



Invention of New Conventional Hyper Loop Transportation System

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ABSTRACT

Existing conventional modes of transportation of people consists of four unique types: rail, road, water, and air. These modes of transport tend to be either relatively slow (e.g., road and water), expensive (e.g., air), or a combination of relatively slow and expensive (i.e., rail). Hyper loop is a new mode of transport that seeks to change this paradigm by being both fast and inexpensive for people and goods. Hyper loop is also unique in that it is an open design concept, similar to Linux. Feedback is desired from the community that can help advance the Hyper loop design and bring it from concept to reality. Hyper loop consists of a low pressure tube with capsules that are transported at both low and high speeds throughout the length of the tube. The capsules are supported on a cushion of air, featuring pressurized air and aerodynamic lift. The capsules are accelerated via a magnetic linear accelerator affixed at various stations on the low pressure tube with rotors contained in each capsule. Passengers may enter and exit Hyper loop at stations located either at the ends of the tube, or branches along the tube length. In this study, the initial route, preliminary design, and logistics of the Hyper loop transportation system have been derived. The system consists of capsules that travel between Amaravathi, Vijayawada and Vijag. The total one way trip time is 35 minutes from county line to county line. The capsules leave on average every 2minutes from each terminal carrying 70 people each (as often as every 30 seconds during rush hour and less frequently at night). This gives a total of 77.4 million people per tube that can be transported each year on Hyper loop. The total cost of Hyper loop is under \$6 billion USD for two one-way tubes and 40 capsules. Amortizing this capital cost over 20years and adding daily operational costs gives a total of \$20 USD plus operating costs per one-way ticket on the passenger Hyper loop

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Introduction

What is Hyperloop?

Short of figuring out real teleportation, which would of course be awesome (someone please do this), the only option for super fast travel is to build a tube over or under the ground that contains a special environment. This is where things get tricky. At one extreme of the potential solutions is some enlarged version of the old pneumatic tubes used to send mail and packages within and between buildings. You could, in principle, use very powerful fans to push air at high speed through a tube and propel people-sized pods all the way from Amaravathi to Vizag. However, the friction of a 350 mile long column of air moving at anywhere near sonic velocity against the inside of the tube is so stupendously high that this is impossible for all practical purposes. Another extreme is the approach, advocated by Rand and ET3, of drawing a hard or near hard vacuum in the tube and then using an electro magnetic suspension. The problem with this approach is that it is incredibly hard to maintain a near vacuum in a room, let alone 700 miles (round trip) of large tube with dozens of station gateways and thousands of pods entering and exiting every day. All it takes is one leaky seal or a small crack somewhere in the hundreds of miles of tube and the whole system stops working.

However, a low pressure (vs. almost no pressure) system set to a level where standard commercial pumps could easily overcome an air leak and the transport pods could handle variable air density would be inherently robust. Unfortunately, this means that there is a non-trivial amount of air in the tube and leads us straight into another problem.

Hyper loop Transportation System

Hyper loop (Figure 2 and Figure 3) is a proposed transportation system for traveling between Amaravathi, Vijayawada, and Vijag, in 35 minutes. The Hyper loop consists of several distinct components, including:

1. Capsule: a. Sealed capsules carrying 28 passengers each that travel along the interior of the tube depart on average every 2 minutes from Los Angeles or San Francisco (up to every 30 seconds during peak usage hours)
- b. A larger system has also been sized that allows transport of 3 full size automobiles with passengers to travel in the capsule.
- c. The capsules are separated within the tube by approximately 23 miles (37 km) on average during operation.
- d. The capsules are supported via air bearings that operate using a compressed air reservoir and aerodynamic lift.

Tube:

a. The tube is made of steel. Two tubes will be welded together in a side-by-side configuration to allow the capsules to travel both directions.

b. Pylons are placed every 100ft (30 m) to support the tube.

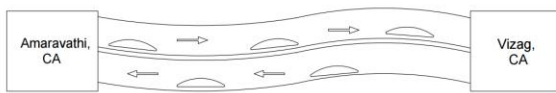
c. Solar arrays will cover the top of the tubes in order to provide power to the system.

3.Propulsion: a.Linear accelerators are constructed along the length of the tube at various locations to accelerate the capsules.

Rotors are located on the capsules to transfer momentum to the capsules via the linear accelerators.

4.Route:

a. There will be a station at Amaravathi and Vijayawada. Several stations along the way will be possible with splits in the tube.



Hyperloop conceptual diagram.

b. The majority of the route will follow I-5 and the tube will be constructed in the median. In addition to these aspects of the Hyper loop, safety and cost will also be addressed in this study. The Hyper loop is sized to allow expansion as the network becomes increasingly popular. The capacity would be on average 840 passengers per hour which is more than sufficient to transport all of the 10 million passengers traveling between Amarravathi and Vijag areas per year. In addition, this accounts for 70% of those travelers to use the Hyper loop during rush hour. The lower cost of traveling on Hyper loop is likely to result in increased demand, in which case the time between capsule departures could be significantly shortened.

Background

When the California “high speed” rail was approved, I was quite disappointed, as I know many others were too. How could it be that the home of Silicon Valley and JPL –doing incredible things like indexing all the world’s knowledge and putting rovers on Mars would build a bullet train that is both one of the most expensive per mile and one of the slowest in the world? Note, I am hedging my statement slightly by saying “one of”. The head of the California high speed rail project called me to complain that it wasn’t the very slowest bullet train nor the very most expensive per mile. The underlying motive for a statewide mass transit system is a good one. It would be great to have an alternative to flying or driving, but obviously only if it is actually better than flying or driving. The train in question would be both slower, more expensive to operate (if unsubsidized) and less safe by two orders of magnitude than flying, so why would anyone use it? If we are to make a massive investment in a new transportation system, then the return should by rights be equally massive. Compared to the alternatives, it should ideally be:

