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Integrated Transportation and Logistics System (ITLS)

ASCE 2021 Blue Sky Challenge
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EXECUTIVE SUMMARY

Over the next 20 years, rapid urbanization, the growth of e-commerce, and changing consumer demands will place ever-greater demands on urban transportation systems. Fast and efficient transportation is necessary for cities' economic sustainability, but the noise and disruption generated by current road networks often comes at the expense of the health, safety, and enjoyment of urban residents. Future transportation systems will need to be fast, efficient, and safe. At the same time, streets must support walkable and livable neighborhoods and be great places for people to connect with each other.

To meet both these needs, UBC Smart City is proposing an Integrated Transportation and Logistics System (ITLS) that will connect businesses, organizations, and citizens of future megacities through a dedicated underground passenger and freight transportation system.

The ITLS will consist of a web-like macro-network designed to rapidly transport people and goods between economic hubs in the megacity. Autonomous, modular pods will travel through 12 ft by 12 ft square tunnels made possible by advancements to non-circular water jet tunnel boring technology. A smaller meso-network with 6 ft square tunnels will radiate out from the nodes in the macro-network, providing a fast and inexpensive last-mile delivery option for goods. Together, these networks will remove a significant portion of goods movement and long-distance passenger movement from the megacity's surface transportation networks, liberating once-congested street space for more community-oriented uses.

Passengers will travel in pods that can hold 6 people individually, while goods will use smaller pods that can flow directly into the meso-network surrounding each node without stopping. Small pods allow the system to run at high frequencies at all times, but pods are designed to couple together into trains to reduce drag whenever possible. Magnetic levitation will lower friction and consequently, the ITLS' operating costs. An artificial intelligence learning algorithm will employ usage data to predict transportation demand and distribute pods onto the network accordingly. Rather than piloting the pods directly, the AI algorithm will provide the pods with customized decision-rules; the pods' ability to communicate with other pods and behave independently within the constraints of the decision rules will reduce reaction times during unexpected delays.

While significant technological developments will be required to make the ITLS a reality, it is expected that system planning can begin in the next 10 years and a prototype could be operational by 2040. Construction will begin with a major route between two high-demand centers and continue outwards one link at a time; this phased approach will provide steady construction jobs for community members and economies of scale to contractors and suppliers.

Benefits of the ITLS include reduced travel and delivery times, reduced noise, emissions, and pollution, as well as reclaimed street space for recreational and community uses. Key to its success will be integration with existing logistics facilities, major transit hubs, and new mixed-use developments. Policies will need to address the risk of displacement and access to services for existing residents in order to ensure the ITLS benefits the communities it serves. Ultimately, the ITLS will enable megacities to remain economically prosperous while creating beautiful public spaces that enhance urban residents' quality of life.

TABLE OF CONTENTS

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1. BACKGROUND AND PROBLEM STATEMENT

Congested roads. Pollution. Crashes. Noise. Today's transportation systems are stretched beyond their limits. We expect our streets to be free-flowing arteries of economic opportunity, and beautiful public spaces for spontaneous human interaction.

Now imagine the picture ten, twenty, or thirty years into the future. Today's sprawling cities will evolve into megacities: massive, polycentric urbanized regions with up to 50 million people. Population growth and finite geographic boundaries will drive densification and send land values to astronomical levels. More people using the same transportation system will exacerbate congestion and expose the limits of road-based transportation. At the same time, the growth of walkable and livable neighborhoods will further cement the role of urban streets as places for people to connect with each other.

These trends will force city leader and urban citizens to choose between which of these needs to serve. Are streets places for efficient movement or human fulfillment? Current transportation systems are attempting to balance both needs but they cannot do so very well.

Technological advancements will bring opportunities, but also challenges, to a megacity's transportation network. On the one hand, electric vehicles are expected to reduce noise, pollution, and emission. Autonomous vehicles may improve safety and present opportunities to manage congestion. One the other hand, increased tolerance for road congestion by occupants of autonomous vehicles could degrade the efficiency of the transportation network and lead to deeper social inequality.

