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2019

The International Mathematical Modeling Challenge (IM^{2}C) Summary Sheet

(Your team's summary should be included as the first page of your electronic submission.)

Human is a complicated species which affect to resources on Earth according to data in era the massive change is usually come from human such as world war, plague etc. Human impact environment also including biophysical environment, ecosystem, biodiversity and natural resource so, considering factor of living human being on Earth is complicated.

Earth carrying capacity, the maximum population size of the species that the environment can sustain in definitely, many scientists do a research that human carrying capacity is about 10 billion people estimating base on the Earth's available resource. Wilson said that the most affect factor is base on food resource if everyone eat only vegetable to be a vegetarian everyone there will area left for enough to support 10 billion people because instead of livestock, planting vegetable which is efficiencies way to produce food energy for human life.

Our goal is to gathering factor that affect the Earth's carrying capacity by considering from the past data of the growth of population including limited factor. Although, the Earth has limited resource, the rate of producing resource is equal to the rate of consumption resource therefore, the limited resource will be considering as unlimited such as plant and food because it can circulate so, the constraint factor is the surface area of the Earth which was the major condition in our model. The area can be divided in vary way so; it is considered to be independent variable. The capability of allocating is to be weighing and rate of the efficiency per one unit of area and time. Due to rate of producing is equal to rate of consumption therefore, the usage of resource per one unit of time.

The strength of our model is use realistic data and flexible in case of the additional or remove factors with ease and comprehend all of the factor that important in daily routine of human life and impact enough even though we cannot comprehend all of the factor that impact and we test simulate with the possible reality data in 2 cases : sufficient way and extravagant way. The result is more than the prediction. However, the data that we test is a good representative in life.

In the future we will predict the changes of each factor in order to increase the carrying capacity according to the current technology and the development of technology in the future.

Introduction

The Earth's carrying capacity for human life is the maximum number of a species an environment can support indefinitely. There are limits to the life-sustaining resources the Earth can provide us. Humans do not reproduce, consume resources, and interact with their living environment uniformly like other species. Therefore, statistical data is needed to estimate the average uses of resources of common people today.

Generally, there are four basic factors that necessary for human to live. Food including water is any substance that is consumed to enhance nutrition for the body. It is the main source of energy for humans. Most of the food is derived from agriculture. The second factor is habitat. Humans need to have a residence. In order to protect themselves from harms. Therefore, humans must rely on suitable areas for their life. The third important factor is medicines. Medicines and health products are important for addressing health problem and improve the quality of lives. They form an indispensable component of health systems in the prevention, diagnosis, and treatment of disease and in alleviating disability. Humans are creatures that have ailments such as other living things. But we have always tried to develop the efficacy of medical treatment. The last factor is the cloth. It is used to protect against cold or heat. At present, the cloth is used for indicating the tradition and individual status.

The estimation of earth's carrying capacity for human life will be considered based on the resources that one person needs for living per one day. Assumingly, the rate of basic needs supply increases constantly and is equal to the rate of consumption by humans.

Assumption

1. Consumable rate does not depend on gender, age, and lifestyle. All people require approximately equal resources. We assume that the numbers of women and men are equal.
2. The location to facilitate is needless. This equation is not included the convenient living parameter such as number of department store, school, park, airport, museum, restaurant, etc.
3. Accor
ding to the limited availability of fresh water, we assume that all water can be repeating treated.
4. Even health parameter is one of the important factors in our life. However, the mental health is not considered in this equation. Otherwise, there will be a lot of factors that affect the Earth's carrying capacity and must be considered in the equation. Therefore, only physically health is counted.
5. The maximum population density of human being can be dramatically increase, since currently our high technology about building construction is high superior.
6. For food supply, the calculation is based on the total energy provided by food and not classified into the type of nutrients
7. Uncontrollable parameter such as devastating diseases, natural disasters and civil war are not included.

Historical data of World Human population

With a population of 7.5 billion people, human is now the species that affect the highest pressure on this planet's environment. Since most ancient ancestors have lived on the Earth for a long time, during this period humans always evolved both culturally and physically by the balance of the availability of food provided by gathering and later by hunting