- Safer
- Faster
- Lower cost

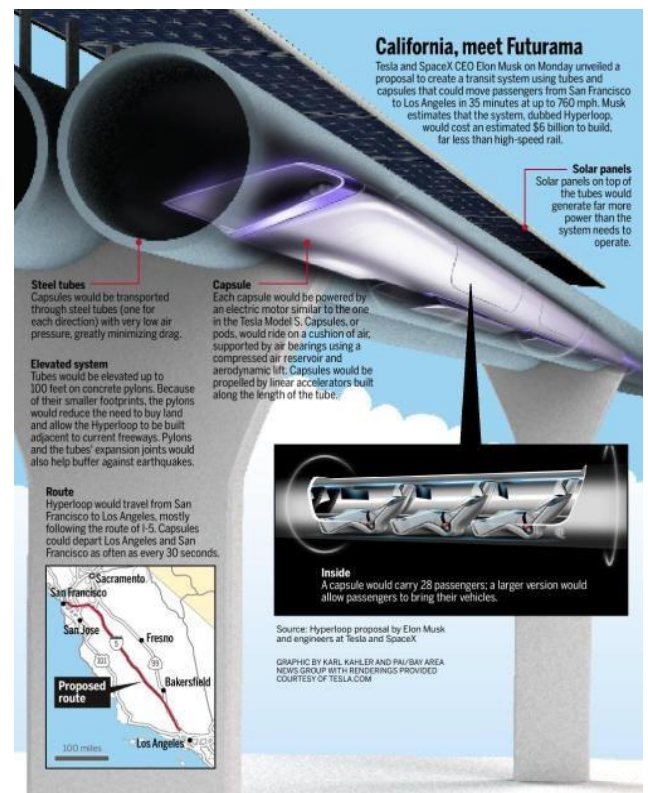
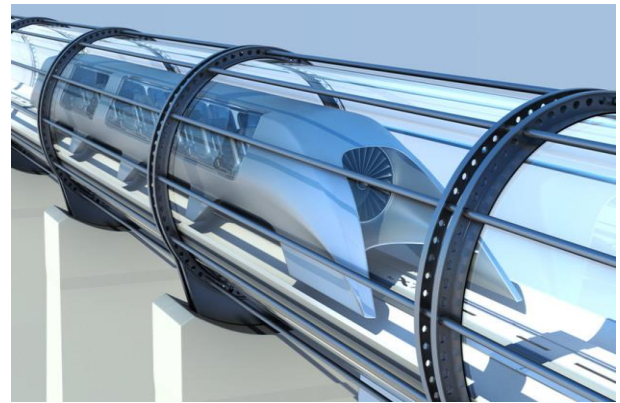
- More convenient

- Immune to weather

- Sustainably self-powering

- Resistant to Earthquakes

●Not disruptive to those along the route Is there truly a new mode of transport –a fifth mode after planes, trains, cars and boats –that meets those criteria and is practical to implement? Many ideas for a system with most of those properties have been proposed and should be acknowledged, reaching as far back as Robert Goddard’s proposals in recent decades by the Rand Corporation and ET3. Unfortunately, none of these have panned out. As things stand today, there is not even a short distance demonstration system operating in test pilot mode anywhere in the world, let alone something that is robust enough for public transit. They all possess, it would seem, one or more fatal flaws that prevent them from coming to fruition.

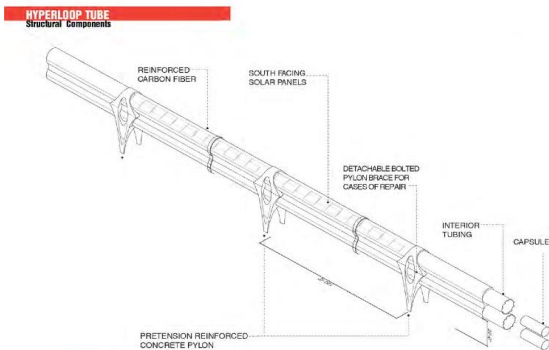
**Passenger Plus Vehicle Hyperloop Tube**

The inner diameter of the tube is optimized to be 10 ft 10 in.(3.30 m), larger than the passenger version to accommodate the larger capsule. The tube cross-sectional area is 92.1 ft²(8.55 m²) giving a capsule/tube area ratio of 47% or a diameter ratio of 68%.The closed passenger plus vehicle Hyper loop tube will be mounted side-by-side in the

same manner as the passenger version as seen in Figure 5. The surface above the tubes will be lined with solar panels to provide the required system energy. This represents a possible area of 22 ft (6.6 m) wide for more than 350 miles (563 km) of tube length. With an expected solar panel energy production of 0.015hp/ft²(120W/m²), we can expect the system to produce a maximum of 598,000 hp (446MW)at peak solar activity. This would actually be more energy than needed forthe passenger plus vehicle Hyperloop system and the specific power requirements will be detailed in section 4.3

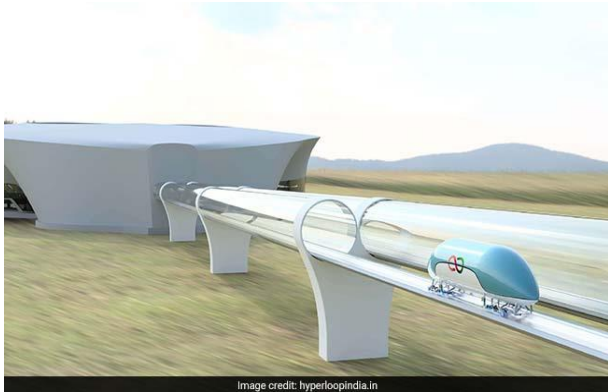
Tube Construction

In order to keep cost to a minimum, a uniform thickness steel tube reinforced with stringers was selected as the material of choice for the inner diameter tube. Tube sections would be pre-fabricated and installed between pillar supports spaced 100 ft (30 m) on average, varying slightly depending on location. This relatively short span allows keeping tube material cost and deflection to a minimum. The steel construction allows simple welding processes to join different tube sections together. A specifically designed cleaning and boring machine will make it possible to surface finish the inside of the tube and welded joints for a better gliding surface. In addition, safety emergency exits and pressurization ports will be added in key locations along the length of the tube.



