# Moo-rings

## Marina Mooring Optimization

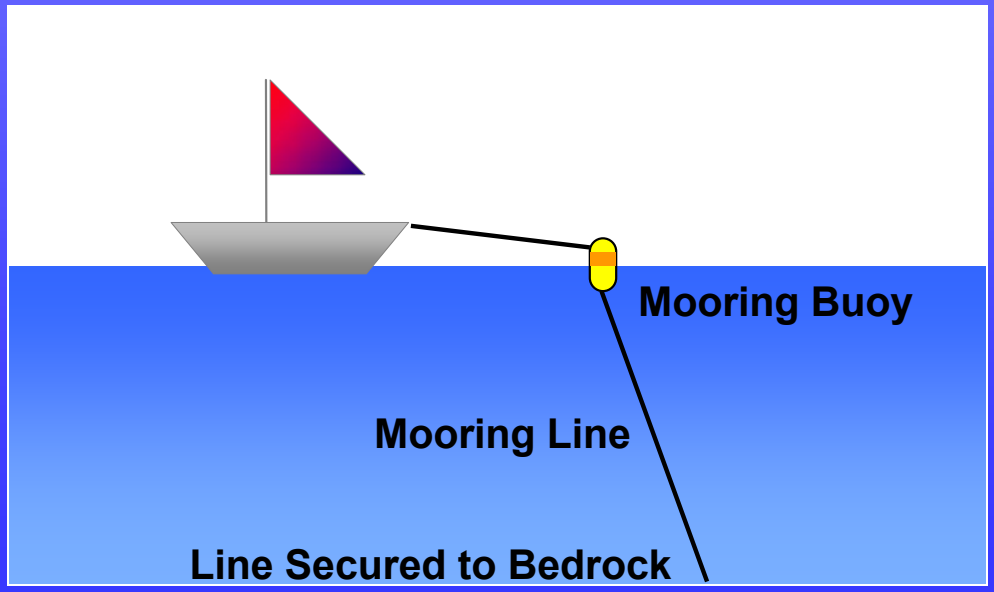
**Group 8 – Route 64**
Brian Siefering
Amber Mazooji
Kevin McKenney
Paul Mingardi
Vikram Sahney
Kaz Maruyama

# Presentation Overview

- Introduction
- Problem Description
- Assumptions
- Model Formulation
- Analysis
- Conclusions
- Lessons Learned
- Questions

# Introduction

- What is a mooring?
- Why an optimization problem?



# Problem Motivation

"Moorings are so scarce that in towns such as Orleans or Truro, the wait to get one can be as long as 20 years. In Sandwich, which has no moorings, only slips, the waiting list is closed with 1,200 waiting for a mere 200 spaces."