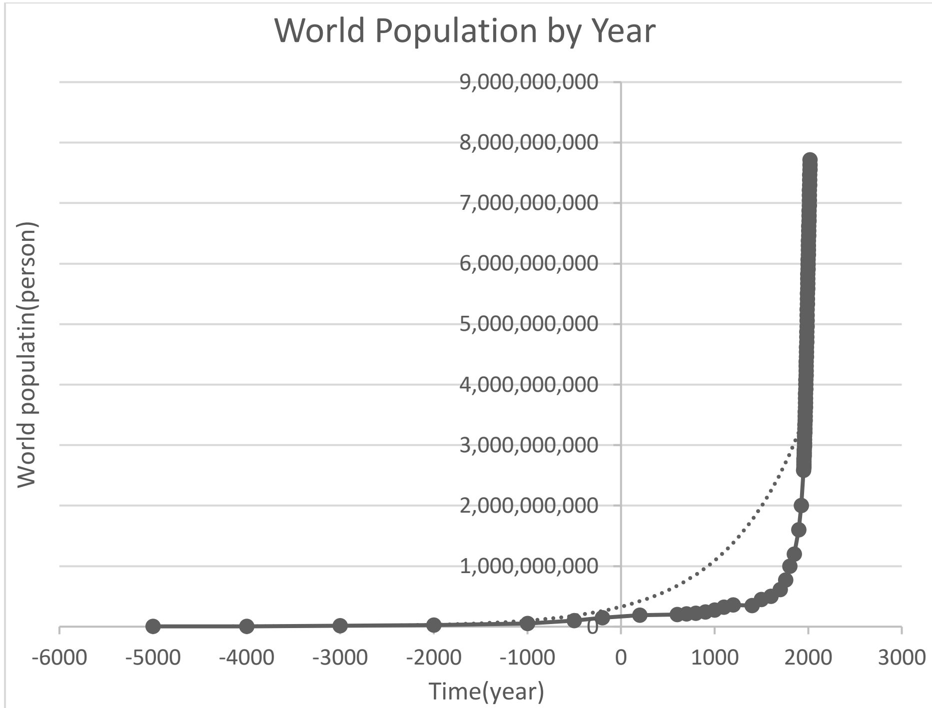
During Pre-Paleolithic and Paleolithic, the human population probably not exceeded 10 million individuals. The population increasing limit was fixed by the way of their lifestyle. So, vast regions were necessary for the survival individually. However, the mean life expectancy at birth was less than 20 years.

With the Neolithic age, the agriculture and domestication revolution, the settlement with agricultural activities and discovery of many things led to a considerable increase of the world human population. At the beginning of the Christian Era, some virtue concepts of the Euro-Mediterranean were codified. The world human population was around 250 million people. Then, at the end of the time that America was discovered by Columbus, the population reached 470 million people.

In the sixteenth century, the population growth was not continue increasing. But it significantly decreased because of pandemic and pestilence diseases. A half of the North European population was killed by the Black Death which is known as one of the most ravaging pandemics in human history. In the fifth century, there was another disease that was epidemic, reducing a lot of the population.

In the middle of eighteenth century, there was the industrial revolution. That made a strong rise of the population. It was shown that technological advances effectively motivated the size of population.

The world population was continue increasing significantly until the last 40 years, it would be considered as a stage apart because of the massive rise in the increasing rate of population growth. Moreover, this increase affects specific geographical areas. While North America and Europe tend to remain steady but a strong increase of population growth associates mainly in South America, Africa and Asia.



Main factors

To calculate The Earth's carrying capacity for human life, our group use constraint as an area to calculate by divide it into 5 main factors. In this calculation, we consider the area used in each factor. By using inequality properties, we reduce the use of each factor to minimum and contempt the human carrying capacity in Earth reasonably under the current condition and limited space. Each value was obtained from the survey and approximated it to realistic.

- **Food**

Every person needs nourishment to survive. Nutriment is from agriculture and livestock which use area too. We classified nutriment into 2 main types. The first type is production on the ground which got shared with the habitat area (agriculture and breeding land animals). Another type is foods that produce in the water which is not a place for a human to live in our condition, for instance, marine animals can be raised in the ocean or lake which will consider as an extensive area. since the volume of the world's ocean is from 1.3-1.5 billion cubic kilometers which is more than enough.

- **Water**

Humans are using about 30% of the Earth's accessible renewable water supply and the rest is being used for agriculture. There are a lot of water resource on the Earth but needs to be recycled then it needs the area for recycling the water sufficiently. This situation includes fresh water from desalination of sea water.

- **Electricity**

Since the electricity began with a physician to facilitate people, a lot of energy sources were used such as natural gas, petroleum, nuclear, fossil. Energy sources are classified as renewable or nonrenewable. Nonrenewable energy sources supply most of energy we use. Their supplies are limited and spend a very long time to form. Therefore, if we attempt to use renewable energy sources, the limited sources on the Earth will be saved. Renewable energy sources include geothermal energy, solar energy and wind energy.

- **Habitat**

House will protect humans from sunlight, rain, harm. Human therefore attempt to live in their habitat safely. House is center of family member, may be different generations of age and have a relationship with each other in some way. Many houses or either a kind of apartments will be a part of the community. A sense of community is important to positive mental health. Even, the mental health is not considered.

