TRANSPOD

INITIAL ORDER OF MAGNITUDE ANALYSIS FOR TRANSPOD HYPERLOOP SYSTEM INFRASTRUCTURE

PRELIMINARY BASIS OF DESIGN

JULY 13, 2017

rec architecture

INTRODUCTION

The purpose of this Initial Order of Magnitude (IOM) analysis is to identify preliminary capital costs for TransPod hyperloop system infrastructure. Estimates were developed from conceptual engineering data and cost data from similar transportation infrastructure projects as well as budget-level cost quotations, where available. This analysis has been performed in collaboration with REC Architecture.

Estimates described within this report are intended to provide a basis for comparison of significant cost differences between the TransPod hyperloop system and alternatives, and are not intended to project budget costs.

The first section of this report will present an initial description of the elevated infrastructure design related to the TransPod hyperloop system.

The second section will provide a detailed cost breakdown per kilometre. Optimizations for elements of the system would be required as we develop the overall system.

Feedback would be most welcome – please send to info@transpod.ca

Background

In May, 2017, the Government of Ontario announced its intention to move forward with a high-speed rail (HSR) project between the cities of Windsor and Toronto. We were pleased, as a first reaction, to see that a province in Canada is taking the lead to implement a precedent-setting transportation system that will ultimately benefit and strengthen its economic growth and global competitiveness.

The study released by the government provided insight into the cost per kilometre for building the HSR line, with a first option at $149M for a train operating at 300 km/h and a second option at $55M for a train operating at 250 km/h. The speeds and associated costs are disappointing. Even if the costs include a contingency factor, they are unquestionably high when compared to innovative next-generation technologies such as hyperloop which, on top of an estimated lower price tag, would offer much higher transportation speeds.

What is hyperloop as employed by TransPod?

TransPod is designing a new 5th mode of transportation, beyond ships, trains, automobiles, and planes, which are slow, inefficient, congested, fossil-fuel dependent, polluting, and vulnerable to weather conditions.

As envisioned by aerospace pioneer Robert Goddard, as well as SpaceX's Elon Musk who introduced the term 'hyperloop,' TransPod is improving beyond the original concept. The company's made-in-Canada design for a next-generation transportation system dramatically increases hyperloop stability and reduces the cost of line construction, by employing a novel combination of electromagnetics, mechanical engineering, and signal processing design. It will provide an attractive choice for consumers and businesses in terms of speed, convenience, and price. It will also achieve significant government policy objectives: reducing highway congestion and maintenance, reducing carbon emissions, being full electric and fossil-fuel free, and increasing economic activity through rapid intercity commerce.

The TransPod hyperloop system will serve ground-based mass transportation and will reach velocities faster than airline travel. It is based on low-pressure tubes carrying TransPod vehicles for reduced air resistance and less friction while being unaffected by weather conditions. TransPod's system is designed to enable passenger and cargo travel at a low-priced, frequent-departure transportation service using environmentally sustainable solar/electric power, at speeds exceeding 1000 km/h. This will effectively improve quality of life for commuters and efficiency for commerce.

A key advantage of hyperloop tube infrastructure vs. a railway track is that the former can be elevated above the ground on pylons, built in pre-fabricated sections that are erected in place, and joined with an orbital seam welder. By building it on pylons, we can limit the need to acquire contiguous land by following alongside linear highway alignments such as Highway 2 in Alberta or Highway 401 in Ontario, with only minor deviations when the highway makes sharp turns.

To broaden the understanding of the TransPod hyperloop system and promote its consideration as a significant alternative to existing modes of transport, we would like to share our preliminary concepts regarding infrastructure costs and initial facts on the following pages.This Initial Order of Magnitude cost analysis is intended to present our current design approach for an elevated tube structure developed using conventional techniques, and is provided with the associated cost breakdown.

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1.0 OVERVIEW

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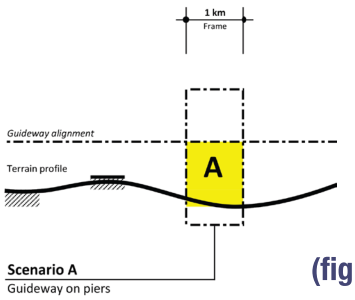
The guideway infrastructure related to TransPod's hyperloop system will consider three types of engineered structures:
- Elevated guideway
- On ground guideway
- Underground guideway

On the following pages, we focus on the cost breakdown of an **elevated guideway structure** as this configuration will be the most prevalent given that the busiest worldwide routes often present a flat-terrain profile. It also has significant advantages compared to a conventional high-speed rail (HSR) system both in terms of safety and cost.

