European Transport \ Trasporti Europei (2023) Issue 90, Paper n° 7, ISSN 1825-3997

https://doi.org/10.48295/ET.2023.90.7

Preliminary technical and economic analysis of a hyperloop line: case study from Italy

Fabio Borghetti*, Federico Ursino, Michela Vischi, Roberto Maja

Politecnico di Milano, Design Department, Mobility and Transport Laboratory, Via Candiani 72, Milano – 20158, Italy

Abstract

The future of mobility and transportation infrastructures has been heavily questioned during the last years. Today we are looking at how the mobility of people and goods will evolve in the coming years. With reference to this topic, Hyperloop has been at the core of the debate. Scientists and engineers believe that this technology is a great opportunity for the modern society. Nonetheless, it still presents several unsolved issues. The purpose of this work is to propose a methodology to perform technical and economic pre-feasibility studies related to the hyperloop system, with specific focus on transport demand analysis, transport sizing of the infrastructure and cost analysis of CAPEX - CAPital EXpenditure and OPEX - OPerating EXpense. For the evaluation of the potential demand, the paper refers to the Multinomial Logit model, calibrated through SP – Stated Preferences surveys. Once the Logit model has been calibrated, it is possible to envisage different scenarios, such as maximum transport demand or maximum revenue, which will be used for the subsequent design of the transport system. As far as the sizing is concerned, some technical parameters of the project are required, such as: length of the route, maximum speed, and acceleration. The combination of the scenarios defined through the calibration of the Logit model and the project parameters, allows to define several scenarios representing the potential performances of the analyzed system. Given the possible performances of the transport service, an analysis of costs and potential revenues that determines the most efficient solution can be carried out. In addition, parametric values per km can be used to define CAPEX and OPEX. The methodology illustrated above, has been applied to a case study in Italy of the Rome-Milan OD (Origin – Destination), as it is one of the national routes with the highest volume of traffic and the largest number of modal choices.

Keywords: Hyperloop; Potential demand; SP surveys; Transport demand; Transport modelling; Transportation planning; Mobility; Transport Economics; Transport management; Passenger Transport; Transport capacity; Transport costs; Transport service

1. Introduction

In modern society, transportation systems for people and goods are an essential element in the economic growth and well-being of a country and the quality of life in urban areas; in fact, transportation is part of social cohesion and demographic development. The

* Corresponding author: Fabio Borghetti (fabio.borghetti@polimi.it)

evolution of transport systems together with an increased awareness of the possible environmental impacts have led in recent years to new mobility systems for the transport of people and goods (Le Pira et al., 2021). Especially in urban areas, the attention of many local authorities has shifted from the supply side, which focuses on service provision to the demand side, where one of the goals is the improvement of service quality where the perspective of users dominates (Barabino et al., 2011). Therefore, generally speaking, the mobility sector is a key factor in our economic and social life, starting from daily commuting to work, meeting family and friends, promoting tourism, to the management and operation of supply chains for goods in our stores and for our industrial production. In this way, the free movement of people and goods is a fundamental freedom of the European Union and its single market (European Commission, 2020). The evolution of transport systems together with an increased awareness of the possible environmental impacts have led in recent years to new mobility systems for the transport of people and goods. In this perspective, the Hyperloop system represents an innovative transport method that should allow mass transport of people (and also goods) between cities at high speed. From a technical point of view, the functioning of the Hyperloop system can be like a subway: in the latter case there are generally more stops, while Hyperloop combines few origins and destinations. In the case where only one origin-destination pair is considered with no intermediate stops, the Hyperloop system is like air transportation (Virgin Hyperloop, 2021).

The mail goal of this work is to propose a methodology to perform technical and economic pre-feasibility studies related to the hyperloop system, with specific focus on transport demand analysis, transport sizing of the infrastructure and cost analysis of CAPEX - CAPital EXpenditure and OPEX - OPerating EXpense.

The paper is organized as follow: in section 2 there is the background with a starting point of the work, section 3 presents the adopted methodology, in section 4 there is a case study in Italy to assess the feasibility of a hyperloop line and section 5 discusses the conclusion and possible developments of the work.