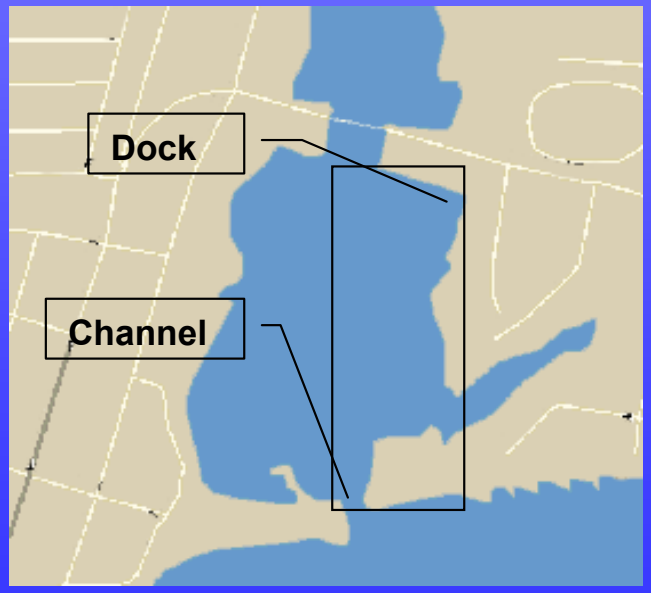
Cape Cod Times
8/10/2003

# Problem Description

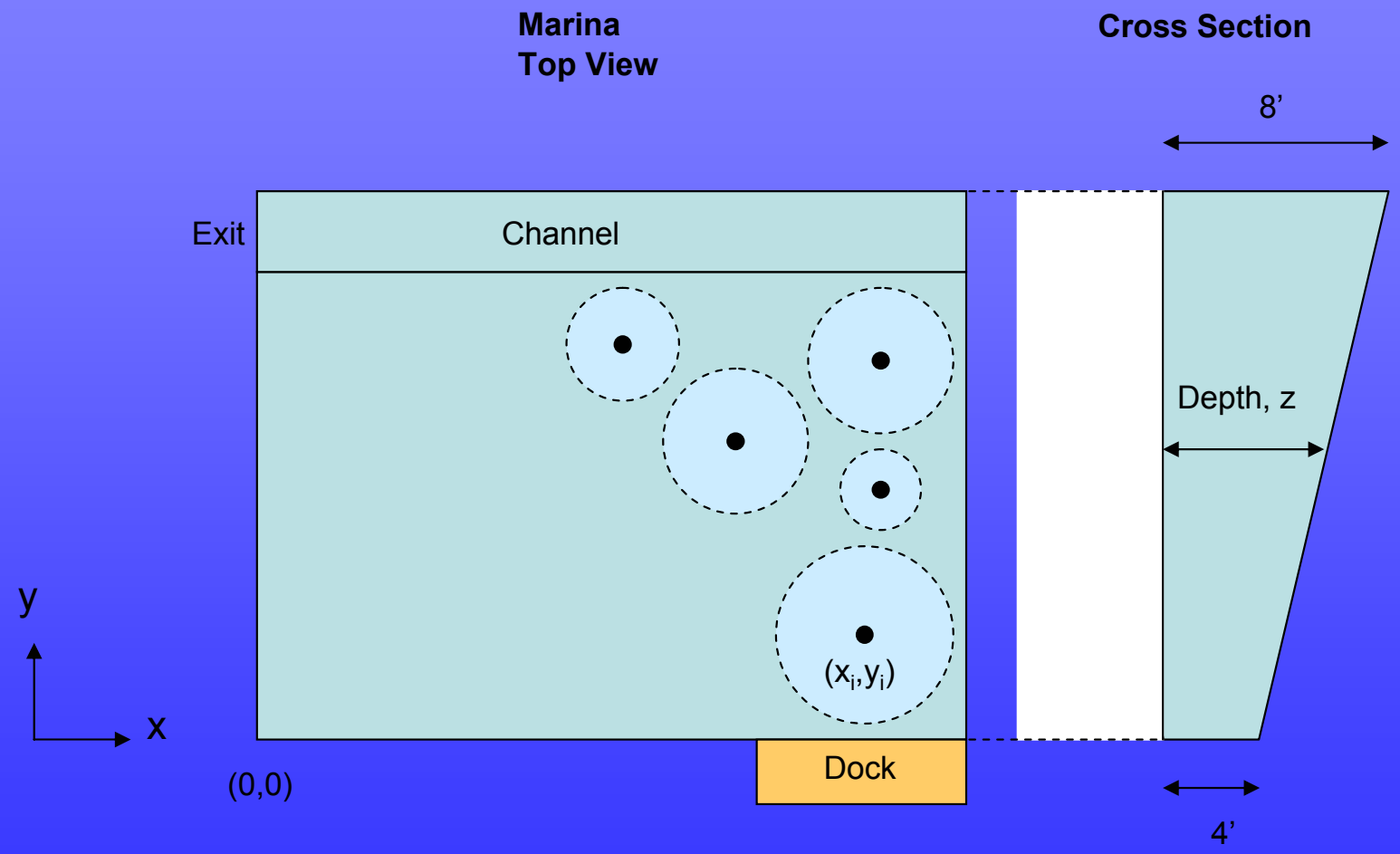
Objective: Maximize Revenue!

(also increase number of moorings in marina)

