Problem A paper:

Bicycle Club

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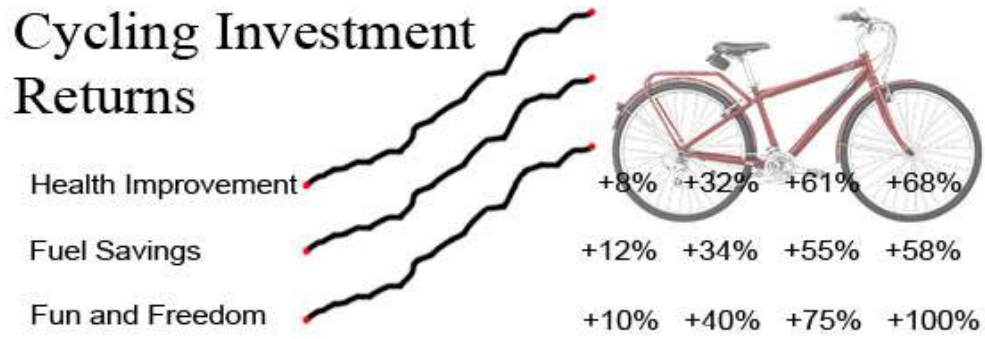
INTRODUCTION

Richard M. Daley, the mayor of Chicago, visited Seoul, the capital of Korea, on September 21st. After he looked around eco-friendly/environmentally friendly policy of Seoul, Richard M. Daley stated that Chicago has no other goal than to reduce 25% of carbon dioxide emission until 2020. With 'Chicago climate action plan,' the citizens hope to make Chicago the best city of bicycle for first-line transportation. Likewise, many countries and states endeavor to induce bicycle as the chief transportation due to the increasing problems of environment and natural resources. Cars and subways emit a great amount of carbon dioxide, which is the main cause of the air pollution and global warming. Moreover, lack of petroleum, the main power source of transportation system except bicycle, motivates people to save the resources by promoting bicycles. In order to encourage bicycle programs, our team models the bike rental system.



OUR MODELING GOALS:

Our goal is to model a system that makes bicycle using convenient

1. Find the locations for bicycle rental program.
2. Set the appropriate number of bicycles in each station.
3. Decide how to expand the business when the program grows.
4. Allocate bicycles to each station for smooth use.

STEP 1

[Pre-Assumptions]

Our team assumes that

1. One can walk at a speed of 70m/min and bicycle rolls 12km/h=200m/min.
2. One gets tired when he or she walks more than 200 meters.
3. Efficiency occurs when you can spare more than 4 minutes.
4. Rental stations can be located ONLY along the streets.
5. The closest subway station from any workplace is no farther than 1 kilometer.

Our main idea is focused on Central Business Districts and expanding the bicycle as a commuting method. We classified the commuting route to 2 types.

[**Situation 1**: Commuting Route: Home > Subway > Workplace]

In situation 1, one can use the system two times.

First, 'Home > Subway'

Second, 'Subway > Workplace'

Since we have assumed that riding a bicycle is worthy enough when it saves more than 4 minutes, we have to find out the minimum distance which saves exactly 4 minutes.

We define x as the distance between a subway station and a business district.

$$\frac{x-200}{200}+\frac{200}{70} \leq \frac{x}{70}-5$$

$$7(x-200)+4000 \leq 20x-7000$$

$$630.7 \leq x$$

The bigger x becomes, the more time one can save. When x is longer than approximately 630m, one can save more than 4 minutes commuting by the bicycle.

There are three groups divided by the possible values of x.

Group 1) 0m≤x≤200m : No need to build a rental station. It is not worthy enough because it saves less than 4 minutes. People can walk.

Group 2) 200m<x<630m : Rental stations are built not now but afterwards according to the residents' needs and the city's budget station.

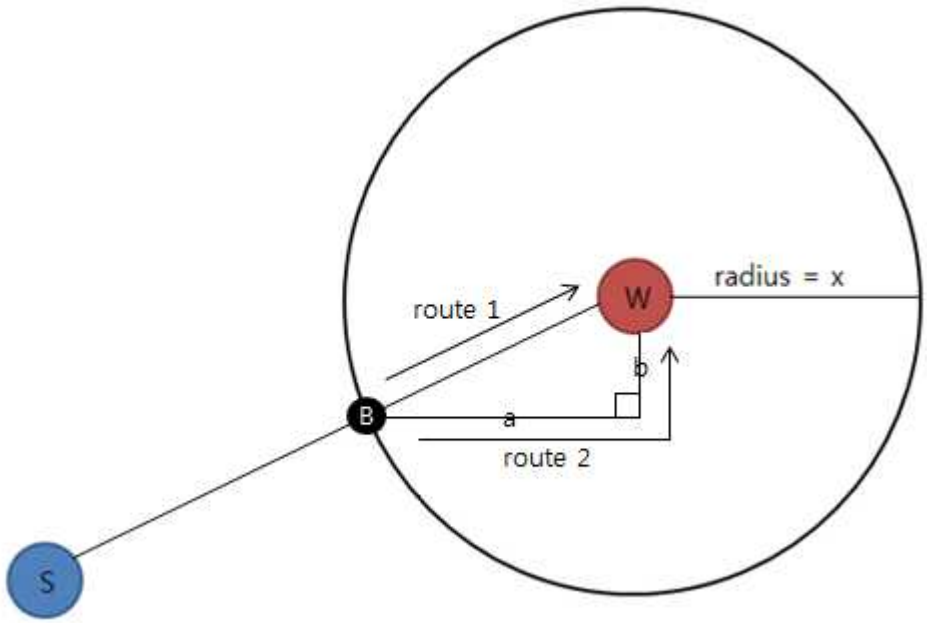
Group 3) 630m≤x≤1km : Efficient enough to build a rental station.