Add to this picture the 21st century e-commerce revolution. While e-commerce sales have been gradually increasing over the previous decades, the fourth quarter of 2020 saw a substantial 32% increase in e-commerce sales as compared to the same period in 2019 (US Dept. of Commerce, 2021). The blurring lines between in-store and online are expected to evolve into the future. Stores may become gathering places, as opposed to locations for distribution or retrieval of merchandise. It may be the norm to visit a store to interact with a project, leading to a purchase of a customized good delivered directly to the consumer at home. For the consumer, this is the ultimate standard of convenience, but it will undeniably lead to an increased demand for delivery services, and increased pressure on the transportation network. For example, the ASCE Future World Vision presents the issue of "175 delivery drones" (Lerner-Lam, n.d.) arriving at precisely 11:45 to deliver lunch to office workers.

Parallel trends leading to increased demand for dedicated short-range goods movement include decreased private vehicle ownership and increased use of peer-to-peer marketplaces such as Kijiji and Facebook marketplace.

As the need for goods transportation increase, so will the need for passenger transportation. Megacities will open up a realm of economic activity by allowing people to commute between what is right now two different cities, for example New York and Philadelphia, or Vancouver and Seattle. This will drive future economic activity that can only be accomplished by having employers and industries in one area. Megacities will no longer have a single "downtown" but many dense, urban centers. Couples specializing in different industries can live in their neighbourhood of choice and commute to different urban centers for work in specialized industries.

Ultimately, the success of a megacity depends on its ability to provide culturally-engaging public spaces where people can interact with other people and build fulfilling relationships - the Future World Vision's Mega City 2070 recognizes this. But to make this possible, transportation planning must become far less car-centric, and prioritize streets as places for people. Leveraging new transportation approaches and technologies will be required to grow sustainable, livable urban environments while maintaining a competitive and productive economy.

2. OUR SOLUTION

Recognizing that future megacities cannot accommodate significantly higher transportation demands with their current infrastructure, we propose an Integrated Transportation and Logistics System (ITLS) that will connect businesses, organizations, and citizens of future megacities through a dedicated underground passenger and freight transportation system.

2.1 Network Design

To achieve high utilization rates, the ITLS will serve a wide range of people and goods transportation needs. In an expansive and densely-populated megacity, the ITLS will provide fast and direct routes between major hubs of activity within the megacity to move people across the region efficiently. The ITLS will also supplement traditional logistics networks by connecting to existing goods movement infrastructure such as ports, airports, railway terminals and distribution centers.

The ITLS is designed to move high volumes of people and goods in a macro-network of tunnels 12 ft by 12 ft square between a relatively small number of stations or nodes. These nodes will be spaced roughly 10 miles apart at regionally-significant destinations including existing central business districts, major transit hubs, and high-capacity logistics facilities. Radiating out from the nodes, a meso-level network designed to transport only goods will use smaller 6 ft by 6 ft tunnels to complete cost-effective last-mile shipments. Passenger transport is not envisioned for the meso-network because, given the smaller scale and the number of individual destinations to serve, it is more efficient for passengers to use existing metro or surface transit networks.

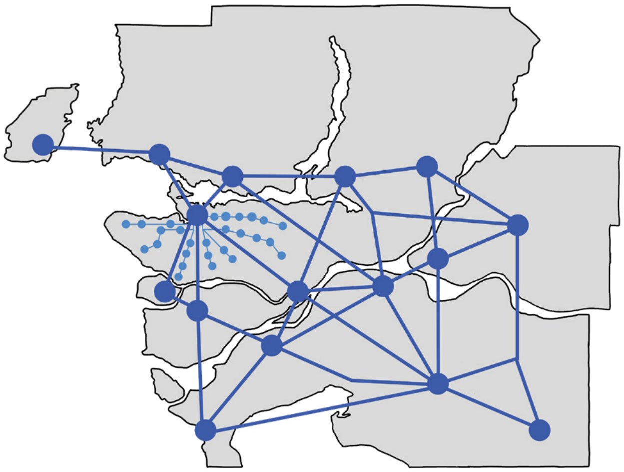

Figure 1 - Conceptual ITLS Network Diagram for Metro Vancouver. The entire macro-network is shown in dark blue. The meso-network is shown in light blue for one of the nodes only.

