Lecture Notes - CIVL1116

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1 Transportaton Engineering

1.1 Fundamentals of Transportation Systems

Transportation is everything involving in moving either people (passengers) or goods (freight) from an origin to a destination. It can be done via land, water, and air. Although clearly essential to the development of society, it also leads to some problems, such as

- Congestion
- Pollution
- Climate Change
- Road Accidents

The objectives of transportation engineering are to optimise the planning, operation, and management of transportation facilities to provide **safe, efficient, rapid, comfortable, convenient, economical, and environmentally friendly** movement of passengers and freight — minimising the aforementioned problems. **Traffic Engineering** is a branch of transportation engineering that deals with the planning, geometric design, and traffic operations of highways and their networks, roads, streets, ... Transportation also interacts with other systems:

- Transportation and Society:
  Transport affects the location of residence, range of provision of goods and services, and influences the way civilisation develops. Transport infrastructure allows for developments to take place. Transportation and the services enabled by it account for a large proportion of the GDP of most countries. It is also a major employer of people.

- Transportation and Economy:
  Economics studies the production, distribution, and consumption of goods

and services. These must be provided from natural resources — transportation allows people to exchange goods, knowledge, and money in a way that speeds up development and improves quality of life. Transport is used by companies as an integral part of their commercial operations, and it is used by individuals to travel for work or leisure. Different types of journey influence the choice of transportation mode. Essentially, decisions are made as a combination of factors, such as minimum total time, cost spent travelling, etc. The same is true for companies.
In conclusion, by reducing the generalised cost of access to facilities, changes in the location of employment and home may occur. The accumulaton of these consequences shape the metropolitan region.

- Transportation and Politics:
  Transportation problems cannot be tackled in a vacuum; any solution to them may affect other areas of life. The transportation planning process aims to tackle simultaneously problems like:
  - Allocative Efficiency (providing efficient movement of goods and people)
  - Social Equity
  - Environmental Impact

  Many issues lead to conflicts of interest, such as
  - Energy:
    Transportation leads to a lot of fuel consumption. It is affected by fuel prices. The government's long–term strategy is to reduce fuel consumption; this can be done through measures such as increasing the fuel tax, subsidising public transport, implementing a park and ride policy, encouraging carpooling, among others.
  - Equity:
    The construction of highway systems benefit private car users, but can break up communities, disrupt farmlands, etc. Additionally, it promotes the growth of car ownership, which leads to a decline in the usage of public transport systems.
  - Environment and Pollution:
    The transportation sector causes pollution in many aspects, such as GHGs, congestion, noise pollution, carbon monoxide emissions. . .

Transportation Systems are composed of several elements and their interactions. Some of these are the government, customers, the general public, competition, the financial community, the supply industry, and stakeholders.
They have three kinds of elements:

- Fixed Facilities

  - Links of a Network (roadways, highways, ...)
    Highways have incredibly high accessibility — virtually every place has access to a road. All categories of road user share the same way, which can lead to congestion and delays.
    Roads can be classified into:
    * Urban: which is subdivided into primary distributors → district distributor → local distributor → access roads → trunk roads.
    * Rural: which is subdivided into rural roads → feeder roads → trunk roads.
  - Nodes of a Network (intersections, terminals, ...)

- Flow Entities
  This refers to vehicles, such as cars, buses, trains, ...

- Control System
  - Vehicle Control (can be manual or automated)
  - Flow Control (Traffic Signal Control)

The three main criterion to evaluate transportation systems are ubiquity, mobility, and efficiency. Ubiquity refers to how accessible the means of transport is. Mobility refers to the quantity of travel that can be handled by the means of transport, reflected in speed and capacity. Efficiency is a measure of the cost vs. the productivity, where cost = direct capital cost + operation cost + adverse effects (e.g. pollution) and productivity = the total amount of transportation provided per unit time.
Let us explore some of the issues faced by transportation in more detail:

- Traffic Congestion
  It exists when demand exceeds the capacity of the transportation systems. Some issues that affect the supply are a lack of or inefficient utilisation of public infrastructure and transportation systems. Issues that affect the demand are peaks and valleys in travel demand.
  This issue can be remedied through supply management (more capacity, funding, land, political support,) demand management (congestion pricing,) and traffic management and control (which includes intelligent transportation systems, traffic signal control, and travel information provision.)

- Safety & Security
  It is affected by factors such as vehicle design, driver profile, driving behaviour, environment, traffic condition, traffic system control, ...

- Equity of Access
  Facilities provided for the elderly, disabled, and low–income individuals. Can they own or acess transportation?

- Funding
  The government's duty is to provide good transportation facilities to citizens while having a limited budget. Thus, it must always balance the benefit of any new facility with the construction cost. Governments can take back a part of the building cost by charging users (e.g. fuel taxes or highway tolls.)
  Private agencies, such as Uber and DiDi, collect trip fares from passengers and pay wages to drivers.

- Environmental Concerns

  - Energy
    Its consumption can be reduced by improving vehicle energy efficiency, replacing fuel vehicles with electric vehicles, and encouraging the use of public transportation.
  - Air
    There are many pollutants, such as CO, NO_x, O_3, CO_2, ...
    It can be remedied through tighter emission control, cleaner fuel, proper vehicle maintenance, and an air pollution control ordinance.
  - Noise
    It can be remedied via a noise control ordinance, noise barriers, pedestrian schemes and vehicle restrictions in residential areas, ...
  - Habitat
    It can be remedied through an environmental impact assessment ordinance
  - Sustainability
    It can be enhanced through integration of land–use transport planning, transit–oriented design (TOD), technologies (e.g. autonomous vehicles, V2V or V2I, electric vehicles), encouraging the use of public transportation, tightening vehicle commission controls, emphasising on pedestrian facilities during urban planning, etc.

Categories of transportation systems:
By ownership, it can be joint, private, or public.
By its purpose, it can be for travelers or freight.
By distance, it can be urban, regional, intercity, or international.
Transportation planning tries to find the best place to build a road, railway, subway station, or other facilities. It is also in charge of defining future policies, goals, investments, designs, ... Transportation operations focus on how to make vehicles move more smoothly on the road.
Some relevant concepts to transportation planning are the following:

1. Zones: the way to divide the planning area. They aid in linking the information of travelling activities/facilities to urban areas. Usually, the larger the zone, the simpler it gets. They can be seen as the nodes in a network.

2. OD pairs: collection of journeys from Origin to Destination. They can be interpreted as nodes connected by imaginary links.

3. Imaginary Links: a representation of highways that connect two zones.

In order to generate travel information, we use an OD Matrix. In this matrix, the **rows** will represent the **origins** and the **columns** represent the **destinations**. The last row will have the **total number of trips attracted to the zone in that column** and the last column will have the **total number of trips originated in the zone in that column**. This information helps us in the planning process.
The transportation planning process goes as follows:

1. Transportation Survey, Data Collections, and Analysis:
   This includes traveler behaviour patterns, nature/intensity of traffic, cost and benefits, ...

2. Use of Transportation Model:
   The model allows us to predict future travel demands and network needs. The classical model has five stages:

   (a) Divide City into Zones
   (b) Trip Generation (forecast the number of trips that will be made. Define the attractors and generators.)
   (c) Trip Distribution (determines trips between zones.)
   (d) Mode Usage (predicts the choice of travel mode.)
   (e) Trip Assignment (Predicts the routes of the trips, traffic, and ridership.)

   The output of this model is the mode share, traffic volume, travel time, monetary cost, and other information.

3. Future Land Forecasts and Policy Strategy Designs

4. Policy Evaluation (several years after implementing the measure.)

Transportation Operations are used by city managers to improve the mobility, accessibility, and sustainability of transportation systems based on the existing transportation facilities. Some examples of these are:

- Traffic Signal Control:
  The signal timing should allocate effective green and red times for each intersection. This timing can be either fixed or adaptive (change depending on real–time situations.) Coordinated control consists in coordinating traffic signals in a region to encourage a *green wave* that allows continuous traffic flow over several interactions.

- Ramp Metering:
  Setting traffic signals at the entrance of a highway. Sensors on the highway adjust the traffic signals so that they turn green when the conditions to merge into the traffic are favourable.

- Travel Time Information Provision:
  Used in intelligent transportation systems (ITS); it provides information such as ETA, real–time road traffic state, and allows the selection of routes and means on transport dynamically.

- Variable Speed Limits:
  Change depending on road, weather, or traffic conditions. Information is gathered via sensors and sent to a traffic operations centre, where it undergoes a review that will decide what speed limits should be posted.

