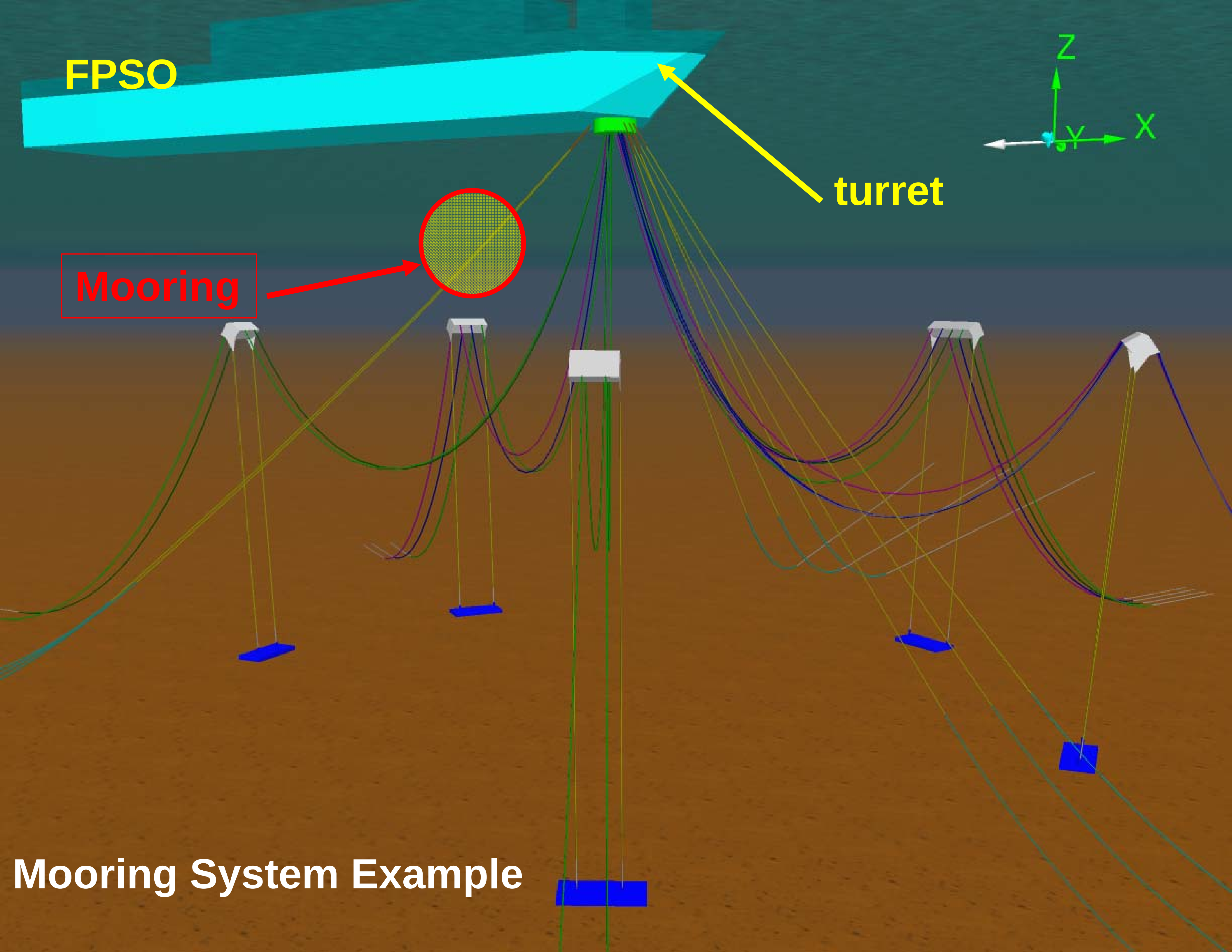

Stybarrow Venture MV16


FPSO
turret
Mooring
Z
X
Y
Mooring System Example

Mooring Cost Sensitivity Study Based on Cost-Optimum Mooring Design

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Types of Optimization Algorithms

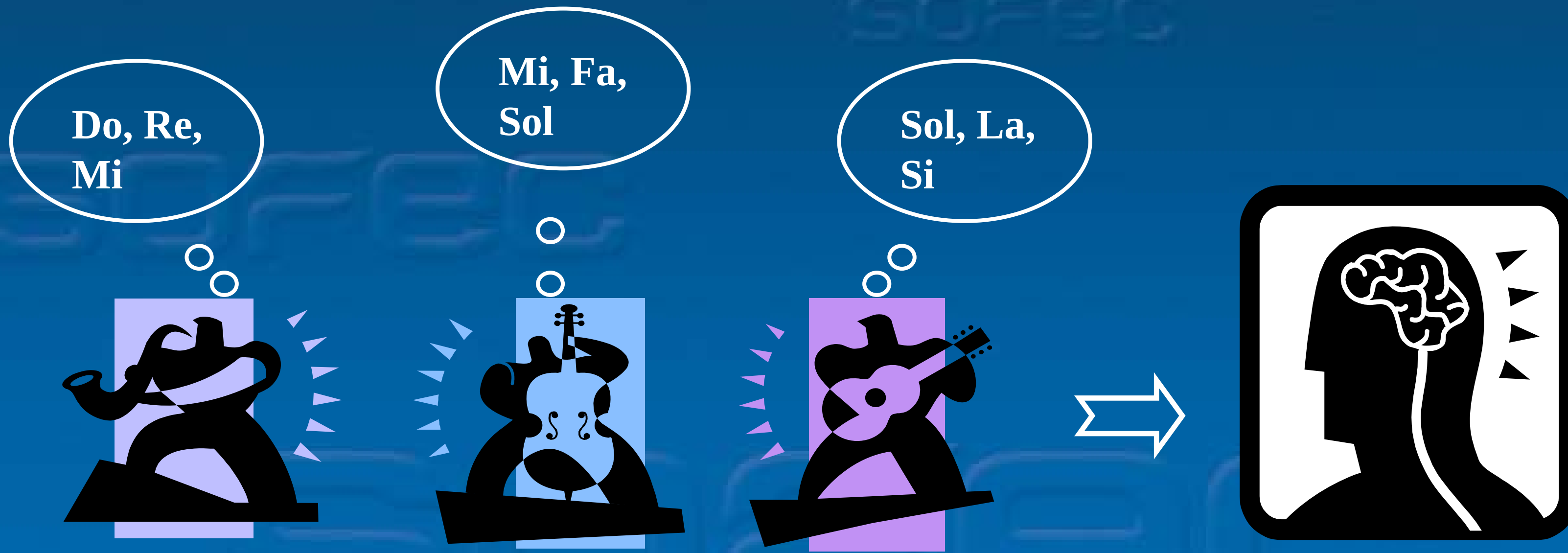
- Mathematical Algorithms
  - Simplex (LP), BFGS (NLP), B&B (DP)
- Drawbacks of Mathematical Algorithms
  - LP: too ideal (all linear functions)
  - NLP: difficult to find derivative, feasible initial vector
  - DP: exhaustive enumeration
- Meta-Heuristic Algorithms
  - GA, SA, TS, ACO, …

Existing Meta-Heuristic Algorithms

- Evolutionary Algorithm (Evolution)
- Simulated Annealing (Metal Annealing)
- Tabu Search (Animal's Brain)
- Ant Algorithm (Ant's Behavior)

Mimicking natural or behavioral phenomena!