Now the problem is where to plan rental stations in the range of 630m and 1km.

#1. We draw a circle whose radius is $100\sqrt{2}$ and whose center is the workplace (=busy quarter, central business district) as the figure below. The radius is $100\sqrt{2}$ because a man can walk 200 meters at its most.

Figure 1 and 2 explains why the radius of the circle has to be $100\sqrt{2}$.

<Figure 1>



W = Workplace
S = Subway Station
B = Bicycle Rental Station

The streets people can actually go on foot are rectangular. Therefore, one can't go by route 1 but by route 2. The length of route 2 = (a+b), and the length of route 1 is the circle's radius; x.
The figure surrounded by route 1 and route is a right triangle. So using the Pythagorean theorem,

$$\mathbf{x^2 = a^2+b^2}$$

Also, the triangle inequality states that for any triangle, the sum of the lengths of any two sides must be greater than the length of the remaining side. This forms another equation :

$$\mathbf{x<a+b}$$

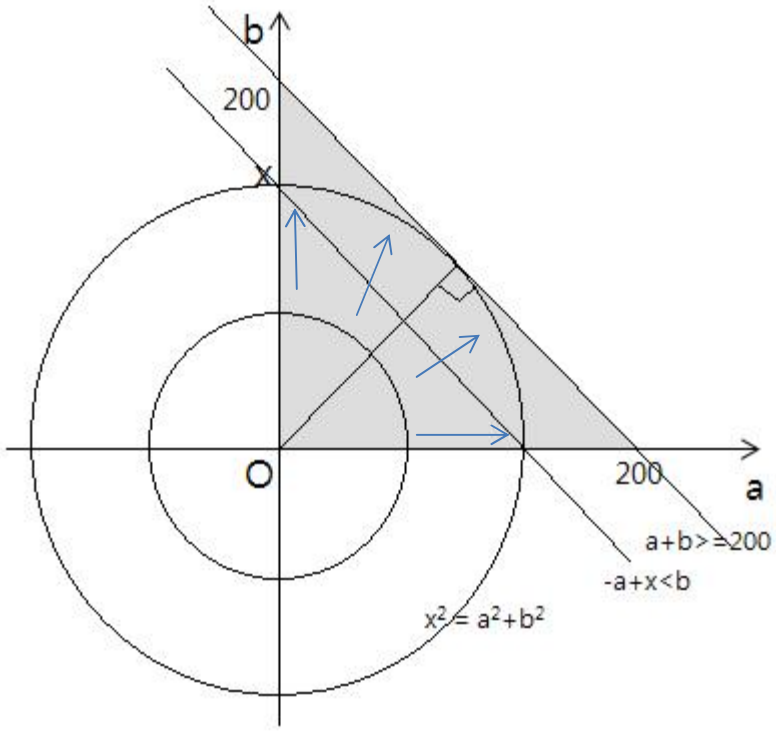
The longest distance one can walk is fixed to 200 meters. So the third equation is :

$$\mathbf{a+b\leq 200}$$

If you draw these three equations into a graph of a-axis and b-axis, it forms the graph below.