Passenger Hyperloop Tube

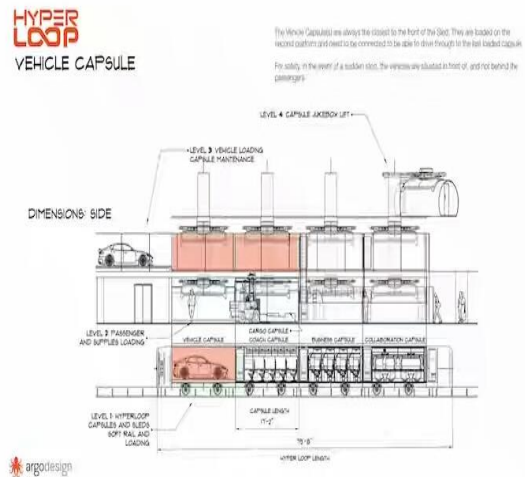
A tube wall thickness between 0.8 and 0.9 in. (20 to 23 mm) is necessary to provide sufficient strength for the load cases considered in this study. These cases included, but were not limited to, pressure differential, bending and buckling between pillars, loading due to the capsule weight and acceleration, as well as seismic considerations. The cost of the tube is expected to be less than \$650 million USD, including pre-fabricated tube sections with stringer reinforcements and emergency exits. The support pillars and joints which will be detailed in section



Passenger Plus Vehicle

The tube wall thickness for the larger tube would be between 0.9 and 1.0 in (23 to 25 mm). Tube cost calculations were also made for the larger diameter tube

which would allow usage of the cargo and vehicle capsule in addition to the passenger capsule. In this case, the cost of the tube is expected to be less than \$1.2 billion USD. Since the spacing between pillars would not change and the pillars are more expensive than the tube, the overall cost increase is kept to a minimum.



Foundation Recommendation

Depending on the nature of soil, type of proposed structure and expected loads on foundations, the recommended type of foundation is generally pile foundation except for a few locations where hard strata was located close to ground level. Pile capacities have been calculated as per IS 2911 Part 2 and IRC 78 while allowable bearing capacity for shallow open footing has been computed from the equation as per IS: 6403 –1981.

Pile Foundation

Pile foundation is a fissible foundation scheme that may be designed where the loadings are heavy medium, upper strata are loose/soft or filled up, and depth of water table is less. The pile load bearing capacity is calculated in as per IS 2911 Part 2 & IRC: 78-2000.



Open Foundation

For the prevailing soil conditions and type of structures, it was observed that shallow open footings can be provided at certain locations. Allowable bearing capacity for shallow open footing has been computed from the equation as per IS: 6403 –1981 & Settlement shall be determined for unit pressure for a specified width of footing based on Corrected SPT values between the level of base of footing and the depth equal to 1.5 to 2.0 times the width of footing. Corrections shall be applied as applicable. Refer; IS: 8009 (Part-1)



Open square footing

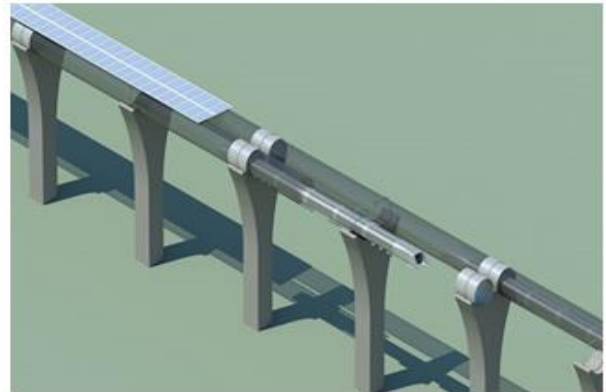
Depending on the field and laboratory observations of subsoil strata, test results and the type of structures proposed at site, the types of foundations, depths and net safe bearing capacities recommended for design purposes are given in the following table. The net SBC/API in the following table are the lower of the values obtained from shear failure criterion as per IS: 6403 and settlement failure criterion as per IS: 8009,



Pylons and Tunnels

The tube will be supported by pillars which constrain the tube in the vertical direction but allow longitudinal slip for thermal expansion as well as dampened lateral slip to reduce the risk posed by earthquakes. In addition, the pillar to tube connection nominal position will be adjustable vertically and laterally to ensure proper alignment despite possible ground settling. These minimally constrained pillars to tube joints will also allow a smoother ride. Specially designed slip joints at stations will be able to take any tube length variance due to thermal expansion. This is an ideal location for the thermal expansion joints as the speed is much lower nearby the stations. It thus allows the tube to be smooth and welded along the high speed gliding middle section. The spacing of the Hyper loop pillars retaining the tube is critical to achieve the design objective of the tube structure. The average spacing is 100 ft (30 m), which means there will be roughly 25,000 pillars supporting both Hyper loop tubes and overhead solar panels. The pillars will be 20 ft (6 m) tall whenever possible but may vary in height in hilly areas or where obstacles are in the way. Also, in some key areas, the spacing will have to vary in order to pass over roads or other obstacles. Small spacing between each support reduces the deflection of the tube keeping the capsule steadier and the journey more enjoyable. In addition, reduced spacing has increased resistance to seismic loading as well as the lateral acceleration of the capsule. Due to the sheer quantity of pillars required, Reinforced concrete was selected as the construction material due to its very low cost per volume. In

some short areas, tunneling may be required to avoid going over mountains and to keep the route as straight as possible. The cost for the pillar construction and tube joints is anticipated to be no more than \$2.55 billion USD for the passenger version tube and \$3.15 billion USD for the passenger plus vehicle version tube.



The expected cost for the tunneling is expected to be no more than \$600 million USD for the smaller diameter tube and near \$700 million USD for the larger diameter tube. Structural simulations (Figure 15 through 20) have demonstrated the capability of the Hyperloop to withstand atmospheric pressure, tube weight, earthquakes, winds, etc. Dampers will be incorporated between the pylons and tube movements in the ground from the tubes.

Station Construction

Hyperloop stations are intended to be minimalist but practical with a boarding process and layout much simpler than airports. Due to the short travel time and frequent departures, it is envisaged that there will be a continual flow of passengers through each Hyperloop station, in contrast to the pulsed situation at airports which leads to lines and delays. Safety and security are paramount, and so security checks will still be made in a similar fashion as TSA does for the airport. The process could be greatly streamlined to reduce wait time and maintain a more continuous passenger flow. All ticketing and baggage tracking for the Hyperloop will be handled electronically, negating the need for printing boarding passes and luggage labels. Since Hyperloop travel time is very short, the main usage is more for commuting than for vacations. There would be a luggage limit of 2 bags per person, for no more than 110 lb (50 kg) in total. Luggage would be stowed in a separate compartment at the rear of the capsule, in a way comparable to the overhead bins on passenger aircraft. This luggage compartment can be removed from the capsule, so that the process of stowing and retrieving luggage can be undertaken separately from embarking or disembarking the capsule's passenger cabin. In addition, Hyper loop staff will take care of loading and unloading passenger luggage in order to maximize efficiency.