As conceptualized in Figure 1, the macro-network's spiderweb shape permits direct travel between origin and destination nodes and eliminates the need to pass through a city center, as many existing metro systems currently require. The web shape also ensures resiliency against disruptions to a single tunnel segment. Despite its high construction costs, the web network is viable provided that nodes serve major transportation hubs like airports and densely-populated catchment areas (of hundreds of thousands or millions of people) so that continual demand for travel exists between every pair of nodes. In contrast, the meso-network's radial form prioritizes the dominant movement of shipments from the node to their final destinations.

Network operations are handled by an advanced artificial intelligence (AI) algorithm that collects usage data from individual pods. The algorithm employs this data to estimate real-time transportation demand and dispatch pods to satisfy the demand, similar to how energy utilities adjust production levels. This ensures the right number of pods are in the right place at the right time.

However, far from commanding the pods through direct orders, the algorithm creates and supplies the pods with flexible decision-rules that inform their individual movements. These decision-rules empower the pods to communicate with neighboring pods and react quickly during unanticipated circumstances. This decentralized decision-making reduces delays and resulting collateral inefficiencies (the domino effect).

2.2 Pod Design

To efficiently accommodate both people and goods movement within the ITLS, the pods travelling through the network will be modular and customizable.

Passenger transport is handled by 12ft x 12ft x 6ft pods that can each carry 6 people between the nodes in the macro-network (see Figure 2). Users will be picked up on-demand from surface loading stations at nodes and lowered into the system, with a booking portal that allows for a pod to be booked for a specific pick-up time. Pods can then be coupled together into long trains to reduce drag. Each pod is designed to extend out a triangular shield at the front or from the back. If a pod is the first or last in a lineup, it will extend out the shield to reduce the drag coefficient of the group. Individual pods will separate from the train for boarding so that pods travelling through the node can maintain perpetual motion.

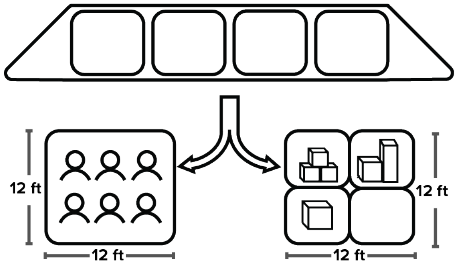

Figure 2 - Passenger and Freight Pods

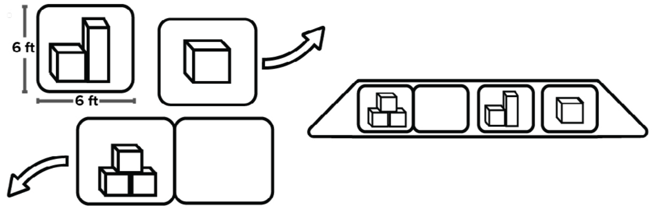

Figure 3 - Freight-specific Pods

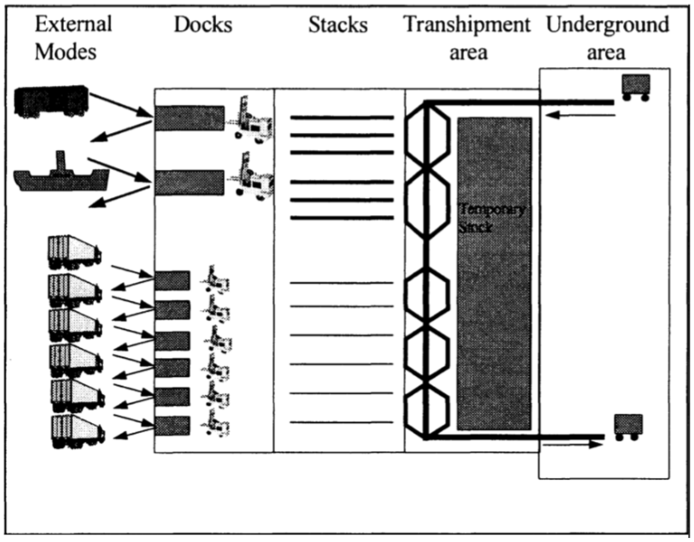

Figure 4 - Cross-Docking

After boarding, pods will accelerate and reconnect with another nearby train or continue travelling alone if doing so is more efficient.