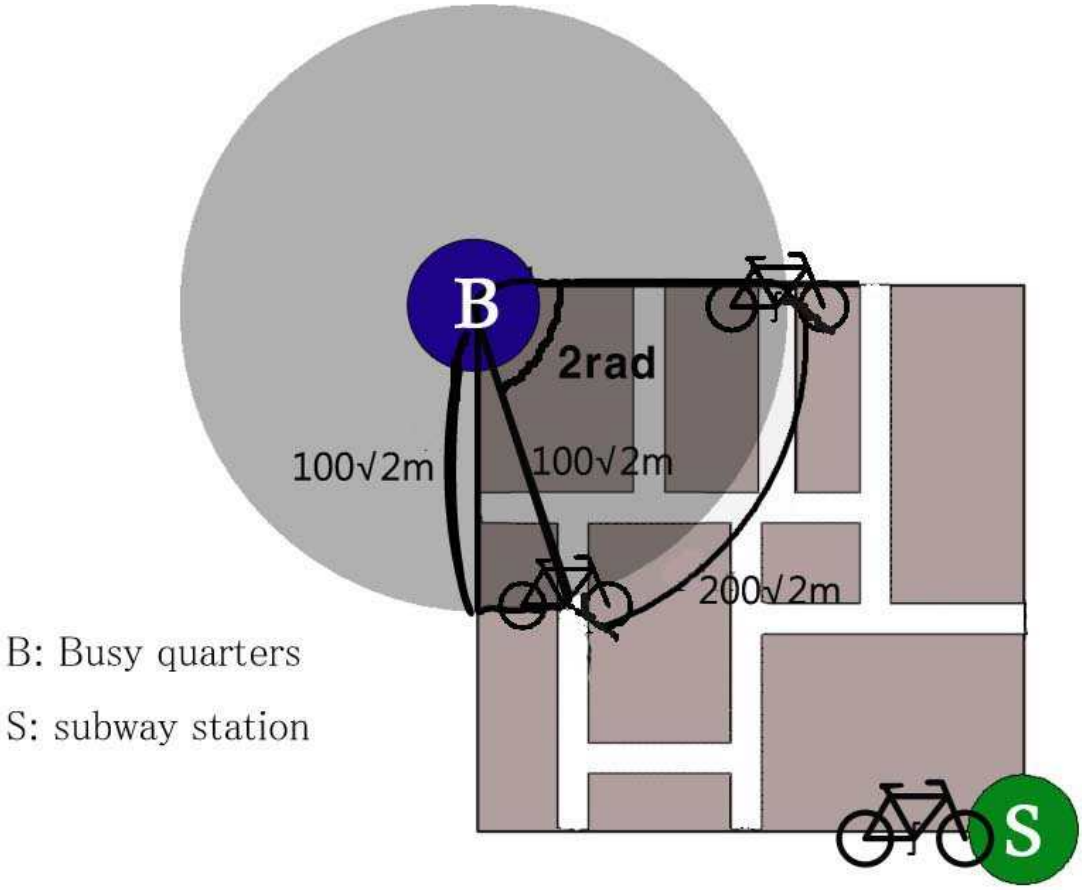
(a>0, b>0; ∵ a and b are the lengths of a triangle)

<Figure 2>

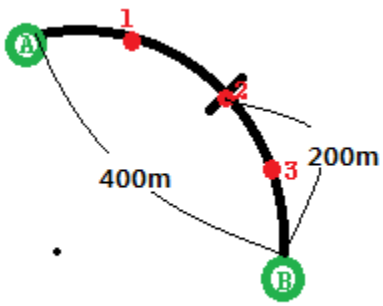


The value of x can grow until $100 \cdot 2^{1/2}$. In order to make the system efficient, x needs to be at its maximum value. Therefore, the radius of the circle must be $100 \cdot 2^{1/2}$.

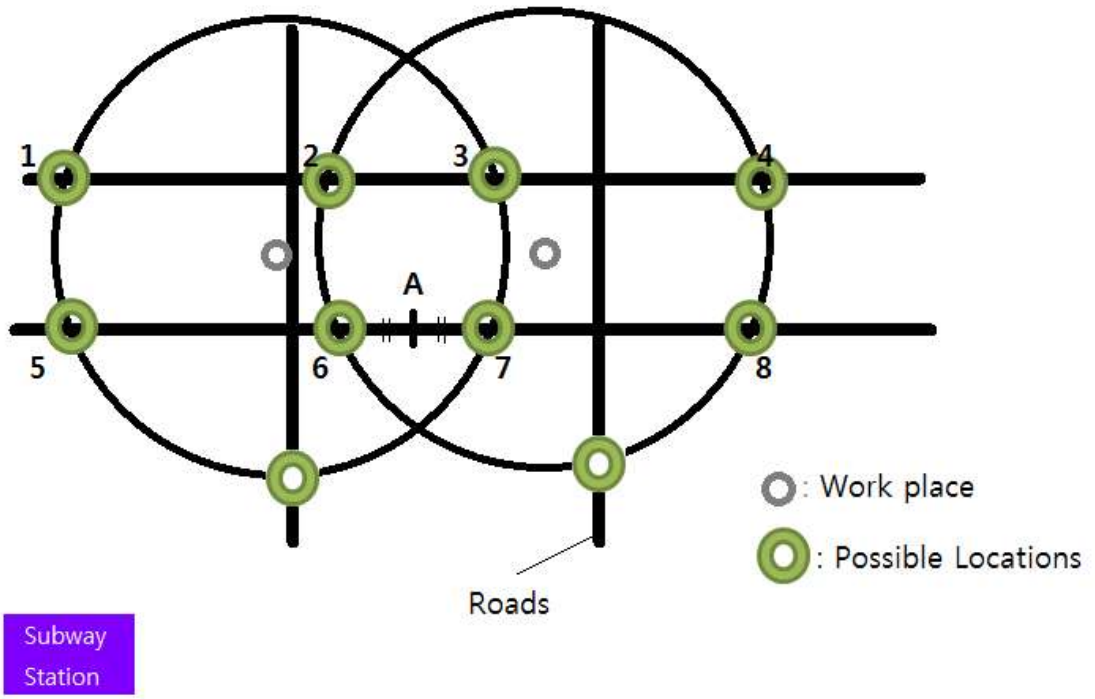
#2. Above all, a rental station must be made next to the subway station. Next, the intersection of the circumference and roads can become a location of a rental station. When they go to work, people can borrow a bike from the station beside the subway and return their bicycles at the closest station of their workplace. When they go home, this process will be reversed.