The transit area at a Hyper loop terminal would be a large open area with two large airlocks signifying the entry and exit points for the capsules. An arriving capsule would enter the incoming airlock, where the pressure is equalized with the station, before being released into the transit area. The doors of the capsule would open allowing the passengers to disembark. The luggage pod would be quickly unloaded by the Hyperloop staff or separated from the capsule so that baggage retrieval would not interfere with the capsule turnaround. Once vacated, the capsule would be rotated on a turntable, and aligned for re-entry into the Hyperloop tube. The departing passengers, and their pre-loaded luggage pod, would then enter the capsule. A Hyperloop attendant would next perform a safety check of the seat belt of each passenger before the capsule is cleared for departure. At this point the capsule would then be moved forward into the exit airlock, where the pressure is lowered to the operating level of the Hyperloop, and then sent on its way. Note that loading and unloading would occur in parallel with up to three capsules at a given station at any time. The expected cost for each station is around \$125 million for a total of \$250 million USD initially.



Passenger Amenities

Passenger amenities such as ticketing counters/automatic ticket vending machines, ticketing gate, etc. are provided in the concourse. Uniform numbers of these facilities have been provided for system wide uniformity, although the requirement of the facilities actually varies from station to station. The same applies to provision of

platform widths and staircase/escalators. Maximum capacity required at any station by the year 2031 for emergency operation has been adopted for all stations. For this purpose, peak minute traffic is assumed to be 2% of the peak hour traffic. For checking the adequacy of platform area, stair widths and requirement additional of emergency evacuation stairs, a maximum accumulation of passengers in the station has been considered to be comprising waiting passengers at the platform (including two missed headways)

and section load expected to be evacuated at the station in case of an emergency

Stairs, Escalators and Lifts

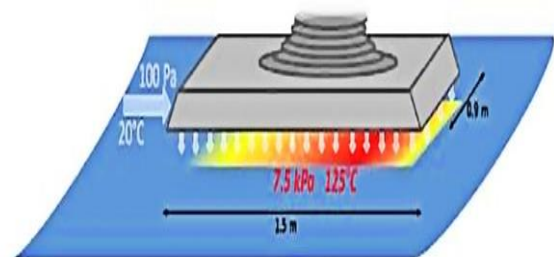
Provisions have been made for escalators in the paid area i.e. from concourse to platforms. On each platform, one escalator has been proposed. In addition, two staircases with a combined width of 6 m are provided on each platform connecting to the concourse. These stairs and escalator together provide an escape capacity adequate to evacuate maximum accumulated passengers in emergency from platforms to concourse in 5.5 minutes. Lifts have been provided one each on either platform, to provide access for elderly and disabled. Since the rise to road from the concourse is about 8m, it is proposed to provide escalators and lifts in addition to stairs for vertical movement of passengers from street to concourse.

Underground Stations

The underground station has been proposed as cut and cover with top-down method. The diaphragm walls for such station constructions would be 80 to 100 cm. thick and will function as a permanent side wall of the station. It is, therefore, necessary to construct the diaphragm walls absolutely watertight and with the required concrete strength. By resorting to top-down method the surface could be restored quickly and further excavations and construction of the station will not hamper the surface activity.

Suspension

Suspending the capsule within the tube presents a substantial technical challenge due to transonic cruising velocities. Conventional wheel and axle systems become impractical at high speed due to frictional losses and dynamic instability. A viable technical solution is magnetic levitation; however the cost associated with material and construction is prohibitive. An alternative to these conventional options is an air bearing suspension. Air bearings offer stability and extremely low drag at a feasible cost by exploiting the ambient atmosphere in the tube. Externally pressurized and aerodynamic air bearings are well suited for the Hyper loop due to exceptionally high stiffness, which is required to maintain stability at high speeds. When the gap height between a ski and the tube wall is reduced, the flow field in the gap exhibits a highly non-linear reaction resulting in large restoring pressures. The increased pressure pushes the ski away from the wall, allowing it to return to its nominal ride height. While a stiff air bearing suspension is superb for reliability and safety, it could create considerable discomfort for passengers onboard. To account for this, each ski is integrated into an independent mechanical suspension, ensuring a smooth ride for passengers. The capsule may also include traditional deployable wheels similar to aircraft landing gear for ease of movement at speeds under 100 mph (160 kph) and as a component of the overall safety system.



Schematic of air bearing skis that support the capsule.

Propulsion

The propulsion system has the following basic requirements:

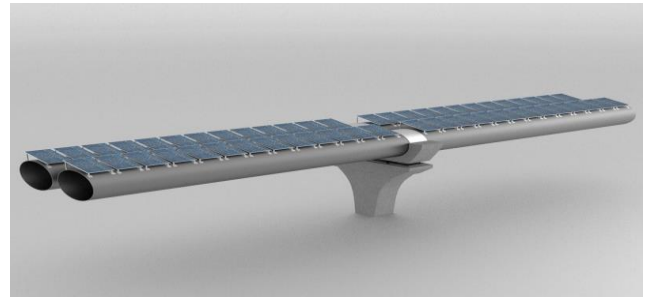
1. Accelerate the capsule from 0 to 300 mph (480 kph) for relatively low speed travel in urban areas.
2. Maintain the capsule at 300 mph (480 kph) as necessary, including during ascents over the mountains surrounding Los Angeles and San Francisco.
3. To accelerate the capsule from 300 to 760 mph (480 to 1,220 kph) at 1G at the beginning of the long coasting section along the I-5 corridor.
4. To decelerate the capsule back to 300 mph (480 kph) at the end of the I-5 corridor.

