On the Development of a Sustainable and Fit for the Future Transportation Network

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1 ABSTRACT

Population growth in cities and expanding city territory as well as population decline in rural areas pose a challenge for the existing transport network. As a consequence, we observe a rapid change in transport infrastructure and transportation technology within the last few years. The development of individually moving drones, for example, reached a new climax with novel applications such as the trial parcel distribution in rural areas in Great Britain and Germany or medicine distribution in Rwanda, Africa. At the same time, there are advancements with respect to land-borne transportation technology, among them the Hyperloop concept presented by SpaceX and Tesla founder Elon Musk with the first test of a prototype propulsion system in May 2016 and the first test on tracks in May 2017, both carried out by Hyperloop One.

Due to the novelty or differentness, it will initially be challenging to integrate them into the existing network and to identify suitable corridors leading to especially beneficial effects on the overall transport network. While TEN-T and the national guidelines already present plans for further development in the transport sector, these strategy papers only provide for existing technologies and therefore have a limited extend. The effects of new technologies and (high-performance) infrastructures are furthermore hardly examined at the moment, although the first test tracks are already being under discussion or even build (for the example of Hyperloop). At present, it remains unclear how these novel transportation technologies will change society, our understanding of spatial proximity, mobility and consequently the logistics sector.

In this work, we give an overview regarding first considerations and reflections on the impacts of the changes and developments in the field of freight transportation. The results presented in this work are based on the outcomes of the research project “inned” (innovative network design) funded by the Austrian federal ministry for transport, innovation and technology (bmvit). Established as an exploration study, the project mainly focusses on the estimation of the impacts of high-performance transportation technologies on the society, spatial proximity and the logistics sector in the course of extending the European transportation network accordingly. In our understanding, we refer to high-performance transportation technologies as mobility systems with either high throughput (fast and/or high utilization loads) or very flexible application. Concrete, we focus in our work on Hyperloop technologies, Cargo-Sous-Terrain, freight airships and drones. Although the mobility system is considered in its entirety, the main focus is on freight transportation.

We investigate the technological boundaries with respect to network design set by the above mentioned high-performance transportation technologies as a first step. Then, a societal assessment is carried out taking spatial, social, economic and environmental aspects into account. Constraints imposed by technology and society are considered when planning an exemplary future European transportation network based on actual (freight) transportation demand. Conclusions are drawn on additional research and development activities that have to be performed in order to reach a sustainable, reliable and fit for the future European transportation network. Further, we report on expected effects of high-performance transportation technologies on geographical proximity and therefore the change in meaning of the term “region”. Finally we show preliminary results on the integration of high-performance transportation technologies into existing transportation networks for some exemplary corridors.

Keywords: network design, high-performance transport infrastructure, intermodality, spatial proximity, future transport networks

2 PROBLEM STATEMENT

Strongly contrasting developments regarding the population trends in cities and rural areas, meaning population growth in already dense areas and population decline in sparcely populated regions, require new approaches for passenger and freight transport. In addition to requirements on rapidity, efficiency, flexibility and safe transport, environmental aspects gain in importance. The transport sector is still accountable for a massive proportion of the greenhouse gas emission, in Austria it accounts for 28 percent in 2015 (umweltbundesamt 2017).

Ambitious targets for climate protection and energy, such as the Paris Agreement (United Nations 2015) on the international level and the 20-20-20 targets (European Commission 2010) on the European level, strongly influence the developments in the transport sector. Within the last few years, these policy papers set the ball rolling with energy efficient products or services, focus on behavioral aspects of usage as well as new or improved transportation infrastructure and transportation technology. Trial parcel distribution in rural areas in Great Britain (The Telegraph 2016) and Germany (Reuters 2014) as well as medicine distribution in Rwanda, Africa (CNN 2016) are just some examples of the developments in the field of individually moving drones. A recent development in the land-borne transportation technology is the Hyperloop concept. This concept presented by SpaceX and Tesla founder Elon Musk is currently carried out by the companies Hyperloop One and Hyperloop Transportation Technology. In May 2016, the first test of a prototype propulsion system (theguardian 2016) and one year later, the first test on tracks was performed (Forbes 2017), both by Hyperloop One.

