tunnel cross-sectional area is influenced by the geological structure, original stress state, drilling method, type of the initial and final casing used. On the basis of conducted analysis of geological conditions on selected vacuum rail routes in Poland, it was assumed that tunnels will be constructed in circular or oval cross-sections.

The diameter of tunnel depends on the assumptions of the system solutions concerning the tube infrastructure, inside which the vacuum rail capsules move.

## POSSIBILITIES OF USING TUNNELING TECHNOLOGY IN THE DEVELOPMENT OF HYPERLOOP SYSTEMS

This research topic was addressed as a part of the project entitled “Potential for the development and implementation of vacuum tube high-speed train technology in Poland in the social, technical, economic and legal context” carried out under the Gospostrateg and financial program by NCBiR. One of the specific objectives of this project was to study the technical possibilities of building a vacuum rail system and the analysis of theoretical operational parameters based on the existing state of knowledge.

Based on the results of conducted research, it can be stated that one of the reasons for the strategic importance of tunnel technology in the development of a new transport system is the need to optimize the routes of new transport system towards the construction of as many straight sections as possible. Adoption of such a recommendation as regards the route of transport tubes will improve the operating conditions of hyperloop vehicles, lead to simplification of their construction and enable to achieve higher travel speeds. The problem of route configuration of transport tubes is well illustrated by the example of simulation studies conducted within the project with the use of Route Planning Tool – EUROLOOP. The aim of these studies was to estimate the travel time of hyperloop vehicle assuming a specific route in Poland. An example of the route of hyperloop system on the Cracow-Warsaw section along the Central Railway Bus was shown in Figure 2.

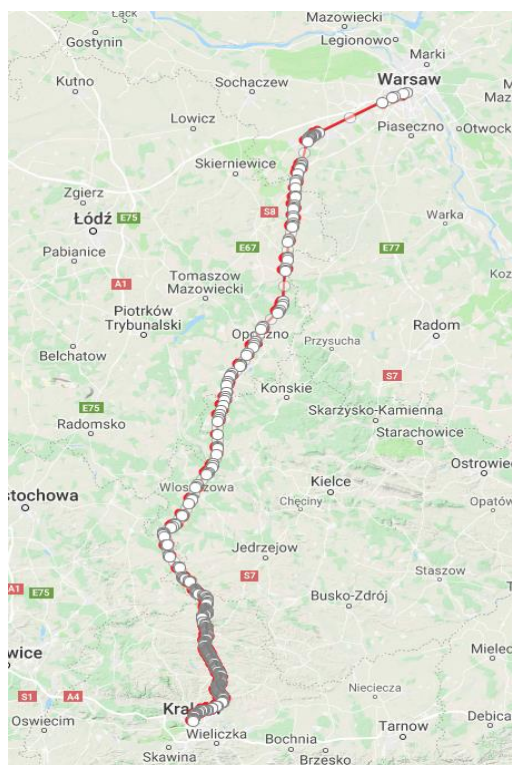
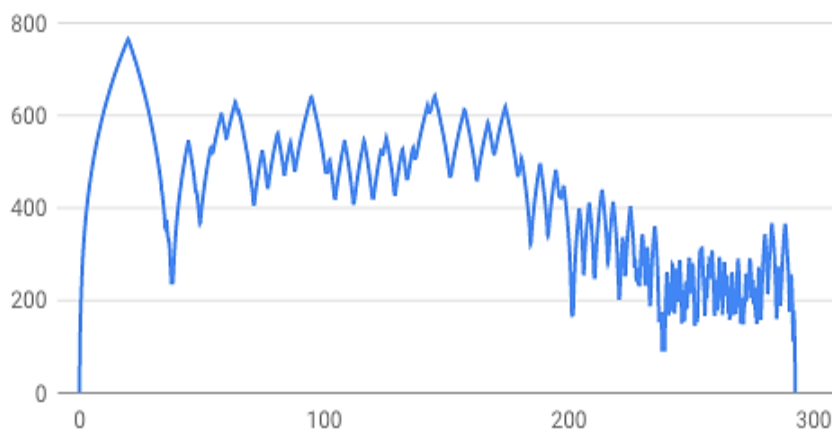