2. Background

In the technical-scientific literature several authors have studied and are studying the Hyperloop transport system from different points of view, including technological, organizational, and economic. The following is a summary of some studies and research useful to frame the work presented. From a general point of view, the work of Mitropoulos et al. (2021) proposes a literature review related to publications on the Hyperloop system in reference to several aspects including: i) the capsule, ii) the infrastructure and the communication system and iii) the identification of the stakeholders involved. The analysis carried out by the authors shows that the activities related to the Hyperloop system are almost equally distributed between Europe (39%) and Asia (38%); moreover, most of the EU stakeholders are located: i) in Spain (26%) and Germany (20%), ii) working on the traction of the capsule (37%) and the tube (28%), iii) studying the impacts, including safety (35%), energy (33%), and costs (30%). Also highlighted within the work is the absence of full-scale facilities making it difficult to perform testing to improve system development. To date, in fact, there are several studies and researches aimed at understanding the feasibility and convenience of Hyperloop systems; from a scientific-technical point of view, there is no shared opinion (Premsagar and Kenworthy, 2022).

The work of Guerrieri (2022) concerns a cost-benefit analysis between three innovative transportation systems (Transrapid, the Hyperloop and HeliRail) and high-speed trains.

The research includes both a financial and an economic analysis within a case study. The results of the work show that the best mass transportation system is high-speed trains except in special cases.

In the work of Rajendran and Harper is analyzed the Hyperloop system between the cities Los Angeles and San Francisco; for what concerns the estimation of the transport demand are considered the road and air trips made between these two metropolitan cities. The authors propose a DMADV - Define Measure Analyze Design and Verify - approach with the objective of: (i) know and define the Hyperloop system operations, (ii) acquire data, (iii) develop the simulation model, and (iv) analyze the results to propose solutions for network operation. The results indicate that the number of Hyperloop capsules in the system and the variability in commuter volume appear to have an exponential impact on the measures, thus recommending market research on these parameters (Rajendran and Harper, 2020). Considering the Hyperloop system between the cities of San Francisco and Los Angeles, the work of Voltes - Dorta and Becker (2018), analyzes possible impacts on users' choice of airports. In fact, the mobility behaviors, and choices of users for long-distance domestic travel are studied. Specifically, the following aspects are considered: i) airport catchment areas, ii) flight frequency, iii) access times, and iv) travel costs to assess a possible change in airport competition if a Hyperloop service is introduced. Another research concerns the development and design of the Hyperloop system from a technical perspective; specifically, the following aspects are addressed: (i) optimal pressure inside a tube to minimize energy; (ii) minimum amount of energy per passenger and per km; (iii) relationship between infrastructure operation and capsule design; and (iv) possible magnetic levitation system for energy consumption reduction (Tudor and Paolone, 2021). The work of van Goeverden et al. (2018) aims to fill the gap in the technical literature by exploring the operational, financial, and social - environmental performance of the Hyperloop system and comparing it to that of the High-Speed Rail - HSR and Air Passenger Transport - APT systems. In fact, it emerges that previous studies have not systematically explored the performance of the Hyperloop system compared to other transportation modes. The main result concerns a low capacity of Hyperloop; this situation implies a limited utilization of the infrastructure. In addition, since infrastructure costs are the most significant, the costs per passenger km are high compared to those for HSR and APT. However, the Hyperloop system has strengths in social and environmental aspects for: i) low energy use, ii) no GHG emissions, and iii) limited noise pollution. Further evaluation needs to be done regarding the safety issue. From this perspective, the study can be considered useful to support the debate on the overall feasibility of the Hyperloop system. Also, in the work of Kowal et al. (2022) the feasibility of implementing the Hyperloop system is evaluated considering an application in Poland. Specifically, a methodology is used to estimate the demand for required capsules. In addition, the investment cost of implementing and operating the system is addressed. In work by Hansen (2020) addresses the use of Hyperloop through a system analysis. The three elements of the research can be summarized as follows: i) long-distance transportation demand analysis considering the current air travel volumes between major airports in Germany and the proposed Hyperloop link between Los Angeles and San Francisco in California, ii) technical feasibility of the Hyperloop system considering vehicle design, capacity, operations, propulsion, guidance, energy supply, traffic control, and safety, iii) possible environmental impacts, investment costs, operation and maintenance of the service. With respect to Hyperloop system networks, the work of Merchant and Chankov (2020) analyzes the importance of routes that once built cannot be changed. Within the work, the routes of the Hyperloop network in Europe are identified and then the importance of these routes in passenger travel mode as an alternative to rail and air transport is evaluated. The authors propose key performance indicators for evaluating the networks: i) average travel time, ii) utilization, iii) passenger service level, and iv) profit. The application is made by proposing two networks with different routes at the European level. The study by Gkoumas and Christou (2020) analyzes the progress of the Hyperloop system development; in particular, problems and challenges are identified providing insights towards testing activities and commercialization of the system. Specifically, the work proposes a two-tiered approach: (i) addressing the security aspects related to the implementation of Hyperloop systems with reference to the technology and (ii) analyzing the developments of the technology using established information and databases. In the study, the various research activities and patents are reported providing insight into possible lines of research and next steps that should be taken. Finally, in the work of Dudnikov (2017) the topic of freight transportation with the Hyperloop system using standard 20-foot containers is addressed. The study analyzes the technical parameters of the tube and capsule providing some estimates of technical and economic indicators such as construction cost and transport capacity. In fact, the work addresses how Hyperloop technology can provide support in the freight transportation industry. Also, in the work of Werner et al. (2016), the implementation of a 300 km long Hyperloop system in northern Germany for freight transport is analyzed. Specifically, the authors identified and evaluated eight elements: i) travel speed, ii) operational costs, iii) safety, iv) noise pollution, v) air pollution, vi) climate impact - carbon footprint, and vii) maintenance aspects. The study was carried out comparing the Hyperloop system and the road system assuming that the modal split of goods would be changed: in this way it was possible to evaluate the possible benefits for the community. The peculiarity of this work is to propose a method both from a theoretical and practical point of view that can be used to analyze the potential demand of an Hyperloop line, to dimension the system and to estimate costs and revenues for an operator. This work is the first of its kind, since, to date, no feasibility analysis of Hyperloop line projects in Italy have been published, neither by Hyperloop Italy itself nor by other entities. Moreover, the literature review shows that few studies have addressed the feasibility analysis of the Hyperloop system on such long routes by comparing more than two different transport services, as in this work. A further innovative aspect of this work consists in the definition of the various levels of performance proposed for the sizing of the system: we did not limit ourselves to evaluate the performance of the Hyperloop based on the information available today, but we evaluated different options considering the performance of the transport systems existing today.