The mentioned examples of technological developments underline that these new infrastructures in transport logistics are increasingly important. At the same time, it is obvious that the introduction of these technologies and infrastructures into the existing transport network is going to be a challenge due to the novelty and differentness. Another important aspect is the identification of corridors which benefit the overall transport network. Currently available strategy papers such as the TEN-T (European Commission 2011) and the national guidelines (bmvit 2012) are limited to existing technologies. Uncertainties associated with developments in the transport domain make forecasts especially challenging since the effects of new technologies and (high-perfomance) infrastructures on society, the concept of mobility and thus the logistics sector are practically unknown even though test tracks for some of the transport options (e.g. Hyperloop) are even already build.

Changes in emission and/or more specific CO2 emissions require a strategic implementation of measures, which can take place, inter alia, in the provision of sustainable infrastructures. On this account, a preliminary analysis of existing alternative technologies and infrastructures is necessary in order to assess how sustainable the use of high-performance infrastructures actually is. For example, Hyperloop is regarded as environmental friendly, although the knowledge on this technology is still very limited in this respect, and hardly any information on its effects on spatial, social or economic structures is available by now. It is for this reason that our research on intelligent network design (“inned”) explores the innovative and novel possibilities for environmental friendly transports in order to reduce CO2 emissions and negative environmental impacts that come along with growing global population and increasing urbanization.

The investigation of the potential of high-performance infrastructures is particularly important with regard to the aspect of mass performance. Although the mass performance is a major added value for rail and waterways, it is also being mitigated by problems in the area of compatibility (including air transport) and time factors (e.g. in the case of waterways). High-performance infrastructures can be even better suited for that purpose.

Efficiency is an important aspect in our society and is commonly associated with costs that have to be constantly optimized in order to remain competitive on the market. Substantial efficient technologies (high-performance infrastructures) are currently reaching market maturity and are expected to be systematically implemented in the existing transport network over future years. To be able to estimate the effects of such an implementation (positive as well as negative) and therefore to make decisions in favor of certain means of transport, a closer look at the network is necessary. The network design determines the efficiency of the transport, which is why it is necessary to look more closely at the circumstances in which technologies can be integrated. Particularly in Europe, where a well-developed transport network meets comparatively small distances and a high population density (compared to the USA), it is not only the effects on the flow of goods and people, but also on spatial, social and economic structures.

The results presented in this work are based on the outcomes of the research project "inned" (innovative network design) funded by the Austrian federal ministry for transport, innovation and technology (bmvit). Established as an exploration study, the project mainly focusses on the estimation of the impacts of high-performance transportation technologies on the society and the logistics sector in the course of extending the European transportation network accordingly. In our understanding, we refer to high-performance transportation technologies as mobility systems with either high throughput (fast and/or high utilization loads) or very flexible application. Concrete, we focus in our work on Hyperloop technologies, high-speed trains, freight airships and drones. Although the mobility system is considered in its entirety, the main focus is on freight transportation.

The work plan foresees the investigation of technological boundaries with respect to network design set by the above mentioned high-performance transportation technologies as a first step. Then, a societal assessment is carried out taking spatial, social, economic and environmental aspects into account. Both, technology and society are expected to impose constraints that have to be considered planning an exemplary future European transportation network based on actual (freight) transportation demand. Finally, conclusions are drawn on additional research and development activities that have to be performed in order to reach a sustainable, reliable and fit for the future European transportation network. The structure of this paper corresponds to this work plan in consideration of the current status of the project.

3 HIGH-PERFORMANCE TRANSPORT INFRASTRUCTURE

When talking about high-performance infrastructure, the first step is to define high-performance. We decided to define high-performance as either high quantities, high speeds and/or high flexibility. Both, high quantities and high speed finally result in high throughput. High flexibility results, however, in rather low cost results. We mainly focus, however, on novel transport technologies, i.e. technologies, which have not (or at least only limited) been applied in real-world settings.

