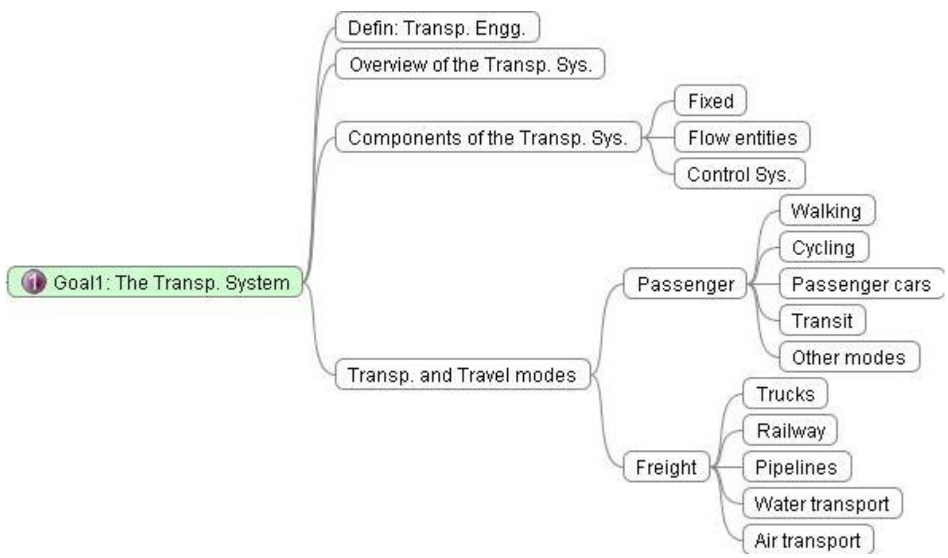
Section 1: The Transportation System

1.1 Learning Goal and objective:

1.1.1 Section goal along with other course goals[1]:

1.1.2 Topics covered in this section:



1.1.3. Intended Learning Outcomes:

By the end of this section, the student should be able to:

1. Recognize the magnitude of investment in the transportation system relative to other engineering system for which comparable statistics are available.
2. Identify different components of the transportation system.
3. Differentiate between the role of different modes of passenger and freight transportation.
4. Conduct a generalized comparison of different modes of transportation and travel based on their relative merits. Recognize the general limitations of typical passenger and freight modes.

[1] Figures prepared using Freemind (free and open-source mind-mapping software): http://freemind.sourceforge.net/wiki/index.php/Download

1.2. Overview of the transportation system

1.2.1 Definitions

Transportation Engineering: the engineering discipline concerned with the creation of transportation systems which serve the movements of people and goods, while maintaining adequate levels of speed, safety, and comfort to the system users with minimized impact on the environment.

Transportation System: An engineering system permitting people and goods to move among origins and destinations at an adequate level of mobility, safety, and comfort and in a reasonable sustainable way.

Note that in this course sustainability will generally refer to environmental sustainability. The context of sustainable development can be defined as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"[2]. Accordingly, a sustainable transportation system has the capacity to function for generations in its current settings without successive deterioration in service capacity.

System user: an entity or an agent that utilizes the transportation system in order to perform a desirable activity.

1.2.2 The Transportation System in Perspective

The following statistical summary provides a global perspective of the variation in size of transportation infrastructure among different countries. The surrogate measure to represent network size is the total length of two-lane equivalent public roads.

Table 1.1: Total length of public roads in 1000 km[3]

Country	Network size	Country	Network size
Australia	810	India	3,314
Canada	1,042	Japan	1,192
France	1,000	US	6,430

Table 1.2: Total length of public roads in 1000 km per capita[4]

Country	Network size (1000 km)	Country	Network size (1000 km)
Australia	39.97	India	3.03
Canada	31.48	Japan	9.35
France	16.43	US	21.55

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[2] United Nations General Assembly (1987) Report of the World Commission on Environment and Development: Our Common Future. Transmitted to the General Assembly as an Annex to document A/42/427 - Development and International Co-operation: Environment.
[3] OECD International Traffic Safety Data and Analysis Group. http://cemt.org/IRTAD/IRTADPublic/we2.html. Accessed September 2010.
[4] *ibid.*

Table 1.3: Length of the road network in Canada in 1000 two-lane equivalent km[5]

Jurisdiction	Paved	Unpaved	Total	Share (paved)	Share (unpaved)	Share (total)
Canada	416	627	1043	100%	100%	100%
ON	120	71	191	28.8%	11.3%	18.3%
SK	29	199	228	7.0%	31.7%	21.9%
AB	62	165	227	14.9%	26.3%	21.8%
BC	48	23	71	11.5%	3.7%	6.8%
QE	81	63	145	19.5%	10.0%	13.9%