Decision Variables: Boat Locations



# Problem Description

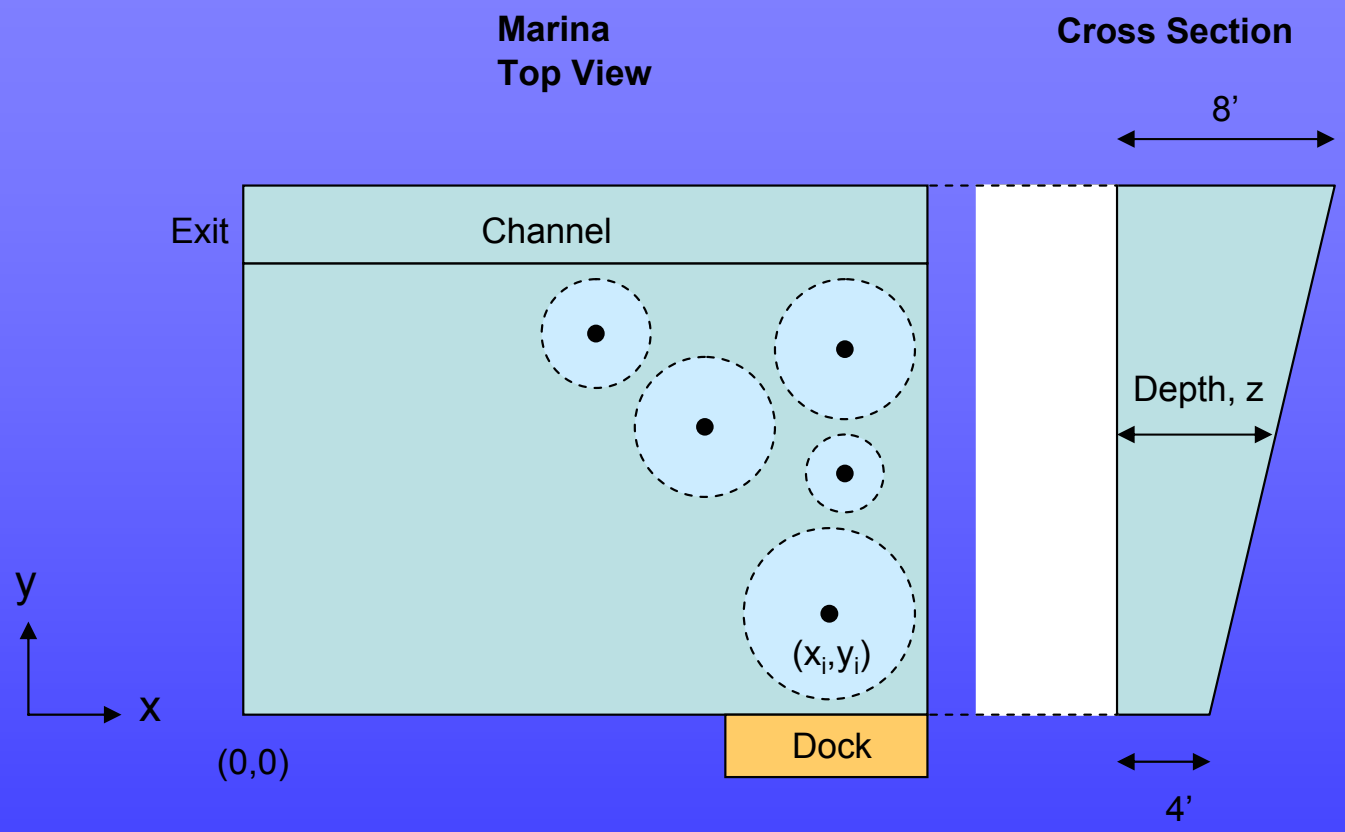


# Assumptions

- *Marina:*
  - The bottom of the marina is linear, sloping down in the +y direction.
  - Tide change is 2 feet or less.
- Moorings:
  - Mooring lines are weightless.
  - Moorings can and will be moved every year.
  - At high tide, the mooring line angle is 30.
- Boats
  - Boats are between 15’ and 40’ in length.
  - Boats are classified into two categories based on their hull depth: boats with hull depths less than 4’ and boats with hull depths between 4’ and 8’.
- Placement
  - Moorings can be precisely placed.
  - The minimum separation needed between boat sweeps is five feet.
  - Bow line length is negligible.
  - Boats will be able to leave moorings without specified lanes designated in a marina.

# Model Formulation

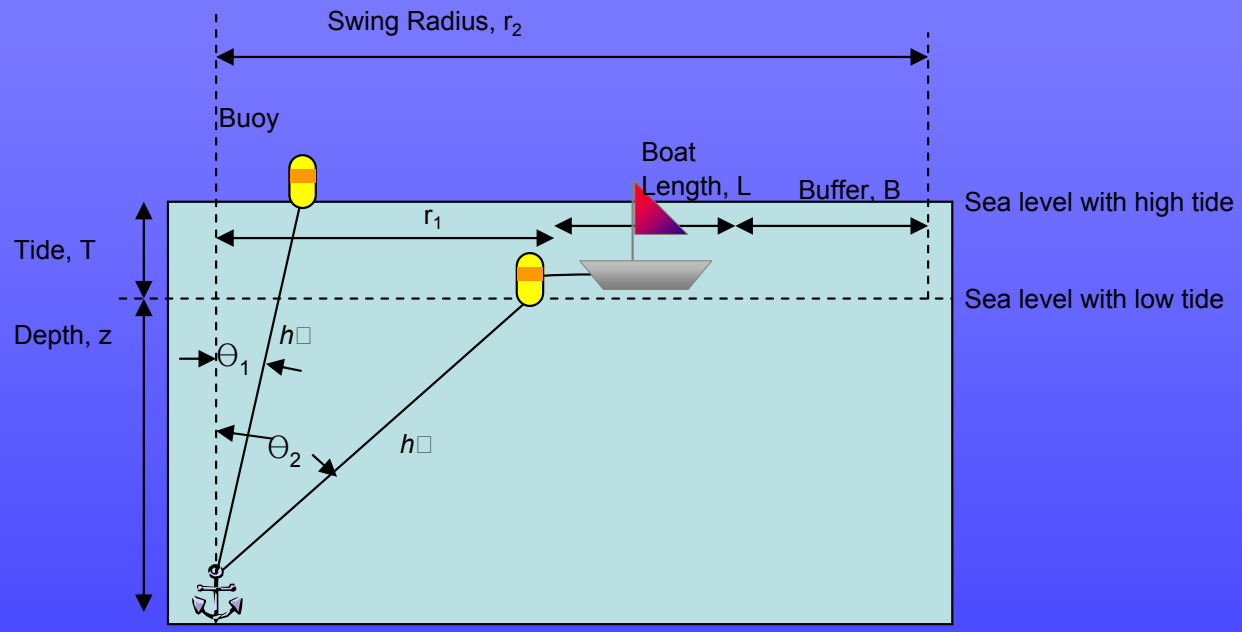
## Harbor Depth




$$z_i = D_{min} + \left[\frac{(D_{max} - D_{min})}{y_{max}}\right] y_i \quad \text{for } 0 < y_i < y_{max}$$

# Model Formulation

## Boat Sweep Radius




$$h_i = \frac{z_i + T}{\cos\theta_1} \qquad r_{2,i} = z_i \tan\left[\arccos\left(\frac{z}{h}\right)\right] + L_i + B$$