Movement of freight will be conducted using pods that are 6 ft x 6 ft x 6 ft (see Figure 3). Individual freight pods will be designed to lock in with one another on all faces of the cube to form a 12ft x 12ft x 6ft or longer pod. Larger pods will travel together in similar chains to the people transportation system. In locations where the larger 12 ft by 12 ft macro-network tunnels meet the 6 ft by 6 ft smaller meso-network tunnels, individual 6ft pods will break off from the larger assembly and enter the meso-network freight tunnels for last mile delivery.

2.3 Station Design

While ITLS' modular pod design will enable most shipments to travel through nodes without stopping, all passenger boarding and significant freight loading will take place at the nodes. To accommodate this activity, the nodes will operate not just as multimodal transit stations, but also as high-capacity distribution facilities integrated with other forms of last-mile logistics. This includes docks for the occasional oversize shipment (larger than 6ft in two or more dimensions) and smart lockers for personal pickups. At meso-network destinations, smart lockers and loading docks are also present but primarily oriented towards smaller packages or shipments.

To minimize delays and goods storage requirements, the ITLS will implement cross-docking - an established logistics framework where inbound shipments are immediately transferred to an outbound dock or vehicle (see Figure 4). For cross-docking to be effective, goods to different destinations will be sorted at the cross-dock to avoid unnecessary travel in the network. For example, if one part of a shipment is destined for Location A, and another part is destined for Location B, the shipment will be split at the cross-dock so that the part bound for Location B does not need travel to Location A unnecessarily.

2.4 Tunnel Construction

Traditional tunnel boring machines (TBMs) are expensive to manufacture, require significant power inputs, and dig at an average rate of 0.003 miles per hour – 1000 times slower than a person's walking pace. Current TBMs (Crossrail, n.d.) have a circular rotating cutter head, followed by a series of trailers that house mechanical and electrical equipment, as well as the personnel required for the excavation of ground material and erection of concrete liners. The ITLS will require a much more sophisticated tunneling technology that can operate on mega-regional scale.

To improve upon existing TBMs, the Federal University of Santa Catarina in Brazil conducted a feasibility study on the use of a non-circular water jet TBM (Santos et al., 2018). This machine will use a high-power water jet and diamond wire cutters in the form of a double shield cutter head. Power consumption is lower due to the lack of mechanical contact between TBM equipment and the rock mass at the excavation front. To reduce costs, sand could be added as an abrasive in the water jets. The non-circular TBM is theorized to excavate up to 174 m of tunnel per day in soft and porous rock, as compared to 55 m per day for a traditional TBM. This makes water jet TBM technology particularly appealing in geographic locations with soft ground conditions like Seattle, WA.