Table 1.4: Government spending on transportation[6]

Year [a]	Expenditure [b]
1998	17,330
1999	18,269
2000	17,813
2001	18,484
2002	19,124
2003	20,387
2004	21,779
2005	23,520
2006	24,846

(a) Year beginning
(b)Consolidated expenditure by All levels of Government in million current CDN Dollars

1.2.3 Components of the Transportation System

Fixed facilities

Fixed facilities are the physical components of the system that are, as the name suggests, fixed in space. They consist of: network of links*, e.g.,* roadway segments and nodes*, e.g.,* traffic intersections. The design of transportation fixed facilities involves many disciplines of civil engineering.

Flow entities

System users that traverse fixed facilities. For example, vehicles, bicycles, and commercial vehicles. The typical focus of transportation engineers is on the physical properties of flow entities, *e.g.*, size, weight, acceleration characteristics, and deceleration characteristics.

Control System

Mechanisms to regulate the movements of flow entities. They may apply to individual (internal) vehicle guidance and to flow control, where in the latter regulations (external) are imposed on a group of vehicles. Aspects of vehicular control depend on driver characteristics, *e.g.*, reaction time, visual acuity, physical, and mental states. Flow control concerns traffic regulatory measures external to the vehicle, *e.g.*, signage, traffic signals, and lane marking.

[5] Transportation in Canada: An Overview Addendum. Report TP 14816E 2007.
[6] *ibid*.

1.2.4 Classification of the Transportation System

Table 1.5: Suggested classification schemes for the transportation system

Classification criterion	Classes
Access by the public	Public and private
Ownership	For-hire and not-for-hire
Medium	Land, water, and air
System users	Passengers and freight
Operation	Manual and automated
For-hire transportation	Common and contract

1.3. Travel models

The transportation system has evolved over time to offer travellers several options for performing trips. Probably, the most common mode used by travellers is the car. Despite the ubiquity of this travel mode, issues of rising operating cost, safety, and access to parking, have increased the relative attractiveness of other modes. The modelling of the decision-making process performed by travellers in choosing a mode will be discussed in Goal 4 of this course. In general, choices are sensitive to the user valuation of differences in travel costs and times among available mode choices. A summary of mode choice statistics for work trips is shown in Table 1.7.

The various characteristics of modes are also offered at different levels vulnerability to collisions. For example, the probability of injury per driven kilometre is 7-70 times higher for cyclists than for vehicle occupants[7]. Pedestrians and cyclists constitute approximately 15% of all collision-induced fatalities and serious injuries in Canada[8]; with a potential social cost of $9 billion/year. Table 1.6 shows a summary of collision statistics for different modes from 2003–2007. Modes vary depending on their environmental footprint, comfort, and speed, among other accounts.

Table 1.6: Fatalities by Road User Class 2003–2007[9]

Road User Class		2003	2004	2005	2006	2007
Drivers	#	1,427	1,388	1,507	1,516	1,444
	%	52	51	52	52	52
Passengers	#	658	648	677	614	609
	%	24	24	23	21	22
Pedestrians	#	379	363	344	382	377
	%	14	13	12	13	14
Bicyclists	#	45	56	52	73	65
	%	2	2	2	3	2
Motorcyclists	#	177	198	229	212	220
	%	6	7	8	7	8
Not Stated/Other	#	82	69	96	98	52
	%	3	3	3	3	2
Total	#	2,768	2,722	2,905	2,895	2,767

[7] Conor, R., Harris, M., Teschke, K., Cripton, P., and Winters, M. (2009) *The Impact of Transportation Infrastructure on Bicycling Injuries and Crashes: A Review of The Literature*. Env. Health, 8(47):1–19.

[8] Reports by Transport Canada: (2007) *Analysis and Estimation of the Social Cost of Motor Vehicle Collisions in Ontario* and (2010) *A Quick Look at Fatally Injured Vulnerable Road Users*.

[9] Canadian Motor Vehicle Traffic Collision Statistics: 2007: TP 3322, Transport Canada, Road Safety and Motor Vehicle Regulation.