Fig. 2 Example of Cracow-Warsaw route

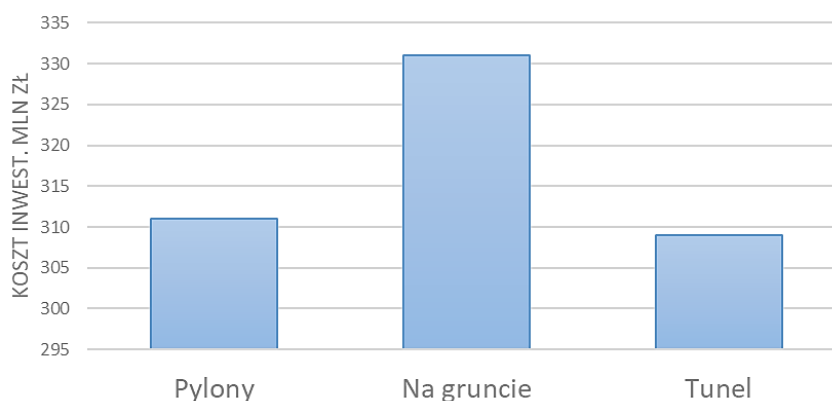
The total length of designed route is 292.5 km. Based on the proposed route, the maximum achievable speed was simulated, assuming geographical terrain, limitation of the maximum values of longitudinal and transverse accelerations safe for passengers and vehicle stability. An exemplary graph of vehicle speed on the Cracow-Warsaw route, assuming a maximum vehicle speed of 1000 km/h, was shown in Figure 3.



**Fig. 3. Graph of capsule speed in km/h depending on the distance covered in km on the Warsaw-Cracow route**

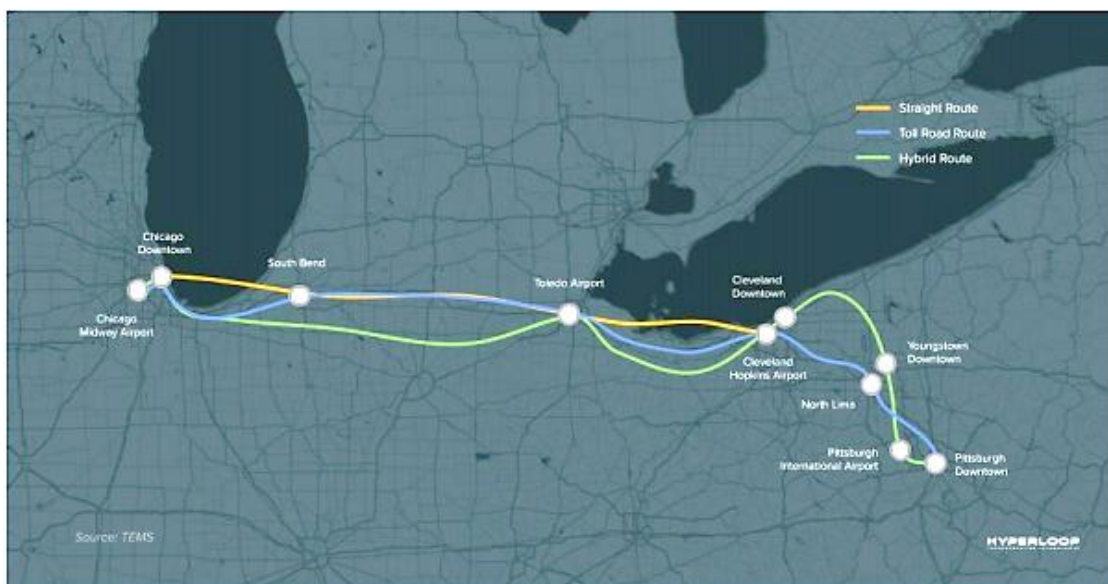
Many simulations carried out as a part of the project have shown that the capsule in most cases is not able to reach its maximum speed. In order to increase the speed, it is necessary to design the route curves with much larger radius, and thus a larger number of built-up areas will have to be passed through. In such a situation it will be impossible to use the currently existing rail areas. The above conclusion, resulting from the model tests carried out, confirms the necessity to conduct a thorough analysis of the possibility of configuring a dedicated hyperloop route in Poland with the largest possible number of straight sections. Obviously, the adoption of such an assumption regarding the development of land infrastructure of the hyperloop system in Poland will require increasing the number of underground route sections. Construction of underground sections of the hyperloop system will involve not only the necessity to meet the limitations in a form of maximum permissible overloads (necessity to increase the curve radius), but also the necessity to bypass built-up areas, especially large agglomerations.

The second important issue, which will significantly affect the choice of leading the transport tubes and configuration of the entire route, are the investment costs. The project attempts to estimate the construction costs of 1 km route of full land infrastructure of the hyperloop system as a function of transport tube diameter. The calculations took into account a number of components such as: preparatory works, geodesic works, earthworks, foundation works, execution of supports and steel tube structures. Figure 4 presents a graph illustrating the total construction cost of 1 km land infrastructure of the hyperloop system in Poland, assuming the transport tube diameter of 4.7 m.