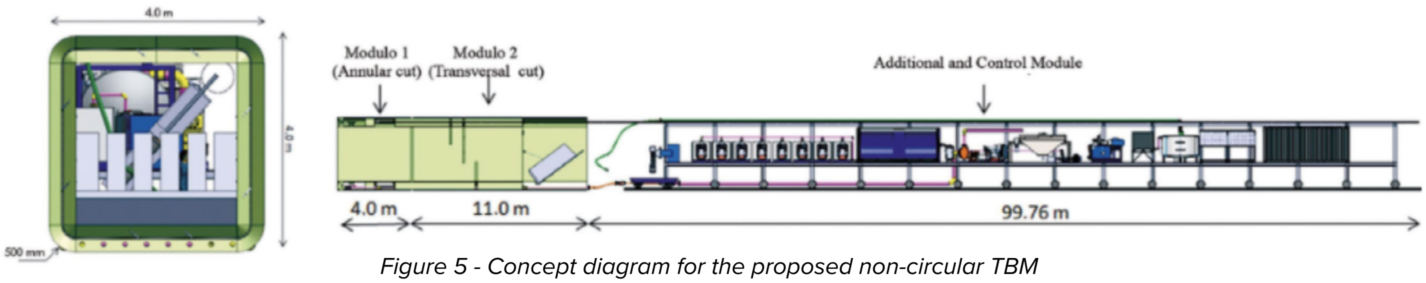

Figure 5 - Concept diagram for the proposed non-circular TBM

Although non-circular TBMs are not yet operational, in Las Vegas and Los Angeles, The Boring Company is currently employing a high-tech TBM solution called Prufrock (The Boring Company, n.d.). Prufrock eliminates the traditional TBM requirement of a launch pit by applying the Ultra Rapid Underpass Method (URUP), significantly reducing tunneling construction costs and time. Prufrock also uses an automatic concrete segment erector and muck removal system to achieve 85% continuity of operations (time spent excavating) compared to 10% for a traditional TBM. This innovation is projected to achieve excavation rates up to 7 miles per day.

With burgeoning populations but finite land area, megacities will be forced to build underground, creating a market demand for improved tunneling technologies. Companies and institutions will recognize the existing technology gap and work to fill it. By 2050, commercialized TBMs may combine features from the non-circular water jet TBM, the next generation Prufrock TBM, and future innovations that haven't been predicted yet. With AI surpassing human-level performance in many domains (Ahuja, 2019), TBMs are expected to become fully automated, further increasing efficiency and lowering costs. Combined, these improvements can make the ITLS viable in heavily urbanized and economically productive megacities.

2.5 Propulsion System

The ITLS pods will be powered by magnetic levitation (Maglev) technology. Maglev works by passing electric current through propulsion coils along the rail line to generate a levitating magnetic field. Linear motors will move magnets on the side of the train, creating forward motion through electrodynamic suspension. Less friction means Maglev trains can travel up to 375 mph (Hansen, 2020) with lower energy consumption than traditional high speed rail. While hyperloop technology was given consideration, the cost of additional infrastructure and energy required to maintain a vacuum is only justified over critically long distances (Janić, 2020). Therefore, hyperloop is not the ideal technology for the proposed ITLS.

Currently, Maglev is estimated to cost millions of dollars per mile more than high speed rail, but technological innovations are expected to reduce this cost over the next few decades (Rote, 1998). By moving both people and goods, the ITLS is expected to see high utilization rates, which increases the benefit of Maglev's increased speed, reliability, and efficiency, while bolstering the associated economies of scale. With potentially similar construction costs, but lower operating costs, Maglev is expected to result in lower overall costs for the ITLS over its decades-long lifespan.

2.6 Project Timeframe

To spread out demand for capital, material, and labor, while still realizing economies of scale, the ITLS will be constructed and inaugurated in segments over time (see Figure 6). Sidewalk Labs in Toronto, Canada selected the dense waterfront district of Quayside as the first phase of their proposed Underground Delivery System (Sidewalk Labs, n.d.). Similarly, the ITLS should start by connecting two dense urban centers within in the megacity where existing transportation demands are high. In addition, as city centers are more likely to have abandoned tunnels that could be repurposed to reduce construction costs.

As it relies on future technologies and expertise that still need to be developed, the ITLS will be planned, designed, and built over many years. Planning for the ITLS could start approximately 10 years into the future, with the first tunnel segment in testing and commissioning by 2040. Full buildout of the ITLS will occur gradually over decades and benefit from the development of new innovations and technologies over time.

