An Automatic Pipe Arrangement Algorithm Considering Elbows and Bends

Dept. of Marine System Engineering, Kyushu University

Yuto Ando

Hajime Kimura

九州大学
KYUSHU UNIVERSITY

Outline

1. Background and Purpose

- Previous Research

2. Routing Algorithm Including Bends

- Approach
- Outline of “Bends”
- Outline of Pipe-rack Area and Aisle Space
- Experiments

3. Conclusion and Challenges

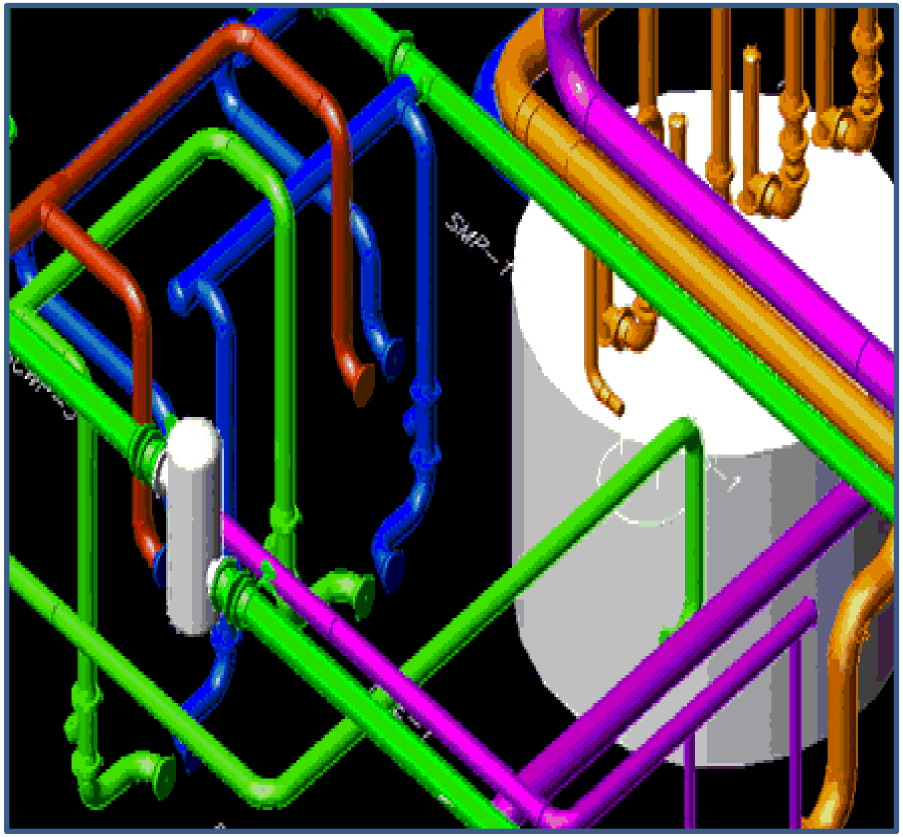
Background

Pipe Arrangement requires …

◆ Keeping to regulations

ex.

- Not to set fuel oil pipelines near to electrical equipment.



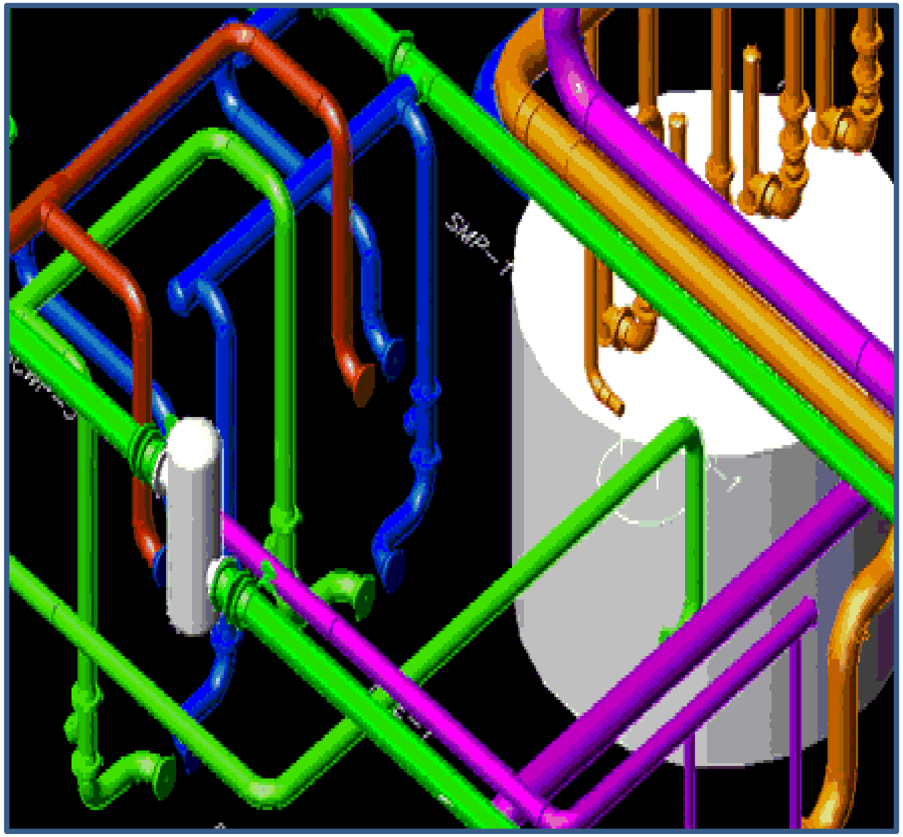
http://www.cadpipe.com/industrial3D.html