3. Methodology

This paragraph illustrates the methodology for estimating the potential transport demand and the consequent dimensioning of an Hyperloop infrastructure. The proposed methodology is articulated in the 4 steps shown in Fig. 1.

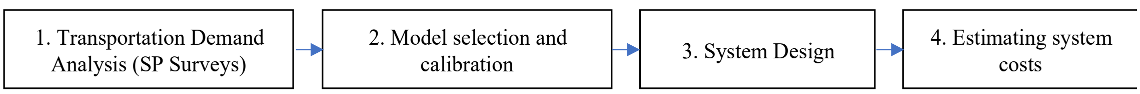

Figure 1: Framework of the study.

3.1 Transportation Demand Analysis

SP (Stated Preferences) surveys based on user-reported preferences are suggested to estimate transport potential demand. To perform these surveys, the following process should be carried out:

- Define *N* attributes representing the characteristics of the proposed transportation infrastructure (e.g., travel time, frequency, cost, etc.)
- Define the modal alternatives to be submitted to the user (e.g., train, plane, car) based on those actually available for the route under study
- Define the scenarios to be submitted to the user. The number of scenarios can be calculated using the Complete Factor Plan equation, which can then be reduced using block decomposition.

Once the attributes and scenarios have been identified and defined, a questionnaire can be submitted to potential users to assess their preferences. Among the models available for the estimation of the probability of choice of each modal alternative the use of the Multinomial Logit model is suggested.

3.2 Model selection and calibration

The next step is to analyze the responses on the SP surveys; this allows the model to be calibrated. After observing the choices of the representative sample of users through the SP surveys, one must find, among all the calculated values, those that provide the most likely estimate. The objective is to model the process of choice of transport mode of users moving on a given territory. To calculate the probability of choice of users can be used the probabilistic utility theory, which allows to identify the alternative of choice more "convenient" for users, which is the one that maximizes their utility. To calibrate the model and therefore to find the values that maximize the user's utility, it is possible to use the maximum likelihood criteria. At the end of the calibration the model can reproduce the choices of the users to vary of the attributes. To verify the reliability of the obtained values it is opportune to carry out the validation of the results, through reasonableness tests as well as the formal tests of the null hypothesis and equality. Finally, it is essential to carry out a sensitivity analysis to define which attributes are more sensitive, in other words, which is more "important" for the users. Such attributes should be heavily considering the phases of dimensioning of the system.