Analogy



= Do   = Mi   = Sol

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x_1 x_2 x_3

x_1	x_2	x_3
100mm 200mm 300mm	300mm 400mm 500mm	500mm 600mm 700mm
= 100mm	= 300mm	= 500mm

⇒ $f\,(100, 300, 500)$

Comparison Factors

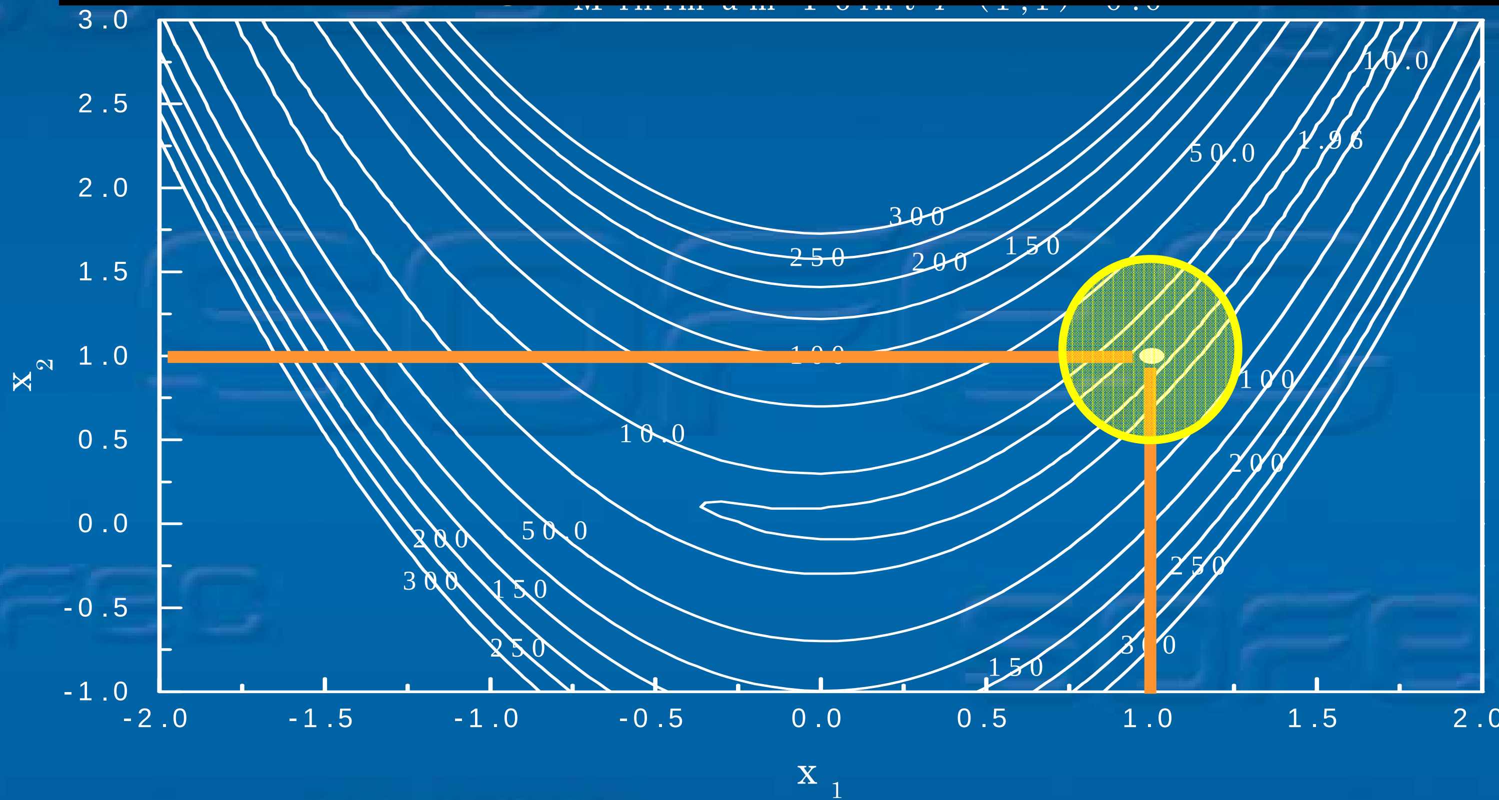
Comparison Factor Process	Optimization Process	Performance
Best state	Global Optimum	Fantastic Harmony
Estimated by	Objective Function	Aesthetic Standard
Estimated with Instruments	Values of Variables	Pitches of
Process unit	Each Iteration	Each Practice

HS Operators

1. Random Play
2. Memory Consideration
3. Pitch Adjust
4. Ensemble Consideration
5. Dissonance Consideration

Benchmark Problem I: Rosenbrock's Banana Function

$$\text{Min } f(\mathbf{X}) = 100(x_2 - x_1^2)^2 + (1 - x_1)^2$$

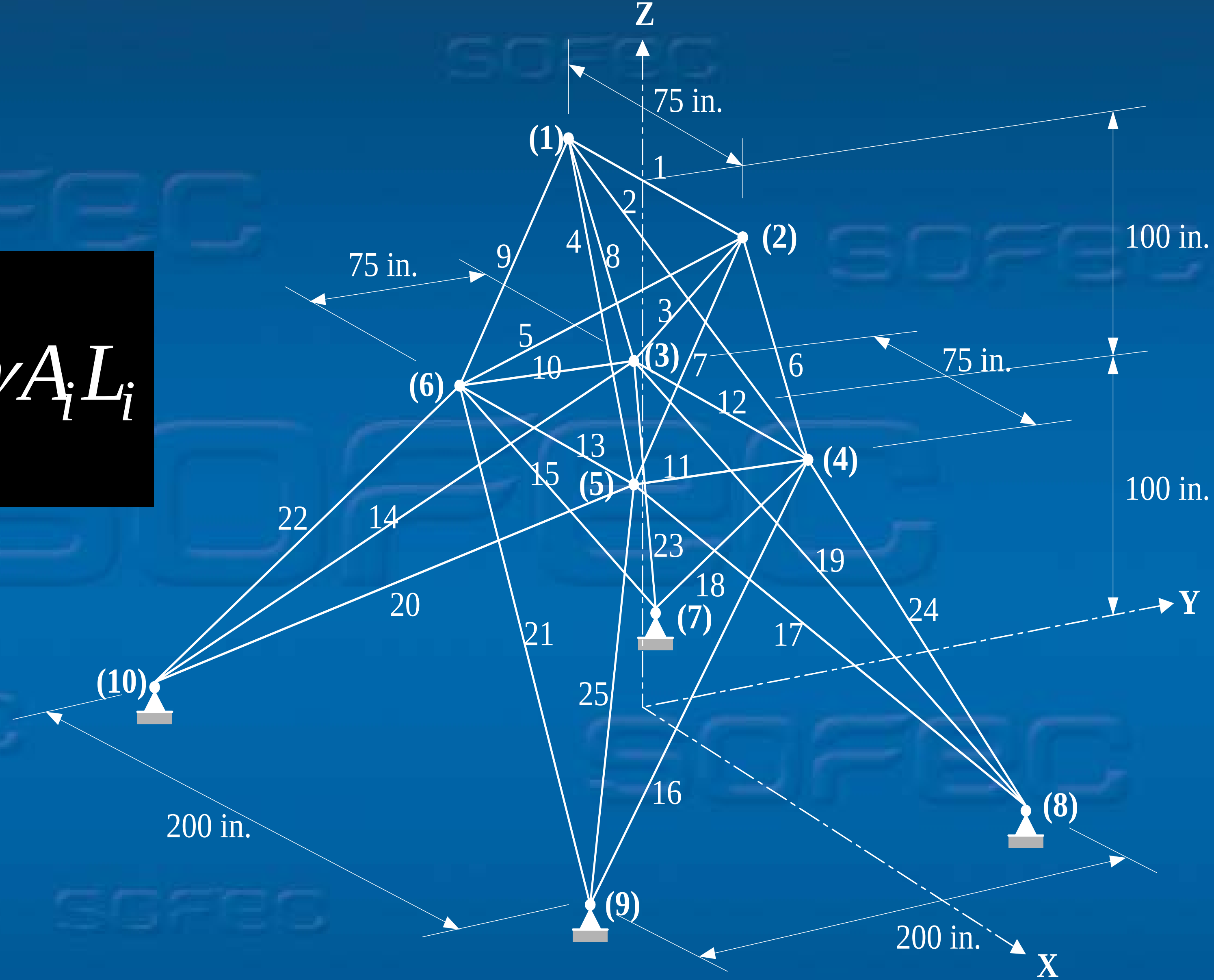


f*(1.000000, 1.000000) = 0.0 (Exact)

f (1.000062, 1.000137) = 0.00000002 (HS)