# Model Formulation

## Mooring Location Boundary Constraints

Prevent boat location and swing circle from exceeding the marina boundaries

$$x_i + r_{2,i} < X_{\max} \quad \forall i$$

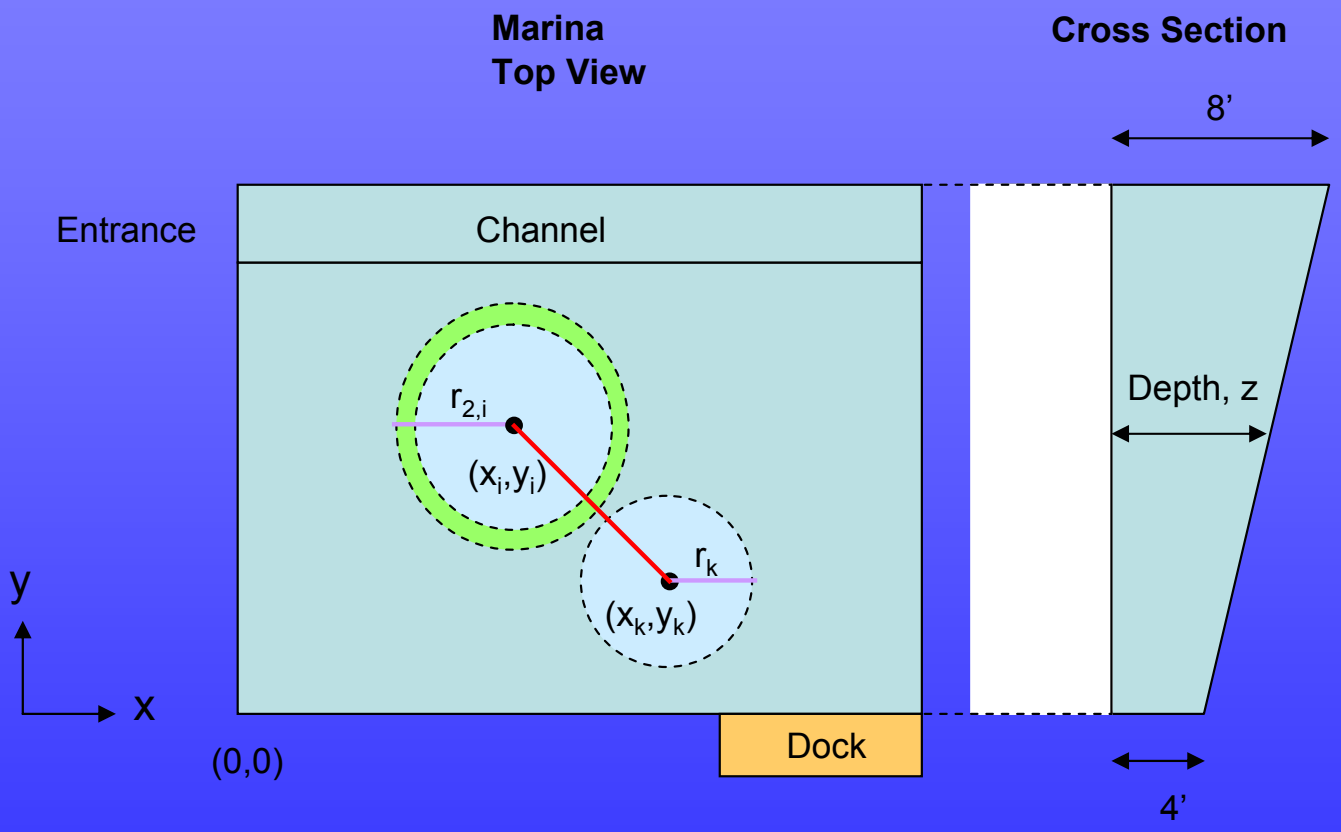
$$x_i - r_{2,i} < X_{\min} \quad \forall i$$

$$y_i - r_{2,i} < Y_{\min} \quad \forall i$$

$$y_i + r_{2,i} < Y_{\max} \quad \forall i$$

# Model Formulation

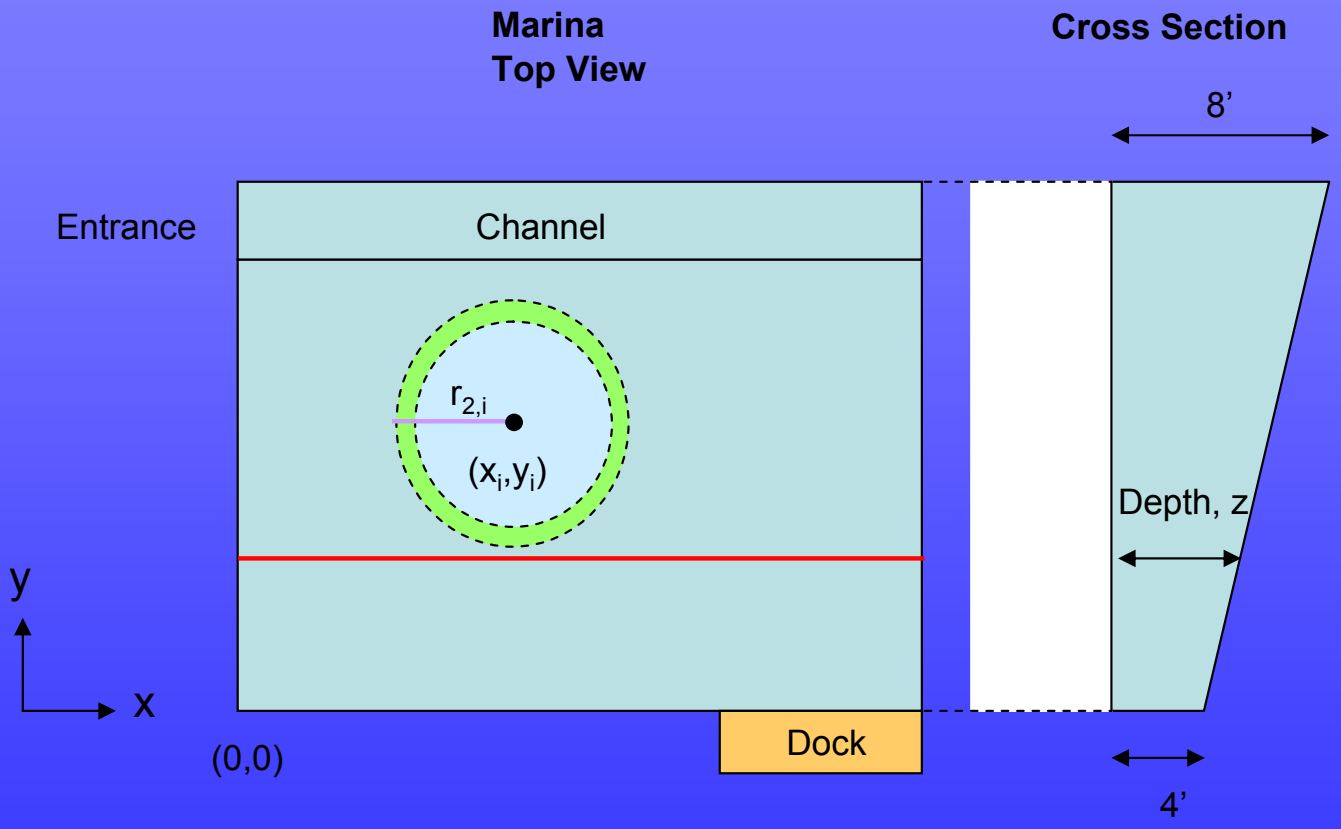
## Mooring Location Boundary Constraint




$$\sqrt{(x_i - x_k)^2 + (y_i - y_k)^2} > r_{2,i} + r_k \quad \forall i,k \neq i$$