Being elevated is safer as you do not have to implement a crossing control system at roadway intersections to mitigate the risk of collisions involving people and/or vehicles. It is cheaper as the land footprint is smaller for a pylon compared to a railway track. Underground grade separations are considered to provide even better safety features but these come at a much higher cost, therefore we have not focused on this approach for this IOM.

1.1 Prototype Route Infrastructure - Guideway on Piers

To establish the framework of this analysis, we are examining a guideway on piers for a standard distance of 1 km with the proper alignment following the terrain profile **(fig. 1)**



(fig. 1)

Scenario A is our working assumption in this document. This working scenario is representing an initial standard of TransPod's hyperloop elevated structure per kilometer.

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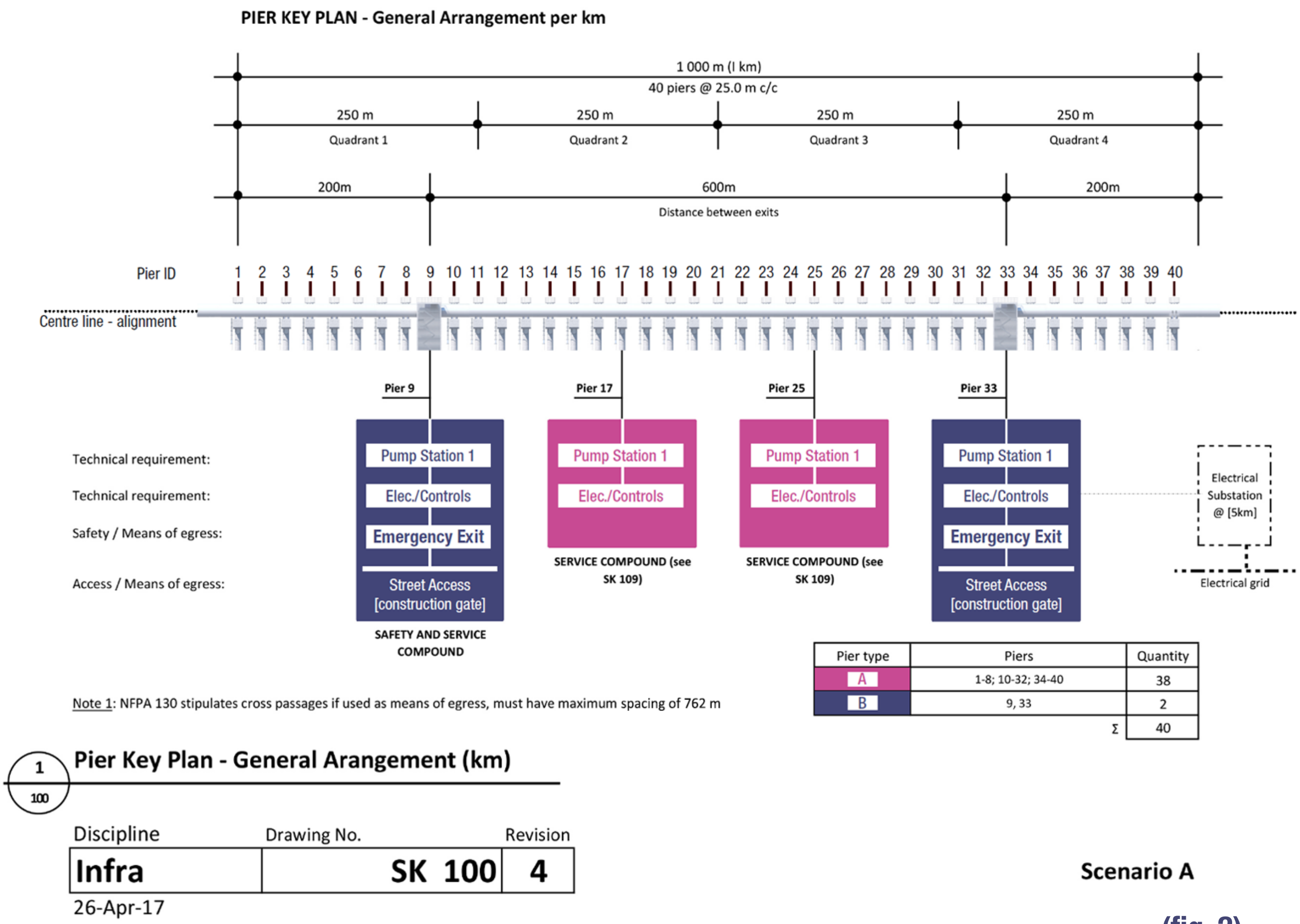
1.2 General Arrangement

TransPod's Scenario A includes the following requirements per km:
- 40 piers (1 pier every 25m).
- 4 pumping stations with their associated electrical controls.
- 2 emergency egress exits (1 every 600m).
- 1 power substation to allow an electrical connection to the grid every 5 km.