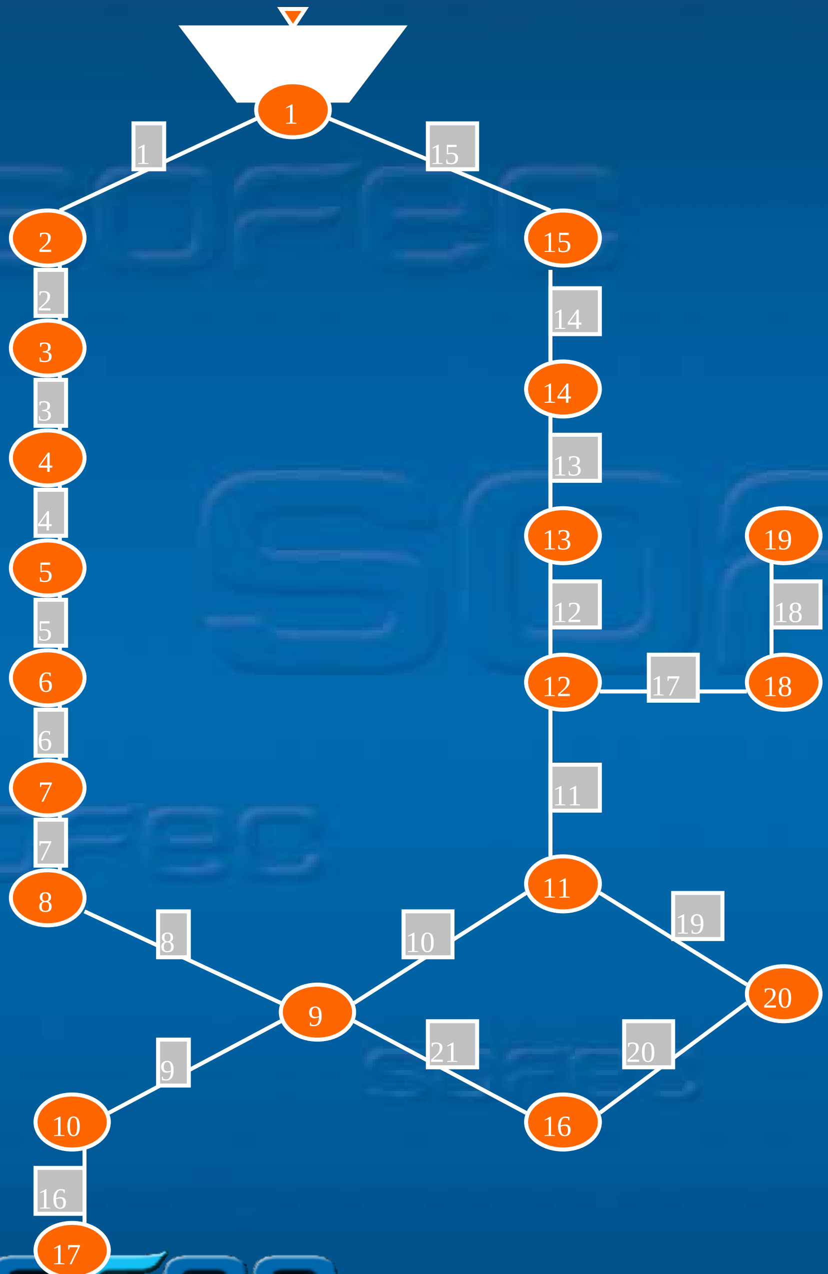
Truss Design – Minimal Weight of Structure

$$W(\mathbf{A}) = \sum_{i=1}^{n} \gamma A_i L_i$$



GA = 546.01 HS = 484.85

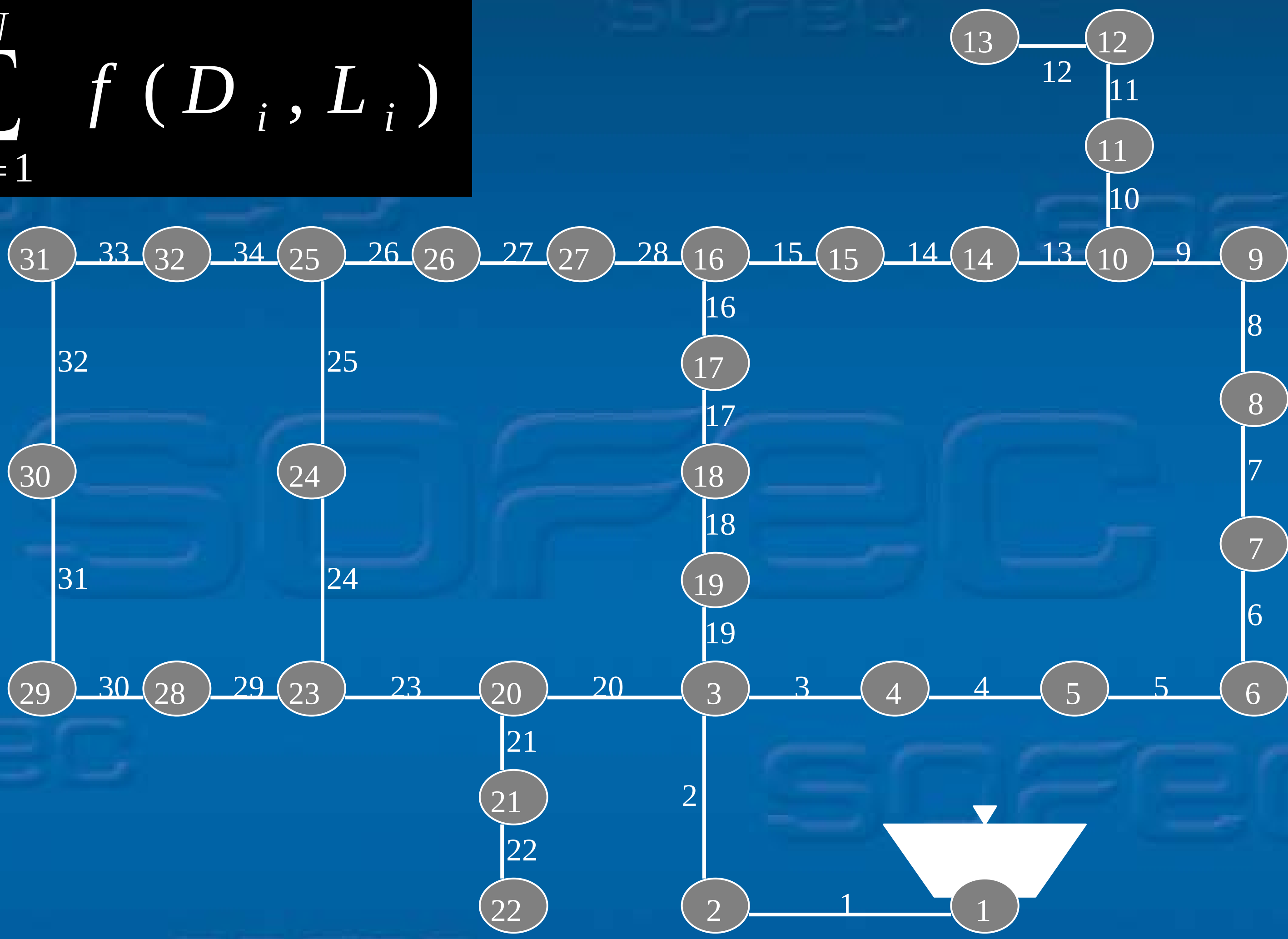
Water Distribution Expansion



- MP: $78.09M
- GA: $38.64M (800,000)
- SA: $38.80M (Unknown)
- TS: $37.13M (Unknown)
- Ant: $38.64M (7,014)
- SFLA: $38.80M (21,569)
- CE: $38.64M (70,000)
- HS: $38.64M (3,373)

