Analytics and Bikes

Baturay Yalçın Saral
Berkan Erdil
Baturalp Köse

Introduction

Station-based bike-sharing system

2 types of user

Full Docks-Empty Docks

Deploy box trucks or vans cause large operating cost

Projects

There are 2 project

1.Re-allocating Dock Capacity

2.Incentive Program-Bike Angels

Re-Allocating Dock Capacity

Aim: Re-allocating capacity among stations

Step 1: Assign docks to stations

Step 2: Identify optimal allocation for bikes

Step 3: Determine re-allocation (at most 1 bike and 1 dock for each iteration)

Incentive Program-Bike Angels

Aim: Reward customer for riding bikes to desired station

UDFs : User Dissatisfaction Function

Function of expected number of dissatisfied users over time

This project is mainly based on UDFs

2 types of unsatisfied customers.

1. No bikes available at the dock and user attempts to rent a bike
2. No empty dock available and user attempts to return a bike

In these situations dissatisfied customers leaves the system without rental / return.

Mathematical Model

Let $x_1 \ldots x_T$ be the sequence of arriving customer and

$X_i \in \{-1, 1\}$ where $X_i=1$ if customer returning a bike

$X_i=-1$ if customer renting a bike

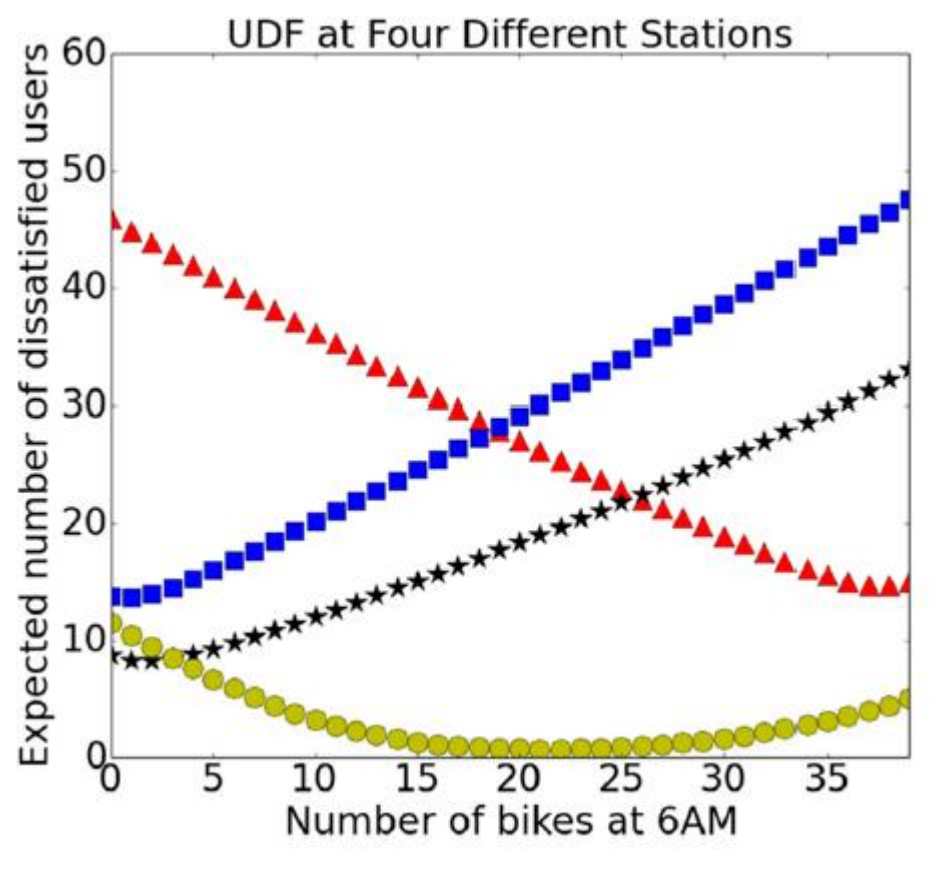
K: Capacity

b_0: beginning bike in inventory

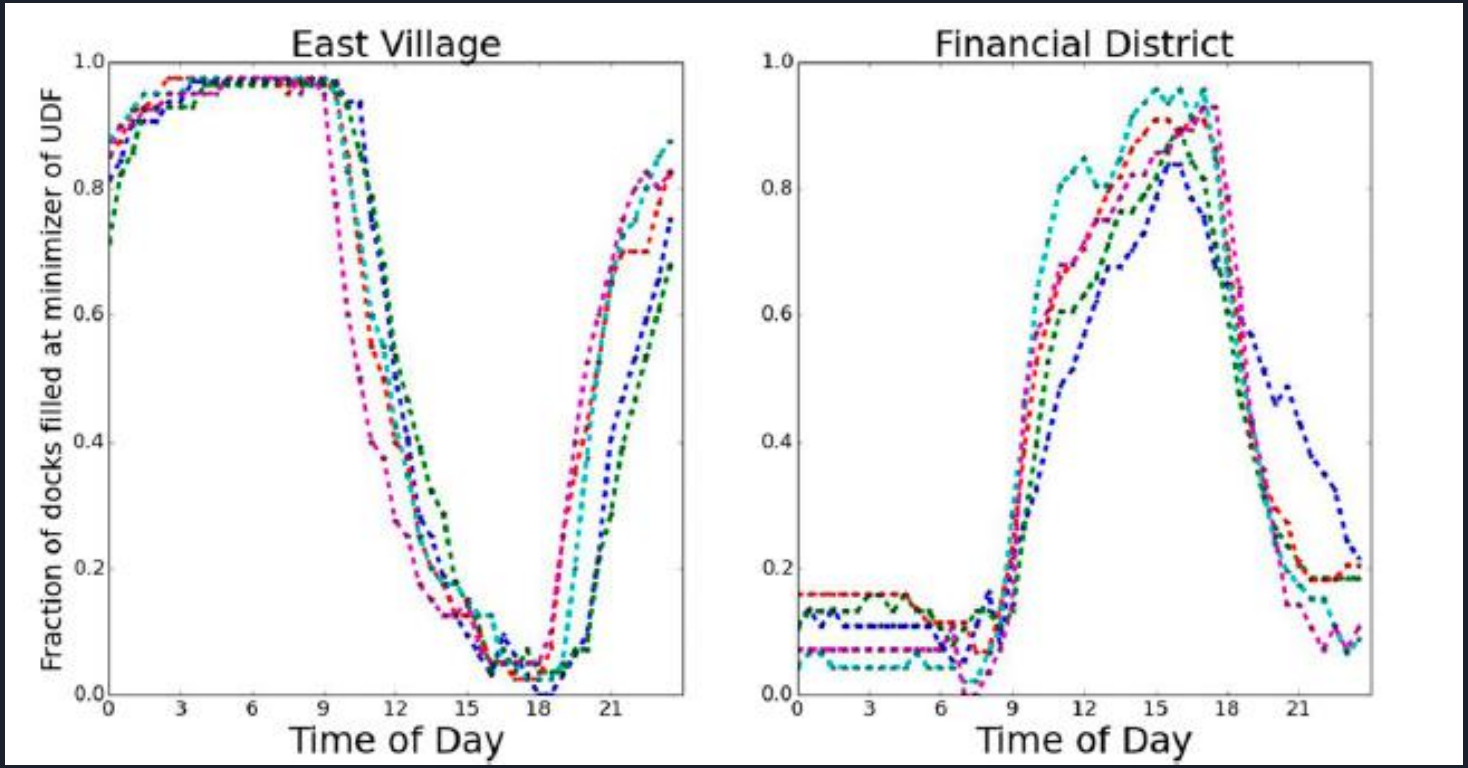
b_t: numbers of bike after arrival of customer t;