3.1 Hyperloop

Elon Musk initially introduced the Hyperloop technology as an idea to shift passenger transport towards a new and sustainable technology. The main idea is hereby to develop a large-scale pneumatic post, i.e., a tube of dimensions such that a capsule with transport capacity for approx. 20 persons. The capsule reaches speeds of up to 1200km/h, which is possible due to reduced air pressure in the tube. The usage of the capsules, also called pods, is for either passenger or freight transport. There are also concepts for pods to be used for freight and passengers at the same time (Taylor 2016). Construction costs are estimated between EUR 9.5mio up to EUR 28.5mio per kilometer with an extra of EUR 27mio per kilometer in tunnels (HTT 2017 and SpaceX 2017).

Obvious advantages of Hyperloop technologies are the high speeds, which enable the (sustainable) connection of areas located further apart (e.g. the often mentioned example of Los Angeles and San Francisco). Due to the short travel times together with the ease of train travelling (compared to air travelling), one has to rethink the term of local proximity. We assume that the introduction of such a high speed connection results in noticeable changes in societal behaviors. E.g., daily commuting between cities located up to 1000km apart becomes not only possible but also physically relevant.

Disadvantages, on the other side, are the necessary construction of tubes, which means that, in addition to often already existing, rail tracks and highways a second transport infrastructure needs to be constructed. Investments are, however, rather high.

3.2 Freight Airships

The concepts of airships is rather old and well known to a broad mass of people due to dramatic historic incidents. Caused by these incidents, the concepts were not pursued over a long period. In the last years, however, the idea became more and more popular again resulting in the fact that currently novel airship concepts are developed and are already tested. The novel concept aims, however, at freight transport only. The main idea is to lift cargo into air with the clear advantage that it is not necessary to construct additional transport infrastructure except at the two ends of a connection. In addition, it would be possible to construct interim terminals for airships or, in extreme situations, to just guarantee that a large enough empty (and smooth) area is available. The construction companies plan different model types with a payload of up to 500t and up to 220km/h max speed (Aeros 2017). However, only smaller variants successfully performed test flights during the last few years.

Beside the advantage that airships are rather flexible with respect to origin and destination of transports, they also build a valuable addition with respect to special transports. Drawbacks are, surely, that the area needed for landing/take-off and cargo handling is rather large compared to the size of cargo transported. In addition, the price for one individual airship is approx. EUR 40mio (Airlander 2017).

3.3 Drones

The absolute opposite to airships are drones. They are rather small, fast and agile. The basic concepts are, however, quite similar. They allow for a flexible and easy to plan transport even in areas where no (or rather limited transportation infrastructure is available. Good examples are the parcel distribution trials in Great Britain (The Telegraph 2016) and Germany (Reuters 2014) or medicine distributions in Rwanda, Africa (CNN 2016).

While drones themselves are rather cheap and there is a wide range of possible application, drones suffer from the fact that they are relatively sensitive to windy weathers. Furthermore, depending on the actual manufacturer, the payload of drones is limited to at most 100kg with many of them being in the range of up to 20kg. Furthermore, the range of drones is limited – especially for the electric ones. At the same time, current laws forbid autonomous flights in some countries (incl. Austria). Even more, based on reports in local media one can expect that societal acceptance of (a high number of) drones in the air will be rather low.

3.4 Cargo-Sous-Terrain

Strictly speaking not a mode of transport, Cargo-Sous-Terrain is a further innovative freight transport concept. Cargo-Sous-Terrain as proposed by the research project and company with the same name combines different ideas and concepts for city logistics (Cargo-Sous-Terrain 2017). First, the main idea is to shift land transport from roads to underground. Second, Cargo-Sous-Terrain relies on a city hub concept, i.e. a logistics concept where a small depot is installed in the city center while at the outer rim of the city a large consolidation hub is established. City hub and consolidation hub are linked via an underground connection. The last mile (from the city hub) is realized by employing sustainable modes of transport like bikes or small e-vans.