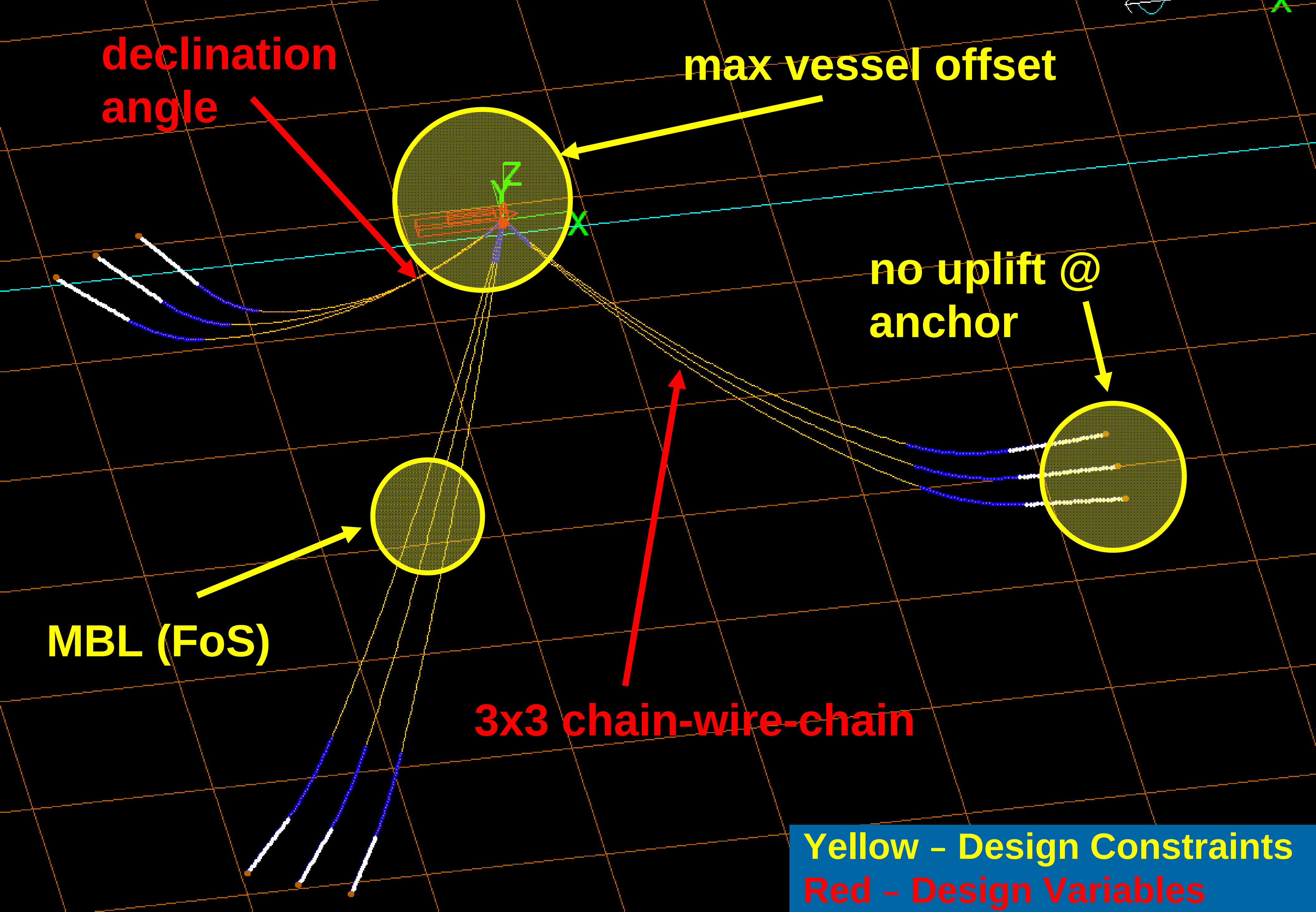
Water Distribution Network Design

$$C = \sum_{i=1}^{N} f(D_i, L_i)$$

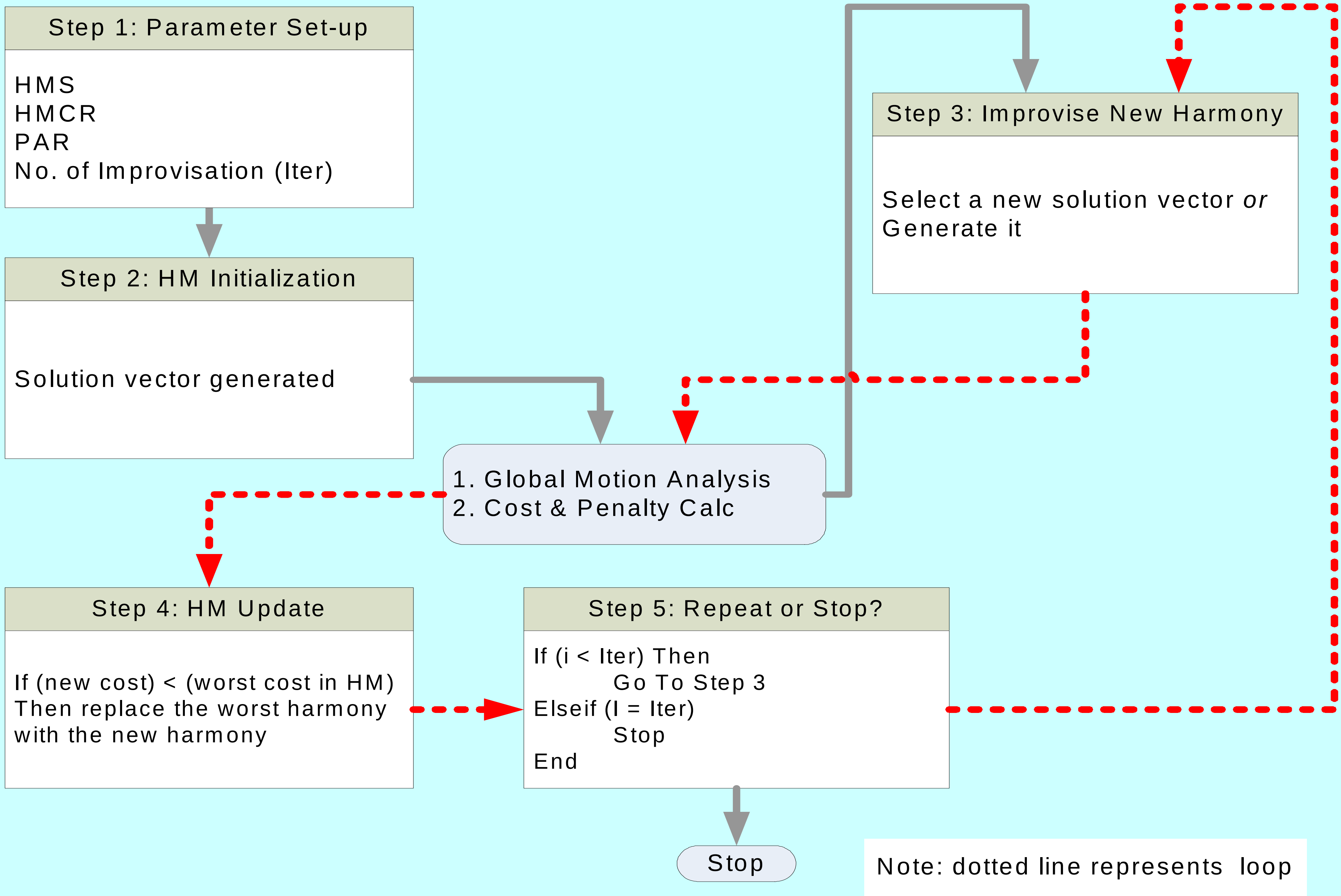


Mathematical = 6.320M GA = 6.073M HS = 6.056M

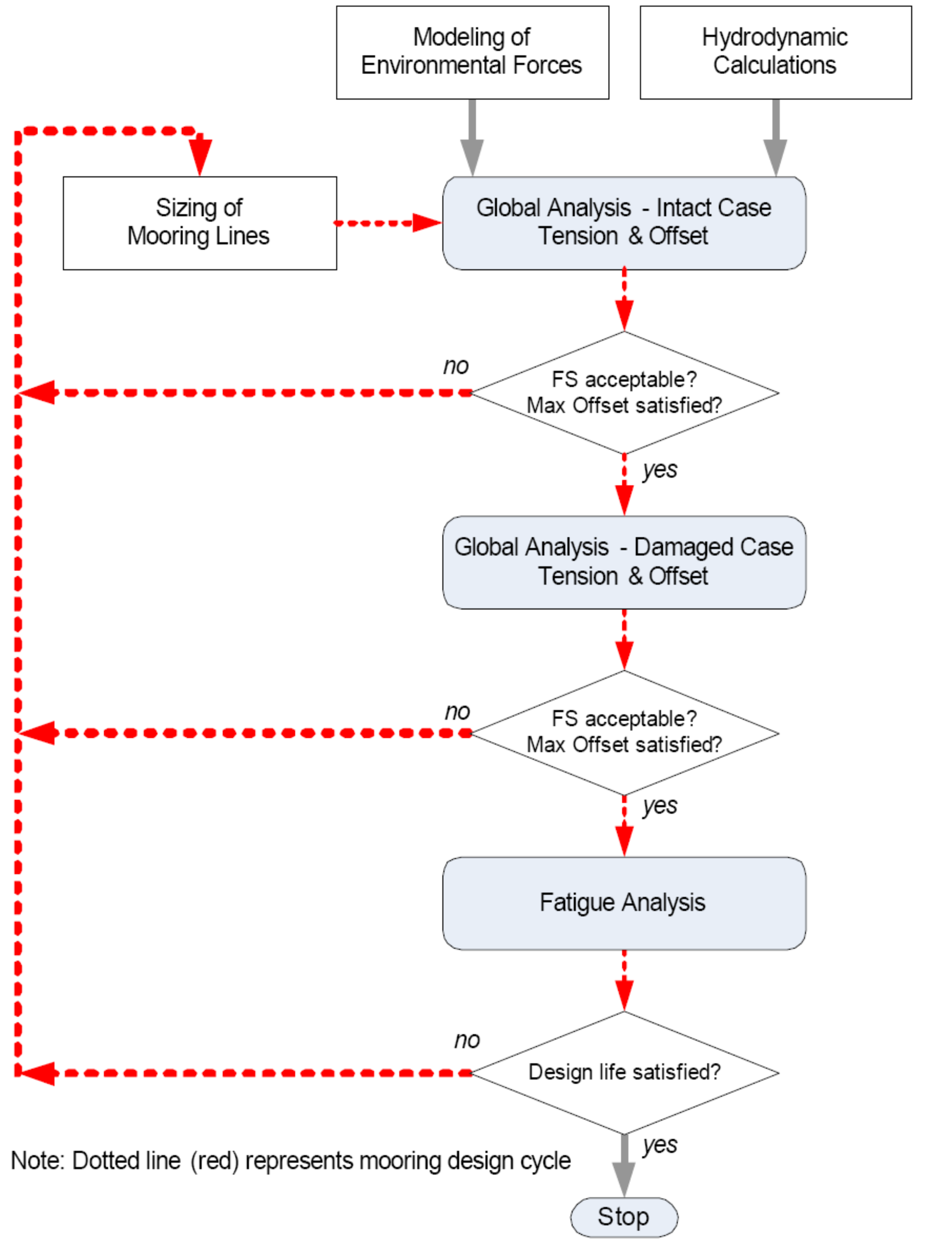
Case Study: Turret-Moored FPSO



Mooring Cost Optimization Process



Typical Offshore Mooring Design Cycle



Harmony Memory

$$\mathrm{HM} = \begin{bmatrix} l_1^1 & l_2^1 & l_3^1 & d_1^1 & d_2^1 & d_3^1 \\ l_1^2 & l_2^2 & l_3^2 & d_1^2 & d_2^2 & d_3^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ l_1^{HMS} & l_2^{HMS} & d_3^{HMS} & d_1^{HMS} & d_2^{HMS} & d_3^{HMS} \end{bmatrix} \Rightarrow \begin{Bmatrix} c^1 \\ c^2 \\ \vdots \\ c^{HMS} \end{Bmatrix}$$

Design Variable Ranges

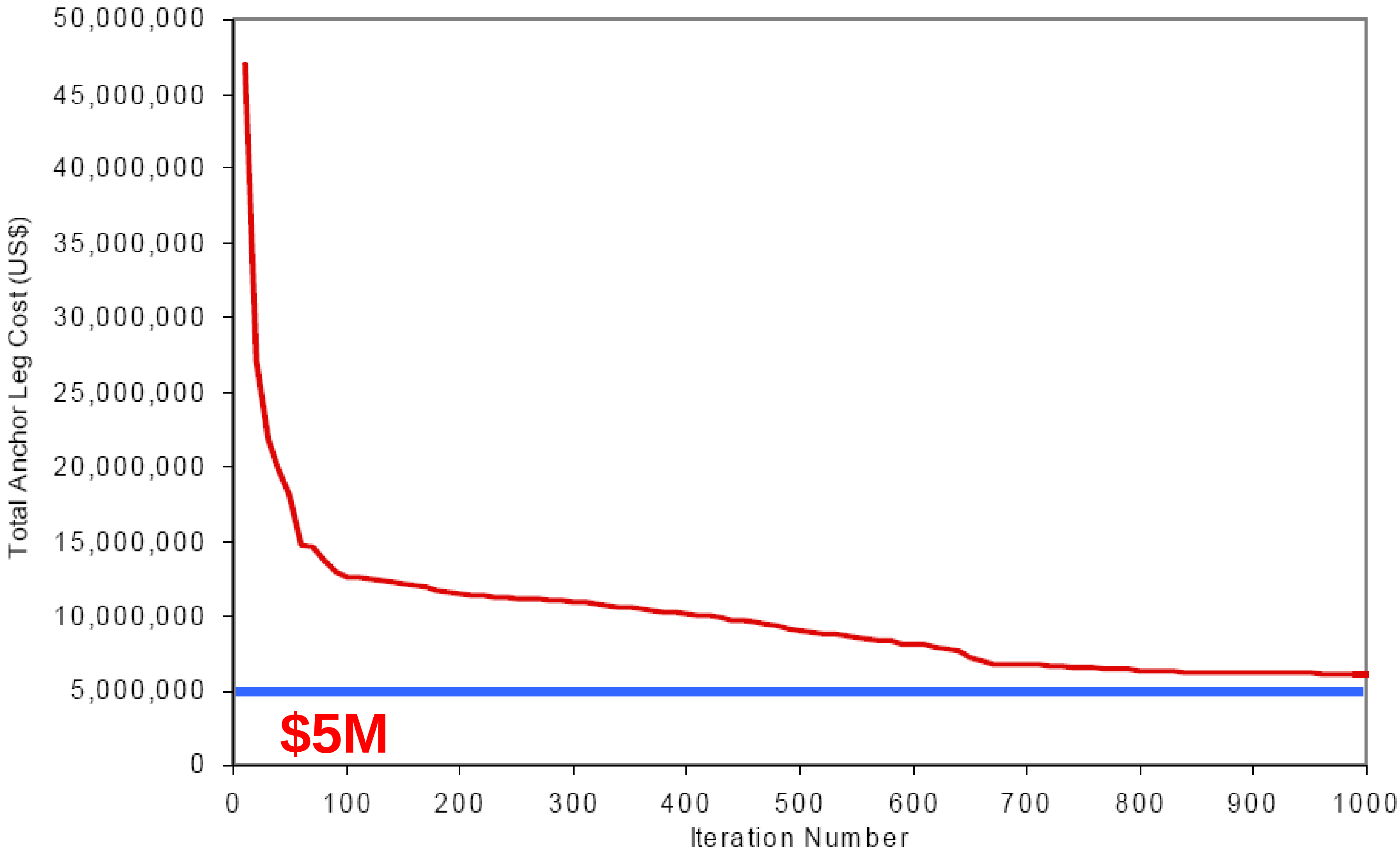
Bound	Length (m)			Diameter (mm)		
	Top Chain	Wire	Bottom Chain	Top Chain	Wire	Bottom Chain
Lower	10	100	100	50	50	50
Upper	200	2000	2000	150	150	150