# Model Formulation

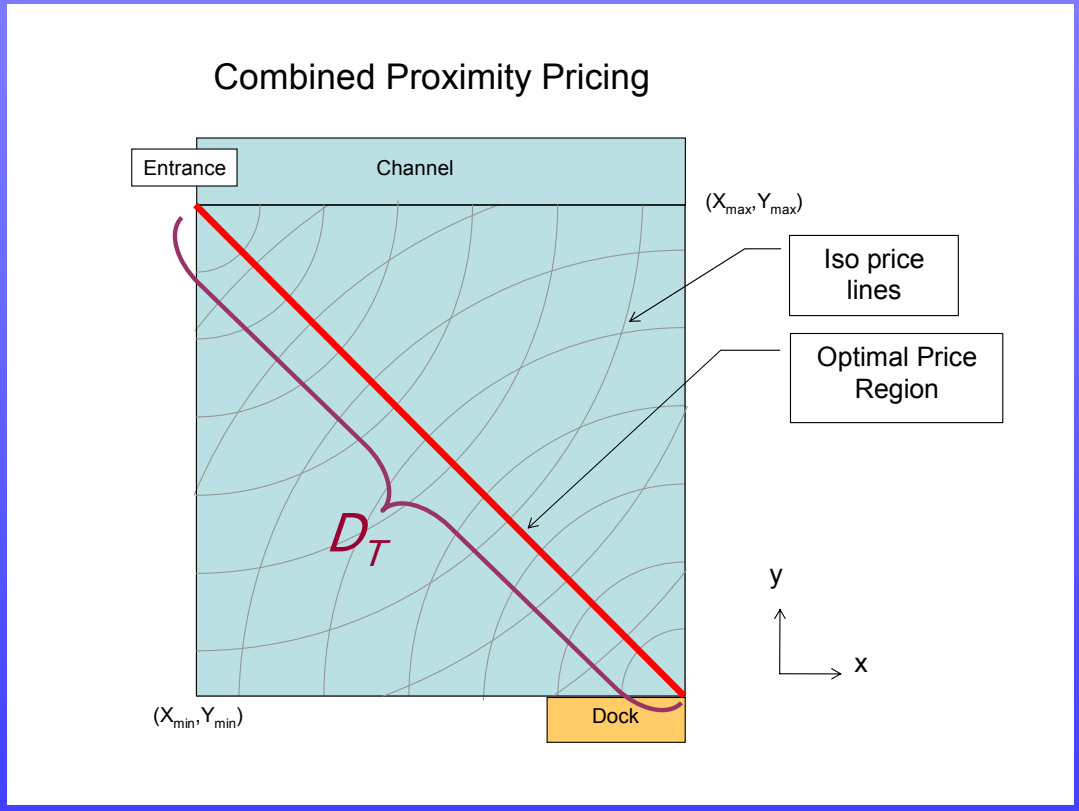
## Mooring Depth Boundary Constraint




$$D_{min} + \left( \frac{D_{max} - D_{min}}{Y_{max}} \right) \left( y_i - r_{2,i} \right) - D_i > 0$$

# Model Formulation

## Dock and Harbor Channel Proximity Price




$$P_{D,\max} = \frac{P_{D,\max} - P_{D,\min}}{D_T}$$

$$P_{C,\max} = \frac{P_{C,\max} - P_{C,\min}}{D_T}$$

$$D_T = \sqrt{\left(X_{\max} - X_{\min}\right)^2 + \left(Y_{\max} - Y_{\min}\right)^2}$$

# Model Formulation

## Objective Function

$$LF = Length\ Fee = \sum_j \sum_i P_j L_{i,j}$$

$$DF = Depth\ Fee = \sum_i P_{H1} D_i + P_{H2}(1 - D_i)$$

$$DPF = Dock\ \mathrm{Pr}oximity\ Fee = \sum_i P_{D,\max} - P_D \sqrt{(X_{\max} - x_i)^2 + (Y_{\min} - y_i)^2}$$