Advantages are obvious like bundling of cargo as well as a shift of freight cargo to the underground. Disadvantages are the extra handling of cargo at the consolidation and city hub. Further, it is necessary that one (neutral) operator is in charge of all city distributions. In addition, construction costs are rather high, as additional infrastructure is needed.

4 IMPACTS OF HIGH-PERFOMANCE TRANSPORT TECHNOLOGIES

To assess the impact of (novel) transport technologies on the societal and economical parameters in regions, an impact assessment was performed. We assumed that an easy accessible high-speed connection between two cities, which is reducing the travel time below one hour, leads to increased commuting between these cities. However, this implies that these two cities close ranks with each other, i.e., in terms of labour and housing market. Thus, the meaning of a “region” is changing since the spatial limitations set by distance and connected travel time are softened.

To analyze the concrete impact, we chose the following approach: First, we decided on the transport technologies to be assessed (described in the previous section). Then, we estimated effects of these technologies on the elements of the transport system. Together with experts, we assessed these effects.

Finally, we performed a multidimensional impact analysis. Details on this procedure are given in Schodl et al. (2017). The result of this impact assessment is a benefit analysis for "typical" network links. These values are then a major input for the network-planning presented in the following section.

5 DESIGN OF FUTURE TRANSPORT NETWORKS

The main idea was to design a transportation network that is fit for future transport requests. This includes, but is not limited to, freight transport. Quite the contrary, it is essential that the transport network fulfills all requirements stated by passenger and freight.

Based on the results obtained via the impact assessment presented in the previous section, it is possible to apply basic service network optimization algorithms (Crainic 2000) with additional constraints, which are motivated by the technological constraints stated by the transport technologies (e.g. capacity and/or meaningful range). Obviously, the main objective is to maximize the benefit of the transport network. This includes that for some regions conventional, already existing transport modes will still be heavily used while the algorithms suggest to implement novel transport technologies for other connections.

To be more precise, we model the existing transport network on a multi-layered graph where nodes represent stations in major cities and the edges represent the connections between them. Each layer is assigned to one transport mode, e.g. road or rail as classical representatives, and Hyperloop or freight airships as high-performance representatives. Edges between stations of one city illustrate the work for transferring/handling goods from a station to another. We denote this graph as infrastructure network. Furthermore, we model the freight transportation on an abstract graph, the so-called service network, where each city is connected with a direct edge. Each edge shows the flow of goods between two cities without specifying the actual route and the transport mode(s). In our approach we have to synchronize the freight transport between these two networks: On the service network we search for future transport requests that should be fulfilled (e.g. because of high importance or high profit) and on the infrastructure network we optimize the actual realization with respect to specific key performance indicators (KPIs). The following KPIs are considered:

- Minimization of infrastructure costs (for the new connections)
- Minimization of transport costs for the transported goods
- Maximization of effectiveness for each transport mode where it is implemented. The effectiveness is a weighted cumulative rating consisting of speed, throughput, flexibility, reliability, noise and emission of the transport technology.
- Maximization of regional bonus effects. This is also a cumulative rating, applied only to the high-performance transportation technologies where social, spatial, economical, ecological, political and technological impacts are considered.

Based on this model, we implemented a mixed integer program that is able to solve small to medium sized scenarios. Fig. 1 shows a small scenario where we tested our approach. The infrastructure network contains six cities and six transport modes. Black connections represent the existing infrastructure network (road, rail and water). Orange, purple and red connections represent possible connections for cargo airship, Hyperloop and Cargo Sous Terrain (CST), respectively. In this scenario, while airship and CST are less restrictive with respect to the geographical conditions, Hyperloop cannot be built between Graz and Budapest due to mountain slopes. The green line is an example for a transport request between Budapest and Linz, realized as road transport between Linz and Vienna and Hyperloop between Vienna and Budapest. In Fig. 2 the same transport request is represented by a direct connection between Linz and Budapest in the service network.