Additional technical details are specified in the General Arrangement **figure 2** below:

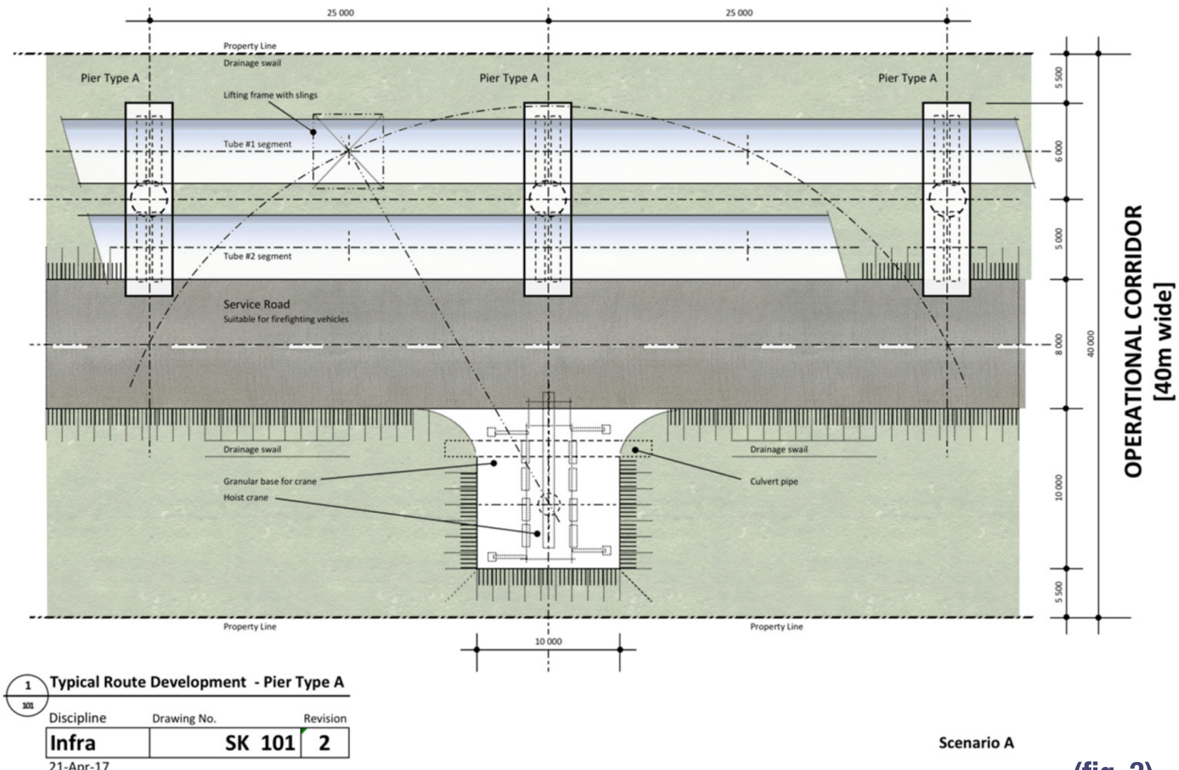


(fig. 2)

1.3 Typical Route Development

TransPod's typical guideway corridor will be 40m wide including a service road for maintenance, emergency services and construction purposes as specified in the **figure 3**.

A 10m x 10m pad is required to accommodate a crane for the installation and eventually the replacement of each tube segment. In certain conditions such as land usage agreements, this construction pad could be considered as temporary which will allow the corridor width to be reduced to 30m and consequently contribute to reduce land acquisition costs.



(fig. 3)