Table 1.7: Employed labour force by mode of transportation to work, by census metropolitan area. (Statistics Canada, 2006 Census of Population)

	Ottawa-Gatineau (Ont.-Que.)	Kingston (Ont.)	Peterborough (Ont.)	Oshawa (Ont.)	Toronto (Ont.)	Kelowna (B.C.)	Abbotsford -Mission (B.C.)	Vancouver (B.C.)	Victoria (B.C.)
Total - modes of transportation	**559,590**	**69,530**	**52,115**	**160,010**	**2,433,060**	**73,025**	**72,280**	**1,003,020**	**158,510**
Car, truck or van, as driver	350,960 (62.6%)	50,850	39,795	126,340	1,547,540 (63.6%)	59,435	60,140	675,075 (67.3%)	102,920
Car, truck or van, as passenger	44,880 (8.0%)	6,445	5,180	13,805	182,440	5,645	7,230	70,990	10,715
Public transit	108,840 (19.3%)	2,865	1,280	12,665	540,495 (22.2%)	1,955	1,275	165,435	16,205
Walked to work	38,335 (6.8%)	6,690	4,075	5,430	115,625 (4.7%)	3,340	2,295	63,415 (6.3%)	16,510
Bicycle	11,640 (1.9%)	1,660	1,215	650	24,690 (1.0%)	1,550	505	16,585 (1.6%)	8,955
Motorcycle	720 (0.1%)	100	50	100	1,540	250	190	2,745	1,195
Taxicab	605	435	155	395	4,800	60	60	1,275	230
Other	3,620	475	360	620	15,920	785	595	7,495	1,775

1.4. Freight Transportation Modes

A number of freight transportation modes are available to move goods through the transportation system. The purpose of this section is to provide a brief introduction to common freight transportation modes and along with review of their main characteristics.

1.4.1 Motor Carriers

The most common mode for freight transportation is the truck. Trucks may provide a fast and door-to-door freight transportation service. Trucks also can interface between different freight transportation modes. This mode has expanded at the fastest rate among all freight transportation modes in the past fifty years. This is expansion is likely due to: [1] growth of the loading capacity of vehicles, [2] relative speed for short hauls, and [3] flexibility in schedules. However, the trucking industry, among other freight transportation modes, has struggled with rising fuel prices over the past year. While trucks have relatively inexpensive capital cost (fixed cost or procurement cost), *e.g.*, vehicle fleet, compared to other freight transportation modes, their rising operating cost (variable cost), *e.g.*, driver wages, fuel, maintenance, insurance, tires, licenses, fleet depreciation, further reduces the potential to generate a strong Economy of Scale (EOS)[10].

Furthermore, the growing focus on sustainability of transportation places an operational requirement on the industry, *e.g.*, carbon tax programs. Trucks often use the same infrastructure along with other road users. This exposes trucks to collisions, delays due to traffic congestion, and delays at weigh stations. The latter restriction, weight enforcement, is necessary for equitable access to public infrastructure without significant damage to pavement from excessive cargo loads.

1.4.2 Railroads

This is a relatively old mode of freight transportation. Railroads are remarked for providing very low rolling resistance to movement. They may suffer from limited access and high construction cost. Rail transportation has been the product of the industrial era, playing a major role in the economic development of Western Europe, North America and Japan. Rail transportation is characterized by high capital costs because the construction of rail tracks and the provision of rolling vehicles (locomotives, cars, repair machinery) are expensive. In addition, railroads operators much own or lease as well as maintain their right-of-way, bridges, tunnels, switches, and terminals. Variable costs are relatively low, and can include: labour, fuel, electricity, insurance, taxes, depreciation, and equipment maintenance and upgrading.

Railroads enjoy a widespread geographic coverage and a high carrying capacity. They are more energy-efficient and environment-friendly in terms of energy used and pollution emitted per ton-km carried, compared with motor carriers. They are generally more suited to transport large-volume or weight and low-value commodities, such as: coal, grain, oil, and chemical products, pulp and paper products, forest products, and manufactured products such as vehicles, machinery, parts, and equipment.

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[10] An Economy of Scale (EOS) is the business operation condition under which the output of more production units reduces the cost per unit. If the total cost (T) of operation is fixed cost (F) in addition to variable cost per unit (V) such that: T=C+V*x, where x is the number of units produced. The cost per unit (t_x) is therefore, T/x = t_x = C/x + V = C(1/x+V/C). it is straightforward to show that is negatively proportional to the capital cost. The smaller $/_x$, the stronger the EOS effect. It is reasonable to assume that variable cost relative to capital cost is negatively proportional to capital cost. For example, a low-maintenance equipment is likely to be expensive.

1.4.3 Pipelines

Pipelines represent an important, yet often underestimated, mode of freight transport. Typical products carried by pipelines include: natural gas, crude oil, other petroleum products, and liquid form chemical products. In Canada, there are approximately 250,000 kilometres of gathering pipelines in the energy-producing provinces of Western Canada, 25,000 kilometres of feeder pipelines in the same region, 100,000 kilometres of transmission lines in Canada, and 450,000 kilometres of distribution pipelines lines in Canada[11]. Accordingly, the total length of the fossil energy (crude oil, natural gas and liquefied natural gas) transportation pipelines in Canada may be over 825,000 kilometres.