	Lower (deg)	Upper (deg)
Declination	20	70

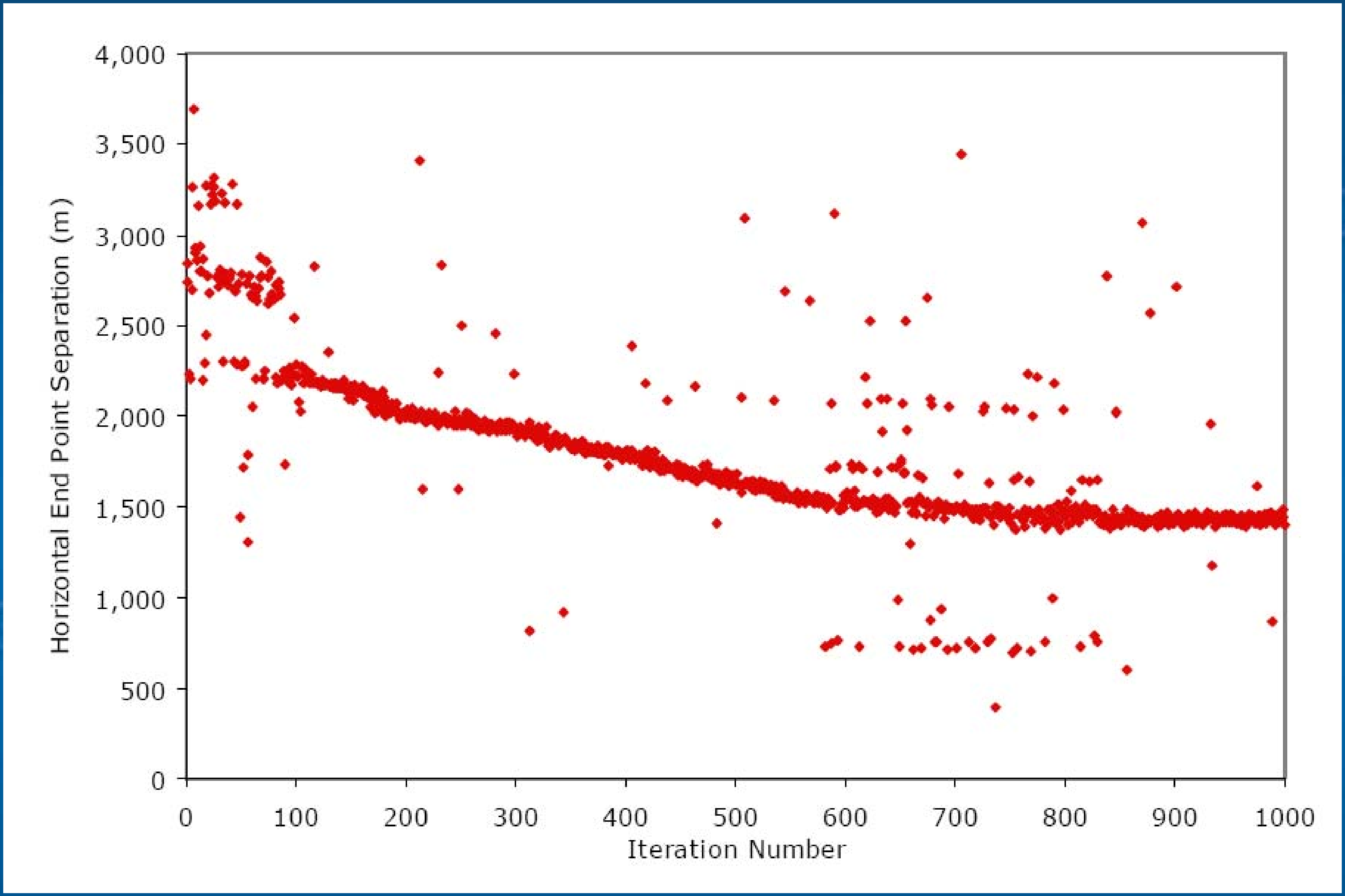
Cost Function

$$C = \sum_{i=1}^{N} f\left(L_i, d_i\right)$$

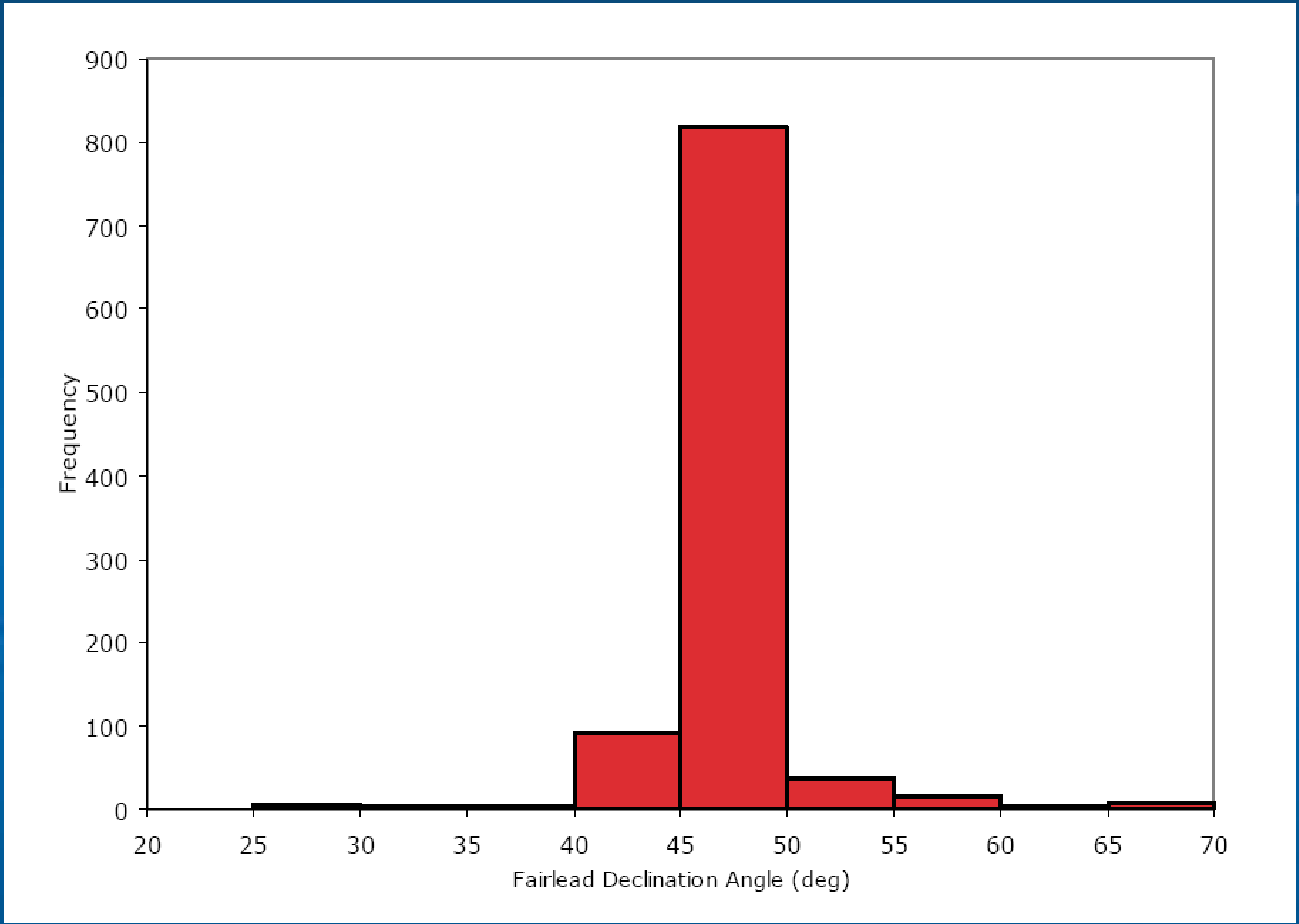
Total Anchor Leg Cost - Solution Search