3.3 System Design

Depending on the modelling results, the dimensioning of the transport service is carried out. It is therefore necessary to define the main characteristics of the route (curvature radius and length), the performance of the vehicles and the transport system. To dimension the system in a precise way, it is possible to represent the running conditions of the vehicles by means of traction diagrams, which allows to know the instantaneous speed trend in a cartesian space-speed plane for the entire route. Based on the performance of the vehicles, it is necessary to define: the frequency of the transport service and the number of vehicles required.

3.4 Estimating System Costs

After defining the characteristics of the route, the transport demand (users) to be satisfied and the performance of the service to be offered, it is necessary to carry out an analysis of potential CAPEX and OPEX costs, as well as potential revenues. In a pre-feasibility phase, costs and revenues can be estimated parametrically.

CAPEX costs, through market analysis, can be traced back to unit costs in relation to the cost of building the infrastructure (e.g., €/km) and the cost of purchasing vehicles. While OPEX costs can be estimated as annual costs for the operation and routine maintenance of the system.

4. Case study: the Milan - Rome connection in Italy

In this study, as an example of the methodology previously described, it has been hypothesized to carry out a pre-feasibility study (only on the transport point of view) of a Hyperloop route that would connect the cities of Rome and Milan in Italy; these cities are now considered the headquarters of the largest institutions and multinationals in the area and therefore poles generators and attractors of demand for transport (mobility). The hypothesized route connects the railway stations of Roma Termini and Milano Centrale and develops for a total length of about 530 km. In the following paragraphs the input data are defined, and the main results obtained are illustrated.

4.1 Transportation Demand Analysis

The potential transportation demand analysis and SP surveys were conducted by defining the following parameters shown in Table 1. An improvement in the performance of the High-Speed Train between Rome and Florence has been hypothesized with a consequent increase in the maximum speed of the line to 300 km/h and therefore a reduction in travel time to 150 minutes.

Table 1: Modal split considered in the survey.

Modal alternatives	*Cost [€]*	*Transport system frequency [min]*	*Travelling time [min]*	*Station entry and exit time [min]*
Hyperloop	80; 150; 200	4; 8	30; 45; 60	15; 30; 45
High Speed Train	50; 100; 150;	15	150; 180; 210	15; 30; 45
Airplane	60; 120; 180	60	45; 60; 80;	45; 60; 90

After defining the modal alternatives and attributes, the Complete Factorial Plan was calculated, for a total of 39.366 scenarios, subsequently reduced through block decomposition to 128 scenarios. The scenarios thus obtained have been inserted in a questionnaire prepared with Google Forms and submitted to a sample of users. Each user was asked to choose one of the 16 blocks of 8 scenarios available. The choice of the users was completely random. At the end of the survey 4069 answers were obtained. Table 2 shows the main data of the survey sample by gender, age and occupation. An example of a questionnaires proposed to users (Scenario 1 and Scenario 2) is shown in Fig. 2.

Table 2: Main sample data of the survey.

Gender [%]		*Age [%]*				*Occupation [%]*	
M	*F*	*<18*	*18 - 24*	*25 - 40*	*>40*	*Students*	*Employees*
70	30	2	84	8	6	85	15

Attributes	Scenario 1			Scenario 2		
Alternatives	Hyperloop	HS Train	Airplane	Hyperloop	HS Train	Airplane
Ticket price	150€	100€	120€	200€	150€	120€
Frequency	4 minutes	15 minutes	60 minutes	4 minutes	15 minutes	60 minutes
Travel Time	30 minutes	150 minutes	45 minutes	60 minutes	180 minutes	60 minutes
Get on – get off time	30 minutes	30 minutes	45 minutes	30 minutes	30 minutes	45 minutes

Figure 2: Examples of questionnaires proposed to users with SP surveys: scenario 1 and scenario 2.