The Hyper loop as a whole is projected to consume an average of 28,000 hp (21 MW). This includes the power needed to make up for propulsion motor efficiency (including elevation changes), aerodynamic drag, charging the batteries to power on-board compressors, and vacuum pumps to keep the tube evacuated. A solar array covering the entire Hyper loop is large enough to provide an annual average of 76,000 hp (57 MW), significantly more than the Hyper loop requires. Since the peak powers of accelerating and decelerating capsules are up to 3 times the average power, the power architecture includes a battery array at each accelerator. These arrays provide storage of excess power during non-peak periods that can be used during periods of peak usage. Power from the grid is needed only when solar power is not available. This section details a large linear accelerator, capable of the 300 to 760 mph (480 to 1,220 kph) acceleration at 1G. Smaller accelerators appropriate for urban areas and ascending mountain ranges can be scaled down from this system. The Hyper loop uses a linear induction motor to accelerate and decelerate the capsule. This provides several important benefits over a permanent magnet motor:

- Lower material cost –the rotor can be a simple aluminum shape, and does not require rare-earth elements.
- Lighter capsule.
- Smaller capsule dimensions. The lateral forces exerted by the stator on the rotor though low at 0.9 lbf/ft (13 N/m) are inherently stabilizing. This simplifies the problem of keeping the rotor aligned in the air gap. Each accelerator has two 70 MVA inverters, one to accelerate the outgoing capsule, and one to capture the energy from the incoming capsule. Inverters in the 10+ MVA power range are not unusual in mining, drives for large cargo ships, and railway traction. Moreover, 100+ MVA drives are commercially available. Relatively inexpensive semiconductor switches allow the central inverters to energize only the section of track occupied by a capsule, improving the power factor seen by the inverters. The inverters are physically located at the highest speed end of the track to minimize conductor cost

Energy Storage Components

Energy storage allows this linear accelerator to only draw its average power of 8,000 hp (6 MW) (rather than the peak power of 74,000 hp or 55 MW) from its solar array. Building the energy storage element out of the same lithium ion cells available in the Tesla Model S is economical. A battery array with enough power capability to provide the worst-case smoothing power has a lot of energy –launching 1 capsule only uses 0.5% of the total energy –so degradation due to cycling is not an issue. With proper construction and controls, the battery could be directly connected to the HVDC bus, eliminating the need for an additional DC/DC converter to connect it to the propulsion system.



As described above, the propulsion elements on the capsule are limited to the rotor and not expected to cost any more than 8,000 crore for the overall system. The bulk of the propulsion cost is for the stator elements connected to the track and for the inverters to drive the stator. All tube-side propulsion costs together for all linear accelerators add up to 70,000 crore million USD. This cost is roughly divided as followed:- Stator and structure materials = 54%-Power electronics (traction inverters, grid tie inverters) = 33%-Energy storage = 13% The solar array and associated electronics provide the required average power of 28,000 hp (21 MW) and are expected to cost approximately 50,000 crore in Indian rupees.

Route

The Hyperloop will be capable of traveling between Los Angeles and San Francisco in approximately 35 minutes. This requirement tends to size other portions of the system. Given the performance specification of the Hyperloop, a route has been devised to satisfy this design requirement. The Hyperloop route should be based on several considerations, including:

1. Maintaining the tube as closely as possible to existing rights of way (e.g., following the I-5).
2. Limiting the maximum capsule speed to 760 mph (1,220 kph) for aerodynamic considerations.
3. Limiting accelerations on the passengers to 0.5g.
4. Optimizing locations of the linear motor tube sections driving the capsules.
5. Local geographical constraints, including location of urban areas, mountain ranges, reservoirs, national parks, roads, railroads, airports, etc. The route must respect existing structures.

For aerodynamic efficiency, the speed of a capsule in the Hyperloop is typically:

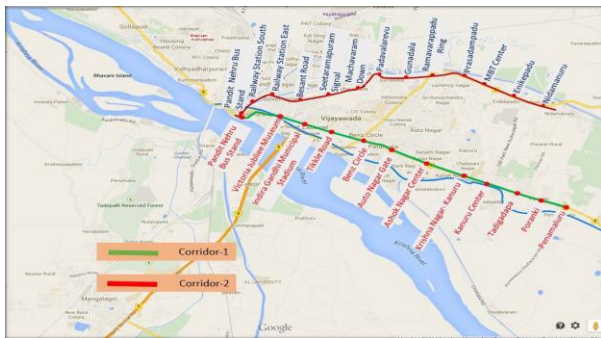
- 300 mph (480 kph) where local geography necessitates a tube bend radii < 1.0 mile (1.6 km)
- 760 mph (1,220 kph) where local geography allows a tube bend > 3.0 miles (4.8 km) or where local geography permits a straight tube.

These bend radii have been calculated so that the passenger does not experience inertial accelerations that exceed 0.5g. This is deemed the maximum inertial acceleration that can be comfortably sustained by humans for short periods. To further reduce the inertial acceleration experienced by passengers, the capsule and/or tube will incorporate a mechanism that will allow a degree of 'banking'. The Hyperloop route was created by the authors using Google Earth.

Station Connections

The stations are isolated from the main tube as much as possible in order to limit air leaks into the system. In addition, isolated branches and stations off the main tubes could be built to access some towns along the way between Amaravathi and Vizag. Vacuum pumps will run continuously at various locations along the length of the tube to maintain

the required pressure despite any possible leaks through the joints and stations. The expected cost of all required vacuum pumps is expected to be no more than 80,000 crore .in Indian currency.



Geographic, Demographic and Socio-Economic profile of Andhra Pradesh

With a geographical area of 1,62,970 sq km, Andhra Pradesh ranks as the 8th largest State in the country. Situated in a tropical region, the state has the 2nd longest coastline in the country with a length of 974 km. The State has a forest area of 36909.36 Sq.Kms, as per the forest records. Andhra Pradesh is the tenth largest state in the Country, in terms of population. As per 2011 Census, the State accounts for 4.10% of the total population of the country. The decadal growth of population rose from 18.88% during 1961-71 to 21.13% during 1981-91. Subsequently a significant decline was observed in the rate of growth of population and decline is

even more prominent at 9.21% during 2001-11, lower than the All-India's growth rate of 17.72 percent. The density of population for Andhra Pradesh is 304 persons per square kilometer, as against 382 persons per square kilometer at all India level in 2011. The sex ratio in the state was up from 983 in 2001 to 997 in 2011 and is higher than all India figure of 943 in 2011. The literacy rate of the State is 67.35 percent in 2011 as compared to 62.07 percent in 2001. The literacy rate of the State is lower than the all India literacy rate at 72.98% percent. Literacy in Andhra Pradesh increased over 37 percentage points from 29.94 percent in 1981 to 67.35 percent in 2011. Female literacy rate has gone up from 52.72 percent in 2001 to 59.96 percent in 2011. Urbanisation has been regarded as an important component for growth realization. The percentage of urban population to the total population in the State is 29.47 percent in 2011 as compared to 24.13 percent in 2001. Sand, silt, and clay are the basic types of soils and most of soils are made up of a combination of these three. The texture of the soil, how it looks and feels, depends upon the amount of each one in that particular soil. There are various types of soils and the formation of soil is primarily influenced by major factors such as climate, altitude and composition of bedrock etc. Disproportion in the distribution of rainfall in the country and excessive heat contribute special characters to the soils. The land utilization classification reveals that 38.09% of the state geographical areas is under net area sown (62.08 lakh hectares), 22.63 % under forest (36.88 lakh hectares), 8.65 % under current fallow lands (14.10 lakh hectares), 12.47% under land put non-agricultural uses (20.32 lakh hectares), 8.27 % under barren and uncultivable land (13.47 lakh hectares) and remaining 7.63% is under other fallow land, cultivable waste lands like permanent pastures and other grazing lands (12.43 lakh hectares) and land under miscellaneous tree crops and groves are not included in the net area sown which is around 2.26% (3.69 lakh hectares)