- **Inhabited**

In some environment on Earth which human cannot live without special equipment such as high mountain, north/south pole, and desert it is hold up to 50% of the Earth's land area (30% of the total area). There are some places that humans are not able to live because of the extreme climate and the weather of that places.[1]

- **Medicine**

Medicines are chemicals or compounds used to cure, stop, or prevent disease and help in the diagnosis of illnesses. These days, medicines come from a variety of sources. Many were developed from substances found in nature, and even today many are extracted from plants. Some of them are made from adding chemical compound together. It is important for our health care. Advances in medications have enabled doctors to cure many diseases and save life more.

- **Transportation**

Transportation systems is the movement of humans. It is so important since transport plays an important part in economic growth and globalization. Inevitable spaces mean requisite areas between several places. For instance, the space between the building, the space between the building and the hospitals. These areas take large amounts of land.

- **Miscellaneous**

Other than five main factors above such as clothes are made to protect cold, sunlight and hard hitting with other objects. So, it is necessary to wear a cloth. These factors can be added to the equation, depending on the specific situation.

General model

Introduction

To provide a good quality mathematical model, all factors must be comprehensive. In general, many factors affect the Earth's carrying capacity. The model is a representation. No mathematical model includes every aspect of the real world. All factors cannot be counted completely. Counted factors that included in the equation were chosen to be critical. The good quality model can be used for prediction in real life problem.

Factors and equation

Let K be the Earth's carrying capacity which is the maximum number of people that Earth can support.

And P be the population. Since the Earth's carrying capacity is the maximum amount of people that $P \leq K$. Therefore, P be the most when $P = K$.

A_t be the area of the Earth's land surface, which is equal to 1.53×10^8 square kilometer.

Area of habitat (A_1)

The area for human habitation depends on the minimum size of the area that one person needs. This area consists of sleeping space, eating space including space for excretion. In general, the lower size for one person, the more people can live in limited area. Nowadays, some people live in the building. Not only the area of land that must be considered, but also the space in the air that can be built for increasing limited area. All building cannot be built in any height. We have restriction of building, both the minimum height that a person can live and the ability to expand the height of the building.

- The minimum size of area for one person = a square kilometer
- Ratio of people living in the building per all people = r people per people
- The minimum height per capita to live = h meters per floor per person
- The maximum height of building by mechanical ability = H meters
- The maximum number of floors = N floors
- The ratio between people living in house to all = μ

Therefore, $\left\lfloor \frac{H}{h} \right\rfloor = N$

If only one people stay in one floor N can also consider as number of people in one building.

Therefore, $\frac{A_1}{a}$ is the number of building

And $\mu \times \left(\frac{A_1}{a}\right) + (1 - \mu) \times \left(\frac{A_1}{a}\right) \times N = P$

Such that $\frac{P \times a}{N(1-\mu)+\mu} = A_1$

Area of food-producing (A_2)

The area for producing food depends on how much food that people on Earth needs in one day. Our body need well-balanced diet which means eating a variety of foods from different group, in the recommended amounts. It is important to choose a variety of foods from within each group because different foods provide different types and amounts of main nutrients. In general, each type of food requires different area for producing. Meat food comes from livestock farming. Different types of animals use unequal area for farming absolutely. But it will be too difficult. So, we separate meats to be in two groups, farming on land and in the water such as fish farming. We naturally cannot diet fresh meat. In the early days, the food processing is also important. Its main aim was preservation to maintain a supply of well-being health. The area for food processing industry must be counted.

- The minimum kilogram of vegetables for one person in one day = x_1 kilogram
- The minimum kilogram of land meats for one person in one day = x_2 kilogram
- The minimum kilogram of marine meats for one person in one day = x_3 kilogram

Human's body would live on healthy if proper amount of food was consumed. According to the publican "Dietary Guidelines for Americans, 2010", at least 1,600 calories and 2,000 calories are required for women and men respectively. We use the average value that is 1,800 calories for one person in a day by our assumption as the ratio of the numbers of women and men are equal. The maximum quantity of food that a person can consume in a day varies from person to person. So, we use the average capacity of people's stomach as we can consume up to 10 pounds or 4.5 kilograms in a day.[2]

- Energy from average planted vegetable = w_1 calories per kilogram
- Energy from average marine meat by livestock = w_2 calories per kilogram
- Energy from average land meat by livestock = w_3 calories per kilogram

Energy from food that was consumed per one person daily is $x_1w_1 + x_2w_2 + x_3w_3$ calories

From minimum condition, $1{,}800 \leq x_1w_1 + x_2w_2 + x_3w_3$

From maximum condition, $4.5 \geq x_1 + x_2 + x_3$

- The minimum size of agriculture area for vegetables one kilogram in one day = y_1 square kilometer

- The minimum size of livestock area for land meats one kilogram in one day = y_2 square kilometer
- The minimum size of livestock area for marine meats one kilogram in one day = y_3 square kilometer
- The minimum size of food producing plan for one-kilogram food producing in one day = z square kilometer

So, the nourishment requires $(x_1y_1 + x_2y_2 + x_3y_3) \times P + z \times (x_1+x_2+x_3) \times P = A_2$

The space of marine livestock is underwater. There are massive water sources on the Earth. This area is not counted as the considerable area of land on the Earth. Therefore, $y_3 = 0$.