4.2 Model selection and calibration

The Multinomial Logit model was calibrated with the maximum likelihood criteria, following the previously described methodology. From the calibration it was possible to estimate the demand of the Hyperloop transport system based on the parameters described above. At the end of the calibration the validation tests were carried out, which had a positive outcome. The sensitivity analysis showed that, the parameter to which users are most sensitive is the cost of Hyperloop. While the least influential parameter turns out to be frequency. Fig. 3 shows the user choice probability (trend) for the Hyperloop transport service with respect to the cost of the ticket.

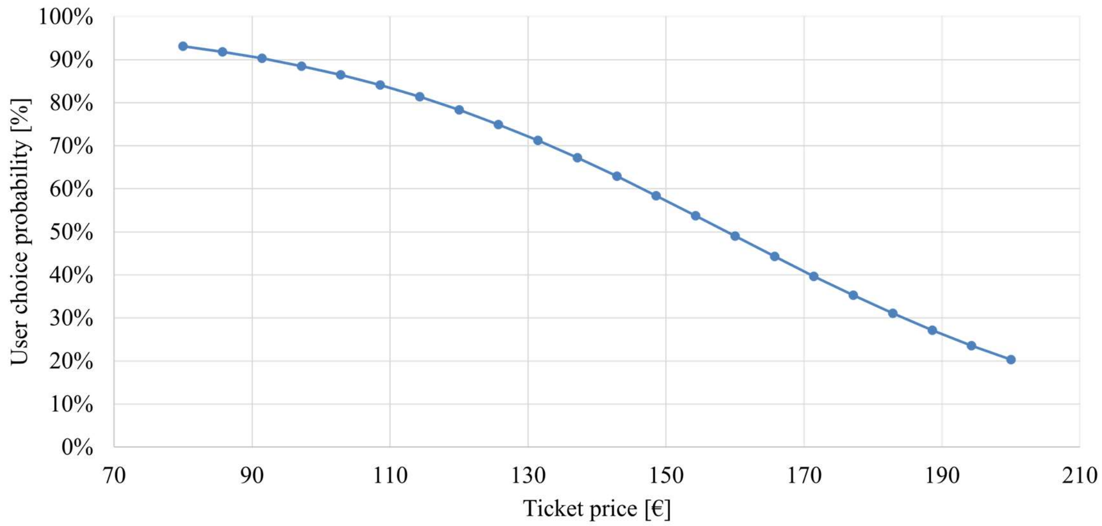

Figure 3: Hyperloop probability of choice as a function of ticket price.

For the attributes: frequency, travel time and time in and out of stations, no particular sensitivity on the part of users was shown. The results regarding the sensitivity of the attributes can probably be attributed to the type of sample that participated in the survey: the greatest number of responses came from students between the ages of 18 and 25.

4.3 System Design

To have a broader vision for the sizing of the service, it was decided to analyze three different scenarios and the relative probabilities of choice (see Fig. 4) according to the three proposed modal alternatives: i) Maximum revenue: the maximum of the revenue - ticket price curve was sought. To calculate the revenue from ticket sales, the probability of choice of the Hyperloop was multiplied by the annual number of passengers traveling the Rome - Milan route in a year (approximately 5.2 million passengers in 2018) and then the value obtained was multiplied by the ticket price associated with that demand. The hyperloop ticket price considered was calculated by holding the values of the train and airplane prices constant at the average values, equal to €100 and €120, respectively. Through the study of the revenue-price curve, the ticket price that maximizes revenue is €124.43. ii) Maximum demand with competitive price: in this scenario the price of the Hyperloop was defined at €80, the minimum predicted by the SP surveys, and, in the same way, the price of the train and the plane was defined at €50 and €60 respectively; iii) Elon Musk: this scenario was developed from Elon Musk's idea proposed in the Alpha Paper in 2013 to charge $20 one way.