The arc between two different rental stations is 400 meters. The figure below explains why the distance is 400 meters.



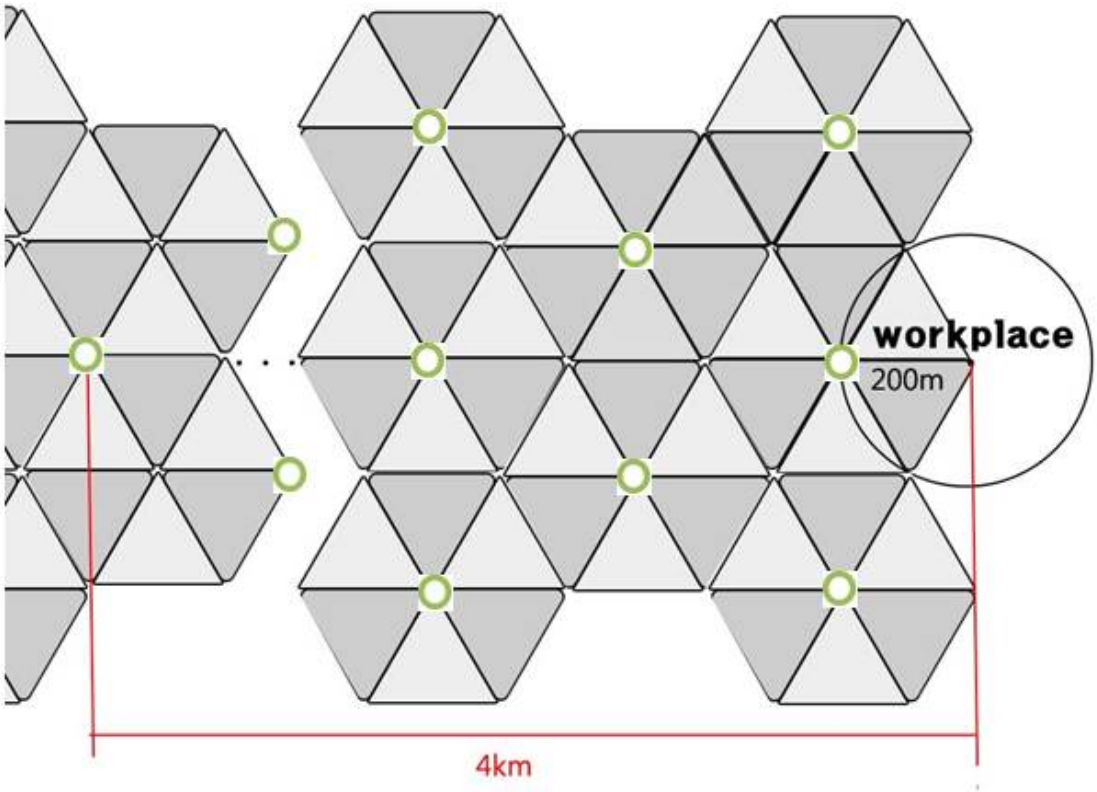
People working at 1 can return their bikes at station A, people working at 3 can return their bikes at station B and people working at 2 can go either way. In this way, everyone walks no more than 200m, satisfying the pre-assumptions.



Furthermore, there may be cases when the two circles intersect each other.
In this situation, first, set possible locations where the two circles meet with roads. Location 1, 5 is too far from the right workplace and location 4, 8 is too far from the left workplace, exceeding 200m; which is the limited distance one can walk. For this reason location 1, 5, 4, 8 fail. Between the streets 2-3 and 6-7, 6-7 is the closer of the two to the subway station. After deciding the 2 locations, draw a perpendicular bisector between these two possible locations. This gradually makes A (the intersection of road 6-7 and the bisector) the final spot for a new rental station.

[Situation 2: Commuting Route: Driving from Home to Workplace]

We agreed that people living within 4km from the workplace can cycle to work.



The green circles show the place where bicycle rental stations can be built outside the central business districts. In this way people can access this system wherever they live in this area by walking 200m at most.

Residents in this area can take a bike at a nearby station and return it when they enter the circle of the workplace which has a 200 meter radius. From this place, people are able to walk until they reach their workplace.

STEP 2

Our team assumes that

① Need for bicycle is proportional to the city's congestion.

② When n(k) cars go through the intersection per hour, the region's congestion is 1.