- Road Pricing (Tolling):
  It reduces congestion in central business districts and encourages people to use public transportation.

- High–occupancy Vehicle (HOV) Lanes:
  Traffic lanes reserved for the exclusive use of vehicles with $1 <$ passengers. This is to encourage the use of ridesharing travel modes and reduce traffic congestion. In some instances, individual vehicles are allowed to use these lanes after paying a fee.

1.1.1 Transportation Economics

Economics analyses the costs and benefits of improving patterns of resource allocation. Microeconomics focuses on the behaviour of individual units (such as consumers, firms, . . .) and macroeconomics studies the wealth of society on a national and international scale. Clearly, the former is the one that targets transportation.
When studying economics in transportation, it is important to notice that the simple laws of economics do not apply to it: the demand for transportation is affected by many factors in a complex way, government intervention creates problems, among others.
The market has two parts:

- Suppliers: provide transportation supply (e.g. roads, vehicles). They care about costs, revenue, profits, welfare. . .
  Transportation is a service, not a good. This means we cannot store it and use it selectively based on demand.
  From the viewpoint of suppliers:
  - Cost: can be fixed (infrastructure) or variable (operations and maintenance)
  - Revenue: fares collected from passengers.
    Profit= revenue - cost

    - Social welfare: Benefits of all stakeholders, including consumers and suppliers.

  Different travel modes have different monetary costs; it is necessary to do a trade–off between time and money.

- Consumers: use transportation services. Different consumers have different cost aversion.
  The demand for transportation is affected by income of customers, price of goods and services relative to other prices. The choice of mode of transportation, similarly, is affected by the purpose of the trip, distance, income, fare, and expected time.

Road capacity is the maximum vehicles that a roadway can hold per hour or day.
Transportation supply is usually measured by level–of–service (LOS.) As traffic volume approaches capacity, the LOS decreases dramatically. It is usually multidimensional: price, travel time, comfort, safety...

Demand for transport is a function of a set of costs perceived by the traveler. We can reduce these costs and LOS measures into a single measure for simplicity. In so doing, we generate the **generalised cost** in monetary unit. We could also use utility or time cost (value of time x time).
Transportation demand is generally inversely proportional to the generalised cost. This can be represented as a demand function (relation between quantity demanded of good and its price.) Similarly, supply can be represented as a function of the quantity of goods a producer is willing to offer at a given price. The point where these two graphs intersect is called **equilibrium**.

1.2 Transportation Technology

Hong Kong has the highest vehicle density in the world, is transit–oriented, 90% of its transportation is done via public transportation, and has a strategic position within Asia. The Hong Kong government aims to provide a safe, efficient, reliable, and environmentally friendly transport system.
Some measures that have been or will be implemented in Hong Kong to achieve these goals are the following:

- Smart Transport Infrastructure: traffic detectors along strategic roads. They detect real–time volume of vehicles and pedestrians to optimise signal time allocations.

- Vehicle Technology: V2X and autonomous vehicles allow automatic daata transmission and communication between vehicles, roadside infrastructure, and a cloud network. AV can also make a more smooth traffic possible.

- Data Sharing and Analytics: seen in traffic flow census, ETA of bus services, parking vacancy data...

- Automated Parking Systems

The right of way (ROW) refers to the travel way on which the transit vehicles operate. There are three basic ROW categories, based on the degree of separation from other traffic.
Category C is for surface streets with mixed traffic. Category B is for streets physically separated by some barriers, but with grade crossings for vehicles and pedestrians (such as LRT systems or HOV lanes.) Lastly, category A refers to a fully controlled ROW without crossings with other vehicles.
The most common transit modes are the following:

- Paratransit:
  includes taxis, ride hailing, dial–a–ride, and minibuses. It focuses on those means of transport without a fixed route or schedule.

- Street Transit Mode:
  Includes regular buses, express buses, and trams. It is for those means that must follow fixed routes, but are neither fully automated nor have a remarkably high capacity.

- Medium–capacity Transit Modes:
  Includes Bus Rapid Transit (BRT), Light Rail Transit (LRT), and Automated Guided Transit (AGT). These do not have a sizable capacity, but operate in either ROW B or A predominantly.

- Rapid Transit:
  Includes the metro. It operates in a fully A ROW, has full signal control, and high speed, reliability, and capacity.

- Intercity and High–speed Rail:
  Long–haul passenger services that connect multiple urban areas. They have few stops and aim to have high average speeds.

Intelligent Transportation Systems (ITS) are implemented to reduce time spent travelling, congestion, fuel consumption and pollution, while improving safety, convenience, and equity.
There are five main areas within ITS:

- Advanced Transportation Management Systems (ATMS)
  They prredict traffic congestion and provide alternative routing. This is done by collecting real–time data with sensors and using it to guide the operations of vehicles. Dynamic traffic control systems will also respond to the information gathered.
  Some applications of ATMS are incident management, ramp metering, and electronic toll collection.

- Advanced Traveler Information Systems (ATIS)
  They proide traffic conditions, scheduled road construction and maintenance, alternative routes, and incidents on the road. This can help passengers decide their time of departure, travel mode, and route of choice.
  Some uses of ATIS are route navigation, on–trip driver information, and parking information.
- Advanced Vehicle Control Systems (AVCS)
  They enhance the driver's control to make travel safer and more efficient. The way in which this is done could be vision enhancement, night vision assist camera, pedestrian detection, ...
  Some uses of AVCS are automated vehicle operation and collision avoidance. This is all done through sensors placed in different parts of the car, as well as communication between vehicles (V2V and V2I)
- Commercial Vehicle Operations (CVO)
  Most commonly seen in weigh–in–motion (used in highways to avoid overweight and to estimate tax), automatic vehicle operations (locates every vehicle in a fleet and sends it to a GPS. Improves routing and scheduling), and electronic toll collection (avoiding the user to stop when charging them).
- Advanced Public Transportation Systems
  Technologies to enhance accessibility of information to users of public transportation, facilities such as octopus payment and ETA provision, among others.

Autonomous Vehicles are an important aspect of transportation technology too. There are different levels of automation, from 1 (driver assistance) to 5 (full automation.) Only levels four or five could allow the driver not to pay attention at all. Vehicles with these levels of automation are not yet commercialised, but testing on them is being done. The core software components of autonomous vehicles are:

- Perception:
  The ability of an autonomous system to collect information from the environment and extract relevant information from it. Generally seen in obstacle and road sign detection.
  This is done through sensors, such as LIDAR (light detection and ranging device), cameras, and a fusion of the two.
- Planning:
  The process of making purposeful decisions to achieve the vehicle's higher order goals, typically to bring the vehicle from an origin to a destination while avoiding obstacles and optimising routes. It includes
  - Mission Planning: planning the routes from an origin to a destination
  - Behaviour Planning: ensures the vehicle follows road rules and interacts well with other vehicles

  - Motion Planning: decides on a sequence of actions to reach a specific goal

- Control:
  The ability to execute the planned actions generated by the higher level processes. Controls things such as the brakes, accelerator, lights, and horn.
  SOme typical methods are PID and Model Predictive Control (MPC)

Vehicle–to–Everything Communications are also important in transportation technology. It is a communication system that allows for vehicles and other parts of the traffic system to exchange information. It allows for a safer and more efficient traffic. V2X has two main components, V2V and V2I.
The way V2X works is by sharing information through high–bandwidth, high–reliability links that allow for real–time communication. One core concept of V2X is *platooning*: a method for driving a group of vehicles together, with very small gaps between elements in the group.

High Speed Rail Systems (HSR) are a type of rail transport that run significantly faster than traditional rail traffic. It uses an integrated system of specialised rolling stock and dedicated tracks. Usually it refers to lines that can handle speeds of at least $250km/h$. Japan, China, and continental Europe all have highly developed lines.

On–demand Ride Services provide service to passengers tailored to their specific time and destination. In contrast to taxis, these services can collect the real– time information of passengers, drivers, and the road to make good decisions. Additionally, they can dinamically adjust the trip fare through surge pricing. Some challenges these services face are matching, pricing, and relocation (moving idle vehicles to regions with large demand.)

1.3 Data Science in Transportation Engineering

1.3.1 Transportation Data

Data Science helps us structure data and discover patterns through complex and advanced analytical tools and algorithms. This field is related to statistics, econometrics, and machine learning. Data Science is used to make decisions and predictions through predictive analytics and machine learning.