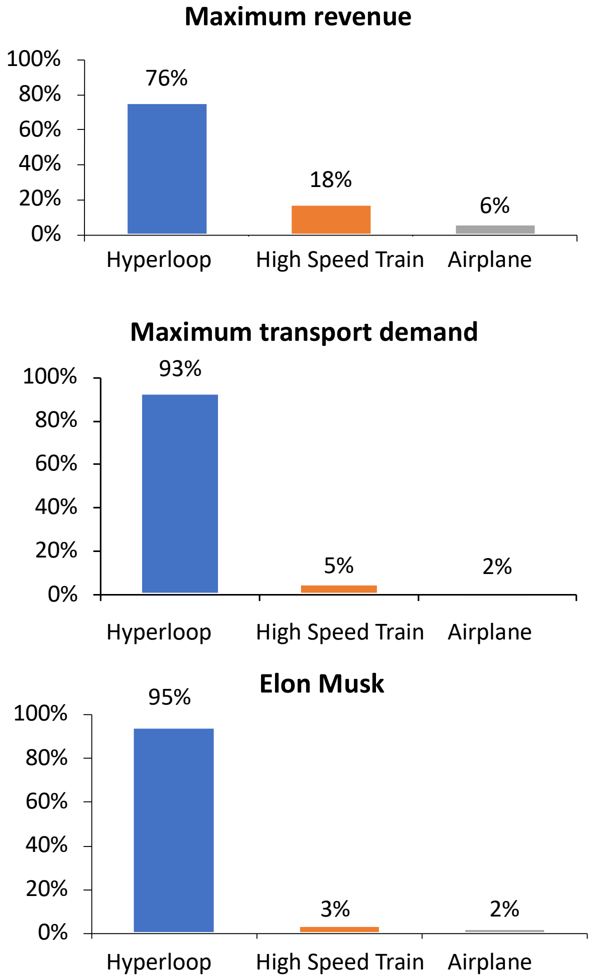

Figure 4: Probability of choice results of the three modal alternatives (Hyperloop, High Speed Train, Airplane) considering the three different scenarios: Maximum revenue, Maximum transport demand and Elon Musk.

For the sizing of the system, since the full potential and performance of the system has never been tested, 3 different levels of performance (A, B and C) have been hypothesized in relation to 3 different possible performances of the Hyperloop system as shown in Table 3.

Table 3: Three levels of performance analyzed. The C level is the one considered for the sizing of the system.

Performance attributes	*Levels of performance*		
	A	*B*	*C*
Max speed [km/h]	970	970	970
Max acceleration [m/s^2]	4.9	9.8	0.7
Max Deceleration [m/s^2]	4.9	9.8	1.2

The analysis and evaluation were carried out considering the values of level C, as lower accelerations are equivalent to greater travel comfort for users, at the expense of a travel time that is slightly higher than that of the other two levels (A and B). As an example, Table 4 shows the parameters calculated by combining the "Maximum revenue" probability scenario with level of performance C.

Table 4: Main features of the Hyperloop service design for the level of performance C.

Travel time [min]	*Trade speed [km/h]*	*Operating speed [km/h]*	*Lap time [min]*	*Number of vehicles [-]*
37.84	602	602	105.41	32

4.4 Estimating System Costs

CAPEX costs have been estimated starting from the unit costs proposed by Delft University, while OPEX costs have been estimated processing the data published by Hyperloop TT in the feasibility study for the Great Lakes region in the United States. Table 5 shows the main results obtained.

Table 5: CAPEX and OPEX estimation.

CAPEX	*Cost in €*	*OPEX*	*Cost in €*
Open air infrastructure cost per km	24,618,000 €	On-board personnel	29,622,000 €
Additional tunnel cost per km	25,430,000 €	Capsule maintenance	24,703,000 €
Exchanges cost per km	10,177,00 €	Administration	20,416,000 €
Expropriations cost per km	5,530,000 €	Track maintenance	19,787,000 €
Station cost	700,000,000 €	Insurance	18,009,000 €
Capsule cost	6,667,000 €	Pump maintenance	9,117,000 €
Total	20,449,439,000 €	Tube maintenance	7.813.000 €
Certification cost	1%	Energy for pumps	6,548,000 €
Rome-Milan cost	20,653,933,000 €	Stations	3,638,000 €
Average cost per kilometer	38,970,000 €	On board services	3,625,000 €
		Energy for propulsion	1,235,000 €
		Total [€/year]	144,512,000 €

In figure Fig. 5 there is the percentage distribution of the main voices considered for the Operational Expenditure Costs evaluation. The two main voices are On-board personnel (20.5%) and Capsule maintenance (17.1%).