2.0 PIER TYPICAL SPAN

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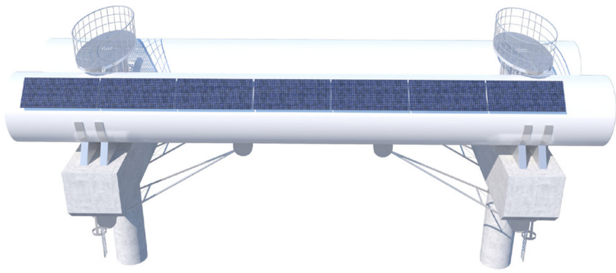
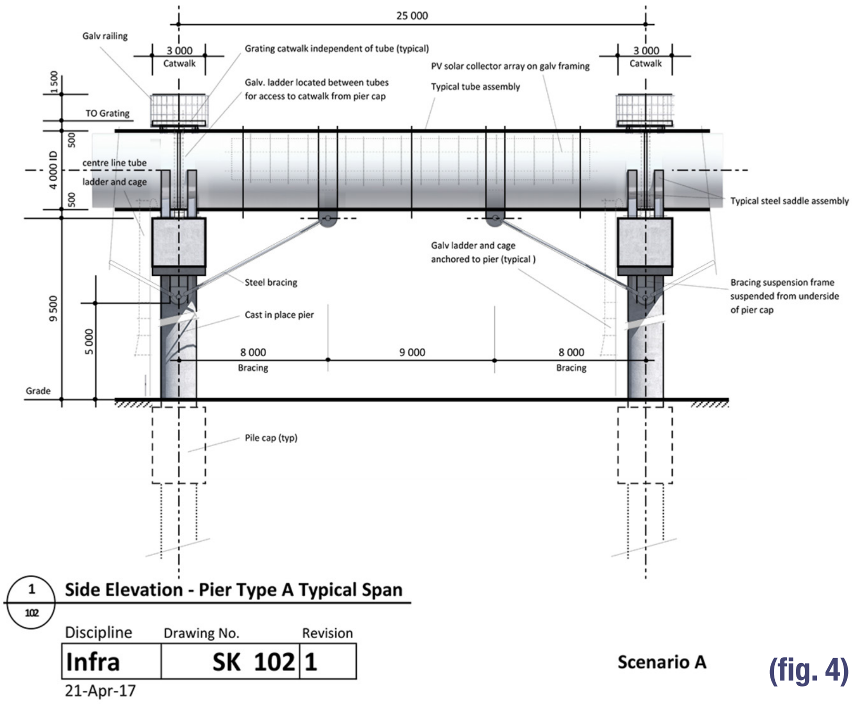
2.1 Side Elevation

The TransPod vehicle's typical span is conventionally composed to rely on standard construction techniques.



You will notice on **figure 4** several elements which are representative of the TransPod hyperloop system.

- Steel bracings are provided to reinforce the tube integrity as vehicles travel inside the tube, and to maintain the shape of the tube over time.
- Standard galvanized framing will be used to install solar panels on the tube to obtain an overall system energy positive. Solar panels will be positioned according to the optimum angle towards the sun (we are also considering a rotating structure).
- A standard catwalk will be built for maintenance activities.



(fig. 4)

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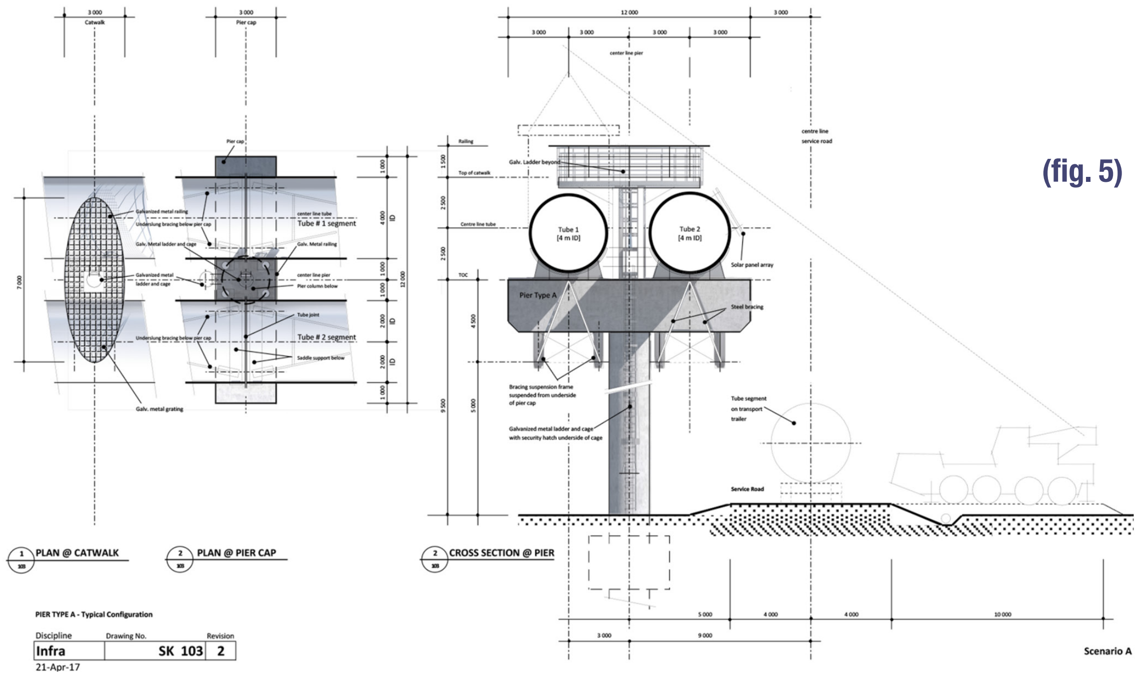
2.2 Cross Section

The **figure 5** represents a cross-section of the elevated structure and illustrates a potential construction scenario to install tube segments over each pier.