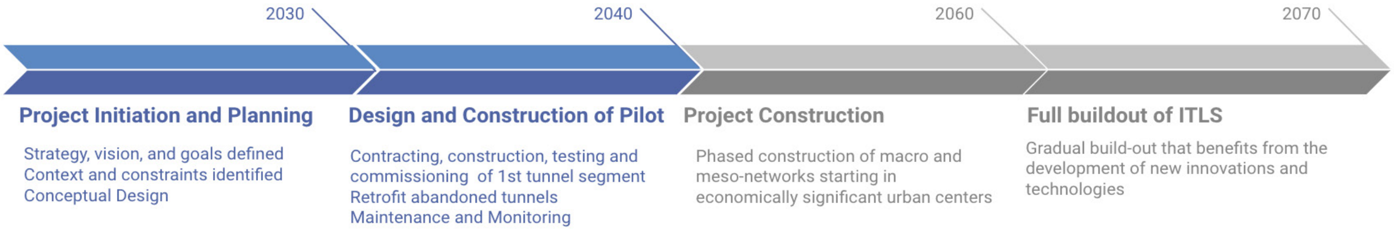

Figure 6 - Project Timeline

3. SOCIETAL VALUE AND APPEAL TO STAKEHOLDERS

In today's dense urban areas, providing efficient high-volume transportation routes for people and goods is often incompatible with the need to improve the quality of public spaces. Even with safer, cleaner, and quieter electric and autonomous vehicles, moving large numbers of people and large quantities of goods at high speeds will remain a noisy and disruptive activity, if done at or above ground.

A dedicated, high-performance transportation system such as the ITLS is necessary for megacities to overcome these challenges. While the ITLS will provide faster transportation, its most significant benefit is decoupling economic growth with increased number of vehicles on the road. This will pave the way for communities to reallocate road and parking space to uses that better serve community values and needs. Citizens will enjoy reduced greenhouse gas emissions, noise pollution, and safer public spaces. The recovered land could be converted to parks and community amenities. As a result of the ITLS, megacity residents will enjoy beautiful green spaces, vibrant urban environments, and places for spontaneous human interaction.

The ITLS, with its nodal network design, will also help megacities orient themselves into hyperlocal communities linked together to form economic and political mega-regions. High-density town centers will provide residents with all everyday services, akin to a fifteen-minute city. This will reduce the distance megacity residents need to travel and increase the megacity's overall social and environmental resiliency.

Beyond its broad appeal to megacity citizens, the ITLS will also appeal to many stakeholder groups.

Local governments are likely to support the ITLS as it can accomplish key policy objectives, including promoting livability and improving transportation access, safety, and reliability. The ITLS will also appeal to municipal leaders for its ability to simultaneously advance economic and social prosperity.

Businesses are expected to benefit from fast and efficient goods movement and benefit from the ITLS' lower delivery costs. Increased redundancy in the transportation network will help businesses through more reliable deliveries and less vulnerability to road construction or collisions.

The development community will partner with the ITLS team by extending the system to new mixed-use developments, providing convenient and inexpensive goods movement for prospective residents and businesses. There is an opportunity for municipalities to work with developers to build or upgrade smaller shipping hubs and holding areas through community amenity contributions. Even if the ITLS is not directly integrated into a development, it will shrink the need to construct expensive underground parking or short term loading spaces. The ITLS will also reduce noise from commercial loading, making mixed-use developments nicer places to live or shop.

Opposition to the ITLS could come from marginalized groups and people with low incomes who may fear displacement or increased living costs arising from increased land values. Cities will need to enact policies that protect residents from displacement and ensure their access to opportunities and services is retained, such as requirements that new development around the ITLS provide housing and services for existing residents. In addition, while tunnel boring is less intrusive than other tunneling methods, construction will still impact nearby residents and business owners.

Even with automated construction methods, ITLS construction will also immensely benefit the local community through skilled employment opportunities, which should be prioritized for traditionally underrepresented people, including women, people of color, and indigenous peoples. Furthermore, the planning and design phase provides an opportunity to digitally map the region's sub-surface and incorporate abandoned underground tunnels into the ITLS system, which could reduce construction costs. Maintenance to the ITLS will be less disruptive than for existing systems given the redundancy in the macro-network and the presence of alternate transportation systems to handle displaced traffic during temporary maintenance activities.

The ITLS' sustainable approach gets to the core of what it means to be a smart, futuristic region: one that uses technology to enhance its residents' quality of life, improves policy to address community values, and recycles existing infrastructure. Future megacities will need to adopt new transportation solutions such as the ITLS to advance regional mobility objectives, without erasing existing histories and tacit knowledge of community members.

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