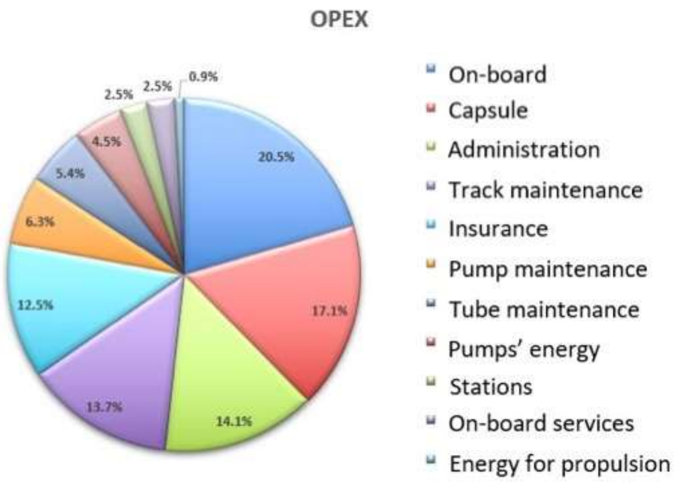

Figure 5: OPEX percentage distribution.

Revenues have been estimated considering the transport scenario "Maximum revenues" where the ticket price is €125: annual revenues from ticket sales are €493,956,500. Assuming that costs are amortized at an interest rate of 2% over 50 years and not considering increases in transport demand, break-even would be reached in 44 years, as shown in Fig 6.

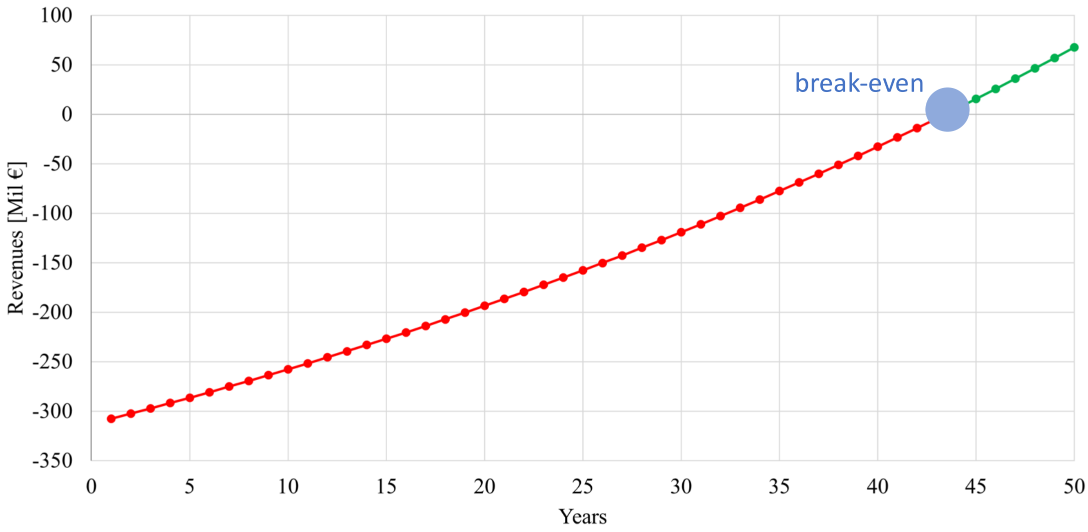

Figure 6: Break-even of the Rome - Milan route in the technical level of performance C.

5. Conclusions

The hyperloop system can offer great performance and therefore could be suitable to connect large cities. In our case study, linking Rome and Milan, in Italy, the high speed and the low travel time could create a new commuting between the two main Italian cities. Surely the most critical aspect is the technological one. In fact, to date, there is not a complete and operational line and, it has never yet reached the cruising speed designed for hyperloop of 1223 km/h. Nevertheless, the high speeds reached by the existing MAGLEV trains, combined with the idea of creating a vacuum inside the tubes, give hope in the possibility of reaching such speeds. The steel tube may have an important impact, both from the environmental and economic point of view, consequently, it is important to highlight the need to evaluate alternative materials always considering the mechanical performance that must be provided in relation to all the stresses that the tube must endure. The main key points of our study are listed below:

- 39,366 scenarios were implemented with SP surveys for the potential transport demand estimation
- 4,069 answers by user sample
- Comparing 3 different modal choices (Hyperloop, HS train and airplane) between Milan and Rome
- 4 attributes per modal choice (ticket price, frequency, travel time, get in – get off time)
- 3 technical levels of performance (A, B and C) were implemented, considering maximum speed, acceleration, and deceleration.