Earthquakes and Expansion Joints

A ground based high speed rail system is susceptible to Earthquakes and needs frequent expansion joints to deal with thermal expansion/contraction and subtle, large scale land movement. By building a system on pylons, where the tube is not rigidly fixed at any point, you can dramatically mitigate Earthquake risk and avoid the need for expansion joints. Tucked away inside each pylon, you could place two adjustable lateral (XY) dampers and one vertical (Z) damper. These would absorb the small length changes between pylons due to thermal changes, as well as long form subtle height changes. As land slowly settles to a new position over time, the damper neutral position can be adjusted accordingly. A telescoping tube, similar to the boxy ones used to access airplanes at airports would be needed at the end stations to address the cumulative length change of the tube.



Safety and Reliability

The design of Hyperloop has been considered from the start with safety in mind. Unlike other modes of transport, Hyperloop is a single system that incorporates the vehicle, propulsion system, energy management, timing, and route. Capsules travel in a carefully controlled and maintained tube environment making the system immune to wind, ice, fog, and rain. The propulsion system is integrated into the tube and can only accelerate the capsule to speeds that are safe in each section. With human control error and unpredictable weather removed from the system, very few safety concerns remain. Some of the safety scenarios below are unique to the proposed system, but all should be considered relative to other forms of transportation. In many cases Hyper loop is intrinsically safer than airplanes, trains, or automobiles.

Fire Fighting Measures

Fire fighting provisions for Elevated & at Grademetro stations is in accordance with the National Building Code of India 1983 (part IV, Fire protection) amendment no. 3 under Fire protection Annexure II. National Building Code (clause 6.4.8). Fire protection and fire fighting system for metro stations stipulates:

1) Wet riser system

a. Main and diesel pump of 1800 l/min capacity to support 3 to 4 hydrant at a time [station building is split into two halves. It is presumed that fire will not break in the two parts simultaneously. There are 3 hydrants in one part. Therefore pump capacity as above are proposed

b. Jockey pump 180 l/min shall also have DG back up.

2) Internal Hydrant

The internal hydrant is provided with 2 nos RRL hose pipes of 38 mm Ø with 63 mm standard instantaneous coupling along with associated branch pipe and cabinet and a first aid hose reel of 25 mm Ø length 45m fitted with 6.5 mm nozzle. One hydrant each at ground level, passage level and platform level in each half of the station building and so located that every part of station is within 30 m radius.

3) Sprinklers are provided in the property development area only. Additional sprinkler pump is not provided as these are not required being the integral part of the station. The two pumps already provided will take care of sprinkler flow requirements.

4) Detectors are provided in the operational areas only, and above false ceiling if the gap is > 750 mm.

5) One manual call box at each level in each half of the station building is provided.

6) The HT panels, LT panels, main LT distribution board and essential power panels shall be provided with linear heat sensing tubes with CO₂ cylinder.

7) A two way fire brigade inlet at ground level on each rising main for hydrants is provided.

8) Draw off connection is provided on the fire water tank for fire brigade.

9) Water tank of 50,000 liters capacity if planned since commercial development is restricted to 250 Sqm.

10) Portable fire extinguishers (CO₂) a set of two is provided in each of the equipment room

Onboard Passenger Emergency

All capsules would have direct radio contact with station operators in case of emergencies, allowing passengers to report any incident, to request help and to receive assistance. In addition, all capsules would be fitted with first aid equipment. The Hyperloop allows people to travel from San Francisco to LA in 30 minutes. Therefore in case of emergency, it is likely that the best course of action would be

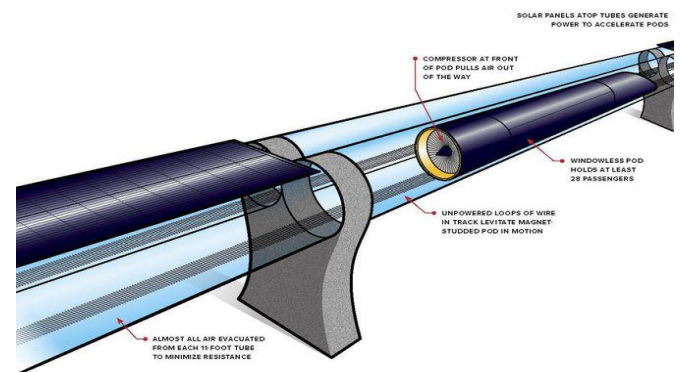
for the capsule to communicate the situation to the station operator and for the capsule to finish the journey in a few minutes where emergency services would be waiting to assist. Typical times between an emergency and access to a physician should be shorter than if an incident happened during airplane takeoff. In the case of the airplane, the route would need to be adjusted, other planes rerouted, runways cleared, airplane landed, taxi to a gate, and doors opened. An emergency in a Hyperloop capsule simply requires the system to complete the planned journey and meet emergency personnel at the destination.

Power Outage

The vast majority of the Hyperloop travel distance is spent coasting and so the capsule does not require continuous power to travel. The capsule life support systems will be powered by two or more redundant lithium ion battery packs making it unaffected by a power outage. In the event of a power outage occurring after a capsule had been launched, all linear accelerators would be equipped with enough energy storage to bring all capsules currently in the Hyperloop tube safely to a stop at their destination. In addition, linear accelerators using the same storage would complete the acceleration of all capsules currently in the tube. For additional redundancy, all Hyperloop capsules would be fitted with a mechanical braking system to bring capsules safely to a stop. In summary, all journeys would be completed as expected from the passenger's perspective. Normal travel schedules would be resumed after power was restored.