- Data Science Analytics can be:

  1. Predictive Causal Analytics: build a model to predict the possibilities of a particular event in the future.
  2. Prescriptive Analytics: not only predict but also suggest a range of prescribed actions to achieve a desired outcome (e.g. self driving cars.)

- Artificial Intelligence is intelligence demonstrated by machines.
  - Machine Learning is a branch of AI that studies algorithms that can improve automatically through experience and the use of data. There are three main types:
    1. Supervised Learning: learns a general rule that maps inputs (features) to outputs (labels) for making prediction. The two most common types are classification and regression. Classification is when the label can only take a discrete amount of values, whereas regression is when the label can take any value within a range.
    2. Unsupervised Learning: its goal is to discover hidden patters from the input data itself. No label (output) is given for learning. It finds clusters in data.
    3. Reinforcement Learning: a computer program interacts with a dynamic environment in which it must perform a certain goal. Here we don't make predictions, we observe a state and determine actions from it.

    Supervised and unsupervised learning are related to predictive causal analytics, while reinforcement learning directly provides solutions to prescriptive analytics.
- Big Data refers to data that is too large for traditional data processing applications. Some of its challenges include analysis, capture, data curation, search, sharing, storage, transfer, among others. Accuracy in big data may lead to better decisions, which in turn leads to higher operational efficiency.

1.3.2 Regression Problems

Firstly, let us define some key terms:

- Dependent variable: variable to be predicted.
- Independent variable: variable used to predict the value of the dependent value. In regression; it is a continuous variable, whereas in classification it is a discrete variable.
- Training: find out the relationship between dependent and independent variables given a known dataset
- Testing: given new independent variables, predict the correspondent dependent variable.

Regression is about finding the relationship between one dependent variable y and a series of independent variables $x_1, x_2, \dots$ Then, given a new sample of an independent variable, we can predict a new depedent variable. Regression can be either linear or nonlinear.
Linear regression can be either simple (one independent variable) or multiple

(several independent variables) whereas non–linear regression can have polynomial functions as linear models, linear basis function models, neural networks, etc.

Simple Linear Regression:
Suppose y and x have the following relationship:

$$y = \beta_0 + \beta_1 x + \epsilon$$

Where parameters β_0 and β_1 are the intercept and slope respectively, and ϵ is an error term that accounts for the variability in y that cannot be explained by the linear relationship between the dependent variable y and the independent variable x.
The parameter values are usually unknown and must be estimated using sample data. Then, sample statistics will be computed as estimates of the intercept and the slope. There are two main steps in the overall regression procedure:

- Training:
  Assume a linear model $y = \beta_0 + \beta_1 x + \epsilon$ with unknown parameters β_0 and β_1. Then, collect a dataset with N samples $(x_1, y_1), (x_2, y_2), \ldots, (x_N, y_N)$. You will use those samples to estimate the intercept and the slope.
- Testing:
  Construct the trained linear model $\hat{y} = \hat{\beta_0} + \hat{\beta_1} x$. For a new test sample with given independent variable x_n, we can predict the corresponding dependent variable by $\hat{y_i} = \hat{\beta_0} + \hat{\beta_1} x_i$.

Here, the slope $\hat{\beta_1}$ measures the change of the mean of the dependent variable y caused by a unit increase of the independent variable x. The intercept $\hat{\beta_0}$ is the estimated value of the dependent variable y when the independent variable x is zero.
We say that there is a positive relationship between x and y if $\hat{\beta_1} > 0$. Similarly, if $\hat{\beta_1} < 0$ we say that x and y have a negative relationship.

A way we can determine the best–fitting straight line is through the *least–squares method*: the line that minimises the sum squares of the lengths of the vertical distances between the observed data points and the fitted values is the most appropriate one. Essentially, our goal will be to minimise the following:

$$\sum_{i=1}^{n} (Y_i - \hat{\beta_0} - \hat{\beta_1} X_i)^2$$

Then, how can we find the optimal values of the slope and the y–intercept so that the sum of squares is minimised? This is a convex optimisation problem, so the optimal solutions can be obtained at the point such that the first–order derivatives of the function with respect to the slope and the intercept are zero. Manipulation of the derivatives eventually gets us to the following formulae:

$$\hat{\beta_1} = \frac{\sum_{i=1}^{n} (Y_i X_i) - N \bar{X} \bar{Y}}{\sum_{i=1}^{n} (X_i)^2 - N (\bar{X})^2}$$

$$\hat{\beta}_0 = \bar{Y} - \hat{\beta}_1 \bar{X}$$

Where $\bar{X}$ and $\bar{Y}$ are the means of X and Y respectively.

1.3.3 Classification Problems

These problems try to map the input to one of a group of discrete categories. For example, identifying if the object in a picture is a bicycle or a car. A common method for this is logistic regression, which is beyond the scope of this course.

2 Environmental Engineering

2.1 Introduction to Environmental Systems

Enviornmental engineering focuses in understanding the interactions between the environment and human systems and minimise the harmful results of such interactions, such as water pollution, climate change, air pollution...
There are two kinds of systems: closed systems, where there is no energy exchange between the system and its surroundings, and open systems, where there is a constant exchange between these two. Closed systems generally handle matter and follow the law of conservation of mass, whereas open systems handle energy and follow the 1^{st} and 2^{nd} Laws.
Matter is composed of atoms, which are made up of electrons orbitting around the nucleus, which is made of protons and neutrons. On the periodic table, the furthest left an element is, the most reactive it is. Reactivity has to do with the amount of valence electrons, electrons in its outermost layer; the least it has, the more likely it is to combine with other elements, since it wants to fill the outermost layer.

Energy is quantified in Joules: $1W = \frac{1J}{s}$. The first law of thermodynamics says that energy cannot be created or destroyed, just transformed. The second law of thermodynamics says that it's impossible to achieve 100% efficiency, because there is lost energy in every process in the form of heat.
Systems are influenced by the input and output. When the input is equal to the output, there is what we call **steady state**; otherwise, a feedback loop is created. Feedback loops can be positive (the result of the change makes the change occur faster) or negative (the result of the change makes the change occur more slowly). Eventually, a negative feedback loop will lead to steady state.

2.2 Water Pollution

Water is a good solvent, which causes it to be easily polluted. Water also has a dipole structure, so it is more positive on its hydrogen ends and more negative in its oxygen ends. This causes hydrogen bonding. Nearby water molecules are attracted to each other by hydrogen bonds. On earth, only around 3.5% of

water is drinkable by humans; we use desalination technologies to make saline water potable, but it is expensive.
The soil can keep moisture because of capillary condensation. This is because, as opposed to open surfaces, the saturation vapour pressure is significantly reduced.
Hydrologic cycle: evaporation and evapotranspiration → condensation → precipitation → runoff → percolation → back to the beginning
It is worth pointing out that evaporation refers to the process of liquid water in the ocean, river, and lake surfaces becoming water vapour; evapotranspiration is the transpiration when the soil water enters plant roots and finally exits into the air. Water can be affected by several kinds of pollutants:

- Physical
  - Turbidity:
    Refers to the relative clarity of water. It can affect it aesthetically, make it not suitable for consumption, harm aquatic animals, and prevent plants from photosynthetising.
  - Taste and Odour
  - Temperature:
    Can have an effect on aquatic life, e.g. setting a cooling tower powered by a local river (power plant cooling.)
- Chemical
  - Oxygen Demanding Waste:
    Can lead to Dissolved Oxygen depletion, which can affect living things in the body of water. It is made up of organic matter such as proteins, carbohydrates, fats, etc. The Biochemical Oxygen Demand (BOD) is the quantity of oxygen required by microorganisms to oxidise organic wastes aerobically into stable products. It helps us determine the strength of oxygen demanding capacity. Chemical Oxygen Demand (COD) is the amount of oxygen required to chemically oxidise the waste. It can be completed in a few hours, it cannot provide information of the biodegradation rate, it uses strong oxidants, and the ratio of BOD/COD tells us the treatability of waste by biological means.
  - Heavy metals:
    Can have toxic effects
  - Pesticides, volatile organic chemicals:
    Can also have toxic effects
  - Nutrients:
    Algal Bloom, which leads to DO depletion and aquatic life dying. Eutrophication is an oversupply of nutrients such as N and P, which lead to the overgrowth of aquatic life. The opposite of it is oligotrophication. The limiting nutrients for algae are N and P. If $N/P > 10$,

P is the limiting one. If this ratio is smaller than ten, N is the limiting nutrient.
N and P can enter water through fertiliser, detergents, direct sewage discharge and industrial waste, water erotion, and natural hidrogen fixation, and well as rain.
Algae in eutrophic lakes are deprived of light. When algae lack sufficient light, they stop creating oxygen and begin to consume it. Furthermore, when huge blooms of algae die, bacterial decomposers lower oxygen levels even further.