So, the equation will be $(x_1y_1 + x_2y_2) \times P + z \times (x_1+x_2) \times P = A_2$

Area of resource (A_3)

The resource that is mainly use is water and electric so, it can divide the area into 2 parts mainly for water treatment process and power station

The main purpose of water treatment process is participated with the removal of pollutants. According to a concern of human health. The area for water treatment plant depends on treatment the used water of the human on the Earth to clear water. The volume of the water for population used to consume or to other several inevitabilities such as showering, teeth brushing, toilet flushing or outdoor watering.

The power station, using hydroelectricity power station can give enough amount of energy and use renewable energy. The variables depend on the chosen method for electricity production.

- Minimum volume of water for one person in one day = V liters
- The area for water treatment plant to treatment water one liter = a_w square kilometer
- Average usage of electricity in one person = W unit
- The area for power station to generate electricity one unit = a_e square kilometer

So, the water treatment plant and power station require

$$P \times (V \times a_w + W \times a_e) = A_3$$

Area of health care (A_4)

This area depends on the number of doctors to comprehensive all area human live on the Earth and the minimum area used for health care. This area for health care facilities includes the settlement of the hospital, the pharmaceutical factory, medical equipment factory and other places for effective therapy.

– The number of people that one doctor comprehensive	= n people
– The maximum doctors can work in one hospital	= n_d doctors
– The area that one hospital and other health care facilities needs	= a_h square kilometer

So, the area for therapy requires $\left(\frac{P}{n \times n_d}\right) \times a_h = A_4$

Area of transportation and inevitable space (A_5)

Transportation area depends on the ratio of the area for transportation such as roads and walk ways per the whole area that humans live. The inevitable spaces include the empty space between many places.

- The area of transportation and inevitable space per one square kilometer of the whole area that human living = a_s square kilometer per one square kilometer
- The area of transportation and inevitable space is $a_s \times (A_t - A_6) = A_5$

Inhabited area (A_6)

50% of total Earth's area is the inhabited area.

Such that $A_1 + A_2 + A_3 + A_4 + A_5 + A_6 = A_t$

$\left(\frac{P \times a}{N(1-\mu)+\mu}\right) + (P \times (x_1y_1 + x_2y_2 + x_1z + x_2z)) + (P \times (V \times a_w + W \times a_e)) + (\left(\frac{P}{n \times n_d}\right) \times a_h) + (a_s \times (A_t - A_6)) + (0.5 \times A_t) = A_t$

Simulation

Introduction

Not all the data always be accessible. Some of the variables are not recorded. For examples, the area of health care that include the settlement of the hospital, the pharmaceutical factory, medical equipment factory and other places for effective therapy. The rate of treatment efficiency per one unit area for therapy is needed for the equation. So, we simulate the value of the variables as much as realistic. Two conditions were simulated. The first condition was simulated as one of the best ways to use sufficiency space. Another condition was simulated to be one of the worst condition, everyone is extravagant with the worst form of space arrangement. To simulate

The first Simulated condition

The variables of this condition are simulated for using every area worthy. It is one of the most economically of both humans' behavior and qualification.

Area of habitat

From the most population density in the world is Monaco which stay 36 square meters per capita.[2] And at least 2.75 m high.[3]

The height limit of the building will not exceed 200 meters high according to the average building height restriction law in the ASEAN.

Area of food-producing

The greatest benefit is to eat 10 portions of fruits and vegetables a day which is equivalent to about 0.8 kilograms per day.[4] And for 2,000 calorie diet need for one person, the USDA recommends a total of 0.0283 kilograms of grain each day.[5] The need of protein for one person which is come from meat is average 0.088 kilograms per day. And one chicken gives 0.756 kilograms of meat and stand for 1.5×10^{-6} square kilometer and chicken use 140 days to fully grown.[b] So, the area for chicken one kilogram will be $\frac{1.5\times10^{-6}}{\frac{0.756}{140}}$ square kilometer in one day.