To determine pier loading, we have used the following loading assumptions:

Typical Pier Loading Assumptions

Tube dead load	2.5 tons per meter
Tube dead load safety factor	1.8
Tube dead load per 25 m segment	112.5 tons
Vehicle dead load per tube, incl safety factor	60 tons
Tube + vehicle dead load	172.5 tons
Number of tubes per pier	2
Total tube + vehicle dead load	**345 tons**

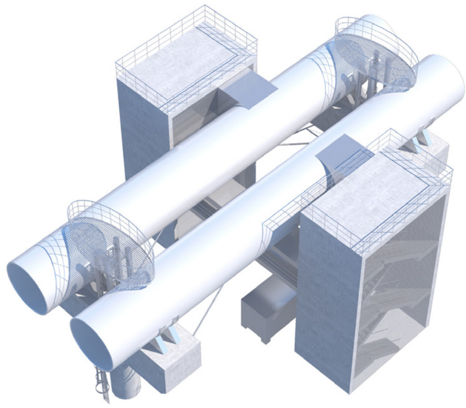


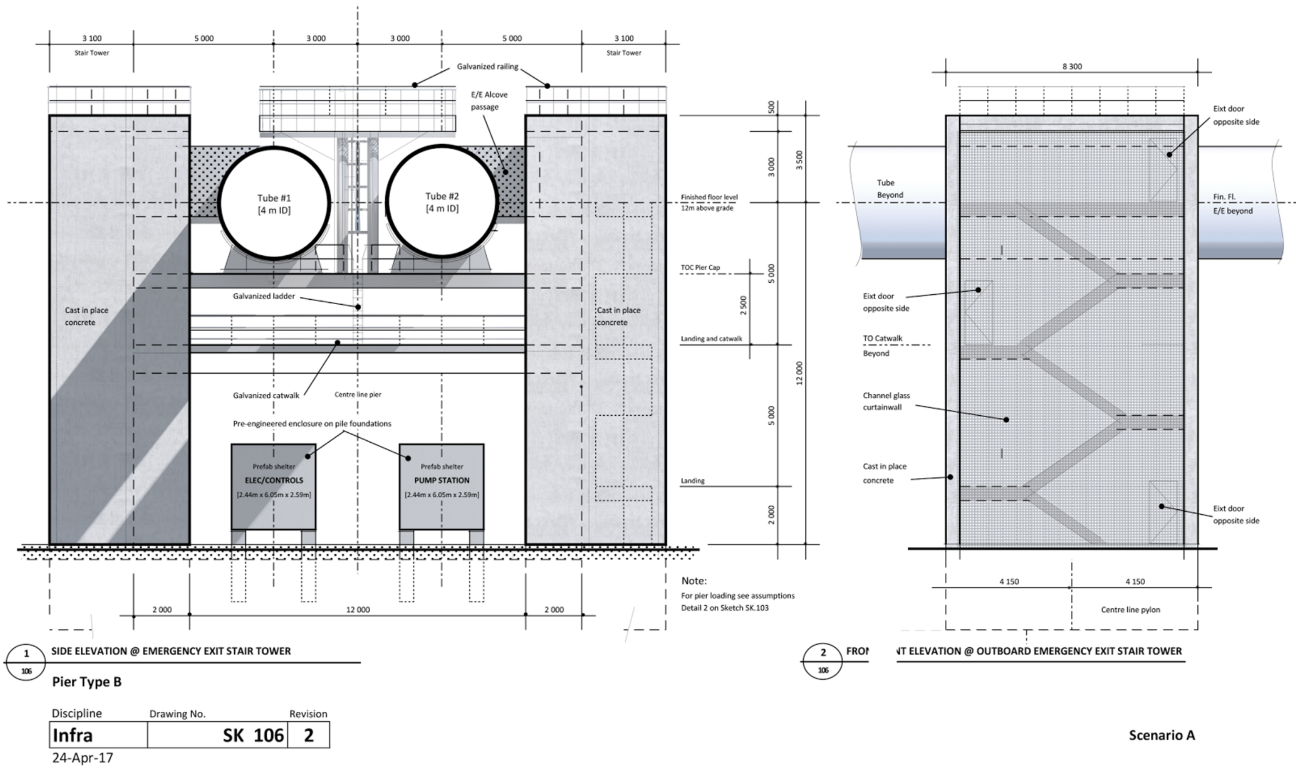
(fig. 5)

2.3 Emergency Exit Stair Tower

As per applicable regulations (refer to NFPA130), the TransPod system will require four (4) emergency exits every 1.2 kilometres, i.e. two (2) on each side.

Those emergency exits must be protected from weather elements at any given time to allow a safe evacuation. Details are shown here below in **figure 6**.