(for clarify n(k), we need more accurate investigation)

The need for bicycle depends more on region's congestion than its population.

$$\frac{(\text{number of cars in the region} \times (\text{region's congestion})^2) \times (1.3)^n}{100 \times \text{number of rental stations in the region}}$$

We defined the number of cars in the region as

$$\{ \frac{\text{Certain region's population}}{\text{City's total population}} \times \text{employed population} \times 0.02 \}$$

So if you substitute this definition to the first formula,

$$\frac{(\frac{\text{Certain region's population}}{\text{City's total population}} \times \text{employed population} \times 0.02 \times (\text{region's congestion})^2) \times (1.3)^n}{100 \times \text{number of rental stations in the region}}$$

= Number of bicycles located at a certain station (before anybody lends/returns a bicycle)

n= years passed after the starting the rental system

The region's congestion is divided into 4 levels as the following:

Very Uncongested = 1

Uncongested = 2

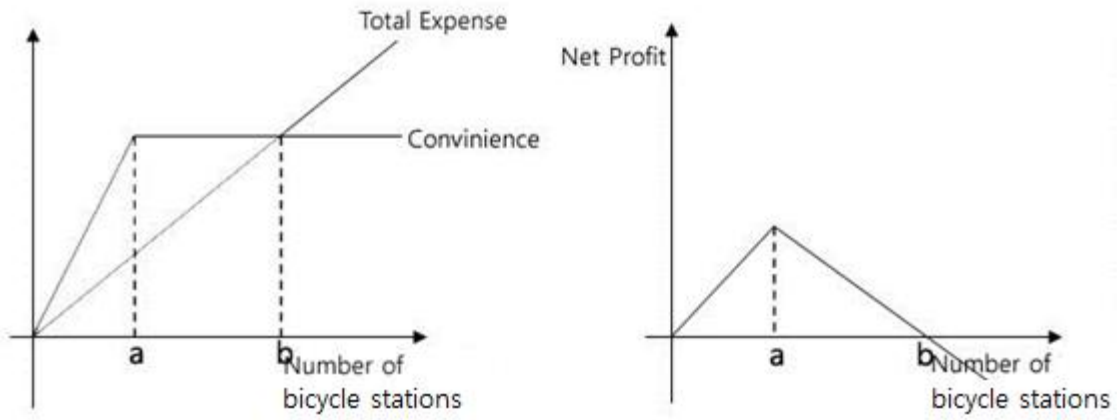
Congested = 3

Very Congested = 4

The number that has to be substituted gets bigger as the road is more congested because more bicycles are needed to replace the cars.

Throughout research, we found out that

The number of rental stations can be determined by the following graph.



As the number of bicycle stations increase, the total expense needed to build new bicycle stations grows too. The convenience people get grows also. However, the number of people using bicycles is limited, and this causes the convenience graph to become horizontal.

The right graph shows the fluctuation in net profit according to the increase in number of bicycle stations. The net profit equals (Total expense - Convenience). Until point a, the net profit increases gradually. But after point b, the total expense grows and after point b, the total expense outweighs the convenience; making the net profit below zero. The point where the net profit is at its maximum is point a. So we found out that it is the most profitable when 'a' bicycle stations are added

Moreover, the total expense cannot exceed the budget. So 'a' should be lesser than the value of (budget / cost of one bicycle). This process will determine the number of bicycle stations.

It is assumed that bicycle users increase 30% each year. We sent an e-mail to Denver B-cycle asking the number of bicycle users, and received a reply.

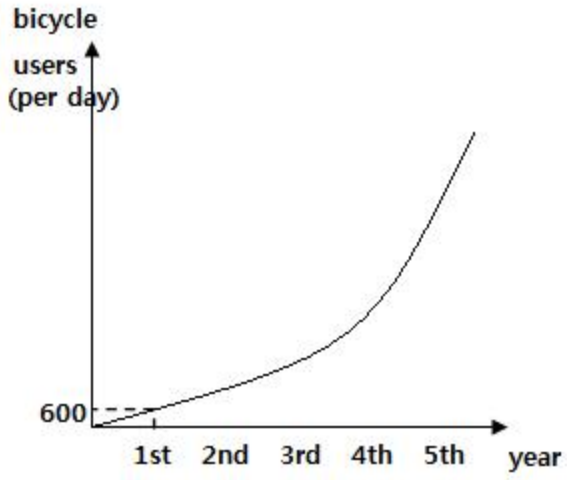
Hi there,

I ran a report over a 4 month period and have an answer for you. Between July 4, 2010 and November 6, 2010, there were a total of 72,091 checkouts. The daily average over that period was 552 bike check-outs per day. I would say from what I have seen, we would usually expect to see 600+ check-outs per day. Now that the weather has been a little colder and wetter, as of October, we have seen the average decline to about 400 per day. The 552 average over those 4 months, however, should be a good number to go by.