$b_t = \min\{\max\{0, b_{t-1} + X_t\}, K\}$

Then dissatisfied customers denoted by $c(b_0,K)$



Sample UDF at four different stations



Bike demand during rush hours

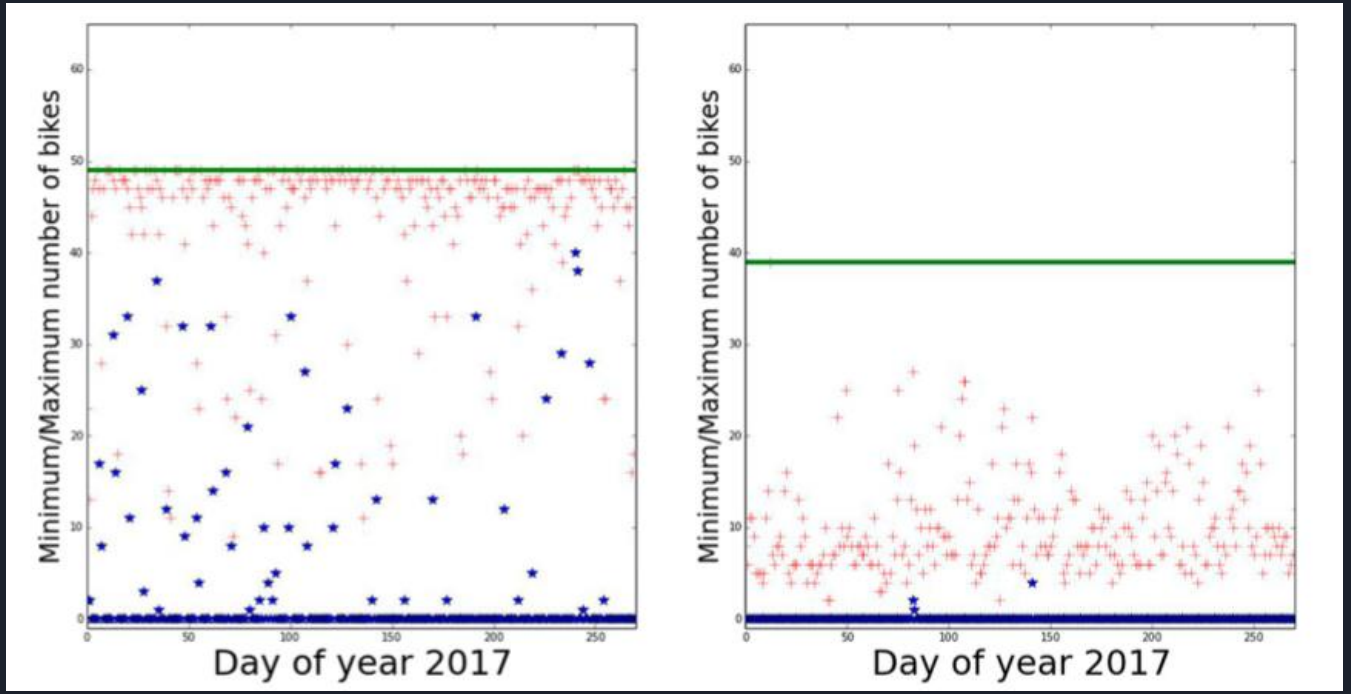
Allocating Capacity

They develop a deeper understanding of demand patterns that underlie Motivate's systems.

Why? Motivate's system was determined before the system themselves launched.

No observation of the actual demand patterns

Purpose: Reducing stockouts.



Minimum Number of Docks Used

Maximum Number of Docks Used

Integer Programming Model

K_i = capacity at station i

INPUT ⟶ ADDITIONAL DECISION VARIABLES

QUESTIONS

TECHNICAL

- Resulting nonlinear IP solution is not obviously solvable.
- In contrast to the optimization over bikes only, the integrality property of this IP's linear relaxation does not need to hold.

PRACTICAL

- Involve more reallocated docks than stakeholders approve.