(fig. 6)

3.0 COST BREAKDOWN

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3.1 Cost Breakdown Summary

TransPod's construction Scenario A has been divided into 10 phases to provide a good overview of the infrastructure cost allocation.

Descriptions and costs of each phase are specified in the table here below:

WP1.2 - Infrastructure

PBS Level	WBS Code	Description	Type Object	REF Object	Cost estimate CAD
2	A-01	PIER TYPE A (38U / Km)	B	001	**$ 3 011 000**
2	A-02	GALVANIZED METAL LADDER	B	001	**$ 262 000**
2	A-03	GALVANIZED CATWALK	B	001	**$ 1 344 000**
2	A-04	TUBE - DIAM 4m; 1000m	E	001	**$ 11 063 000**
2	A-05	SOLAR PANELS	E	001	**$ 2 310 000**
2	A-06	EMERGENCY EXIT (2U / 1Km)	B	001	**$ 1 504 000**
2	A-07	SERVICE ROAD	R	001	**$ 1 660 000**
2	A-08	POWER SUBSTATION (1U / 5Km)	E	002	**$ 392 000**
2	A-09	SERVICE COMPOUND (4U / 1Km)	E	003	**$ 1 386 000**
2	A-10	INDIRECT COSTS	C	001	**$ 2 293 000**
					$ 25 225 000
2	A-10	CONTINGENCIES & RISKS	C	001	**$ 3 670 000**
					$ 28 895 000

Assumptions

Foundations are considered with good soil, with no piles.

The service road (A-07) is based on a 5 m wide road.

For the pier type A (A-01), according to our calculations based on the typical pier load assumptions:
- The pier column diameter can be reduced to 1.50 m DI
- The pier cap sizes 1.50 m (W) x 2.0 m (H) x 8 m (L)
- The caisson pile cap can be reduced to 3 m x 3m x 1 m

The galvanized metal ladder and catwalk are related to the pier type A.

Indirect costs include only management costs; no escalation, currency risks, insurances, taxes are considered.

Contingencies and risks allocations are base on a 8% ratio each.

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3.2 Cost Breakdown Detail by Phase

A-01 - Pier type A (38U per Km)

	Unit	Quantity	U	Unit overall cost $	Total cost
Concrete work					
Construction site installation					**$ 261 869**
Foundations (3m x 3m x 1m, leveled to 50cm)					**$ 661 662**
Concrete pier 1.50m Diam; 8m (H)			38		**$ 753 958**
Pier cap (pier cap: 1.50m x 2.0m x 8.0m)			38		**$ 1 174 032**
Others	ea	2	1	**$ 14 500**	**$ 29 000**
Misc	ea	5%		**$ 2 618 652**	**$ 130 933**
Pier type A (38U / km)					**$ 3 011 454**

A-02 - Galvanized metal ladder and cage (per Km)

	Unit	Quantity	U	Unit overall cost $	Total cost
Ladder	U	1	40	**$ 6 500**	**$ 260 000**
Cage	U	3	40	**$ 15**	**$ 1 800**
Galvanized metal ladder and cage (per Km)					**$ 261 800**

A-03 - Galvanized catwalk (per Km)

	Unit	Quantity	U	Unit overall cost $	Total cost
Catwalk structure	kg	4 000	40	**$ 7 000**	**$ 700 000**
Ladder (height: 5m)	U	1	40	**$ 4 400**	**$ 176 000**
Cage					**$ 468 000**
Railing	m	18	40	**$ 290**	
Catwalk grating	m^2	18	40	**$ 360**	
Galvanized catwalk (per Km)					**$ 1 344 000**

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A-04 - Tube diameter 4m & equipment (per Km)

	Unit	Quantity	U	Unit overall cost $	Total cost
Tube 25m (L) / 4m (ID)	U	40	2	**$ 58 246**	**$ 4 659 685**
Steel saddle support	U	40	2	**$ 14 500**	**$ 1 160 000**
Tube equipment (electrical / mechanical)	m	1 000	2	**$ 2 330**	**$ 4 659 685**
Bracing connections	U	2	40	**$ 7 300**	**$ 584 000**
Tube diameter 4m & equipment (per Km)					**$ 11 063 371**

A-05 - Solar panels (per Km)

	Unit	Quantity	U	Unit overall cost $	Total cost
Structure	m	1 000	2	**$ 150**	**$ 300 000**
Panels	m²	2 500	2	**$ 360**	**$ 1 800 000**
Misc (technical suggestions, junction)	ea	10 %		**$ 2 100 000**	**$ 210 000**
Solar panels (per Km)					**$ 2 310 000**

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A-06 - Emergency exits (4 EA per Km)