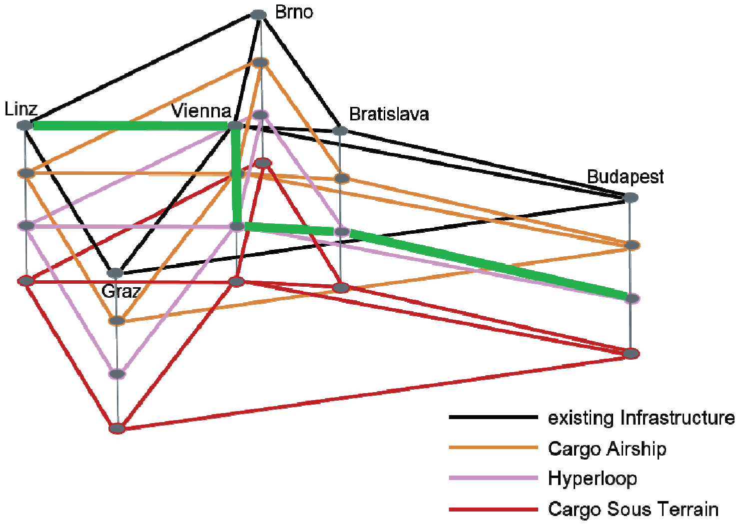

Fig. 1: Example for an infrastructure network.

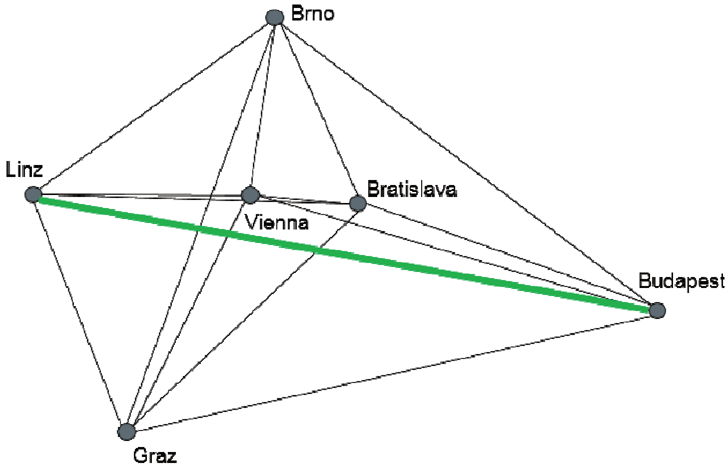

Fig. 2: Example for a service network.

In the experimental computation we considered the amount of food transported between the six cities based on Eurostat (2014). The effectiveness ratings were taken from Pfoser et al. (2017) and the regional effects ratings from Schodl et al. (2017). Costs for the high-performance transportation technologies were taken from preliminary information (Airlander 2017, HTT 2017, SpaceX 2017, Cargo-Sous-Terrain 2017) and summarized in Table 1. The costs for freight transportation via Hyperloop were reduced since the infrastructure is designed to be used for passenger and freight. We further set a capacity limit on the existing infrastructure since otherwise the high-performance transportation technologies will not be used due to high investment costs.

	Station costs	Track costs	Transport costs
Hyperloop	€ 200mio	€ 40mio per km	€ 0.05 per ton per km
Freight airships	€ 100mio	€ 1mio per km	€ 0.45 per ton per km
Cargo Sous Terrain	€ 150mio	€ 45mio per km	€ 0.10 per ton per km

Table 1: Costs for high-performance transportation technologies.

In Fig. 3 and Fig. 4 we present two example results of our model. Fig. 3 shows that the cargo airship infrastructure is nearly fully built since it has the cheapest infrastructure costs. It is mainly used for freight transport whenever the capacity of the existing infrastructure is exhausted. Graz is only connected via the existing infrastructure because the transport demand is relatively low compared to the other cities. CST is used on a relative short route between Vienna and Bratislava (~70km) where the construction cost is still bearable in relation to the efficiency of the technology. Hyperloop is not built at all due to its high costs.