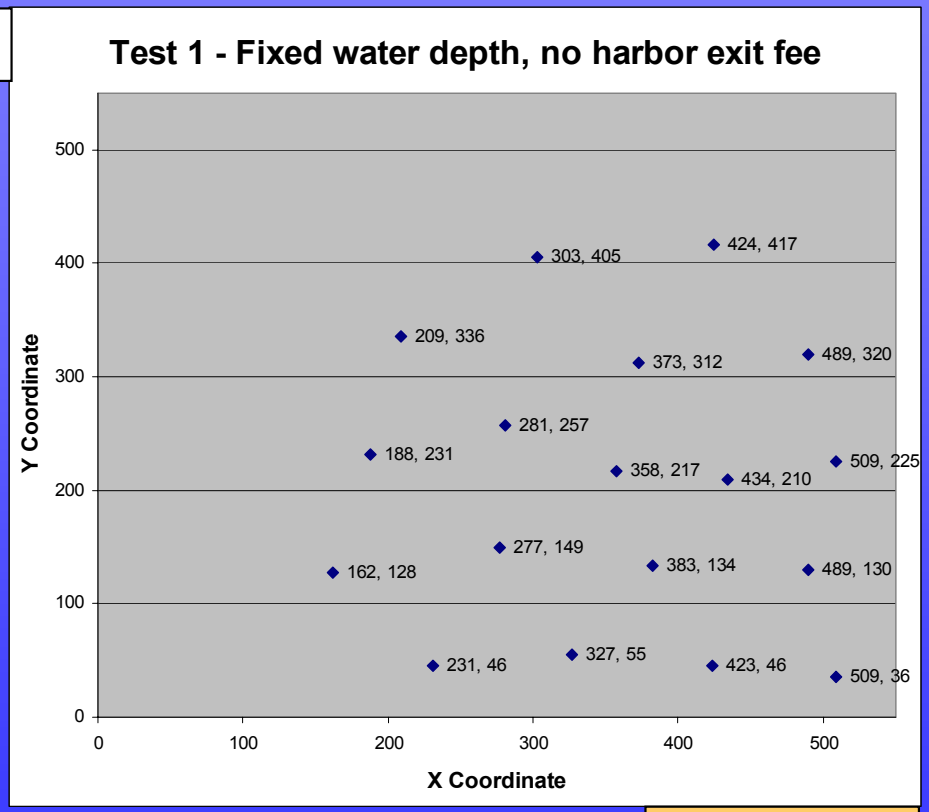
$$CPF = Channel\ \mathrm{Pr}oximity\ Fee = \sum_i P_{C,\max} - P_C \sqrt{(Y_{\max} - y_i)^2 + (X_{\min} - x_i)^2}$$

$$Mooring\ Fee = LF + DF + DPF + CPF$$

# Analysis

## Run 1 – Constant Harbor Depth and No Channel Exit Fee

Exit

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# Analysis

## Run 2 – Constant Harbor Depth and No Dock Fee

$ $ $

Exit

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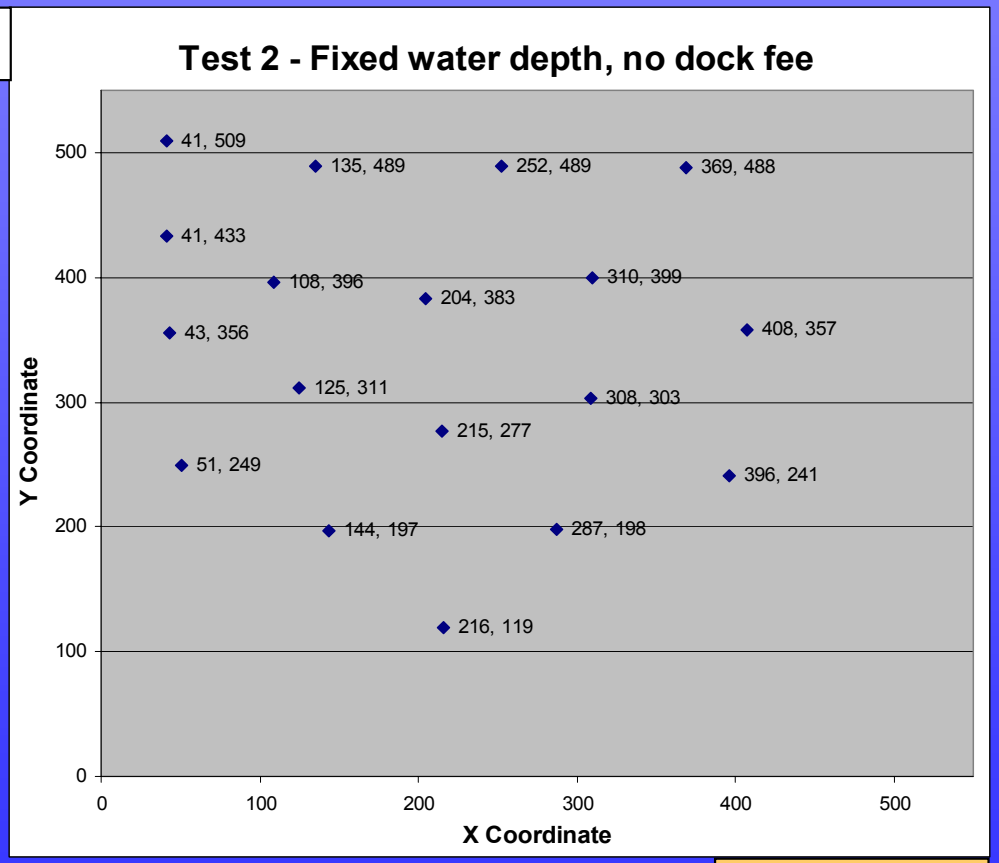