- Biological
  - Pathogen:
    Disease-causing organisms
  - Virus, bacteria, protozoa, helminthes

As seen above, Dissolved Oxygen (DO) is extremely important; since the oxygen in water cannot be used by organisms, the free oxygen is the one that will perform important functions: it is a key water quality measure for bodies of water, aquatic organisms need it to survive, and it is needed for biological treatment processes (bacterial decomposers). However, DO is poorly soluble in water (around $9mg/L$) at $20C$. Solubility depends on two factors: the higher the temperature or the salinity, the lower the solubility. Henry's Law can allow us to calculate the saturated DO value in water: $DO_S = K_H P_{O2}$, where K_H is the Henry's Law Coefficient of Oxygen and P_{O2} is the partial pressure.

2.3 Water Treatment

There are three types of water treatment systems:

1. Drinking Water System:
   It has three steps: collection, treatment (to kill pathogens and remove pollutants), and distribution.
   The treatment has three targets: making the water pathogen free, chemically safe, and free from turbidity, colour, odour, and taste. When it comes to surface water, it tends to have a lot of suspended soils and biological matter, so the purpose is to disinfect it and remove particles. Ground water, on the other hand, is high in dissolved solutes and may contain volatile organic compounds, so the purpose of treatment is to soften this water and disinfect it. Surface water treatment goes through the following steps:
   (a) Screening and grit removal
   (b) Primary and Secondary Sedimentation
   (c) Sludge Processing

(d) Rapid Mixing and Coagulation:
Coagulation–flocculation is a chemical water treatment technique typically applied prior to sedimentation and filtration to enhance the ability of a treatment process to remove particles. Coagulation netrualises charges and forms a gelatinous mass to trap particles. Flocculation is gentle stirring to encourage the particles to agglomerate into masses large enough to settle or be filtered out. A common coagulant is alum. When the alum is mixed with water, it decreases the pH value of water.

(e) Flocculation

(f) Filtration:
The goal here is to remove small particles, including pathogens. Rapid filtration involves sand, coal particles, ...

(g) Disinfection:
It aims to kill pathogens in water (primary disinfection) and prevent pathogen regrowth in water (secondary; found in water distribution systems). Some common disinfectants are free chlorine, chlorine gas, and hypochlorite salts.

(h) Fluoride dosing

Groundwater Treatment undergoes the following steps:

(a) Aeration
(b) Lime/soda ash dosing
(c) Coagulation
(d) Flocculation
(e) Sedimentation
(f) Recarbonation
(g) Filtration
(h) Sludge Processing
(i) Disinfection

2. Wastewater System

3. Storm Water System

About one third of Hong Kong's land is designated as water gathering grounds, where surface runoff is collected for storage. The water resources in Hong Kong come 18% from rainwater, 59% imported from Mainland China, and 23% come from seawater (used for flushing). The government's goal is to diversify water resources to be better prepared for uncertainties. Some measures being considered are desalination (still under construction and presents significant environmental impact), recycled water, and osmosis.

2.4 Wastewater Treatment

Wastewater can come from:

- Domestic or municipal wastewater:
  Origin are residences, institutions, commercial facilities...
- Industrial wastewater
- Infiltration and inflow:
  Water that eventually enters the sewer from leaking pipes, submerged manholes, groundwater infiltration, etc
- Stormwater

The treatment of this water aims to meet regulatory limits that protect consumers and the environment. Wastewater is constituted by more than 99.9% water. Other major components are suspended solids, organic matters and pathogens. Some common treatment methods are:

- Physical Treatment:
  Removal of pollutants through physical forces, such as filtration and sedimentation. This is mainly used for the removal of suspended solids.
- Chemical Treatment:
  Chemicals are added to convert or destroy contaminants. Some examples are coagulation-flocculation for solids, disinfection for pathogens, chemical precipitation for phosphorus.
- Biological Treatment:
  Employing microorganisms to convert or destroy contaminants. It is also used to remove nutrients such as nitrogen and phosphorus. Some examples are activated sludge process, trickling filter, and membrane bioreactor.

There are three levels of wastewater treatment:

1. Primary Treatment:
   Physical removal of part of the suspended solids, usually through sedimentation. Other common techniques are grit chambers and screens. It takes away around thirty percent of BOD and 60 percent of SS. In enhanced primary treatment, chemical treatment increases the amount of solids removed; techniques such as coagulation and flocculation are employed.
2. Secondary Treatment:
   Biological Treatment for degradation of organic matter and solids. It removes around 90 percent of BOD and 90 percent of SS. It is carried out in a biological reactors with techniques such as activated sludge process.

2.5 Air Pollution

Air pollutants can be primary (directly emitted from the source due to combustion or evaporation) or secondary (formed from reactions between existant pollutants under certain conditions, for example ground level ozone). Some common ones are:

- Combustion of methane under ideal condition (complete combustion). It releases CO_2
- Incomplete combustion. Releases CO_2 as well as traces of CO and HC
- Nitrogen reacts with oxygen at high temperature and produces NO_x
- Impurities in fuel, which lead to $CO_2, HC, NO_x, SO_x, Pb, Hg, etc$

Photochemical Smog is formed of VOCs, NO_x, and sunlight. VOCs are Volatile Organic Compounds, chemicals that contain organic carbons. Their source are the evaporation of solvents, fuels, and partially burned fuels. They can cause cancer in people.

Mobile sources (such as cars, trucks) account for most of CO and half of NO_x pollution. Stationary sources (chemical manufacturing, power plants, and others) are the creators of most of $SO_x, Hg, VOCs$ and half of NO_x emmissions.

Some criteria pollutants:

1. Carbon Monoxide:
   Source: incomplete combustion fuel. Most of it comes from transportation. It can reduce the blood's ability to carry oxygen; it binds with hemoglobin.

2. Lead (Pb):
   It mainly comes from leaded gasoline. It may lead to brain damage and reduced intelligence in the development of children.

3. Oxides of Nitrogen (NO_x):
   Only two nitrogen oxides are important air pollutants: NO and NO_2. Their sources can be thermal (reaction of nitrogen and oxygen at high temperatures) or fuel (formed by the oxydation of nitrogen compounds in fuel).
   NO is a colourless gas with no known adverse health effects at typical atmospheric conditions. It is the precursor of ground-level ozone and photochemical smog, and also prone to be oxidised to $NO_{2]}$.
   NO_2 is a reddish brown gas that can lead to respiratory damage, acid rain, eutrophication

4. Sulfur Oxides SO_x:
   It refers to SO_2 and SO_3. It mostly comes from the combustion of fossil fuels that contain sulfur. These compounts can easily lead to acid rain (rainfall with lower pH), damage plants, corrode building materials, and affect human health, since it is highly soluble in water (which affects the upper respiratory system) and it may combine with particulates to reach deeper into the lungs.

5. Ground-level Ozone (O_3):
   It is a secondary pollutant that is produced when NO_x, VOCs and sunlight come together. It is the most abundant photochemical oxidant. Its effects are to damage plants and create strong respiratory issues.

6. Particulate Matter PM:
   Fine solids or liquids suspended in the atmosphere. They are also called aerosols and include dusts, fumes, fog, and smog. Primary PM is emitted directly into the atmosphere from the source and remains unaltered whereas secondary PM is formed by primary PM reacting with gases or moisture in the atmosphere. The distribution of particle size is important to determine the behaviour of PM in the respiratory tract.

When it comes to motor vehicle pollutants,

- CO:
  Vehicles emmit around 75 percent of it.

- NO_x:
  Vehicles emmit around 40 to 50 percent of it. Vehicles worldwide are fitted with catalytic converters so that NO and HC are converted into water, nitrogen, and less harmful gases.

- Hydrocarbon HC:
  Vehicles emmit around 40 to 50 percent of it.

- Lesser amounts of particulates and SO_x

- Lead (Only if leaded gasoline is used)

When it comes to stationary sources, power plants contribute to most of SO_x and a significant portion of NO_x and particulates. Some measures to control it are:

- Pre-combustion:
  Reduces the emission potential of fuel (fuels with less S and N)

- Combustion control:
  Improves combustion itself

- Post-combustion control:
  Removes pollutants from stack gas through selective catalytic reduction. A common way is to inject ammonia to boiler flue gas to reduce NO_x. Particulate removals are another common mechanism used; there are gravity settlers, cyclones, electrostatic precipitators, and others.

