“Roads? Where we're going we don't need roads.” Using Agent-based modeling to analyze the economic impact of Hyperloop introduction on a supply chain

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Abstract.

The opportunity to connect distant areas in a quick and economical way has always been a critical element for the growth of trade and for economic development. Significant progress is often accompanied by the emergence of new transport models, as it happened in the 21st century China with high-speed railways, a driving force for its economic growth. In 2013, the publication of the Hyperloop Alpha white paper presented the opportunity for a great innovation in transportation, which could have an even more disruptive effect. In this paper, we will estimate the possible impact on a Supply Chain of the construction of a Hyperloop line for goods transportation. We develop an agent-based model of a simple Supply Chain system to simulate the introduction of a faster transport line. We observed that a positive relationship exists between the introduction of a faster line and the performance of the firms near the cities connected by the new line. We conclude that the adoption of a Hyperloop could bring a significant effect on the region in which it is implemented. Since the technology is in its infancy, there is still room for further research.

Keywords: Agent-based Modeling, Hyperloop, Economic Models, Supply Chain, Regional Development, Infrastructure Development

1 Introduction

Individuals’ desire to travel has led to some of humanity's most amazing creations, like ships, cars and airplanes, which now have an enormous influence on our life. The more the technologies advance, the more the quantity of goods and products transported become vital for the development of the world. In 2013, Elon Musk presented a first proposal for the Hyperloop, a new technology that could radically revolutionize the transportation of goods and people. It consists of capsules traveling inside airless tubes, reaching speeds over 1200 km per hour [12]. This innovation could offer many advantages over traditional travel methods. For example, it could reduce travel time, ticket costs, and construction costs compared to a conventional high-speed line [5] [18]. The goal of this preliminary research is to understand if the practical application of Hyperloop technology could lead to improvements in freight transport and supply chain performance, and in which kind of regions would be better to implement it. The methodology we adopt is agent-based modeling, a well-known technique for modeling real-world dynamical systems in a wide set of applications [1]. We developed an agent model of a trading system based on a simple supply chain, and we analyzed the impact of a new single fast line, which stands for the Hyperloop, on the firms in the connected areas. Firstly, we found a positive correlation between the introduction of a Hyperloop and the performances of the firms nearby it. Secondly, we concluded that the first Hyperloop line should be introduced in a region already economically and infrastructurally developed. Furthermore, we proposed a list of some possible developments and future research that are needed to be addressed. The remaining of the paper is structured as follows: in Section 2, we introduce previous research on the topic; in Section 3, we show the model and the methodology adopted; in Section 4, we show the results and discuss them. Finally, in Section 5, we conclude and define future possible research trajectories.

2 Literature analysis

2.1 Hyperloop

Although Hyperloop has begun to spread through newspapers and companies reports, scientific production on the subject is still limited. We performed a literature search on Scopus to find scientific works available on the topic, finding only 16 documents. The query was asked on February 1st, 2020 with the next research key: ((TITLE (hyperloop*) AND KEY (hyperloop*)) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT TO (DOCTYPE , "cp")) AND (LIMIT-TO (SRCTYPE , "j") OR LIMIT-TO (SRCTYPE , "p"))). All the results were recent: the first document on this topic was published in 2017. However, the number of papers published is also growing over the years, suggesting an increasing interest in the field. The majority of the papers regarded the different areas of design and construction of a Hyperloop system. The main topics were magnetic levitation systems [3] [11] and testing activities [10] [13]. Some papers [6] [15] focused on safety and the possible physical impacts on passenger's transportation of the use of Hyperloop technology. There was also a work related to the modeling and analysis of the possible performances of the Hyperloop technology [17], comparing it with high-speed rail and air transport. However, the analysis only concerned passenger transport, without considering the possible effects of the Hyperloop introduction on freight transport.

2.2 Impact of high-speed trains

In the previous paragraph we see that, to the best of our knowledge, there is not any literature related to the possible impact of a Hyperloop on the development of a region. Hence, we collected information on the influence on development of high-speed trains, the latest technologies introduced for the rapid transport of goods. This choice was made to have a clearer image of the phenomenon we wanted to analyze. The research was carried out with Scopus on February 1st, 2020 with the following key: (TITLE ("railway*" OR " high speed trains" OR " High* Rail*" OR "Transport Development") AND KEY ("Development" OR "accessibility" OR "economic growth" OR "Urban growth)). The following thematic areas have been excluded because they are not congruent with the aims of the research: “EART, PHYS, MATE, ARTS, MEDI, CHEM, CENG, BIOC, HEAL, PHAR, PSYC, IMMU, VETE.” The main results are reported in Table 1.