Political Constraints

(Department of Transportation)

Operational Constraints

(From Motivate)

Gradient Descent Search: Local and Global Optima

$$\begin{aligned} \underset{\vec{b}}{\text{minimize}} \quad & \sum_i c_i(b_i, K_i) \\ \text{s.t.} \quad & \sum_i b_i \leq B, \\ & \forall i \;\; 0 \leq b_i \leq K_i. \end{aligned}$$

c_i = Cost at station i

b_i = The number of bikes at station i

K_i = The number of docks at station i

B = Total number of bikes available

When dock moves are considered,

$$\sum_i |K_i - \bar{K}_i| \leq 2k$$

$\bar{K}_i$ = Current number of docks at station i

At most 2k docks are removed.

- We can define an undirected graph on the set of feasible solutions by associating one node with each feasible solution.
- Adjacency: If their respective allocations differ by at most one dock and one bike being reallocated.

LOCAL OPTIMUM = Node with objective value no more than that of each node adjacent to it.

- By looking at feasible solution, we can iteratively update to the best solution on the neighborhood of the solution currently obtained.

Multimodularity (Hajek 1985)

- More general property of UDF.
- One can view this property as a kind of multidimensional diminishing returns property.

Example:

Station: 10 empty dock, 10 full dock

+1 full dock

Same as, 11 empty dock, 10 full dock

+1 full dock

k^{th} iteration = moving at most k docks

- Without constraint: local optimum = global optimum
- If local optimum ≠ global optimum

Find another feasible solution with better objective function value. Choose feasible solution closest to the local optimum in the graph.

If there are multiple nodes equally close, choose one arbitrarly.

In Practice

- We can find that the potential of reallocated capacity faces strong diminishing results.

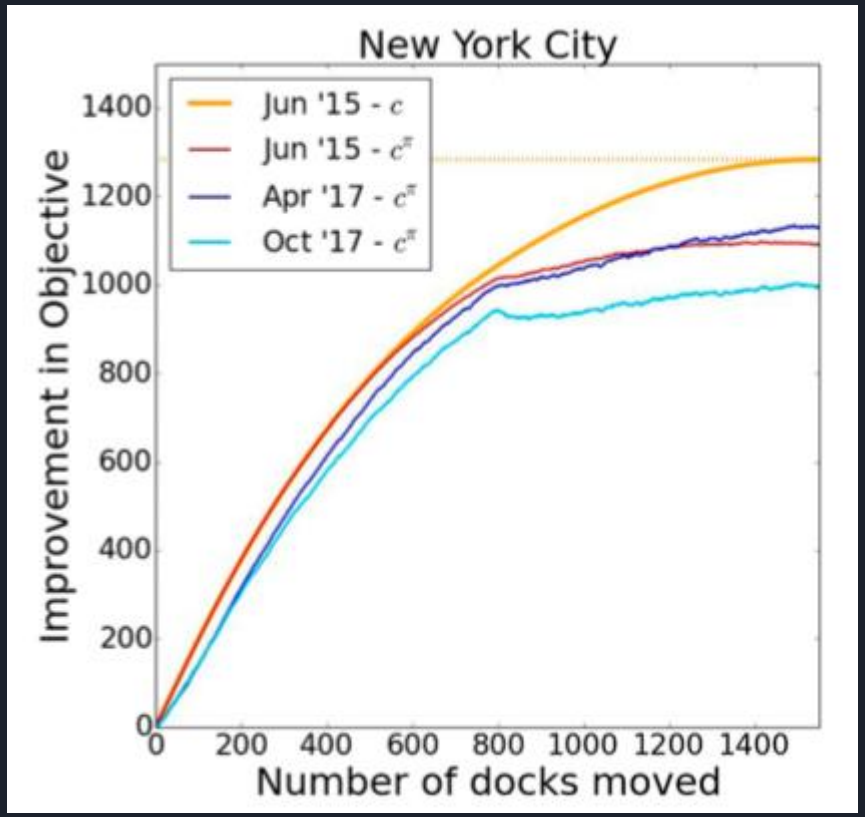
Example: In NYC the potential of reallocated capacity can be realized through strategic reallocations of a few hundred docks.