For fruit and vegetables, we chose tomato and green cabbage because it can grow anywhere and are easy to grow with any climate and landscape[6] which tomato on average, one acre (4.047×10^{-3} square kilometer) of tomato produces about 17,009.714 kilograms of tomato and green lettuce on average, it give about 20,000 heads of lettuce per acre which is about 9,480.5 kilograms. For wheat, yield per one acre (4.047×10^{-3} square kilometer) of area harvested with wheat is projected to be some 138.8 kilograms.[7] So, the area for tomatoes and green lettuce one kilogram is $\frac{4.047\times10^{-3}}{17009.714}+\frac{4.047\times10^{-3}}{9480.5}$ square kilometer and the area for wheat one kilogram is $\frac{4.047\times10^{-3}}{138.8}$ square kilometer. And use area of food processing plants for food processing 1 kilogram is 2×10^{-6} square kilometer similar as realistic.

Area of resource

Each person uses about 90 gallons of water which is about 340.687 liters of water.[8]

Water treatment plant can treat 400 million liters of water per day which is the same size as the Bell MTS place that holds 0.041 square kilometer.[9] So, the area for one water treatment plant to treat water one liter is $\frac{0.041}{4\times10^8}$ square kilometer.

Each person uses average 8.568 units in one day. [d] One station of hydroelectricity generate 24000 units and holds 1.6 square kilometer. [e] So, the area for one station of hydroelectricity to generate one unit is $\frac{1.6}{24000}$ square kilometer.

Area of health

The one doctor can comprehensive patients 1000 population.[10]

The one hospital contains 134 doctors.[11]

The one hospital can comprehensive patients 134,000 population.

The area of one hospital 0.1712 square kilometer similar as realistic.

Area of transportation and inevitable space

In order to not be too much density, the standard width of road is 3.4 meters wide and there have to be 2 lanes so the total width is 6.8 meters and the road density should be a kilometer of road per 100 square kilometer.[13] So, the area of road per one square kilometer is 6.8×10^{-5} square kilometer.

Variables

Area of habitat

H = 200 meters, h = 2.75 meters per floor per person, $a = 36\times10^{-6}$ square kilometer, μ = 0.83

Area of food-producing

x_1 = 0.8283 kilograms, $y_1 = 2.9822\times10^{-5}$ square kilometer, x_2 = 0.088 kilograms, $y_2 = 1.9841\times10^{-6}$ square kilometer, $z = 2\times10^{-6}$ square kilometer per kilogram

Area of resource

V = 340.687 liters, $a_w = \frac{0.041}{4\times10^8}$ square kilometer, W = 8.568 units, $a_e = 6.667\times10^{-5}$ square kilometer

Area of health care

n = 1000 patients per doctor, n_d = 134 doctors per hospital, a_h = 0.1712 square kilometer

Area of transportation and inevitable space

$a_s = 6.8\times10^{-5}$ square kilometer per one square kilometer of habitat area

Calculation

From the model,

$$\left(\frac{P\times a}{N(1-\mu)+\mu}\right) + (P\times (x_1y_1 + x_2y_2 + x_1z + x_2z)) + (P\times V\times a_w) + \left(\left(\frac{P}{n\times n_d}\right)\times a_h\right) + (a_s\times (A_t - A_6)) + (0.5\times A_t) = A_t$$

Substitution the variables

$$A_1 = \frac{P\times a}{N(1-\mu)+\mu} = \frac{P\times a}{\left[\frac{H}{h}\right](1-\mu)+\mu} = \frac{P\times a}{\left[\frac{200}{2.75}\right](1-0.83)+0.83} = \frac{P\times 36\times 10^{-6}}{\left[\frac{200}{2.75}\right](1-0.83)+0.83} = \frac{P\times 36\times 10^{-6}}{13.07}$$

$$A_2 = (x_1y_1+x_2y_2+x_1z+x_2z)\times P$$

$$= (0.8283\times 2.9822\times 10^{-5} + 0.088\times 2.778\times 10^{-4} + 0.8283\times 2\times 10^{-6} + 0.088\times 2\times 10^{-6})\times P$$

$$A_3 = P\times (V\times a_w + W\times a_e) = P\times \left(340.687\times \frac{0.041}{4\times 10^{8}} + 8.568\times 6.667\times 10^{-5}\right)$$

$$A_4 = \frac{P}{n\times n_d}\times a_h$$

$$= \frac{P}{1000\times 134}\times 0.1712$$

$$A_5 = a_s\times (A_t - A_6)$$

$$= a_s\times 0.5\times A_t$$

$$= 6.8\times 10^{-5}\times 0.5\times 1.53\times 10^{8}$$

$$A_6 = A_t\times 0.5$$

Then,

$$\frac{P\times 36\times 10^{-6}}{13.07} + (0.8283\times 2.9822\times 10^{-5} + 0.088\times 2.778\times 10^{-4} + 0.8283\times 2\times 10^{-6} + 0.088\times 2\times 10^{-6})\times P + P\times \left(340.687\times \frac{0.041}{4\times 10^{8}} + 8.568\times 6.667\times 10^{-5}\right) + \left(\frac{P}{1000\times 134}\right)\times 0.1712 + 6.8\times 10^{-5}\times 0.5\times 1.53\times 10^{8} + 0.5\times 1.53\times 10^{8} = 1.53\times 10^{8}$$

$$P\times 6.2638\times 10^{-4} = (1 - 6.8\times 10^{-5})\times 0.5\times 1.53\times 10^{8}$$