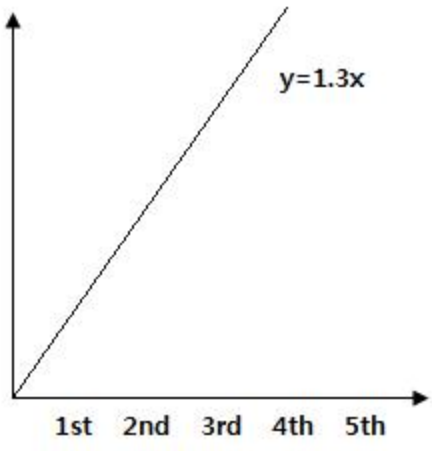
Hope this helps,

Tyler Reeder
Customer Relations
Denver Bike Sharing
(303) 825-3325

This year, people checked out about 600 bikes per day, the graph will show this fact.



Graph 1



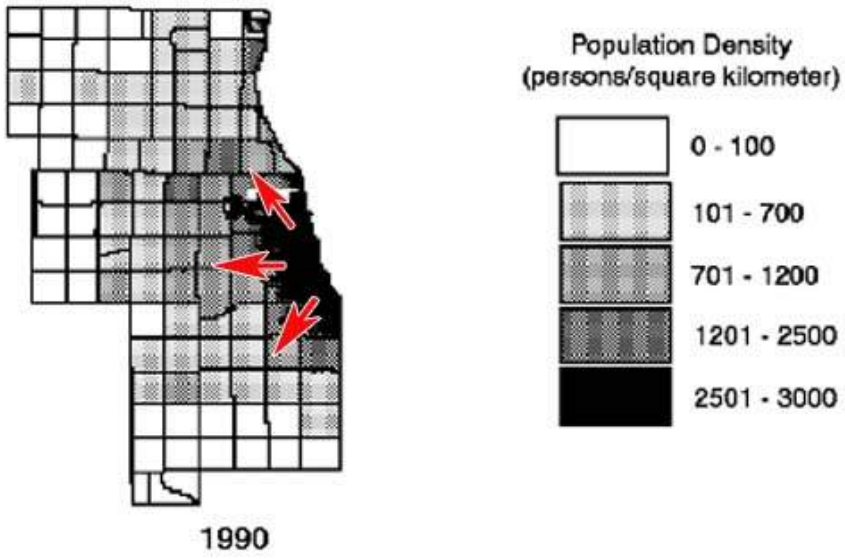
Derived function of Graph 1

$$X_{n+1} = x_n \times (1.3)^n$$

If this year's number of bicycle users are x_n, the following year's users will be X_{n+1} people.
So this will determine how many bicycle stations to build each year.

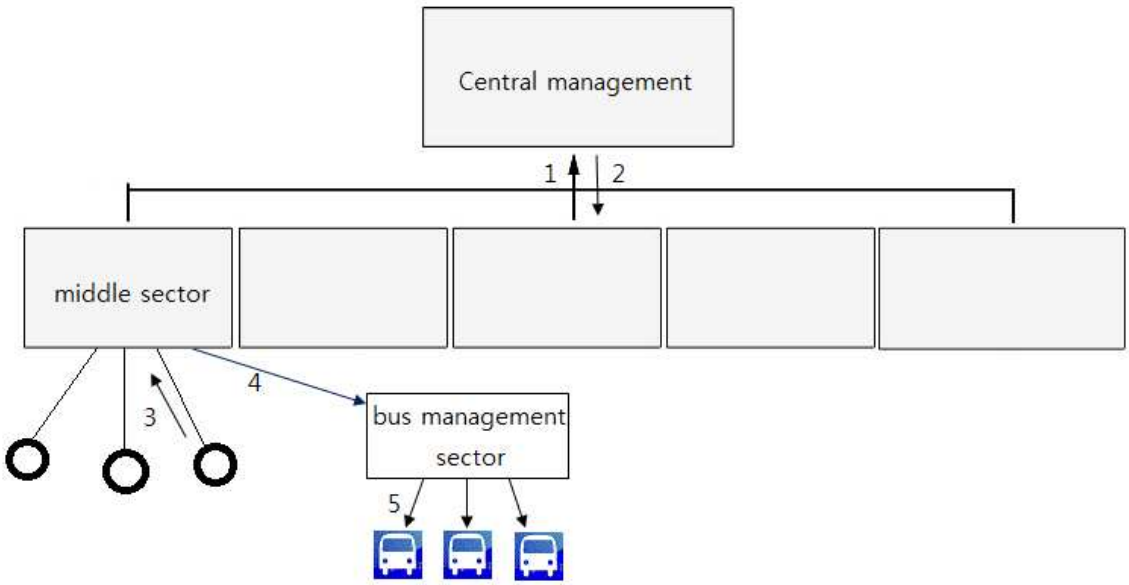
STEP 3

Adjust STEP 1 to place the rental station of expanded area. Locate extra stations in population order. (Census done in 1990, the latest population research of Chicago.)