Moving thousand of docks

Robustness

- In addition to daily rebalancing the bikes, physical reallocation of docks is a much more complicated operational procedure.
- Dock reallocations must be thought of on at most an annual basis. Because demands is heavily affected by seasons.

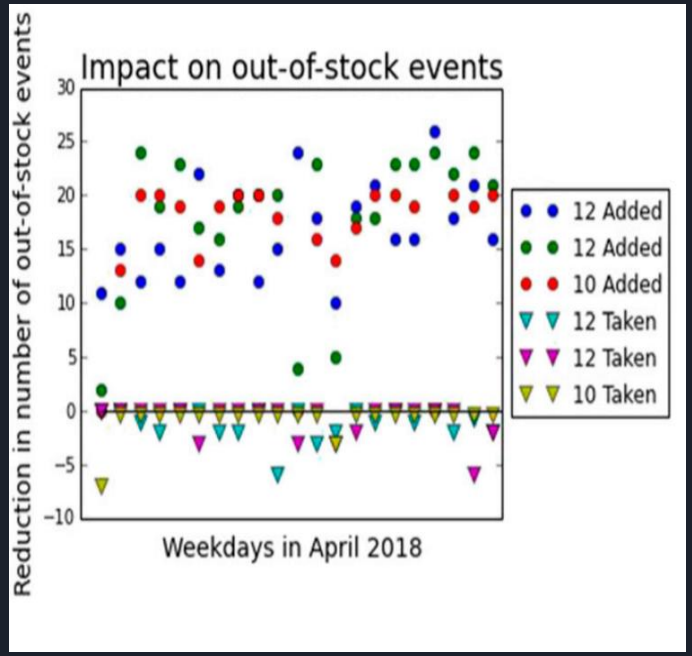
Example: NYC number of stations increased from 330 to 700 since 2015.



The improvement from reallocated capacity is extremely robust despite the strong seasonal effects on total demand.

Implementation and Evaluation

- November 2017,Motivate launched a pilot project
- Relocation of 34 docks
- Additional and reduced capacities in 3 stations.
- April 2018, number of stockouts decreased while the demand is the same.
- For Additional Capacity reduced stockouts on average = 1.5 per dock per day
- For Reduced Capacity increase in stockouts = 0.08 per dock per day
- Rebalance = 1.42 fewer bikes per dock reallocated



Bike Angels

-In ride-sharing sector, mostly dynamic pricing is used.

-Not feasible for Motivate.

- Annual subscriptions.

- “CitiBike” application is developed.

- An incentive program called “Bike Angels” is developed for the app.

Bike Angels

How does this program work?

- Encourage rides that are beneficial for system balance
- Based on a map that labels each stations as neutral, return or rent.
- Customers would receive points for trips
- Customers would receive rewards

Earning Points

EXAMPLE TRIPS

1 point: Start at neutral station, bike to 1-point Drop Off

0 points: Trips with Drop Off points at trip start will not earn points

2 points: Start at 2-point Pick Up station, bike to neutral station

0 points: Trips with Pick Up points at trip end will not earn points

3 points: Start at 2-point Pick Up station, bike to 1-point Drop Off station

0 points: Biking from empty to full stations won't earn points either

Points and Rewards

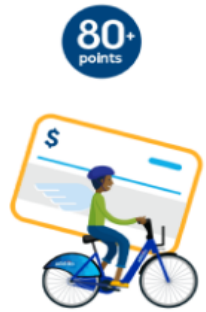
Every Bike Angels point you earn is added to your **monthly, annual,** and **lifetime** point totals. We'll be adding new rewards throughout the year.

Monthly Rewards

Monthly points earn rewards that keep you and friends riding longer. Monthly points reset the 1st of each month.