**Fig. 4 Preliminary evaluation of investment costs for the construction of 1 km of hyperloop infrastructure in Poland**

The analysis shows that the cost of tunnel infrastructure can be comparable with other methods of transport tubes. It means that in the situation of hyperloop system route configuration with a large number of straight sections, the use of tunnel technology is not only a predisposed option due to technical requirements, but it is also justified from the investment cost point of view. Another example confirming the high potential of tunnel construction in the area of hyperloop technology is the example of research on the system application in the United States in the Great Lakes area (Great Lakes Hyperloop Feasibility Study by NOACA, HTT, and TEMS, 2019). The analyses considered three route variants, which are shown in Figure 5.



**Fig. 5 Concepts of running hyperloop routes in the United States on the Chicago-Pittsburgh section**

The blue color indicates the conventional route, which uses the existing routes. Orange is used to mark the route that has the shortest distance and minimizes the number of curved sections. The third concept, marked in green, is a kind of indirect solution allowing to minimize the need to acquire new areas for the

investment. Table 1 presents the estimated investment costs for different route configurations.

**Table 1 Cost overview of Great Lake Hyperloop system for different route configurations**

Cleveland – Chicago No Stops			
All costs in Millions of 2018 dollars	Toll Road Option	Hybrid Option	Strait Line Option
<b>Guideway Infrastructure</b>	<b>\$8,446</b>	<b>\$7,738</b>	<b>\$14,095</b>
<b>Stations + Vehicles</b>	<b>\$549</b>	<b>\$549</b>	<b>\$549</b>
<b>Guidance + Propulsion</b>	<b>\$7,912</b>	<b>\$8,080</b>	<b>\$6,131</b>
<b>TOTAL COST</b>	<b>\$16,907</b>	<b>\$16,366</b>	<b>\$20,774</b>
<b>Miles</b>	<b>330.0</b>	<b>337.0</b>	<b>315.3</b>
<b>Cost Per Mile</b>	<b>\$51.23</b>	<b>\$48.56</b>	<b>\$65.89</b>

The research shows that the highest investment costs concern the so-called “Strait Line” route. Investment costs for this variant are higher by about 25% in relation to the other two proposals. Nevertheless, the construction of hyperloop route according to the “Strait Line” concept assumes shortening the route and making a relatively large number of underground and even underwater sections. The presented example shows that even under such difficult and extreme conditions of hyperloop infrastructure installation, there are reasonable technical and economic reasons to build a shorter and faster route for the new transport system.

## CONCLUSIONS

On the basis of routing simulations, it has been shown that in order to fully exploit the potential of vacuum rail, it will be necessary to build infrastructure using tunnel construction. The use of tunnel techniques will allow to increase the possibility of free shaping of the characteristics of hyperloop routes, which will ultimately determine the basic functional parameters of a new transport system. Undoubtedly, the construction of vacuum rail tunnel infrastructure will be a challenge for the existing underground construction. However, it should be noted that an undertaking on such a scale will contribute to the development of tunneling technology in such aspects as: development of machines and technologies for mining of weak and concise rocks (Gospodarczyk et al. 2013, Gospodarczyk et al. 2016; Stopka 2020), development of blasting technique, including new explosives; progress in the construction of TBM tunneling machines; development of prefabricated reinforced concrete casing, development of monolithic concrete casing resulting from progress in concrete technology allowing to obtain materials of very high strength, with particular emphasis on self-compacting concretes; progress in the technology of repetitive, sliding formwork; development of means, equipment and

technologies for spraying concrete; progress in the development of injection materials and technologies improving the properties of weak and water-permeable rocks; development of the geodetic technology level and equipment for tunnel construction.

## ACKNOWLEDGEMENTS

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**Abstract.**

Hyperloop is a new concept of transport system the main assumption of which is to use hermetic tunnels where air pressure is very low compared to atmospheric pressure. It enables significant reduction of traffic resistance and, as a result, energy consumption. One of the most important elements of this system is land infrastructure with transport tubes. This system component has a significant impact on the construction costs related to the whole system and affects its functional parameters (e.g. capsule travel speed). Appropriate configuration of the route of a new transport system will require the use of all possible ways of leading transport tubes, including tunneling. The paper presents the key premises that prove a large potential application of tunnel technologies in the development of a new transport system.

**Keywords:** Hyperloop, tunneling, low-pressure ultra-speed trains, vacuum tube ultra-speed train