Table 1. Main results of bibliographic research about high-speed trains.

Finding	Sources
There was a positive relationship between rail transport and GDP growth, a relationship not necessary present with passenger transport. This was especially true for high capacity lines.	Weidong 2008, Hang 2011, Sun 2012, Wang et al. 2009
The evolution of the railway network was also capable of changing the pace and development paths of urban areas.	Wang et al. 2009, Huang et al. 2016
Accessibility of stations is a key element for attractiveness of high-speed lines, since it influenced the total travel time. With lower accessibility (or reduced interconnections), total travel time was stable and there were not significant benefits.	Wang et al. 2013, Brezina and Knoflacher 2014
For passenger transport, high-speed trains had no advantages over traditional lines under 150 km, while they are particularly effective between 400 and 800 km.	Gleave 2004, Chen & Hall 2011

3 Model presentation

The purpose of this model is to observe how the introduction of a higher speed transportation line dedicated to goods between two urban centers impacts on the performance of the firms around them. To achieve this goal, we simulated the behavior of a simple supply chain composed by different levels, in which a single kind of good is produced, exchanged in a single direction, and consumed.

The model scenario is a squared territory. There are two kind of agents: Cities and Suppliers. Cities are uniformly randomly distributed in the territory, while Suppliers are uniformly randomly distributed around the Cities. Each Supplier is connected to his City by “roads,” while the Cities are connected to each other by “railroads.” The link breeds differ from each other in travel time and the travel cost per unit of space, which is higher for the "roads" connection. It embodies the higher cost and lower speed of local transport. The supply chain is divided into different tiers. Suppliers with a tier equal to one are directly supplying the Cities, the final market of the model, and the final destination of goods. At the same time, suppliers with the highest tier are producers. Each tier has the same number of Suppliers. In every tier, Suppliers define their selling price by applying a mark-up to their average cost of the stock, that includes buying and transportation cost.

Agents have some commerce constraints. First, they can only commerce with agents with an adjacent tier (plus or minus one). Secondly, agents can receive goods only from Suppliers with a higher tier. Thirdly, agents can ask for products only to a limited set of suppliers, which is selected through an evaluation score (from now on ES). ES is the mean of normalized values of travel time from the asking agent to the Supplier, travel cost from the asking agent to the Supplier, quality of Supplier goods and cost of Supplier goods. Selected Suppliers are ranked by the ES. Except for producers, every agent has the same number of selected Suppliers. Cities' demand is generated by a pseudo-random continue uniform distribution and depends on the population level of the City, a constant parameter defined at the beginning of the simulation. At each time step, Cities have an incoming demand and ask the Suppliers in their network to fulfill it. If a Supplier has enough stock, the demand is satisfied. Otherwise, the City receives all the stock of the first Supplier and ask another Supplier for goods. This process keeps on until the demand is satisfied or available Suppliers finish. Suppliers with higher ES would be chosen before Suppliers with lower ES. The same supplying process is also repeated for every non-producing Supplier.

So, at each time step, the demand of the City goes upstream on the supply chain until it arrives to producers, which generate a number of goods equal to the minimum value between the production constraint and the incoming demand. There is no limit in the quantity of goods an agent can sell in a single time step (except for a non-negative constraint for sold goods and stock level). Thus, at every time step, there are some goods that are still in transit. To conclude, each agent starts the simulation with the same amount of cash. Every time step, it will earn cash for selling goods, spend cash for buying goods, and for covering fixed costs, equal for every agent in the market.

4 Model Analysis

4.1 Methods

We executed an experiment on the model to observe the effect of the introduction of a single Hyperloop line on the supply chain. We analyzed the impact on a ten years' time frame (520 steps of one week), introducing the new connection after five years, and observed if it implied a higher differential performance of the Suppliers around the

Cities connected by the Hyperloop compared to the others. We implemented both the model and experiment with NetLogo, a well-known agent-based simulation platform. We especially exploited BehaviourSpace, a tool for performing multiple experiments at the same time with different parameters. We executed 128000 simulations overall, to have highly reliable results [16]. The measure we used to evaluate the relative effect of a faster line for the Suppliers near the connected Cities is the difference between the average percentual increase of cash level of Suppliers near the connected Cities and the average percentual increase of cash level of the other Suppliers (from now on REFL). The increase is calculated from the introduction of the high-speed line to the last time step of the simulation. The idea behind this measure is to detect the effect of the fast line without interferences, since the supply chain had already stabilized before. The higher the REFL, the higher the impact of the new line on Suppliers' performances in the simulated model. Furthermore, it is a proxy of the differential performance of Suppliers connected with the new link.