One 24-hour day pass for one (extremely lucky) friend

Free 1-week membership extensions for every 20 pts



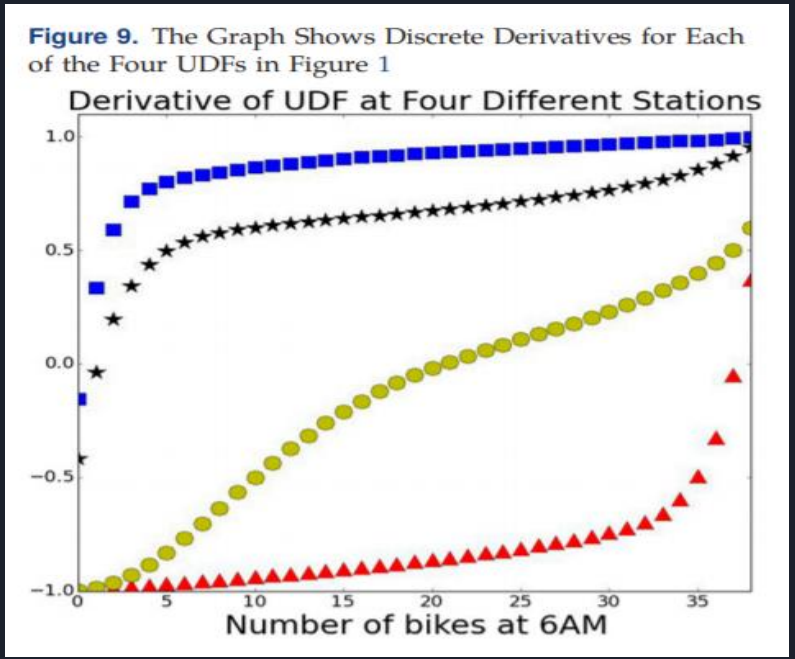
Cold hard gift cards delivered right to your email

- **10 points**: 24 hour Day Pass for one extremely lucky friend (expires 3 months after earned)
- **20-80 points**: Free 1-week membership extension for every 20 points
- **80+ points**: Gift cards delivered right to your email, $1 per 10 points above 80

Bike Angels

Static Program-First Trial Of an Incentive Program

- Fixed labels
- Advantage: User Experience
- Disadvantage: Inefficient trips can be rewarded.
- Discrete derivative of UDF is computed to evaluate the impacts of incentivized return.

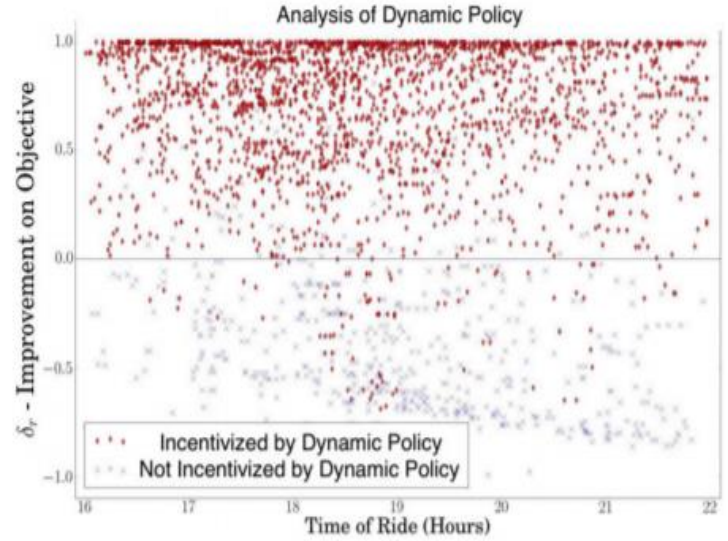


Bike Angels

Dynamic Policy

- A data set from static program is used for investigating the frequency of relabeling.
- Relabeling stations in every 15 minutes is sufficient for efficiency.
- If the time interval increase, efficiency decrease.