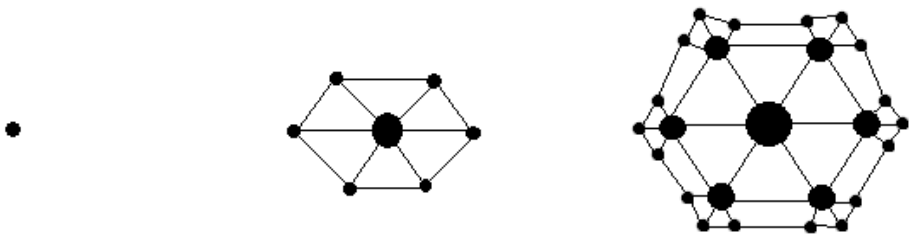
STEP 4

The numbers and the sizes of each station's type depend on its centrality. They communicate by a network database connecting all stations in the city.

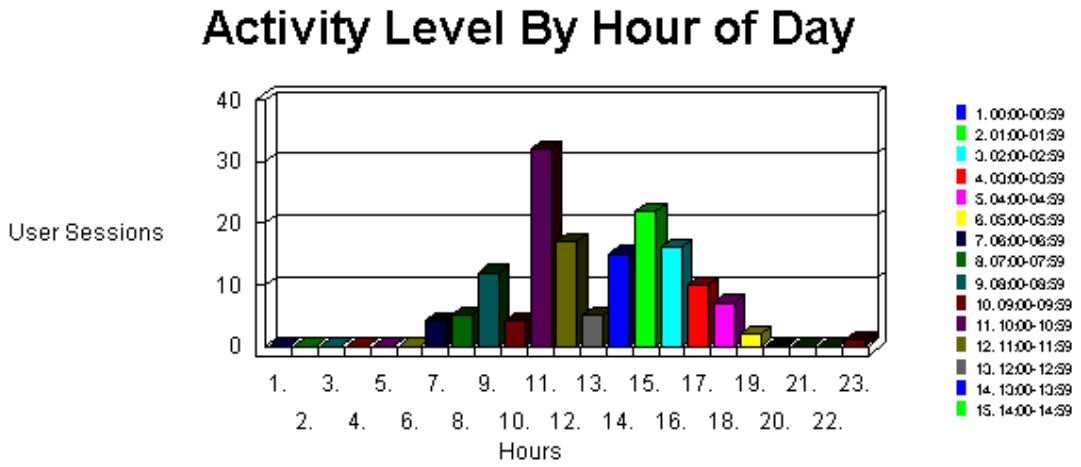


Arrow 1. The largest station supervises the total system. It collects all information and determines how many bicycles each station should have. According to this information, it also allocates the buses that run to rearrange the bicycles. Furthermore, it is in charge of lost or damaged bicycles too.
Arrow 2. The middle sector reports the information received from the smallest stations.
Arrow 3. Individual stations report how many bicycles are rented and returned.
Arrow 4. The middle sector sends the order

-weighted graph

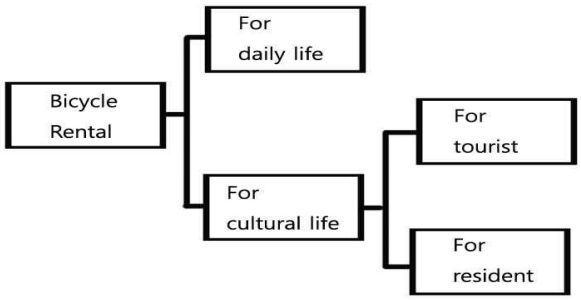


Buses for allocating will run through the city between am12:00 and am5:00 when the activity levels are low in the attached graph.



STRATEGIES FOR OUR PLAN

① Divide the categories of bicycle rental usage.



For daily use – <step1>

For cultural use – Find the overlapped area where hotels and attractions are located.

② Compare and contrast with other nation's system.