4.2 Results

In our analysis, we focused on five parameters: the number of Cities in the model, the number of connections for every City, the number of Suppliers in the model, the number of tiers in the modelled supply chain, and the transportation cost per unit of space. We chose these parameters because they were the ones that could give us better insights about where and how a Hyperloop connection should be developed.

Table 2. REFL per different number of Cities and connections between Cities.

	# Cities connections (per City)		
# Cities	2	4	Total
5	322,8%	351,6%	337,2%
20	171,0%	262,0%	216,5%
Total	256,5%	312,4%	284,4%

From Table 2, we saw that the average impact of the introduction of a high-speed line is positive (a global performance better by 284,4%). Additionally, RELF decreased with the number of Cities and increased with the number of Cities connected to each City. The impact of a single line is diluted with a bigger number of Cities, because for a random Supplier is more probable to have a nearer Supplier of another City. On the other side, more connections between Cities meant more possible paths in the network to go from one City to another. The consequence was that, with the same number of agents, on average, each Supplier was easier to reach than before, and then the part of ES related to distance became more sensitive to small variations. With the introduction of a new line, it was more likely than before that the increase of performance of the track changed the previous equilibrium in the selection process of Suppliers.

Table 3. REFL per different number of Suppliers and tier of the supply chain.

	# tiers of supply chain		
# Suppliers	2	4	Total
40	373,6%	89,1%	229,2%
80	498,8%	182,6%	337,8%
Total	437,2%	136,7%	284,4%

From Table 3, we learned that the RELF increased with the number of Suppliers in the model and decreased with the number of tiers in the supply chain. Ceteris paribus, there were more Suppliers in the area influenced by the new connections, and we expected them to select more often Suppliers from the new connected Cities than others. So, while the first relation was justified by the presence of an aggregation phenomenon, the second could be explained analogously to the relation with the number of Cities.

Table 4. REFL per different level of transport cost.

Transport cost	REFL
0.02	424,0%
0.08	153,8%
Total	284,4%

In Table 4 we observed that there is a negative correlation between the transport cost per unit of space and the REFL. This negative correlation is related with the fact that the more the line cost, the less likely it was for Suppliers around the Cities to be selected because the ES would be lower.

4.3 Discussion

From the analysis of experiments, we got four main insights. First, to have a higher marginal benefit, the positive relationship between RELF and the increment of connections between Cities could suggest that the first Hyperloop lines should be developed in regions with already a higher infrastructural development. This was confirmed by the negative correlation between RELF and the number of Cities in the model and by the higher connections/Cities ratio. Second, the positive association between the number of Suppliers and RELF indicated that a Hyperloop line would bring higher benefits if it would be developed in regions with a higher index of competitiveness. Third, the presence of higher travel cost implied lower values of REFL. It hinted that the effect of Hyperloop on a supply chain system would depend from the performance of the technology. Also, there would be a threshold in the performance/cost ratio: under that level it would be not convenient to invest in a Hyperloop line. This was not only relevant for policymakers but also for the firms which are developing the technology and their stakeholders. Potentially, they could know in advance the technological standards they had to achieve to sell their systems and have a positive return from the investment. Fourth and last, in our experiment the RELF decreased when the number of tiers of the supply chain increased. This meant that the development of a line could be more efficient if the supply chain would be shorter.

5 Conclusions and Future Research

In conclusion, we can confirm that faster transport lines could bring a positive effect on the area in which they would be developed. Nevertheless, to analyze the global benefit of the investment it would still be necessary not only to quantify and study the impact on the transportation of people, but also to have reliable information about the performances of this technology. Regardless, our study concluded that the development of a Hyperloop line for transporting goods would be positive, especially for regions with a high number of firms and a high level of infrastructure development.

Anyway, this is preliminary work and there is space for further development. For example, it is possible to expand the actual model and replicate real scenarios. It could also be interesting to add multiple goods in the supply by introducing a sort of circular economy, introducing maximum transport capacity for each transport line, or implementing a more sophisticated decision making for both Cities and Suppliers. Another remarkable advance could be to simulate the introduction on a Hyperloop line directly on a real-world case, with real data, to give precise highlights to investors and policymakers. In conclusion, it would also be interesting to change the subject of study and analyze the impact of a Hyperloop on tourism and economic growth of different regions through an agent-based model.

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