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# Analysis

## Run 3 – Fixed Harbor Depth, Equal Proximity Pricing

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Exit

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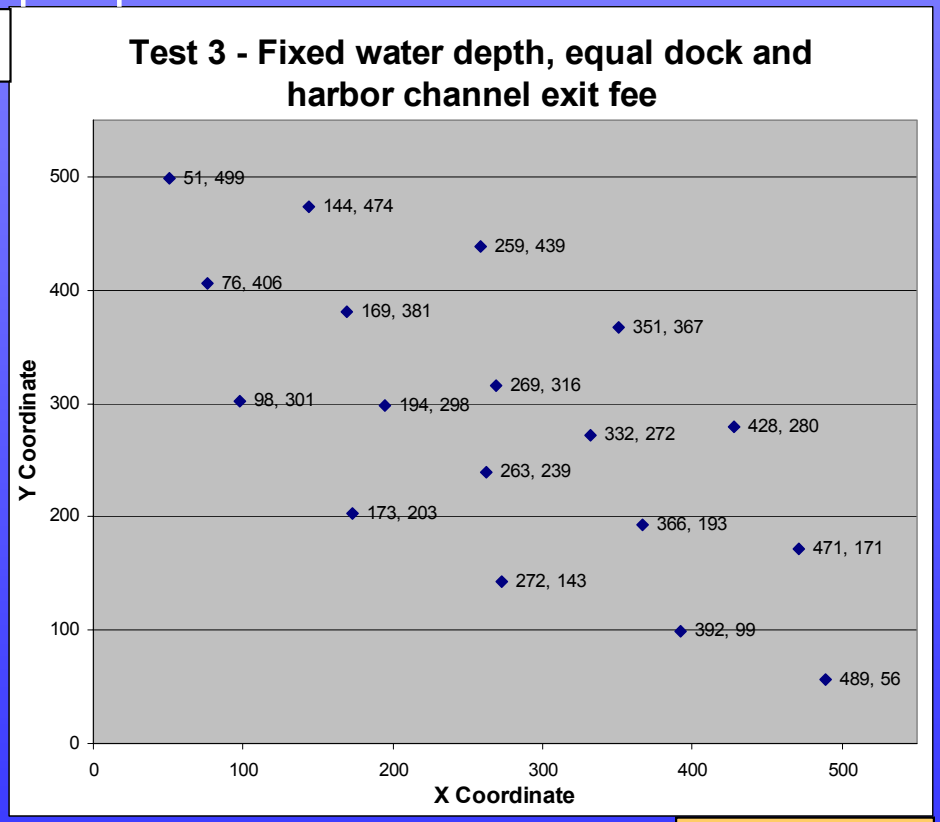


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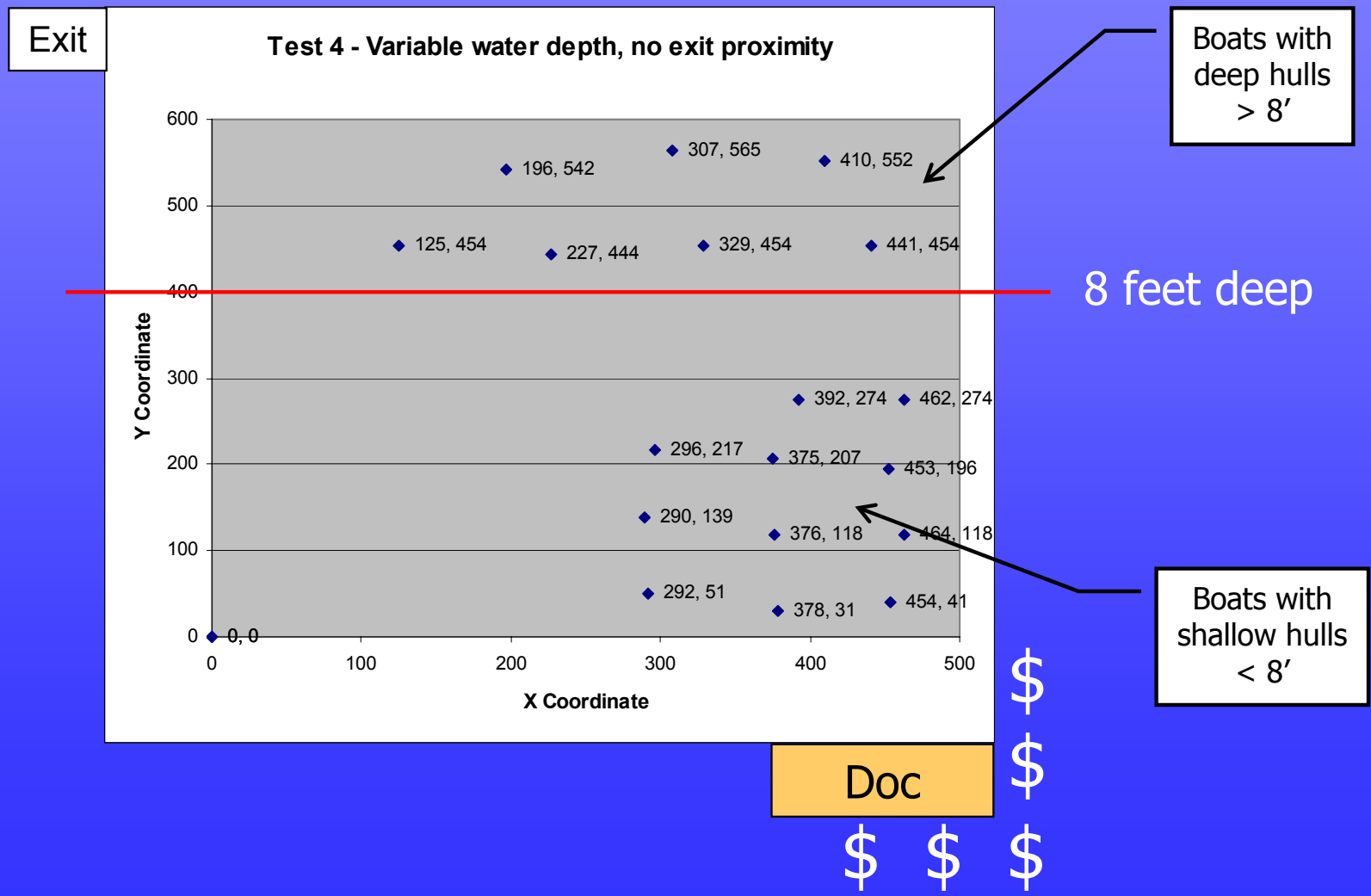
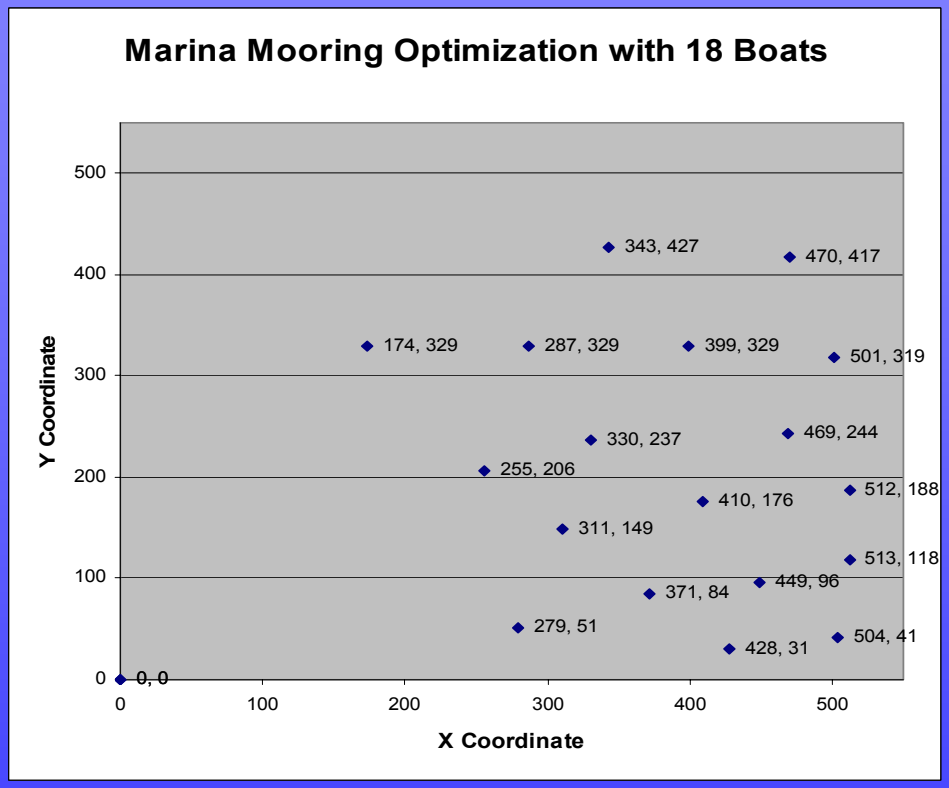
# Analysis