In Fig. 4 we modified the scenario settings by neglecting the infrastructure costs. The biggest impact is that the cargo airship is not used anymore. Compared to the other technologies, it is less effective in the cumulative rating. While the CST operates on the triangle between Vienna, Brno and Bratislava, the Hyperloop network now reaches every city except Graz. We can see the main connection goes from Linz to Budapest and a branch from Bratislava to Brno. The reason why Bratislava is selected as branching point instead of Vienna is the much higher transport demand between Brno and Bratislava.

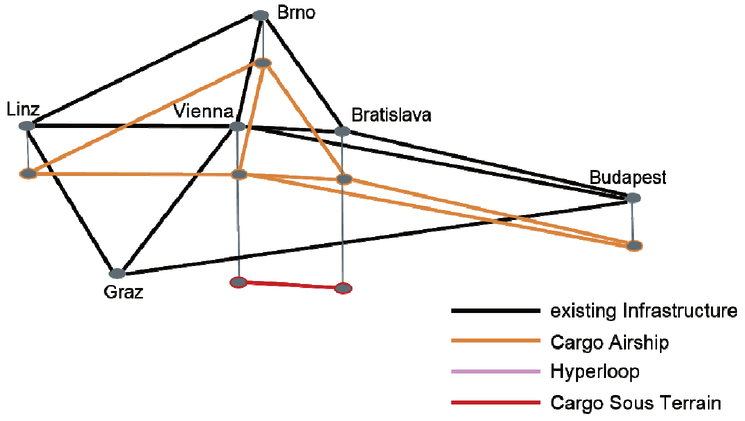

Fig. 3: Example result for the scenario in Fig. 1.

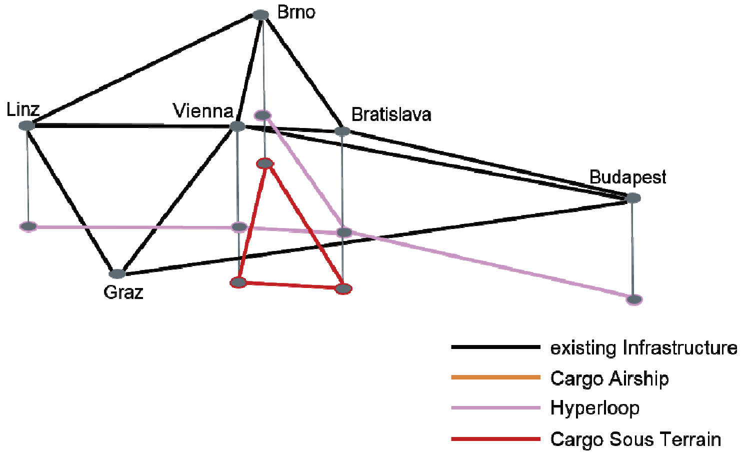

Fig. 4: Result for the scenario in Fig. 2 if infrastructure costs are neglected.

We want to highlight that the basic idea of the overall approach is to (re-)plan the transport network as a whole. I.e., we are not focusing only on a small region or one country but address the problem as a European one. Therefore, it is essential that the methods developed and employed during the assessment step allow a deduction from showcases towards a more general level. Nevertheless, we emphasize that the results obtained via this approach only represent a supporting tool which has to be thoroughly evaluated by the planners in a subsequent step.

6 CONCLUSIONS

We are facing, on the one hand, an increasing demand and high expectations for passenger and freight transportation as a result of population growth and urbanization. On the other hand, goals as the Paris Agreement force us to rethink our current transport system. This opens the door for the introduction of novel transport technologies, which have the potential to be more sustainable with respect to social, economic but also ecological aspects. We, therefore, dare to propose a novel holistic network planning approach, which aims at optimizing the whole (European) transport network in order to gain the most positive effects. As the planning (and building) of a transport network is a rather costly and time-consuming task, we emphasize the importance of such supra-regional planning approaches. Even if these cannot come up with an optimal final decision, they can support the planners in their decision-making.

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