2.6 Climate Change

Atmosphere of the Earth:

- Thermosphere:
  Absorption of solar energy by atomic oxygen
- Mesosphere:
  Good air mixing
- Stratosphere:
  Dry air. UV absorption by ozone which leads to T inversion
- Troposphere:
  80% of mass, almost all water, clouds. The temperature decreases are 5 to 7 C per km.

Most of the atmosphere is made up of oxygen and nitrogen. The greenhouse gases are carbon dioxide, methane, and nitrous oxide, water vapour, among others. Ozone is the gas in charge of UV protection.
The greenhouse effect:
The greenhouse effect is the way in which heat is trapped close to Earth's surface by "greenhouse gases." These heat-trapping gases can be thought of as a blanket wrapped around Earth, keeping the planet toastier than it would be without them.
The carbon cycle:
Carbon is an essential element for all life forms on Earth. Whether these life forms take in carbon to help manufacture food or release carbon as part of respiration, the intake and output of carbon is a component of all plant and animal life. Carbon is in a constant state of movement from place to place. It is stored in what are known as reservoirs, and it moves between these reservoirs through a variety of processes, including photosynthesis, burning fossil fuels, and simply releasing breath from the lungs. The movement of carbon from reservoir to reservoir is known as the carbon cycle.
Carbon can be stored in a variety of reservoirs, including plants and animals, which is why they are considered carbon life forms. Carbon is used by plants to build leaves and stems, which are then digested by animals and used for cellular growth. In the atmosphere, carbon is stored in the form of gases, such as carbon dioxide. It is also stored in oceans, captured by many types of marine organisms. Some organisms, such as clams or coral, use the carbon to form shells and skeletons. Most of the carbon on the planet is contained within rocks, minerals, and other sediment buried beneath the surface of the planet.
Because Earth is a closed system, the amount of carbon on the planet never changes. However, the amount of carbon in a specific reservoir can change over time as carbon moves from one reservoir to another. For example, some carbon in the atmosphere might be captured by plants to make food during photosynthesis. This carbon can then be ingested and stored in animals that eat the plants. When the animals die, they decompose, and their remains become sediment, trapping the stored carbon in layers that eventually turn into rock or minerals. Some of this sediment might form fossil fuels, such as coal, oil, or natural gas, which release carbon back into the atmosphere when the fuel is

burned.
The carbon cycle is vital to life on Earth. Nature tends to keep carbon levels balanced, meaning that the amount of carbon naturally released from reservoirs is equal to the amount that is naturally absorbed by reservoirs. Maintaining this carbon balance allows the planet to remain hospitable for life. Scientists believe that humans have upset this balance by burning fossil fuels, which has added more carbon to the atmosphere than usual and led to climate change and global warming

Global Warming and climate change have several dangerous major effects. One of which is ocean acidification. When there is a higher concentration of CO_2 in the water, there is more carbonic acid, which decreases the pH in the ocean. Lower pH makes it more difficult to form $CaCO_3$, which is a material in shells and other hard parts of marine organisms. Some consequences of this are increased potential for dissolving shells, affects coral reefs, and affects the marine food chain.
Futheremore, there is ozone depletion. In the troposphere, ozone is an air pollutant; however, in the stratosphere, it absorbs UV light, which protects human health. Ozone can be descructed by Cl and Br radicals. This creates deep issues.

3 Structural Engineering

3.1 Introduction to Structural Engineering

A structure is an assemblage of components so that the structure can withstand loads that are acting or will act on them. Structural Engineering focuses on identifying such loads, selecting the appropriate materials to build the structure, designing the dimensions of the members, among other features.
Some common structures are:

- Building: provides shelter above ground
- Bridge: provides means of traversing over a site
- Tower: supports transmission lines
- Tunnel: provides means of traversing under a site
- Retaining walls: retain earth
- Containments: provide means of material storage
- Platforms: provide a platform for material or machinery storage

Structures can also be categorised according to their type:

- Truss: Members are connected at their ends by frictionless pins

- Beam: Members are straight beams connected end to end
- Arch: Members are curved beams
- Frame: Members rigidly or semi–rigidly connected
- Cable: For example, cable–stayed bridges

Structures are connected to the ground at certain points called supports. When the structure experiences any forces, the supports develop forces, called reactions, that oppose the tendency of the structure to move. Initially, a structure can be unstable if either there are not enough supports to provide reactions that satisfy equillibrium conditions or due to an inadequate arrangement of its members.
There are two ways materials can fail, depending on their composition:

1. Brittle Behaviour: The relationship between stress and strain is fully linear, until the peak stress is reached. When this happens, the material just fractures and cannot carry any load. Undesirable, since it can produce catastrophic failure.

2. Ductile Behaviour: Initially linear up to a stress value named *yield stress*. When this is reached, the stress will remain constant and the material will stiffen. The peak stress will be considerably higher than the yield stress, and once the peak is reacherrd, the material will fail. In practice, the maximum allowable strain is limited to a multiple of the yield strain (often of the order of 5). Ductile behaviour is more desirable since a member will not lose its load capacity when yielding occurs (although it cannot carry additional loading). This allows people to notice the issue and address it before an accident takes place.

Buckling failure is a phenomenon associated with long slender members subjected to compressive loaading. As the axial loading is increased, the member remains straight until a critical load value is reached; when this happens, the member adopts a deflected configuration similar to inelastic action. If the member is flexible, the critical loading is generally less than the axial compressive strength based on yielding.
Structures must be designed so that they don't fail or deform excessively under the loads they may experience. It is thus important to predict what these loads might be with accuracy. Some sources of loadings are:

- Interaction with the environment, which includes gravity, wind, earthquake, water, earth pressure, and thermal variations
- Function related to the structure, for instance gravity-type load for bridges or an uniformly distributed gravity floor load in the case of most buildings.
- Construction of the structure. The construction loading will depend on the process followed to assemble the structure. Detailed forced analyses at various stages of the construction are required for complex structures.

Long-term loads (such as the weight of the structure itself) are called dead loads. Loads whose magnitude or location are subject to change are called temporary loads. Temporary loads can be impulsive (rapid increase over short time and then dropoff), cyclic (alternates in direction and the period may change for successive cycles), or quasi-static (slow build up, eventually reaching a steady state).

3.2 Theory of Sustainable Engineering

Sustainable Construction has three dimensions:

1. Social Sustainability:
   Depends on satisfaction, employment, regional spin-offs...
2. Economic Sustainability:
   Maintenance, mobility costs, risk management, life cycle costs, flexible use, reliability...
3. Ecological Sustainability:
   It has three objectives of protection, the ecosystem (waste avoidance, emissions, pollutants, land use), human health (pollutants, sick building syndrome, toxicity of building materials), and natural resources (resource efficience in terms of materials and recycling economy).

Structural design has different requirements concerning material technology, manufacturing, assembly and erection, disposal... Optimisation must be applied to all of these aspects while guaranteeing that the requirements of sustainable development can be met.
Sustainable design of structures should consider the following principles of sustainability:

- Design for Safety
- Design for Serviceability
- Design for Adaptability
- Design for Structural Efficiency
- Design for Durability and Minimal Maintenance and Life-cycle Costs
- Design for Risk Reduction and Value Protection
- Design for Aesthetics
- Design for Minimal Ecological Footprint

Structural Efficiency in particular embodies the ideas of a correct choice of static scheme (influences the life cycle behaviour of the structure and must be clarified from the beginning of the design process), appropriate use of construction materials/structural solutions, and the concept of structural optimisation (helps the designer find the most suitable shapes, a better exploitation of construction materials, and reduces structural weight).

3.3 Structural Resilience and Sustainability to Natural Hazards

The three pillars of sustainable development are the social, the environment, and the economic. The intersection of the social and the envionrment is bearability. The intersection of the social and the economic is equitability. Lastly, the intersection of the environment and the economic is viability.
Hazards have two features that affect how deep their impact is. Firstly, the intensity of the hazard significantly exceeding the value assumed for the ultimate limite state (ULS) design. Secondly, events being large scale, with multiple stakeholders (lives, structures, industries) simultaneously at risk of loss — synchronous failure!

In order to reduce disaster risk, the design must include retrofitting before the disaster and possibilities of reconstruction after it happens.