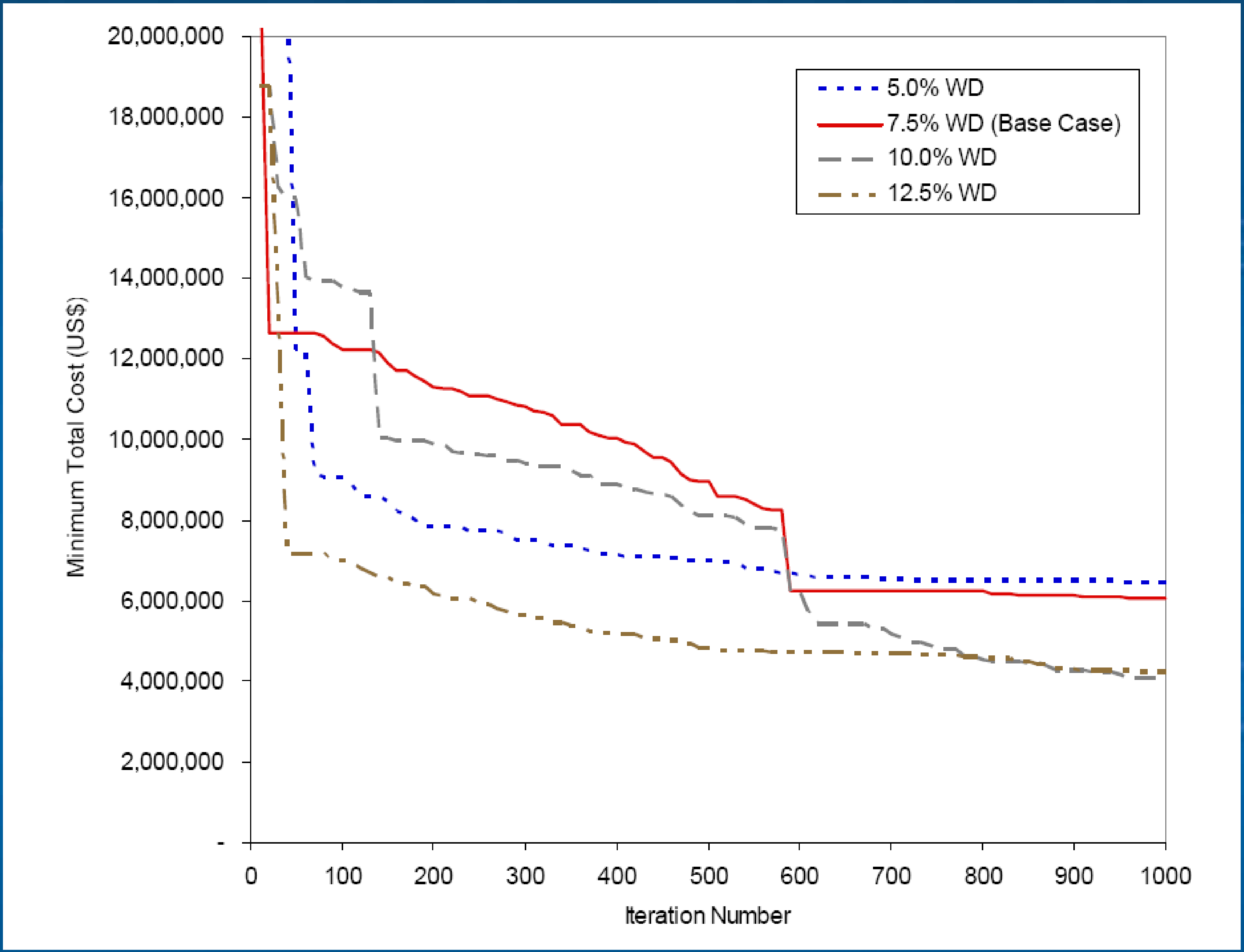
Trend - Horizontal End Point Separation (Base Case)



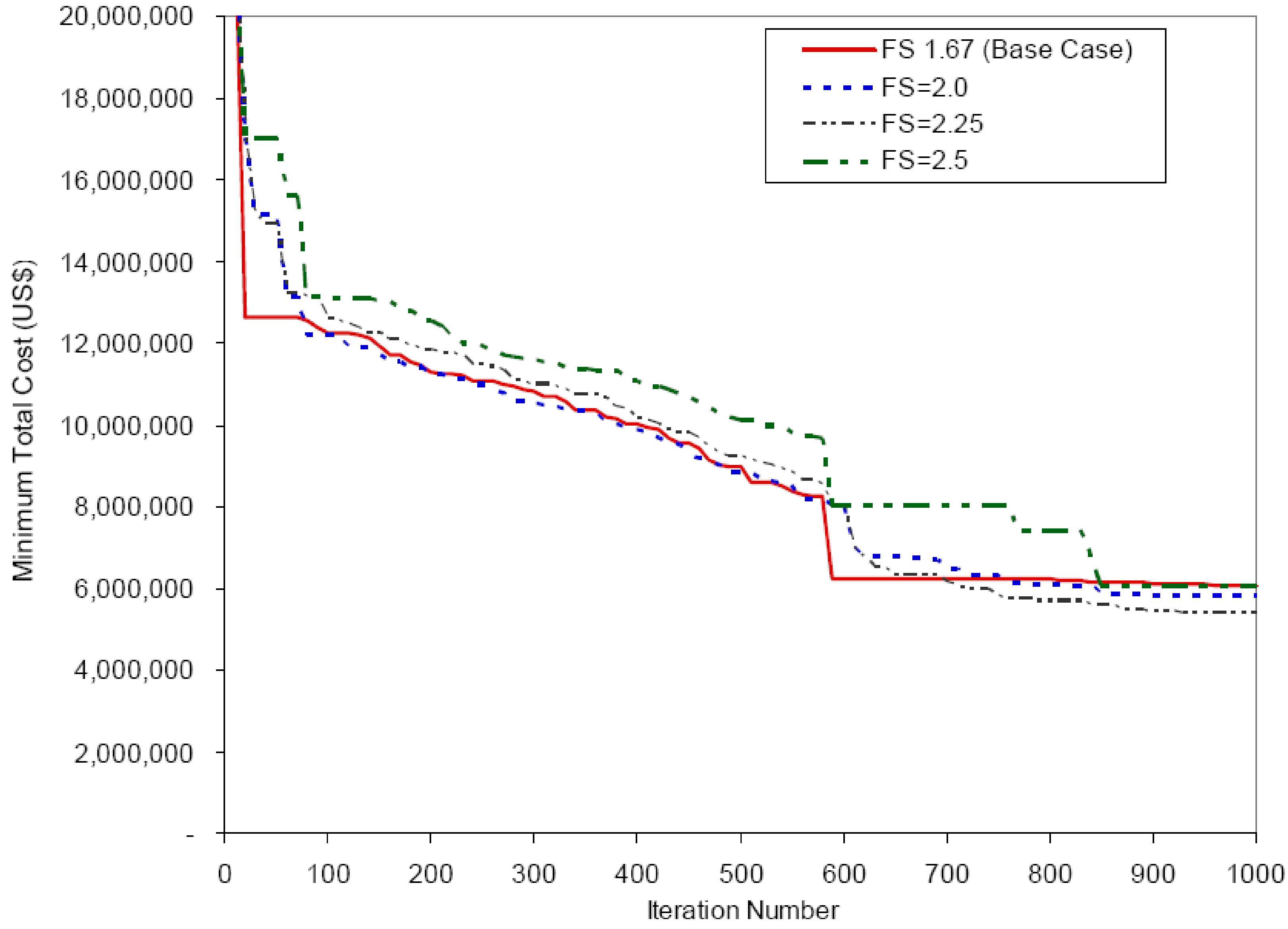
Distribution of Declination Angles Over Entire Iterations