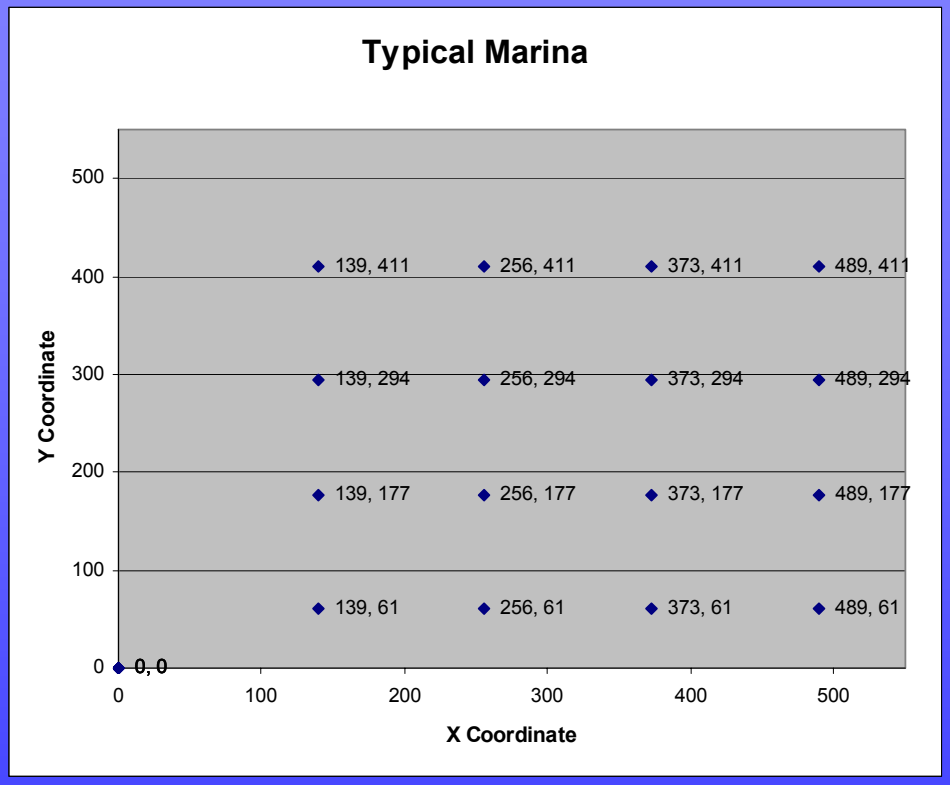
## Run 4 – Variable water depth



# Results




VS.




Revenue = $6,706.93

Revenue = $5,523.56

21.4% IMPROVEMENT !!!

# Conclusions

- Optimization can significantly increase marina profits.
- Optimization can significantly increase number of moorings in marina
- Model is flexible to accommodate constraints of any marina

# Lessons Learned

- Need more powerful solver to increase number of boats and constraints in optimization.
- Need separate proximity pricing scheme for each boat length category.
- Would be convenient to include a boat adding algorithm.
- There are ways to make solver behave better.

# Questions ?