Therefore,

$$P = 1.2214\times 10^{11}$$

$$= 122.14 \text{ billion people.}$$

The second simulated condition

The variables of this condition are simulated as extravagant as possible. It is one of the most wasteful way of both humans' behavior and qualification.

Area of habitat

We assume that one person should have 50-square meters (50×10^{-6} square kilometer) to live and at 5 meters high.[3]

The height limit of the building will not exceed 200 meters high according to the building height restriction law in the USA.

Area of food-producing

Assume that one person eats the same amount of grain but increase eating land meat about 4.54 kilograms per day.

Area of resource

In one day, one person would use more water approximately 500 liters of water.[8]

Water treatment plant can treat 400 million liters of water per day which is the same size as the Bell MTS place that holds 0.041 square kilometer.[9] So, the area for one water treatment plant to treat water one liter is square kilometer.

Each person use average 70 units in one day.[d] One station of hydroelectricity generate 24000 units and holds 1.6 square kilometer.[e] So, the area for one station of hydroelectricity to generate one unit is $\frac{1.6}{24000}$ square kilometer.

Area of health care

The one doctor can comprehensive patients 1000 population.[10]

The one hospital contains 134 doctors.[11]

The one hospital can comprehensive patients 134,000 population.

The area of one hospital 0.1712 square kilometer similar as realistic.

Area of transportation and inevitable space

In order to not be too much density, the standard width of road is 3.4 meters wide and from the most lanes in Asian (China) has 50 lanes so the total width is 170 meters and the road density should be a kilometer of road per 100 square kilometer.[13] So, the area of road per one square kilometer is 1.7×10^{-3} square kilometer. Plus the entertainment area which hold about 10% of land area.

Variables

Area of habitat

H = 200 meters, h = 5 meters per floor per person, $a = 50 \times 10^{-6}$ square meter, $\mu = 1.0$

Area of food-producing

x_1 = 0.8283 kilograms, x_2 = 4.54 kilogram, y_1 = 2.9822×10^{-5} square kilometer, y_2 = 1.9841×10^{-6} square kilometer, z = 2 × 10^{-6} square kilometer per kilogram

Area of resource

V = 500 liters, $a_w = \frac{0.041}{4\times10^8}$ square kilometer, W = 50 units, a_e = 6.667×10^{-5} square kilometer

Area of health care

n = 1000 patients per doctor, n_d = 134 doctors per hospital

Area of transportation and inevitable space

a_s = 1.7×10^{-3} square kilometer

Calculation

$$\left(\frac{P\times a}{N(1-\mu)+\mu}\right) + (P\times (x_1y_1+ x_2y_2+x_1z+x_2z)) + (P\times V\times a_w) + (\left(\frac{P}{n\times n_d}\right)\times a_h) + (a_s\times (A_t - A_6)) + (0.5\times A_t) = A_t$$

Substitution the variable

$$A_1 = \frac{P\times a}{\left[\frac{H}{h}\right](1-\mu)+\mu}$$

$$= \frac{P\times 50\times 10^{-6}}{40(1-1)+1}$$

$$= P\times 50\times 10^{-6}$$

$$A_2 = (x_1y_1+x_2y_2+x_1z+x_2z)\times P$$

$$= (0.8283\times 2.9822\times 10^{-5}+ 4\times 1.9841\times10^{-6}+ 0.8283\times 2\times 10^{-6} + 4.54\times 2\times 10^{-6})\times P$$

$$= (7.8364\times 10^{-6} + 8\times 10^{-6})\times P$$

$$A_3 = P\times (V\times a_w + W\times a_e)$$

$$= P\times (500\times \frac{0.041}{4\times10^8} + 70\times 6.667\times 10^{-5})$$

$$A_4 = \frac{P}{n\times n_d}\times a_h = \frac{P}{1000\times134}\times 0.1712$$

$$A_5 = a_s\times (A_t - A_6) + 0.1\,(A_t - A_6)$$

$$= a_s\times 0.5\times A_t + 0.05\,A_t$$

$$= 1.7\times 10^{-3}\times 0.5\times 1.53\times 10^8$$

$$A_6 = A_t\times 0.5$$

$$= 0.5\times 1.53\times 10^8$$

Then,

$P \times 50 \times 10^{-6} + (2.47 \times 10^{-5} + 7.8364 \times 10^{-6} + 1.656 \times 10^{-6} + 8 \times 10^{-6}) \times P + P \times (500 \times \frac{0.041}{4\times10^{8}} + 70 \times 6.667 \times 10^{-5}) + \frac{P}{1000\times134} \times 0.1712 + 1.7 \times 10^{-3} \times 0.5 \times 1.53 \times 10^{8} + 0.5 \times 1.53 \times 10^{8}$