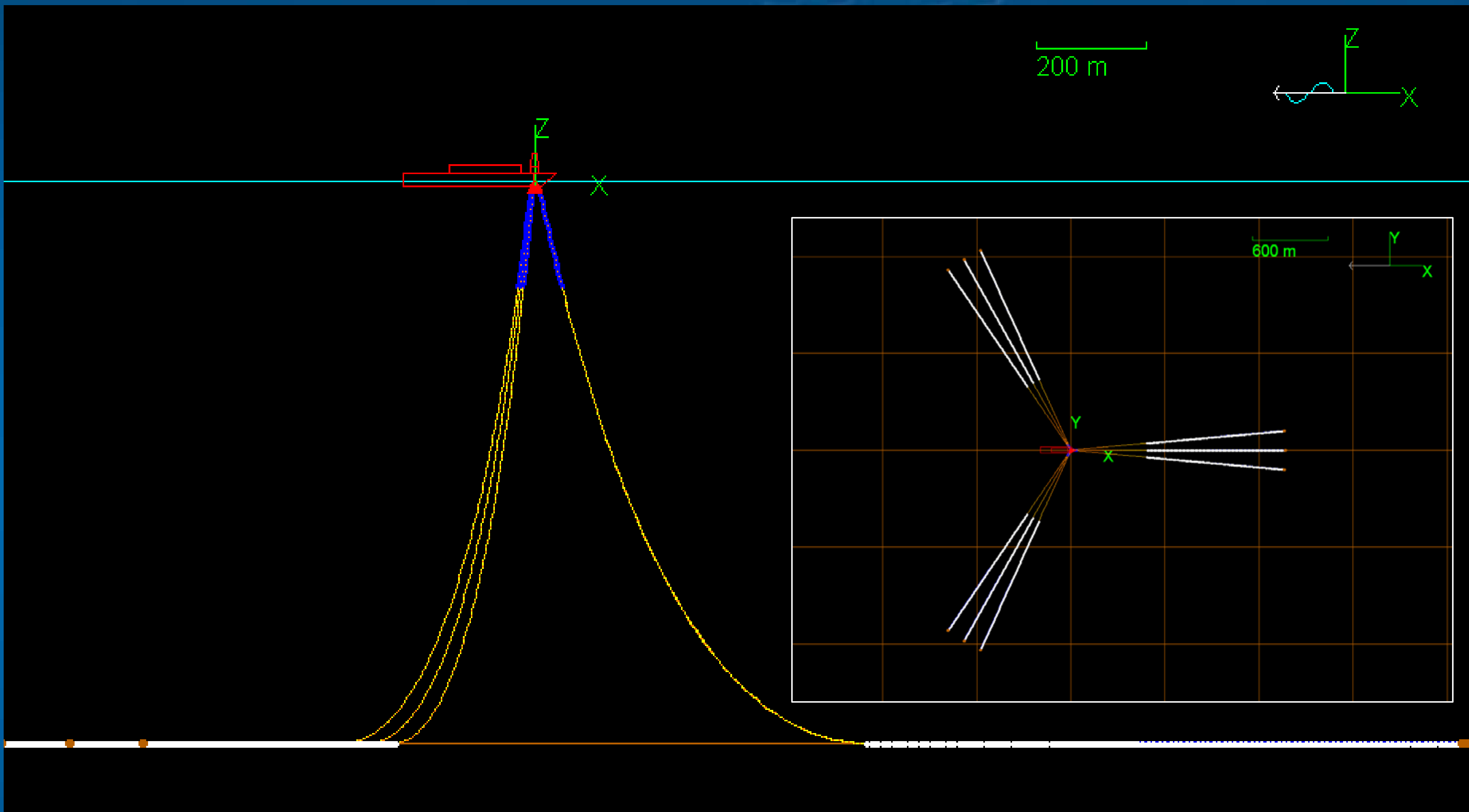
Maximum Offset Sensitivity Study Results



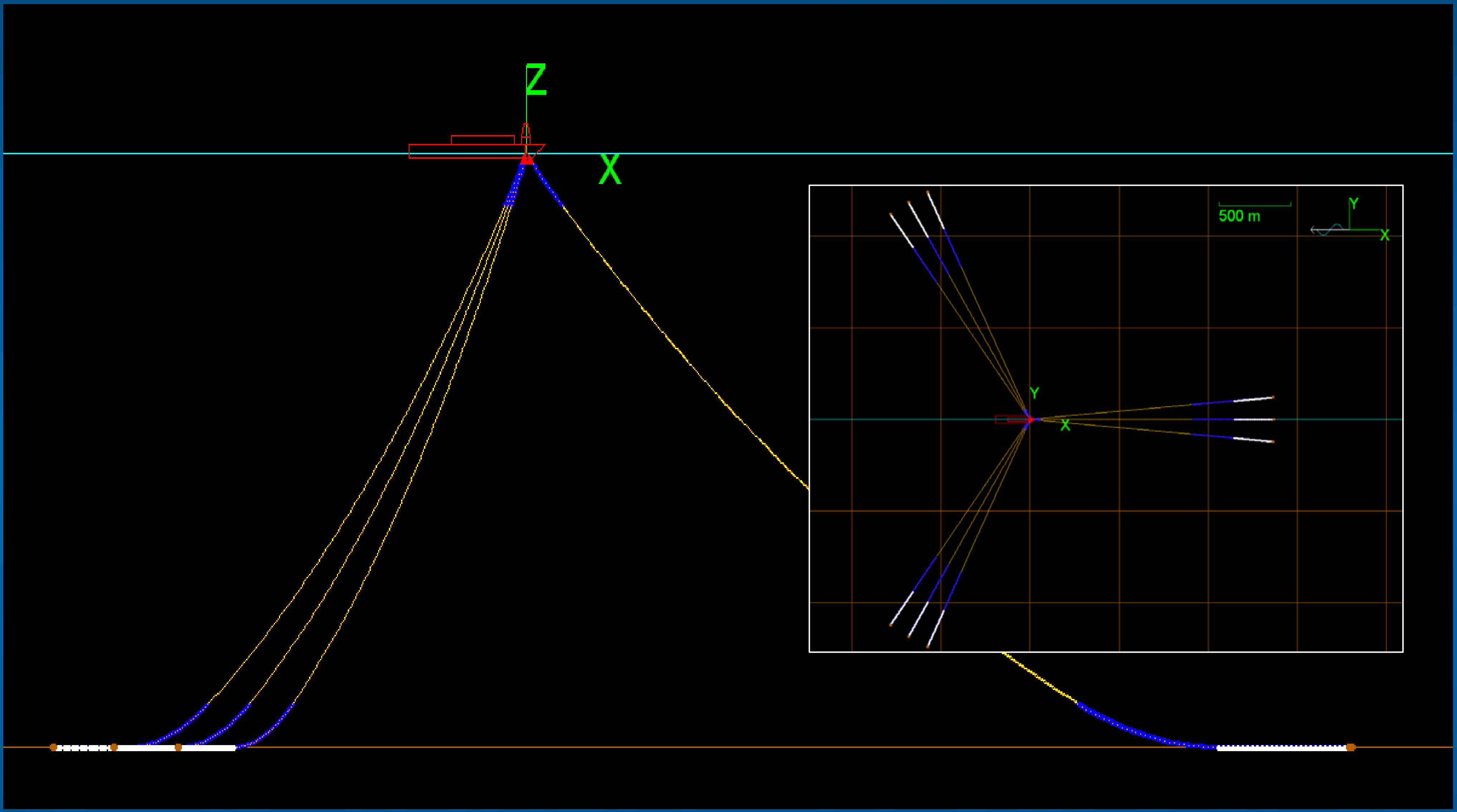
Factor of Safety Sensitivity Study Results



One of Initial 10 Vectors



One of 10 Final Solutions in Harmony Memory



Concluding Remarks

- Trend of finding cost-optimum mooring designs was presented over required given maximum iterations;

- Well behaved convergence of the Horizontal End Point Separation (HEPS) was observed, distribution of the optimum declination angles of the anchor leg system was investigated;

- Cost-optimum mooring designs were first found by using Harmony Search algorithm, and sensitivity study was carried out for the two parameters: (1) maximum FPSO vessel offset requirement and (2) factor of safety for the mooring system.

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Thank you!