Figure 11. A Scatterplot Depicts the Set of Incentivized Rentals and Returns by the Static Program for a Limited Period During Afternoon Commutes



Example in Turkey

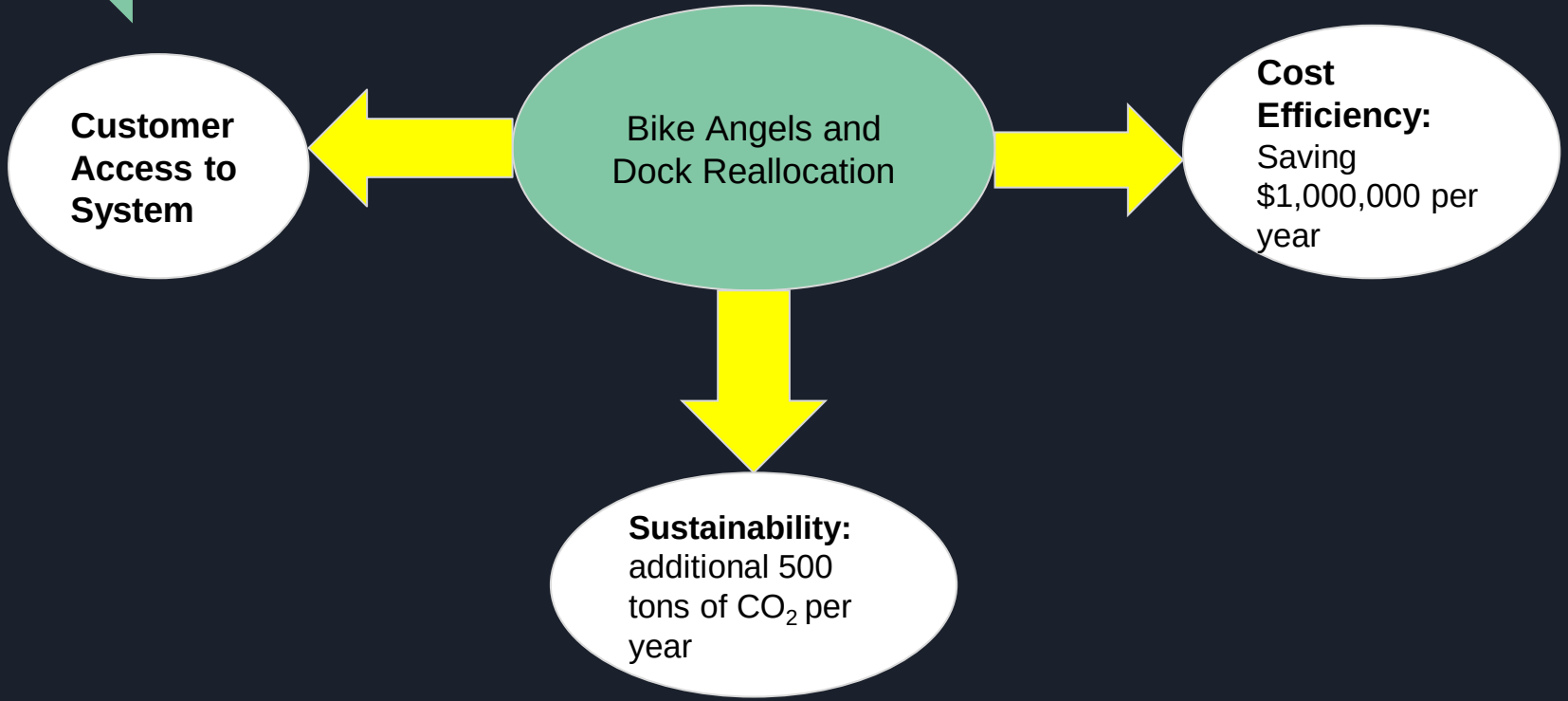
- MARTI

Avaible at Bilkent too.

It is collected by vehicles time to time.

There is no docks with certain capacity.

Conclusion


Customer Access to System
Bike Angels and Dock Reallocation
Cost Efficiency: Saving $1,000,000 per year
Sustainability: additional 500 tons of CO_2 per year

References

Daniel Freund, Shane G. Henderson, Eoin O'Mahony, David B. Shmoys (2019) *Analytics and Bikes: Riding Tandem with Motivate to Improve Mobility*. INFORMS Journal on Applied Analytics 49(5):310-323. https://doi.org/10.1287/inte.2019.1005

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“Thank You”