$= 1.53 \times 10^{8}$

$P \times 4.76 \times 10^{-3} = (1 - 1.7 \times 10^{-3}) \times 0.5 \times 1.53 \times 10^{8}$

Therefore,

$$P = \frac{0.9983\times0.5\times1.53\times10^{8}}{4.76\times10^{-3}}$$

$$= 1.6249 \times 10^{10}$$

= 16.249 billion people.

Analysis of modelling

This model depends on many factors but the most effective is using electricity because the consumption of electricity per capita is large amount while the power plant can not generate the energy enough to fulfil and it is not worthwhile to the area used the followed by the food producing because to have enough nutrient have to do crop and livestock which hold a lot of space. The Earth's carrying capacity that we got is greater than the prediction of scientist that 10 billion people show that the data above in the second condition is estimated to base on prediction to be as close to 10 billion as possible in the calculation.

Memo

Step 1: Researching

To find the constraint value and plan everything to depend on that value base on real information from searching in internet and if it is not available then find the good example of that value which contain all needed information or ask professional instead.

Finding the good example

The good example must contain the standard information to calculate each value needed that depend on the constraint.

Step 2: Calculation

After getting all the value needed then and convert into the same unit of the constraint.

Step 3: Normalizing values

$$Normalized\ value\ = \frac{value\ -\ worst\ value}{ideal\ value\ -\ worst\ value} \times 100$$

After we have got the data, transform the data to be in the same term as the other values (Normalization). Normalization usually means to scale a value, enabling to be more easily comparing data. Label it between 0 -100

Step 4: Final Earth's carrying capacity

To find the Earth's carrying capacity after knew constraint value and some other limited condition the calculate the main factor of human that wants to compare to one unit constraint value and then search the information about it to set the model to make this constraint value depend on the number of population and when the constraint value meet its limitation so, the number of population is equal to the Earth's carrying capacity for human.

Future Condition

- **Technology**

To increase food production rate and improved agriculture and develop the medic to control many diseases and use technology to make inhospitable area to be able to live. These will increase the carrying capacity by reduce the amount of area required in nourishment and health factor.

- **World population**

Since the revolution of industry, there was a huge increase of world population. Then, the growth rate of world population continues increasing significantly, due to a decreasing death rate from the development of technology which is more rapidly than birth rate. Therefore, the world population tends to increase extremely in the future.

- **Habitat**

In the future, each person would use less area because mostly people will live in an apartment or condominium, according to the statistic that the rate of people who decided to live in the building increase. And there will have more area to do something else.

Engineering capability will be better. New designed construction that is effective and worthy might be created. We will have more options to be the settlement. Recently, many attraction or resorts attempt to attract people by the underwater rooms. There are many places which can be adapted to be humans' habitat such as underground or under the sea. Then, more areas can be counted as the available area for habitation.

- **Inhabited**

From development of machinery or implement, the limitation by geography and climate is tentatively able to be resolved. Some inhabited area will be available, enabling people to take those places for effective activities.

- **Electricity and water**

A lot of environmental organization and agencies campaigned against using nonrenewable energy to maintain limited resources such as petroleum, fossil and coal. In the future, people attempt to use more renewable sources. Then, the area of power plants per one person will take less amount of area. On the other hand, people tend to use steady amount of electricity. Therefore, the area required of both two resources would be decreased.

- **Food**

Improving agriculture by genetic modification to make plant grow faster and give more production and increased food production rate also by genetic modification to make livestock healthier, grow fast, strong, live long and more off-spring and develop it to prevent side effect to consumer. This can reduce the area required but can still produce same production rate. Therefore, the area required for food-producing and food-processing rate will be decreased.

- **Health**

According to a report from the Stanford University School of Medicine, "The sheer volume of health care data is growing at an astronomical rate: 153 exabytes were produced in 2013 and an estimated 2314 exabytes will be produced in 2020". An explosion of health data was indicated. It means that medical treatment in the future must be easier. Due to modern technology which has been developed to spend less time and more effective, making a reduction of needed area for health care per person.