Structural Resilience is the ability to rapidly resume the usage of structures following a shock incident or event. It requires appropriate design for life safety and environmental protection and appropriate damage limitation design to reduce the needs for repairs or reconstruction after a shock event. It is also necessary to have a design that facilitates both maintenance and recovery works, as well as the spectrum of severity of potential extreme events. Ancient Chinese timber pagodas have excellent seismic performance because of their lateral flexibility (provides seismic isolation). Connections in these structures allowed degrees of freedom such that structural deformations could be attained without damaging the material during the earthquake. The distributed bracket sets and mortise-tenon joints had good energy dissipation capabilities.

3.4 Life-cycle Assessment

Life-cycle Assessment (LCA) is a methodology to determine the environmental aspects and potential impacts throughout a product's life, from raw material acquisition through production, use, and disposal. Some common metrics used are:

- Global warming potential (kg CO_2 equivalent). Possible increase in the temperature of Earth and her oceans.
- Acidification (moles of H^+ equivalent). Increase in acidity of bodies of water.
- Eutrophication (kg of N or PO_4 equivalent). Excess nutrients in water bodies leading to oxygen depletion and algae growth.
- Stratospheric ozone depletion (kg CFC-11 equivalent). Reduction of the ozone later
- Photochemical ozone creation (kg NOx or C_2H_6 equivalent). Air pollution affecting human health.

3.5 Green Buildings

Some commonly used strategies are:

- Solar water heating
- Reducing air leakage through the building envelope
- Effective window placement
- Onsite generation of wind and/or solar power
- Self-sensing and self-healing concrete
- Smart temperature and airflow control over the HVAC system
- Photovoltaic panels
- Thermal energy storage systems

4 Geotechnical Engineering

4.1 Introduction to Geotechnical Engineering

The cycle of rocks and soils * Geotechnical engineering focuses on the engineering behaviour of earth materials and how they respond to external stimuli. The biggest challenge faced by geotechnical engineers nowadays is the *grand sustainability challenge*: stabilising the currently disruptive relationship between Earth's two most complex systems, human culture and the living world. There are four ecosystems: the atmosphere (air), hydrosphere (aquatic medium and water), the lithosphere (land and terrestrial medium), and the biosphere (plants and animals excluding people). In addition to those, there is a new term: geomicrobiosphere.
Carbon offsettings are a common way to aim for sustainable development: it is reducing/avoiding greenhouse gas emissions or removing carbon dioxide from the atmosphere to make up for emissions elsewhere. It also consists of shifting towards renewable energy. Some of the techniques employed by geotechnical engineers are:

- CCUS: Carbon Capture, Utilisation, and Storage
- Shallow Geothermal Energy (in urban areas, ground source heat pumps).
- EGS: Enhanced Geothermal Systems, also known as deep geothermal
- Unconventional geo-resource tapping (for instance, shale gas)
- Offshore wind farm
- Geological disposal of nuclear waste

- Modern waste management system
- Preventing geoenvironmental hazards (such as using discharge pipelines for high water levels due to inadequate drainage)

4.2 Modern Waste Containment System

Landfills are isolated systems. Before we talk about how they are constructed, we need to understand the concept of groundwater. Water beneath the ground exists as ground water and soil moisture. Groundwater occurs in the area where water has filled all the pore spaces. Soil moisture is above the saturated zone, in an area where the pores are filled with both water and air. The boundary between the saturated and unsaturated zones is the water table. The depth of this table will vary depending on precipitation and climate. It is zero in marshes and swamps, whereas it is hundreds of meters in some desert areas. At perennial lakes and streams, it is above the land surface. The water table tends to rise and fall with the surface typology.
When constructing a landfill, we need to consider

- Haul distance
- Location restrictions (airports, flood plains, wetlands, seismic impact zones...)
- Available land area
- Site access
- Soil conditions and topography
- Climatologic conditions
- Surface water hydrology
- Geologic and hydrogeologic conditions
- Local environment conditions
- Ultimate use for completed landfills

Leachate is generated from liquid squeezed out of the waste (primary leachate) and by water that percolates through the waste (secondary leachate). It consists of a carrier liquid (solvent) and dissolved substances (solutes).
Landfills should be able to prevent groundwater pollution, collect leachate, permit gas venting, and provide for groundwater and gas monitoring. Some core components are

- Bottom and lateral side liner system:
  The liner system is the single most important element of a landfill. It is a barrier against the advective (hydraulic) and diffusive transport of leachate solutes. It isolates the waste and prevents contamination of the

surrounding soil and groundwater. The liner system has multiple barriers and drainage layers. The barriers may contain a geomembrane, a compacted clay layer, a geosynthetic clay layer, or a combination of all of them.

- Leachate collection and removal system:
  Prevents the buildup of leachate head on the liner and it drains it to a treatment plant.

- Gas collection and control system:
  Landfills generate large quantities of gas, namely CH_4 and CO_2. This system collects the gas during decomposition of organic components. The gas can be used to produce energy or flared under controlled conditions.

- Final cover system:
  It consists of a barrier and drainage layers. It acts as a hydraulic barrier to minimise water infiltration into the landfill to reduce the amount of leachate generated after closure.

- Stormwater management system

- Groundwater monitoring system

- Gas monitoring system

4.3 Chemical and Bio-mediated Processes

Geosystems subject to extreme or changing environments will have additional non-mechanical strains and the mechanical properties of its materials will be affected. Material strength may be altered too.

4.3.1 Chemical Erosion

Chemical degradation is the processes of gradual loss of the engineering qualities of a material. Resilience Engineering is the objective to build infrastructure able to withstand long-term persistent environmental exposure without suffering complete failure and being able to at least restore its critical functions.
Performance assessment provides a proof of satisfactory response to a number of scenarios of local failures of the system during the entire service life. It is absolutely necessary for complex and large infrastructures, including nuclear waste repositories, carbon sequestration facilities, and unconventional energy facilities. PA is normally done through mathematical modeling to simulate the long-term behaviour of engineered structures.
Degradation, the gradual process of loss of a desired property of a material (strength, permeability, stiffness) generated by the environmental processess of the surroundings need to be assessed. In so doing, it can be identified and tackled appropriately. Some examples of non-mechanical degradation processes are stress corrosion, historic building stone dissolution, and acid rain-assisted slope

instability.

4.3.2 Bio-mediated Geotechnics

Considering the soil as a living ecosystem offers the potential for innovative and sustainable solutions to geotechnical problems. Bio-mediated implies utilising geochemical reactions regulated by subsurface microbiology, such as mineral precipitation, gas generation, and biofilm formation. Some challenges that bio-mediated ground modification might face include upscaling the processes from the laboratory to the field, in-situ monitoring of reactions, reaction products and properties, management of treatment by-products, developing integrated geotechnical and biogeochemical models, and establishing the durability and longevity/reversability of the process.
Microbes are ubiquitous in soils at surprisingly high concentrations. They have a permanent biological presence in soil, which makes many engineers to consider soil as a living ecosystem rather than an inert construction material.
Multicellular organisms, such as ants and worms, alter soils through mechanical and biological processes. They are effective at soil grading, densification, and creating preferential flow paths (macropores) in soil. They also adapt and optimise their efforts considering capillary forces at particle contacts. Worm excretion can strengthen soil along the tunnelling paths.
Unicellular microbial organisms, which consist primarily of bacteria, generally do not affect soil properties directly; rather, they locally exploit geochemical processes, which in turn affect soil properties. Enzyme activity controls reaction rates.
There are two primary strategies for a bio-mediated soil improvement, the bioaugmentation (microbes injected into the soil) and the biostimulation (where natural microbes are stimulated).
Bio-mediated chemical processes have the potential to modify:

- Physical properties, such as density, gradation, porosity, saturation
- Conduction properties, such as hydraulic, electrical, thermal
- Mechanical properties, such as cementation, stiffness, dilation, compressibility
- Chemical properties, such as reactivity, buffering, cation exchange capacity

Microbially Induced Calcite Precipitation (MICP) is the primary focus of research in bio-geotechnical engineering to date. It is an environmentally friendly, ecological technique. It consists of bio-induced hydrolisis, followed by the desired calcite precipitation. This process can effectively increase compressive strength, shear strength, tensile strength, and decrease permeability. It is however influenced by factors such as bacteria type, soil type, chemical concentration, injection rate, injection frequency, and confining conditions during treatment.
Some challenges faced by MICP in field implementation are:

- Surface heterogeneity
- Treatment schemes for uniform improvement
- Construction, operation, and maintenance
- Service life (50 or more year time frame)
- Performance monitoring
- Modelling of biogeochemical treatment process
- Feasibility for different applications

5 Construction Project Management

5.1 Introduction of Construction Industrialisation

Industrialised construction is a paradigm for smart and sustainable city construction considering the synergy among assets, processes, information, energy, and stakeholders.