	Unit	Quantity	U	Unit overall cost $	Total cost
Concrete work					
Construction site installation					**$ 66 497**
Additional earthworks - networks (for 25 m length) - excavations					**$ 76 194**
Foundations (2m x 2m x 1m, leveled to 50cm)					**$ 130 272**
Elevations BA					**$ 331 900**
Pier					**$ 97 600**
Others	ea	2		**$ 14 500**	**$ 29 000**
Misc	ea	5%		**$ 145 200**	**$ 7 260**
Elevators					**$ 72 600**
Max load of 1600 kg	U	1	1	**$ 72 600**	
Metal works (2U / km)					**$ 284 190**
Doors	U	3	2	**$ 3 600**	
Galvanized catwalk beyond tubes	m	6	2	**$ 1 230**	
Stairs	U	5	2	**$ 14 500**	
Galvanized railing	m	42	2	**$ 300**	
Grating up to finished floor level	m²	26	2	**$ 1 160**	
E / E alcove passage	U	2	2	**$ 4 400**	
Electrical / Mechanical	U	2	2	**$ 51 000**	**$ 204 000**
Channel glass curtain wall	m²	200	2	**$ 510**	**$ 204 000**
Emergency exits (2U / 1Km)					**$ 1 503 513**

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A-07 - Service road (per Km)

	Unit	Quantity	U	Unit overall cost $	Total cost
Earthworks (for 1km) - See SK 101/2					**$ 607 800**
Clearing & grubbing	m²	18 000	1	**$ 6**	
Earth excavations	m³	14 700	1	**$ 4**	
Disposal	m³	14 700	1	**$ 30**	
Service Road					**$ 375 000**
Granular service road (5m x 1000m x 0,3) Base form	m²	5 000	1	**$ 60**	
Impregnation and coating (5m)	m²	5 000	1	**$ 15**	
Granular crane pads	U	40	1		
Landscaping	m²	25 000	1	**$ 4**	**$ 100 000**
Cables / Channels	m	1 000	1	**$ 150**	**$ 150 000**
Lighting (tubing and cables)	m	1 000	1	**$ 90**	**$ 90 000**
Lighting (fixtures)	U	40	1	**$ 2 180**	**$ 87 200**
Drainage	m	1 000	1	**$ 250**	**$ 250 000**
Service road (per Km)					**$ 1 660 000**

A-08 - Power substation (1U per 5Km)

	Unit	Quantity	U	Unit overall cost $	Total cost
Building & equipment	U	1	0.20	**$ 1 961 972**	**$ 392 394**
Power substation (1U / 5km)					**$ 392 394**

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A-09 - Service compound (4U per Km)

	Unit	Quantity	U	Unit overall cost $	Total cost
Elec / Controls					**$ 202 284**
Concrete apron	m^3	11	4	**$ 540**	
Prefabricated shelter	U	1	4	**$ 39 239**	
Fences	m	20	4	**$ 147**	
Gate	U	1	4	**$ 2 452**	
Pump Station					**$ 1 183 272**
Concrete apron	m^2	11	4	**$ 540**	
Vacuum pump	U	1	4	**$ 245 247**	
Prefabricated Shelter	U	1	4	**$ 39 239**	
Fences	m	20	4	**$ 147**	
Gate	U	1	4	**$ 2 452**	
Service compound (4U / 1Km)					**$ 1 385 556**

A-10 - Indirect - Risk - Contingency

	Unit	Quantity	U	Unit overall cost $	Total cost
Management		10 %	1	**$ 22 932 088**	**$ 2 293 209**
Subcontractors					
Insurance					
Escalation (2% / y for 10 y)			1	**$ 22 932 088**	
Risk (8%)		8 %	1	**$ 22 932 088**	**$ 1 834 567**
Contingency (8%)		8 %	1	**$ 22 932 088**	**$ 1 834 567**
Indirect costs					**$ 5 962 343**