At this period, one of effective biological technology was invented, Optogenetics, it associates the use of light to control cells in living tissue. It is widely speculated that it might provide new solutions in therapies. The outcomes of this technology will make we reach when false memories of taking drugs can be generated in humans as well. The method is almost available now. There are a lot of work that has been invented to make. Therefore, the area for humans' therapy will be greatly reduced.

- **Transportation**

In the future human would not need to drive by themselves because intelligent technologies like AI, IoT and LiDAR have turned driverless cars from a vision to a present reality, as so many companies have announced their plans of launching driverless cars and trial runs of these cars are already going on in different cities of the world.

Recently, Drive.ai, a Silicon Valley-based startup building self-driving car software, announced that it will offer free rides to passengers in Frisco, Texas. Driverless cars will overwhelm the existing automobile industry and undertake will be its biggest and most breathtaking transformation since its inception in the beginning of the 20th century. Then people would not need to learn how to drive so the driving schools do not need to exist. So, we can increase the area for other needed activities.

The number of lanes will be reduced because there will be Hyperloop and flying taxis. Hyperloop is the low-pressure tube which the passengers could travelling at 700 miles an hour in floating pods which is very fast and flying taxis would be existed soon because nowadays big companies such as Uber, Boeing, and Airbus have started developing this technology. Silicon Valley startups are also showing enthusiasm about flying taxis. Uber plans to fly these taxis by 2023 and for this endeavor it has also partnered with NASA[20]

Conclusion

1. Currently, there are seven major factors that we consider crucial to limit the Earth's carrying capacity for human life: food, habitat, resources (water and electricity), nourishment, health care, transportation and inevitable space
2. The proposed model is $\left(\frac{P\times a}{N(1-\mu)+\mu}\right) + (P\times (x_1y_1 + x_2y_2 + x_1z + x_2z)) + (P \times V \times a_w) + ((\frac{P}{n\times n_d}) \times a_h) + (a_s \times (A_t - A_6)) + (0.5 \times A_t) = A_t$ while Earth's carrying capacity is K and other description and the explanation can be read in page 5-7
   From the simulation, the best scenario yields the maximum of K which is 1.2214×10^{11} people. The worst scenario yields the minimum of K which is 1.6249×10^{9} people.
3. To raise the carrying capacity of the Earth for human life in the future, population have a trend to increase exponentially because of the reduce of death rate which is caused from the improvement of technology that effect many factors. Every variable can increase the trend of the Earth's carrying capacity due to the improvement of the technology such as agriculture, industry, livestock, fishery, communication, transportation and medical. In the future, human will have more ability because of the need of the comfortable life. Ability to breakthrough limitation such as the maximum height of the building to reduce other factors area requirement which mean to increase Earth's carrying capacity.

Reference:

[1] Chiarelli B. & Annese M.,2009, The Carrying Capacity of the Environment as it relates to Human Consumerism.

[2] http://www.curiousmeerkat.co.uk/questions/much-land-Earth-inhabited/

[3] http://statisticstimes.com/demographics/countries-by-population-density.php

[4] https://theconstructor.org/building/rooms-minimum-height-size-standards/5116/

[5] https://www.builderonline.com/money/economics/80-percent-of-americans-prefer-single-family-homeownership_o

[6] https://www.cbsnews.com/news/for-a-longer-life-researchers-say-eat-this-many-fruits-and-veggies-per-day/

[7] https://healthyeating.sfgate.com/much-whole-grain-should-eat-day-6492.html

[8] https://robinsonloveplants.com/fruits-vegetables/

[9] https://www.statista.com/statistics/237705/global-wheat-production/

[10] https://water.usgs.gov/edu/qa-home-percapita.html

[11] https://winnipeg.ca/waterandwaste/water/treatment/plant.stm

[12] https://www.who.int/gho/health_workforce/physicians_density/en/

[13] https://www.quora.com/What-is-the-average-number-of-doctors-per-hospital

[14] https://www.quora.com/What-is-the-maximum-quantity-of-food-that-a-single-person-can-consume-in-a-day

[15] https://www.nationmaster.com/country-info/stats/Transport/Road-density/Km-of-road-per-100-sq.-km-of-land-area

[16] https://www.geospatialworld.net/blogs/5-futuristic-transportation-technologies/

[17] http://agriculture.gov.ie/media/migration/farmingschemesandpayments/farmbuildings/farmbuildingspecifications/wordversions/RecAnimalAreas.doc

[18] https://data.worldbank.org/indicator/eg.use.elec.kh.pc

[19] https://www.un.org/en/development/desa/population/publications/pdf/ageing/household_size_and_composition_around_the_world_2017_data_booklet.pdf

[20] https://www.geospatialworld.net/blogs/5-futuristic-transportation-technologies/