5.2 Construction as a Manufacturing Process

5.3 Mass Customisation with Project Management

5.4 Sustainable Development of the Built Environment

A Exam Key Points

A.1 Transportation Engineering

- How does traffic congestion influence our society and economy?
  Traffic congestion occurs when demand exceeds supply when it comes to transportation. The saturation of transportation services can shape the metropolitan area by altering the places where people decide to leave (usually avoiding congested areas) and deciding where they are willing to go for leisure or for work (not likely to subject themselves to traffic). In terms of economy, traffic congestion influences the mode of transportation people choose, as well as the amount and distance of trips they make. Traffic congestion will affect the location of residence and range of provision of goods and services. People tend to avoid living in places that are subjected to frequent congestion. Furthermore, congestion has been proven to affect the environment negatively, which contributes to deterring people from setting home in such areas.
  When it comes to economy, traffic congestion increases the costs in terms of time and money for people to travel from one place to the other. This means firstly that users are more likely to utilise public transportation or

alternative means to move and that they are less likely to want to travel far from home, be it for leisure or work. This affects the local economy and the overall shape of the metropolitan area.

- What measures can the government take to reduce traffic congestion?
  Some measures the government can take to tackle this issue are ramp metering, subsidising public transportation, high-occupancy lanes, traffic signal control, variable speed limits, and tolling.

- What are the benefits of subsidising public transportation?
  It alleviates traffic congestion, by incentivising people to use it in favour of private vehicles. Furthermore, it has positive effects on the environment, since it decreases the total amount of fuel consumed per capita (as opposed to individuals using private vehicles).

- Why do some governments (like the ones in Hong Kong and Singapore) impose a fuel tax?
  Fuel taxes are mainly implemented as a measure to protect the environment. Its aim is to incetivise users to use less fuel (since it gets more expensive) and use greener transportation methods, such as cycling or public transport. It is also a measure for governments to recover the capital they invested in creating and/or maintaining existing transport infrastructure.

- Explain how to build up a linear regression model and how to estimate its coefficients, including the slope and the intercept.
  Our basic formula will be $y = \beta_0 + \beta_1 x + \epsilon$ Our job is to find appropriate values for β, considering β_0 is the y-intercept and β_1 is the slope. If the slope is larger than zero, we say there is a positive relationship between x and y.
  The following formulae allow us to obtain the desired results:
  $$\hat{\beta_1} = \frac{\sum_{i=1}^{n}(Y_i X_i) - N\bar{X}\bar{Y}}{\sum_{i=1}^{n}(X_i)^2 - N(\bar{X})^2}$$
  $$\hat{\beta_0} = \bar{Y} - \hat{\beta_1}\bar{X}$$
  Where $\bar{X}$ and $\bar{Y}$ are the means of X and Y respectively.

A.2 Environmental Engineering

- Please describe the hydrologic cycle in your own words. Mainly explain the five processes.

  1. Evaporation and evapotranspiration: Here, the water evaporates and goes to the atmosphere. Evaporation refers to the process of liquid water in the ocean, river, and lake surfaces becoming water vapour; evapotranspiration is the transpiration when the soil water enters plant roots and finally exits into the air.

2. Condensation: Condensation is the process by which water vapor in the air is changed into liquid water; it's the opposite of evaporation. Condensation is crucial to the water cycle because it is responsible for the formation of clouds.
3. Precipitation
4. Runoff: is precipitation that does not soak into the soil but instead moves on the Earth's surface toward streams.
5. Percolation: is the movement of water through the soil itself. Finally, as the water percolates into the deeper layers of the soil, it reaches ground water, which is water below the surface. The upper surface of this underground water is called the "water table".

- What is eutrophication? List human activities that cause eutrophication. How can eutrophication be controlled?
  Eutrophication is an oversupply of nutrients, mainly N and P in bodies of water, which lead to the overgrowth of some aquatic life (in a phenomenon known as algal bloom). In these types of water bodies, algae are deprived of light. When they don't have enough light, they stop creating oxygen and begin to consume it, which kills a lot of algae. This triggers a positive feedback loop, since decomposer bacteriae will further lower the oxygen levels.
  N and P can enter bodies of water through fertilisers, direct sewage discharge, polluted rain, as well as industrial waste.
  The ways we can control eutrophicaton is by controlling the algae's limiting nutrient (usually P) which prevents them from expanding and triggering algae bloom.

- What is water hardness? How can we reduce water hardness? Hard water is water with a high mineral content. The simple definition of water hardness is the amount of dissolved calcium and magnesium in the water. It can be reduced through diluting the hard water with some type of soft water. That is RO water, rainwater, deionized water. If using rain water, do not collect right away, since the first part of the rain will be full of pollutants. RO water can be expensive.

- List six criteria pollutants. Why is PM2.5 dangerous to human heath?

1. Carbon Monoxide
2. Lead (Pb)
3. Oxides of nitrogen (NO_x)
4. Sulfur Oxides (SO_x)
5. Ground-level Ozone (O_3)
6. Particulate Matter

PM2.5 can be dangerous to human health because they can enter the respiratory tract. Since they are small, they can reach sensitive areas in the inferior airways, even alveoli!

- What is the greenhouse effect? List four greenhouse gases and three effects of global warming. How can we control global warming?
  The greenhouse effect is the way in which heat is trapped close to Earth's surface by "greenhouse gases." These heat-trapping gases can be thought of as a blanket wrapped around Earth, keeping the planet toastier than it would be without them. Some greenhouse gases are:

  1. Carbon Dioxide (CO_2)
  2. Methane (CH_4)
  3. Nitrous Oxide (N_2O)
  4. Water Vapour (H_2O)

  We can control global warming by reducing our emmission of greenhouse gases through the usage of alternative energy/less fossil fuels.

- How does an increased atmosphere CO_2 content cause ocean acidification? What is the effect of ocean acidification?
  When there is a higher concentration of CO_2 in the water, there is more carbonic acid, which decreases the pH in the ocean. Lower pH makes it more difficult to form $CaCO_3$, which is a material in shells and other hard parts of marine organisms. Some consequences of this are increased potential for dissolving shells, affects coral reefs, and affects the marine food chain.

A.3 Structural Engineering

- What are the structural types classified according to their functions? Give three examples.
  - Building: provides shelter above ground
  - Bridge: provides means of traversing over a site
  - Tower: supports transmission lines
  - Tunnel: provides means of traversing under a site
  - Retaining walls: retain earth
  - Containments: provide means of material storage
  - Platforms: provide a platform for material or machinery storage

- What are the three dimensions of sustainability in sustainable construction?
  Ecological sustainability, social sustainability, and economical sustainability.

- What are the principles of sustainability which should be considered and applied in the sustainable design of structures? Give three examples.
  Some of the principles of sustainability that should be considered and applied in the sustainbale design of structures are:
  - Design for Safety
  - Design for Serviceability
  - Design for Adaptability
  - Design for Structural Efficiency
  - Design for Durability and Minimal Maintenance and Life-cycle Costs
  - Design for Risk Reduction and Value Protection
  - Design for Aesthetics
  - Design for Minimal Ecological Footprint
- What are the pillars of sustainable development?
  The pillars of sustainable development are the Economic, the Social, and the Environmental. These three will intersect with each other in areas like equitability, viability, bearability, and ultimately, they all generate sustainability.
- What are the key features of natural hazards leading to disasters?
  The two key features of natural hazards leading to disasters are the intensity of the hazard exceeding the value assumed for the Ultimate Limite State when designing the structure and the events being large scale, which means that many lives, structures, and industries are simultaneously threatened by the hazard – which can lead to simultaneous failure.
- What is structural resilience? What are the requirements of structural resilience? Give three examples.
  Structural resilience is the capacity of using structures rapidly after the occurrence of a hazard or a shock event. Three of the requirements of structural resilience are:
  Design to facilitate maintenance and recovery works
  Design that supports efficient damange limitation, which reduces the possible needs of repair reconstruction after a hazardous event.
  Consider all the aspects of preparation and recovery for a hazard event.
- Why did ancient Chinese timber pagodas show excellent performance in the past earthquakes?
  Their excellent resilience in the face of earthqualkes is due to their lateral flexibility (which increases the structure's recoverable seismic isolation.) Furthermore, the connections in these pagodas have cerain degrees of freedom – this allows for the structure to move to a certain extent without permanently deforming or damaging the material. Additionally, the distributed bracket sets and mortise-tenon joints have good capabilities to disperse the energy from the earthquakes.