Structural Integrity of the Tube in Jeopardy

A minor depressurization of the tube is unlikely to affect Hyperloop capsules or passengers and would likely be overcome by increased vacuum pump power. Any minor tube leaks could then be repaired during standard maintenance. In the event of a large scale leak, pressure sensors located along the tube would automatically communicate with all capsules to deploy their emergency mechanical braking systems.



Elevated Section - Choice of Superstructure

The choice of superstructure has to be made keeping in view the ease of constructability and the maximum standardization of the formwork for a wide span ranges. The segmental construction has been chosen mainly due to the following advantages:

- Segmental construction is an efficient and economical method for a large range of span lengths and types of structures. Structures with sharp curves and variable super elevation can be easily accommodated.
- Segmental construction permits a reduction of construction time as segments may be manufactured while substructure work proceeds and assembled rapidly thereafter.
- Segmental construction protects the environment as only space required for foundation and sub-station is required at site.

The superstructure is manufactured at a place away from busy areas and placement of superstructure is done with the system erected from piers at heights

Earthquakes

California is no stranger to earthquakes and transport systems are all built with earthquakes in mind. Hyperloop would be no different with the entire tube length built with the necessary flexibility to withstand the earthquake motions while maintaining the Hyperloop tube alignment. It is also likely that in the event of a severe earthquake, Hyperloop capsules would be remotely commanded to actuate their mechanical emergency braking systems.

Human Related Incidents

Hyperloop would feature the same high level of security used at airports. However, the regular departure of Hyperloop capsules would result in a steadier and faster flow of passengers through security screening compared to airports. Tubes located on pylons would limit access to the critical elements of the system. Multiple redundant power sources and vacuum pumps would limit the impact of any single element.

Reliability

The Hyperloop system comprising all infrastructure, mechanical, electrical, and software components will be designed so that it is reliable, durable, and fault tolerant over its service life (100 years), while maintaining safety levels that match or exceed the safety standard of commercial air transportation.

Cost

The overall cost of the tube, pillars, vacuum pumps and stations is thus expected to be around \$4.06 billion USD for the passenger version of the Hyperloop. This does not include the cost of the propulsion linear motors or solar panels. The tube represents approximately 70% of the total budget. The larger 10 ft 10 in. (3.3m) tube would allow the cargo and vehicle capsules to fit at a total cost including the tube, pillars, vacuum pumps, and stations around \$5.31 billion USD. This minimal cost increase would allow a much more versatile Hyperloop system.

Table 8. Total cost of the Hyperloop passenger transportation system.

Component	Cost (million USD)
Capsule	54 (40 capsules)
Capsule Structure & Doors	9.8
Interior & Seats	10.2
Compressor & Plumbing	11
Batteries & Electronics	6
Propulsion	5
Suspension & Air Bearings	8
Components Assembly	4
Tube	5,410
Tube Construction	650
Pylon Construction	2,550
Tunnel Construction	600
Propulsion	140
Solar Panels & Batteries	210
Station & Vacuum Pumps	260
Permits & Land	1,000
Cost Margin	536
Total	6,000

Passenger only

Passenger plus vehicle

Table 9. Total cost of the Hyperloop passenger plus vehicle transportation system.

Component	Cost (million USD)
Cargo Capsule	30.5 (20 capsules)
Capsule Structure & Doors	5.5
Interior & Seats	3.7
Compressor & Plumbing	6
Batteries, Motor & Electronics	4
Propulsion	3
Suspension & Air Bearings	5.3
Components Assembly	3
Passenger Only Capsule	40.5 (30 capsules)
Capsule Structure & Doors	7.4
Interior & Seats	7.6
Compressor & Plumbing	8.2
Batteries, Motor & Electronics	4.5
Propulsion	3.8
Suspension & Air Bearings	6
Components Assembly	3
Tube	7,000
Tube Construction	1,200
Pylon Construction	3,150
Tunnel Construction	700
Propulsion	200
Solar Panels & Batteries	490
Station & Vacuum Pumps	260
Permits & Land	1,000
Cost Margin	429
Total	7,500

Future Work

Hyperloop is considered an open source transportation concept. The authors encourage all members of the community to contribute to the Hyperloop design process. Iteration of the design by various individuals and groups can help bring Hyperloop from an idea to a reality. The authors recognize the need for additional work, including but not limited to:

1. More expansion on the control mechanism for Hyperloop capsules, including attitude thruster or control moment gyros.
2. Detailed station designs with loading and unloading of both passenger and passenger plus vehicle versions of the Hyperloop capsules.
3. Trades comparing the costs and benefits of Hyperloop with more conventional magnetic levitation systems.
4. Sub-scale testing based on a further optimized design to demonstrate the physics of Hyperloop

Constraining the Problem

The Hyperloop (or something similar) is, in my opinion, the right solution for the specific case of high traffic city pairs that are less than about 1500 km or 900 miles apart. Around that inflection point, I suspect that supersonic air travel ends up being faster and cheaper. With a high enough altitude and the right geometry, the sonicboom noise on the ground would be no louder than current airliners, so that isn't a showstopper. Also, a quiet supersonic plane immediately solves every long distance city pair without the need for a vast new worldwide infrastructure. However, for a sub several hundred mile journey, having a supersonic plane is rather pointless, as you would spend almost all your time slowly ascending and descending and very little time at cruise speed. In order to go fast, you need to be at high altitude where the air density drops exponentially, as air at sea level becomes as thick as molasses (not literally, but you get the picture) as you approach sonic velocity

Structural Integrity of the Tube in Jeopardy

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Background

The corridor between Amaravathi, Vijayawada and Vizag, to Tirupati one of the most often traveled corridors in the American West. The current practical modes of transport for passengers between these two major population centers include:

1. Road (inexpensive, slow, usually not environmentally sound)
2. Air (expensive, fast, not environmentally sound)
3. Rail (expensive, slow, often environmentally sound)

A new mode of transport is needed that has benefits of the current modes without the negative aspects of each. This new high speed transportation system has the following requirements:

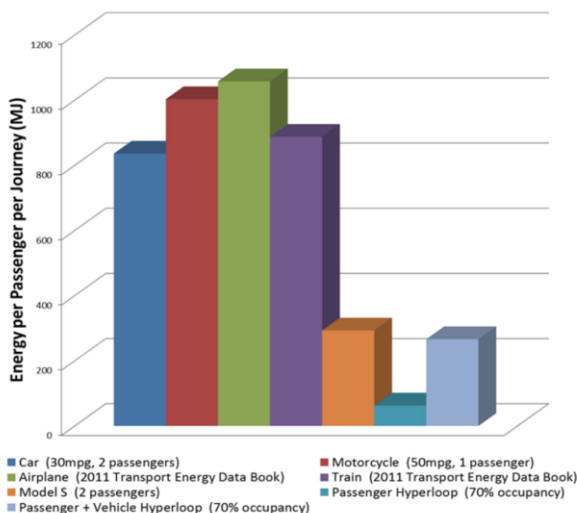
1. Ready when the passenger is ready to travel (road)
2. Inexpensive (road)
3. Fast (air)
4. Environmentally friendly (rail/road via electric cars)

The current contender for a new transportation system between Amaravathi and Vizag is the "Metro High Speed Rail."

The parameters outlining this system include:

1. Currently \$68.4 billion USD proposed cost
2. Average speed of 164 mph (264 kph) between Amaravathi and Los Vizag
3. Travel time of 4 hours and 38 minutes between Amaravathi and Vizag
 - a. Compare with 1 hour and 15 minutes by air
 - b. Compare with 5 hours and 30 minutes by car
4. Average one-way ticket price of \$105 one-way (reference)
 - a. Compare with \$158 round trip by air for September 2013
 - b. Compare with \$115 round trip by road (\$4/gallon with 30 mpg vehicle)

A new high speed mode of transport is desired between Amaravathi and Vizag; however, the proposed Metro High Speed Rail does not reduce current trip times or reduce costs relative to existing modes of transport. This preliminary design study proposes a new mode of high speed transport that reduces both the travel time and travel cost between Amaravathi and Vizag. Options are also included to increase the transportation system to other major population centers across Vizag. It is also worth noting the energy cost of this system is less than any currently existing mode of transport (Figure 1). The only system that comes close to matching the low energy requirements of Hyper loop is the fully electric Tesla Models.



Energy cost per passenger for a journey between Amaravathi and Vizag for various modes of transport.

Environmental Impacts

A total of 101 structures of various dimensions shall be affected by the proposed project. Majority of the structures are privately owned. According to the results of the present study, it is found that about 337 trees are likely to be lost due to the project. Four trees have to be planted for each tree cut. Hence 1348 trees to be planted. These trees would have occupied about 96 ha in the forest. No no-forest land is available, hence 96 ha have to be re-afforested in degraded forests in or around Amaravathi Utility/Drainage Problems:

The alignment will cross drains/nallahs large number of sub-surface, surface and utility services, viz. sewer, water mains, storm water drains, telephone cables, overhead electrical transmission lines, electric pipes, traffic signals etc. These utilities/services are essential and have to be maintained in working order during different stages of construction by temporary/permanent diversions or by supporting in position.

Mobility:

Metro lines will facilitate people to move quickly towards urban centres and return from there. Any reduction in number of private vehicles will result in reduction of accidents which will involve savings from damage to vehicles and savings towards medical and insurance expenses to persons involved in accidents.

Less Air Pollution:

With the construction of Hyper loop, there will be less vehicular traffic by road, and consequently less air pollution, and hence the air quality will improve.

Reduction in Traffic Congestion

Hyper loop will reduce the congestion and journey time on roads because of diversion of some traffic to Metro. Reduction in traffic congestion will save the necessary capital investment and vehicle operating cost as well as increase in time saving per vehicle.

Environmental Management Plan:

The project will provide higher living standard, better quality of life, less travel time, better connectivity and transport facilities. The management plans are essential to ensure that stress/ loads on the systems are within carrying capacity. The management plan aims at maintaining the environmental quality of project area minimal in pre-project stage. An environmental management strategy plans were developed to mitigate the adverse impacts.

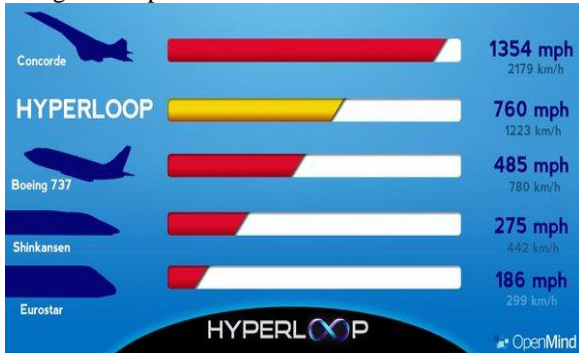
Security Measures for Hyper loop system

Metro is emerging as the most favoured mode of urban transportation system. The inherent characteristics of metro system make it an ideal target for terrorists and miscreants. Metro systems are typically open and dynamic systems which carry thousands of commuters. Moreover the high cost of infrastructure, its economic impotence, being the life line of city high news value, fear & panic and man casual ties poses greater threat to its security. Security is a relatively new challenge in the context of public transport. It addresses problems caused intentionally. Security differs from safety which addresses problems caused accidentally. Security problems or threats are caused by people whose actions aim to undermine or disturb the public transport system and or to harm passengers or staff. These threats range from daily operational security problems such as disorder, vandalism and assault to the terrorist threat

Conclusions

A high speed transportation system known as Hyperloop has been developed in this document. The work has detailed two versions of the Hyperloop: a passenger only version and a passenger plus vehicle version. Hyperloop could transport people, vehicles, and freight between Amaravathi and Vizag in 35 minutes. Transporting 7.4 million people each way every year and amortizing the cost of \$6 billion over 20 years gives a ticket price of \$20 for a one-way trip for the passenger version of Hyperloop. The passenger only version of the Hyperloop is less than 9% of the cost of the proposed passenger only high speed rail system between Amaravathi and Vizag. An additional passenger plus transport version of the Hyperloop has been created that is only 25% higher in cost than the passenger only version.

This version would be capable of transporting passengers, vehicles, freight, etc. The passenger plus vehicle version of the Hyperloop is less than 11% of the cost of the proposed passenger only high speed rail system between Los Angeles and San Francisco. Additional technological developments and further optimization could likely reduce this price. The intent of this document has been to create a new open source form of transportation that could revolutionize travel. The authors welcome feedback and will incorporate it into future revisions of the Hyperloop project, following other open source models such as Linux.



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