France - Financial burdens for stolen and broken bicycles > profits

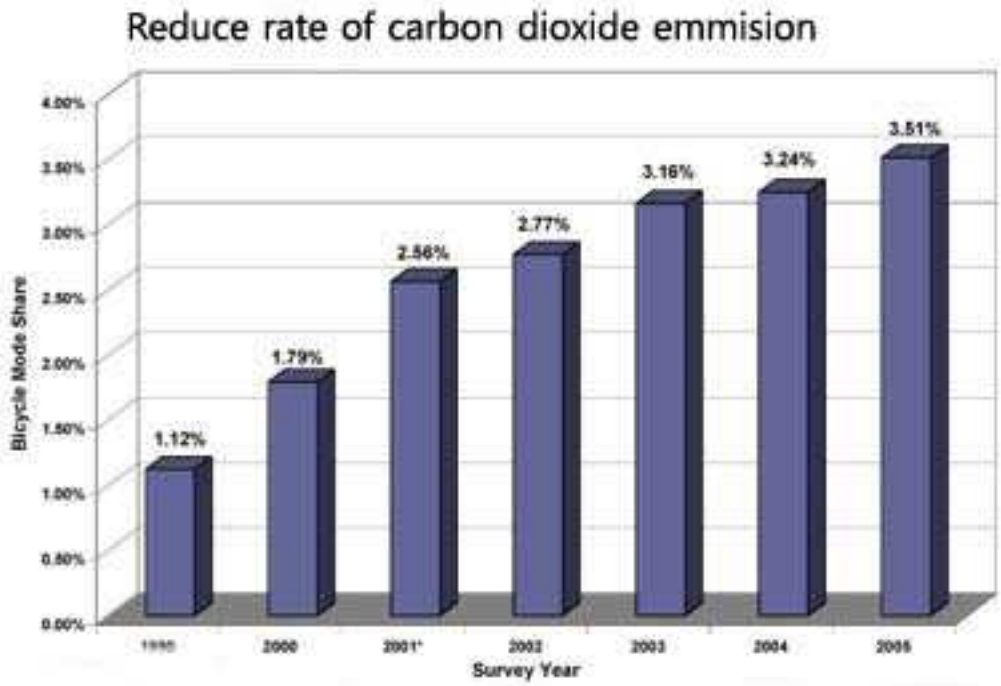
England - Manage the raising funds with the Bank Barclays

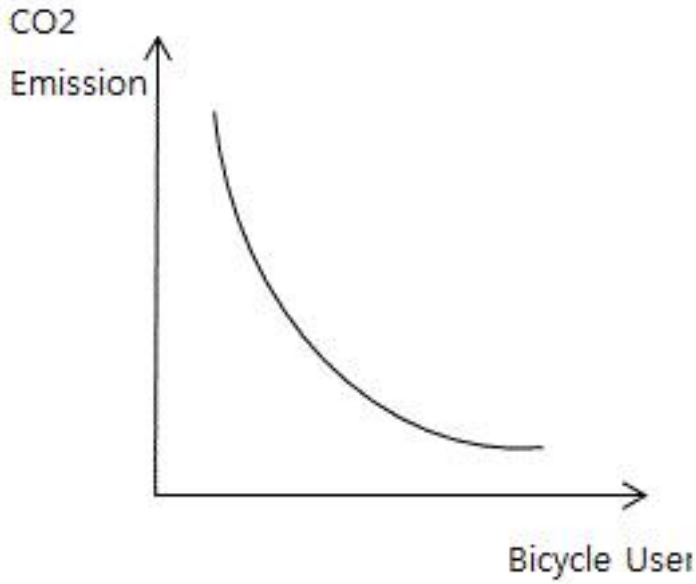
③ Consider region's special features and adjust the differences to the new policies.

Ex) Temperature of winter in certain region is too low to operate bicycle rental system.

EXPECTED RESULTS

- CO_2 emission would be reduced by 30% in 5 years.
- Congestion in the city would be eased.
- It would be the solution for the lack of parking lots or expensive parking fee.





[Model 1-Chicago]

그림 1-Present locations of Bcycle rental station

Orange line – Congested area

Black line – More congested area

Blue circle – possible locations for bicycle rental station.

Considering the mass congestion around the downtown and long intervals of CTA (Chicago Transit Athority), locating rental stations in circled area would be most beneficial.

그림 2- Hotels and tourist attractions

Red dots – Tourist attraction

Green dots - Hotel

Setting rental stations in these area which tourists are concentrated and these areas are narrowly spreaded, would raise the economic profits of city's tourism industry.

[Model 2-Denver]

Red circle – Subway station

Denver city already has efficient amount of subway stations in its business district and B-cycle rental stations in their central region.
We focused on the edges around the central area which has a large population.

Blue circle – Possible locations for bicycle rental stations

Light blue rectangle – Area with a large population.

We set possible locations near the main roads and area with a large population.

[Model 3- Des Moines]

Brown circle – Possible locations for bicycle rental stations

The river crosses over the middle of city Des Moines. As the map shows, hotels and tourist attractions are dispersed around the river. We selected the sites of rental stations considering the accessibility to those locations related to tourists.

Dear mayor of Chicago,

We know Chicago has been dealing with problems like increasing gas emissions, high parking fee, lack of parking space, etc.

We thought of a way that can solve all these serious problems at one swoop and also can bring positive economic benefits in your city's tourism industry.

According to our research, people feel like riding bicycles either when they have to walk too long a distance or when their cars can't move fast enough because of traffic congestions.
Moreover, the demand of bicycles in each station depend on not only region's population but also on its traffic volume.

Considering all of these facts, the best location for rental station is the place near the busy business district with a large floating population.
In the case of tourism, we did research on all the hotels and tourist attractions of your city and could locate ideal rental station sites that can induce more business and tourism.

If rental stations are built around that overlapping area, it will benefit both tourists and the city. Moreover, buses for reallocation of bicycles will settle the matter of imbalance (which resulted from difference in density demands) in the night time.

We truly believe that we can prove our system's success through accurately designed mathematical and scientific methods.