- What is LCA? Give three examples of LCA metrics and their impact.
  LCA stands for Life Cycle Assessment, a methodology and framework to evaluate a product's impact to the environment throughout its entire lifetime: from being a raw material and becoming manufactured all the way to the point in which the material is disposed or recycled. Some examples of LCA metrics are:

  - Acidification, which measures how the product can affect the acidity of water bodies, and thus affecting aquatic life. This measures the moles of H+ equivalent.
  - Global Warming Potential, which measures the potential the product have to increase the temperature of Earth's atmosphere/oceans. This measures kg of CO2 equivalent.
  - Eutrophication, which measures the potential for the product to generate an excess of nutrients in water bodies – thus generating negative effects such as algae bloom, oxygen depletion, and others. This measures the kg of N or PO_4 equivalent

- What are climate-change adaptable strategies in green buildings? Give three examples.
  These are strategies that try to minimise the polluting effects that buildings may have. Some examples are

  - Solar water heating
  - Reducing air leakage through the building envelope
  - Effective window placement
  - Onsite generation of wind and/or solar power
  - Self-sensing and self-healing concrete
  - Smart temperature and airflow control over the HVAC system
  - Photovoltaic panels
  - Thermal energy storage systems

A.4 Geotechnical Engineering

- What is sustainable development?
  Sustainability is about stabilising the currently disruptive relationship between Earth's two most complex systems, human culture and the living world. Sustainable development is the collective responsibility to advance and strengthen the interdependent and mutually reinforcing pillars of sustainable development – economic development, social development and environmental protection – at the local, national, regional and global levels

- What can geotechnical engineers do for adaptation to Climate Change?
  For adaptation to climate change, they can use techniques such as:

  - CCUS: Carbon Capture, Utilisation, and Storage
  - Shallow Geothermal Energy (in urban areas, ground source heat pumps).
  - EGS: Enhanced Geothermal Systems, also known as deep geothermal
  - Unconventional geo-resource tapping (for instance, shale gas)
  - Offshore wind farm
  - Geological disposal of nuclear waste
  - Modern waste management system
  - Preventing geoenvironmental hazards (such as using discharge pipelines for high water levels due to inadequate drainage)

- How do soils enter the rock cycle?
  In the weathering process, rocks of any type will be broken down by wind, water and alternating freezing and thawing to form gravel, sand, silt and clay. Surface rocks are reduced to ever-smaller size. The resulting sediments are the basis for the eventual formation of soil.

- Why understanding of geomaterials is important for a civil engineering project?
  Because

- What is design principle of modern landfills?
  Landfills should be able to prevent groundwater pollution, collect leachate, permit gas venting, and provide for groundwater and gas monitoring. Some core components are

  - Bottom and lateral side liner system:
    The liner system is the single most important element of a landfill. It is a barrier against the advective (hydraulic) and diffusive transport of leachate solutes. It isolates the waste and prevents contamination of the surrounding soil and groundwater. The liner system has multiple barriers and drainage layers. The barriers may contain a geomembrane, a compacted clay layer, a geosynthetic clay layer, or a combination of all of them.
  - Leachate collection and removal system:
    Prevents the buildup of leachate head on the liner and it drains it to a treatment plant.
  - Gas collection and control system:
    Landfills generate large quantities of gas, namely CH_4 and CO_2. This system collects the gas during decomposition of organic components. The gas can be used to produce energy or flared under controlled conditions.
  - Final cover system:
    It consists of a barrier and drainage layers. It acts as a hydraulic

barrier to minimise water infiltration into the landfill to reduce the amount of leachate generated after closure.

  - Stormwater management system
  - Groundwater monitoring system
  - Gas monitoring system

- How does contamination occur under a landfill?
  In unsealed landfills and open dumps above an aquifer, waters percolating through landfills and refuse dumps often accumulate or mound within or below the landfill. This is due to production of leachate by degradation processes operating within the waste, in addition to the rainwater percolating down through the waste. The increased hydraulic head developed promotes downward and outward flow of leachate from the landfill or dump. Downward flow from the landfill threatens underlying groundwater resources whereas outward flow can result in leachate springs yielding water of a poor, often dangerous, quality at the periphery of the waste deposit. Observation of leachate springs or poor water quality in adjacent wells/boreholes are indicators that leachate is being produced and is moving. Leachate springs represent a significant risk to public health, so their detection in situation assessment is critical in order to prevent access to such springs.

- What are the fluxes normally considered in the subsurface transport?
  Advective flux, diffusive flux, and dispersive flux.

- What is chemical degradation?
  Chemical degradation is the processes of gradual loss of the engineering qualities of a material.

- List three examples of non-mechanical driving processes related to loss of stability.
  Stress corrosion, historic building stone dissolution, asphalt moisture damage, crack propagation, and acid rain-assisted slope instability.

- Describe the effect of Climate Change on coastal regions.
  It can cause chemical erosion. Sea level rise could erode and inundate coastal ecosystems and eliminate wetlands.

- What are bio-mediated geotechnical approaches? How can bio-processes assist with geotechnical engineering?
  Bio-mediated geotechnical approaches consist of geochemical reactions regulated by subsurface microbiology. They include mineral precipitation, gas generation, biofilm formation and biopolymer generation.

A.5 Construction Project Management

- What UN Sustainable Development Goals are related to the built environment?

- Climate Action:
  Total decarbonisation of the built environment. SDGs: 7, 9, 13, 17
- Health and well-being:
  A built environment that delivers healthy, equitable, and resilient buildings, communities, and cities. SDGs: 3, 6, 11, 10
- Resources and circularity:
  A built environment that supports the regeneration of resources and natural systems, providing socio-economic benefit through a thriving circular economy. SDGs: 8, 12, 15

• Why does climate change matter?
The Earth is 1.1C warmer than it was in the late 1800s. The global mean temperature will only keep on rising and causing issues, such as rising sea levels, catastrophic storms, intense droughts, extreme rainfall events, declining biodiversity, and potential impact on human life (health, ability to grow food, housing...)

• What is an embodied emission?
Embodied emissions are all greenhouse gas emissions that are released as part of making a product or service ready for your consumption or use

• What is on–site renewable energy technology?
Generating energy at the site of the building itself, such as through photovoltaics (solar power), small wind turbines (wind power), micro combined cooling heating and power (CCHP) and emerging renewable energy technologies (e.g. fuel cells).

• Please describe the production strategies introduced in class as well as their features.

  - Craft Production:
    Highly skilled workforce, training through apprenticeship. Made up of artisans, who have pride in their owrk. General purpose, flexible tools and machines (e.g. to drill, grind, cut), the final product is always unique (even if from same blueprint), parts and replacement aprts must be manufactured from scratch (long process of custom fitting) and extremely decentralised organisations.
  - Mass Production:
    The complete and consistent interchangeability of parts and simplicity of attaching them to each other. Parts are thus easy to attach, simple, and interchangeable.
  - Lean Production:
    Team of multi-skilled workers at all levels of organisation. It includes highly flexible, automated machines, just-in-time delivery of supply chain, and elimination of waste (less labor, less inventory, less rework)

- Agile Production:
  Highly customised products at costs comparable to mass production. The core is mass customisation.

- What is the definition of projects, processes, and platforms?
  - A project is a series of activities, defined with a starting point and an end point, with a certain amount of resources allocated. It exists only once and has its own unique prerequisits.
  - A process is a continuous flow of activities that uses information and resources to fulfill its role, to create value for the customers. It does not have a clear start and endpoint in time.
  - A platform is a set of common components, modules or parts that form a common structure from which a stream of derivative products can be efficiently developed and produced. It allows multiple products to be built within the same technical framework.

- Compare the features of project design and platform development. Project design:
  - Unique team, solutions, and building
  - Starts from low levels of common knowledge
  - Input from production is rare
  - Limited levels of details in design stage
  - The project is always a prototype
  - Scarce conditions for continuous improvements

  Platform development:
  - Continuity is the foundation
  - Solutions are based on repetitive use
  - A platform development team is composed of multiple competencies
  - High level of details in development stage
  - Solutions can be tested before implementation