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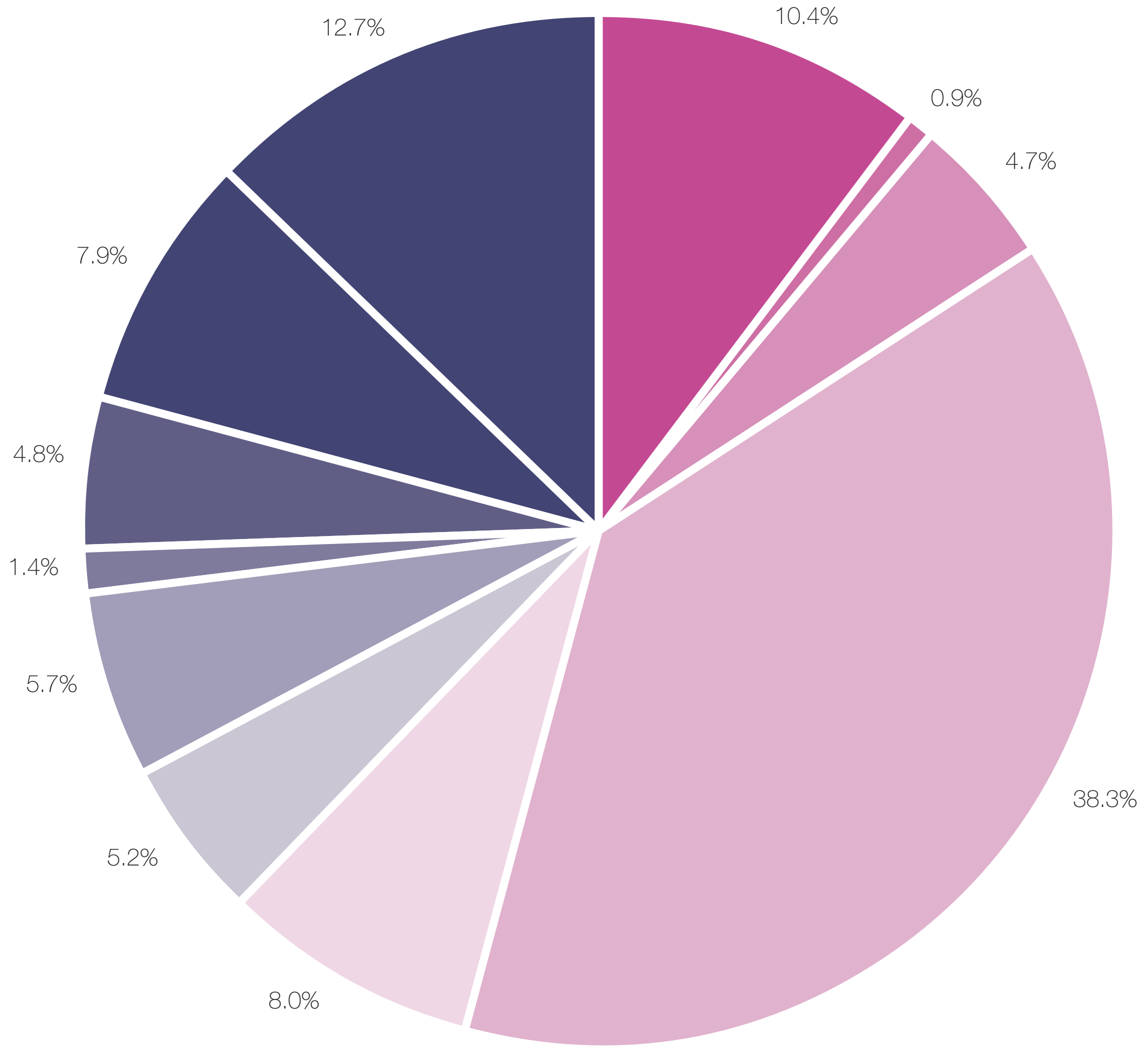
3.0 COST BREAKDOWN (cont'd)



10.4%	A-01	PIER TYPE A (38U / Km)
0.9%	A-02	GALVANIZED METAL LADDER
4.7%	A-03	GALVANIZED CATWALK
38.3%	A-04	TUBE - DIAM 4m; 1000m
8.0%	A-05	SOLAR PANELS
5.2%	A-06	EMERGENCY EXIT (2U / 1Km)
5.7%	A-07	SERVICE ROAD
1.4%	A-08	POWER SUBSTATION (1U / 5Km)
4.8%	A-09	SERVICE COMPOUND (4U / 1Km)
7.9%	A-10	INDIRECT COSTS
12.7%	A-10	CONTINGENCIES & RISKS

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4.0 FUTURE WORK

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Looking Forward

Future work will entail incremental improvements of the current analysis to further reduce the overall cost of the system and increase the competitiveness of the TransPod hyperloop system vs. high-speed rail. As an example, the cost of the pier structural work could be vastly improved with pre-fabricated components as well as other sub-structures.

We will also consider other configurations such as on-ground and underground structures to assemble a working hypothesis of the overall infrastructure cost regardless of the terrain profile. Keeping in mind the potential for incorporating new boring techniques, the underground option might present some valuable engineering opportunities.

This Initial Order of Magnitude analysis is identifying preliminary capital costs for TransPod's hyperloop system infrastructure. With an initial cost per km of $29 million, it's confirming that we can build a more affordable transportation system providing a much faster service. Ultimately, the cost of implementing a TransPod system between Toronto and Windsor would be 50 per cent less than the projected cost of HSR.

As a conclusion, if we are to make a massive investment in a new transportation system, then the return on investment should by rights be equally massive. The answer must allow us to future-proof ourselves with innovative and forward-looking technology that provides significant advantages in terms of speed, affordability, and environmental sustainability.

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