Pipelines are characterized by high capital costs depending on: pipe diameter, conveyance distance, viscosity of the conveyed fluid, and terrain. Construction costs vary according to the pipe diameter and increase with the distance. The pumping and control mechanisms may also be more expensive for fluids with high viscosity. Pipelines enjoy relatively very low variable costs, *e.g.*, labour, administration, and insurance.

1.4.4 Water Transportation

Water transportation is one of the oldest forms of mass freight transportation; especially over long distances. Terminals serving water vessels have historically supported urban development around them, *e.g.*, Alexandria, Los Angeles, Mumbai, New York City, Singapore, and Yokohama.

Typical products carried over domestic waters are: coal, coke, iron, steel, grains, lumber, earth materials, chemicals, petroleum products, and paper. Typical products carried by oceangoing vessels are: sugar, coffee, grains and foods, oil, petroleum products and chemicals, machinery, and consumer products.

Water transportation is characterized by high fixed costs. For example, a container ship may have an initial price of more than $50 million. Operating costs, *e.g.*, fuel, maintenance, and loan servicing, may be high. However, operating costs are typically low enough, relative to fixed costs, to generate a strong EOS. In general, water transportation can provide the cheapest per unit of all transport modes, particularly fit for heavy industrial activities.

1.4.5 Air Carriers

This is relatively one of the newest mode of freight transportation. It is also the fastest mode of transportation for high-value goods. Air transportation is characterized by high fixed as well as operating costs. Fixed costs may include: aircraft fleet, maintenance facilities, computer reservation systems, management, logistics, airport counters, baggage handling facilities, and offices. Operating costs may include: landing fees, fuel, maintenance, and commissions to travel agencies.

Air transportation may provide fast terminal-to-terminal transportation along with reliable scheduling service (except in adverse weather conditions). The disadvantages of this mode are: relatively limited frequency of flights, capacity restrictions, and sometimes inadequate service to small cities. Access is relatively limited because airports are often located at the outskirts of urban areas.

The general characteristics of the freight transportation modes presented in this section are summarized in the following table.

[11] Canadian Energy Pipelines Association. http://www.cepa.com/pipelines-101/types-of-pipelines. Accessed, Sep 2011.

Table 1.8: Some ratings of general characteristics of freight transportation

Mode	Fixed cost	Variable cost	Access	Capacity	Speed	Sustainability[+]	Specific advantages	Specific disadvantages
Trucks	Low	High	High	Low	Med.	Low	-Door-to-door -Versatile -Intermodalism	-Poor EOS
Railways	High	Low	Low	High	High	High	-Geog. coverage -Speed for long distance - V. good EOS	- Right-of-way must be purchased or leased
Pipelines	V. High	Low	Low	High	Low	High	-Excellent EOS -Minimal labour	-Slow service -Specific to liquids
Water	High	Low	V. Low	V. High	V. Low	varies	-Community development -Excellent EOS -Minimal labour	-Access through sophisticated terminal
Air	High	High	Low	Low	V. High	V. Low	- Speed	- Capacity restriction

+ Please refer to the definition of *sustainability* in section 1.2.1

1.5. Practice Questions and Problems

1. Select one of the following engineering activities: [1] the construction industry, [2] the pulp and paper industry, [3] water treatment, and [4] waste management, and conduct a comparison with transportation in terms of annual investments, volume of green-house-gas emissions, and cost of reported operational failures. You may include in the aforementioned selection set other engineering activities. You may conduct the comparison at municipal, provincial, national, or international levels. Comment on the results.

2. Discuss the role of flow control for improving the sustainability of the transportation system. Give two real-life examples.

3. Discuss Economy of Scale (EOS) as a business parameter and the level of competition among freight transportation providers. Apply your reasoning to the freight transportation modes presented in this section.

4. The total cost of freight for company A is defined as a function of the cargo load as follows: $.5x$, where C is the total annual cost in $CDN and x is the number of tons transported per year. The cost function for company B is defined as follows: $C = 1E6 + 1.5x$. Both companies are contemplating raising their annual shipping activities from 10 million tons this year to 20 million tons by the end of the next year. Assume that the parameters of the cost models remain constant.

- Which company, A or B, enjoys stronger EOS?
- Discuss analytically or using numerical examples the potential of both companies for achieving increased profit by increasing their shipping activities.
- Hypothesize which company may be faced with more business competition.