The main achieved results of the SP surveys are:

- Lowest ticket price 80 € - observed user choice probability 93 %
- Highest ticket price 200 € - observed user choice probability 20%
- With reference to the technical level of performance C, the breakeven would be reached in 44 years, considering a ticket price of 125 €.

Further development should investigate issues such as a larger representative sample for SP analysis, safety, and deeper economic and financial aspects considering the evolution of available technology. Finally, the feasibility of using Hyperloop for freight transportation should also be investigated.

References

Barabino, B., Deiana, E., & Tilocca, P. (2011). Urban transport management and customer perceived quality: A case study in the metropolitan area of Cagliari, Italy. Theoretical and Empirical Researches in Urban Management, 6(1), 19-32.

Dudnikov, E. E. (2017). Advantages of a new hyperloop transport technology. Paper presented at the Proceedings of 2017 10th International Conference Management of Large-Scale System Development, MLSD 2017, doi:10.1109/MLSD.2017.8109613

European Commission (2020). Sustainable and Smart Mobility Strategy - putting European transport on track for the future. Available on: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020DC0789&from=EN (accessed on 17 March 2022)

Gkoumas, K., Christou, M. (2020). A triple-helix approach for the assessment of hyperloop potential in Europe. Sustainability (Switzerland), 12(19) doi:10.3390/SU12197868

Guerrieri, M. (2022). Hyperloop, HeliRail, transrapid and high-speed rail systems. technical characteristics and cost-benefit analyses. Research in Transportation Business and Management, 43 doi:10.1016/j.rtbm.2022.100824

Hansen, I. A. (2020). Hyperloop transport technology assessment and system analysis. Transportation Planning and Technology, 43(8), 803-820. doi:10.1080/03081060.2020.1828935

Kowal, B., Ranosz, R., Klodawski, M., Jachimowski, R., & Piechna, J. (2022). Demand for passenger capsules for hyperloop high-speed transportation system-case study from poland. IEEE Transactions on Transportation Electrification, 8(1), 565-589. doi:10.1109/TTE.2021.3120536

Le Pira, M., Tavasszy, L. A., Correia, G. H. D. A., Ignaccolo, M., & Inturri, G. (2021). Opportunities for integration between mobility as a service (MaaS) and freight transport: A conceptual model. Sustainable Cities and Society, 74 doi:10.1016/j.scs.2021.103212

Merchant, D. V., Chankov, S. M. (2020). Towards a European hyperloop network: An alternative to air and rail passenger travel. Paper presented at the IEEE International Conference on Industrial Engineering and Engineering Management, 2020 - December 128-132. doi:10.1109/IEEM45057.2020.9309907

Mitropoulos, L., Kortsari, A., Koliatos, A., Ayfantopoulou, G. (2021). The hyperloop system and stakeholders: A review and future directions. Sustainability (Switzerland), 13(15) doi:10.3390/su13158430

Premsagar, S., & Kenworthy, J. (2022). A critical review of hyperloop (ultra-high speed rail) technology: Urban and transport planning, technical, environmental, economic, and human considerations. Frontiers in Sustainable Cities, 4 doi:10.3389/frsc.2022.842245

Rajendran, S., & Harper, A. (2020). A simulation-based approach to provide insights on hyperloop network operations. Transportation Research Interdisciplinary Perspectives, 4 doi:10.1016/j.trip.2020.100092

Tudor, D., Paolone, M. (2021). Operational-driven optimal-design of a hyperloop system. Transportation Engineering, 5 doi:10.1016/j.treng.2021.100079

van Goeverden, K., Milakis, D., Janic, M., Konings, R. (2018). Analysis and modelling of performances of the HL (hyperloop) transport system. European Transport Research Review, 10(2) doi:10.1186/s12544-018-0312-x

Virgin Hyperloop (2021). Available on: https://virginhyperloop.com (accessed on 17 March 2022)

Voltes - Dorta, A., Becker, E. (2018). The potential short-term impact of a hyperloop service between San Francisco and Los Angeles on airport competition in California. Transport Policy, 71, 45-56. doi:10.1016/j.tranpol.2018.07.013

Werner, M., Eissing, K., Langton, S. (2016). Shared value potential of transporting cargo via hyperloop. Frontiers in Built Environment, 2 doi:10.3389/fbuil.2016.00017a