Background

Pipe Arrangement requires …

- ◆ Keeping to regulations
- ◆ Meeting demands

ex.
- To shorten the total length
- To set along with the ship hull



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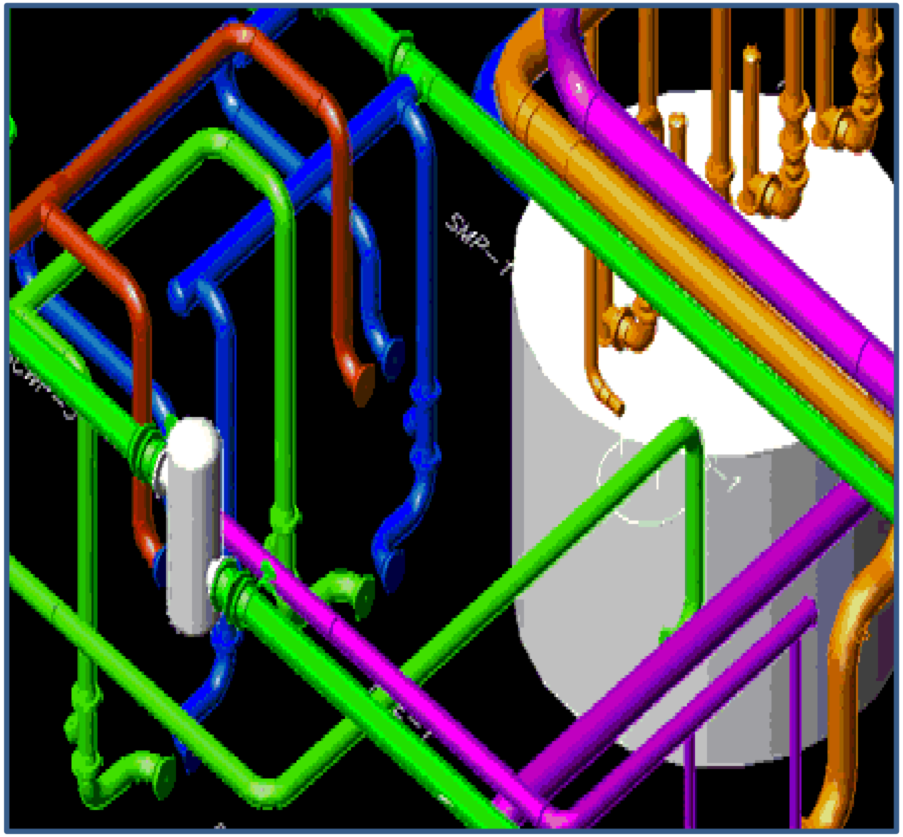
Background

Pipe Arrangement requires …

- ◆ Keeping to regulations
- ◆ Meeting demands
- ◆ Originality by each ship



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Pipe Arrangement requires …

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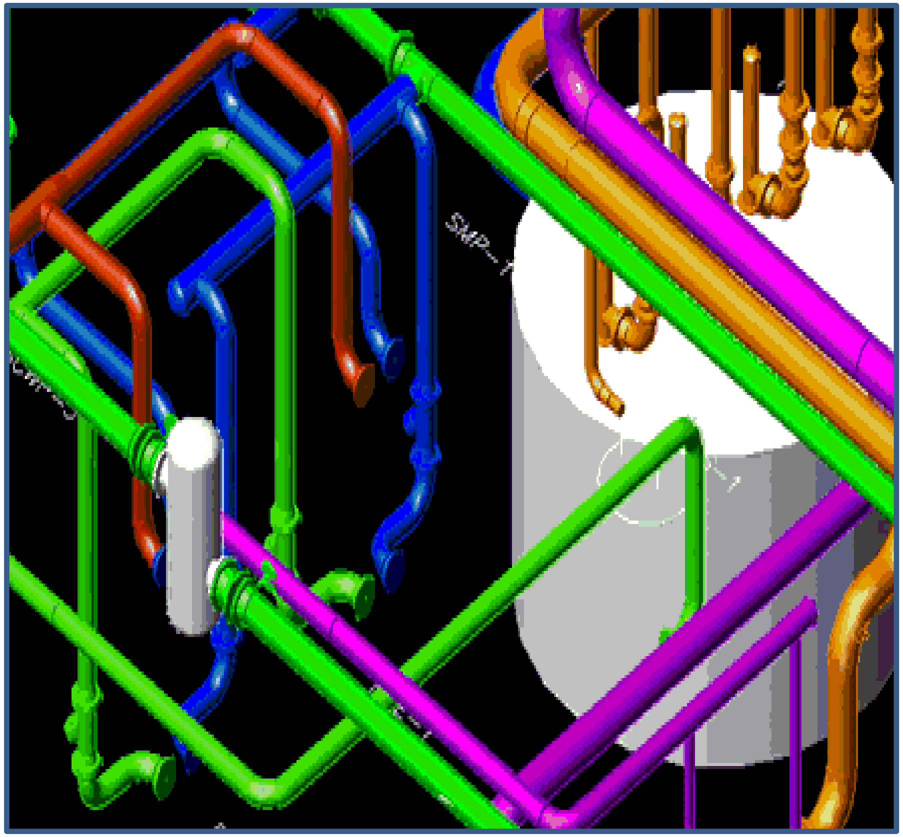
Experiences of skilled designers



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Background

Pipe Arrangement requires …

- Keeping to regulations
- Meeting demands
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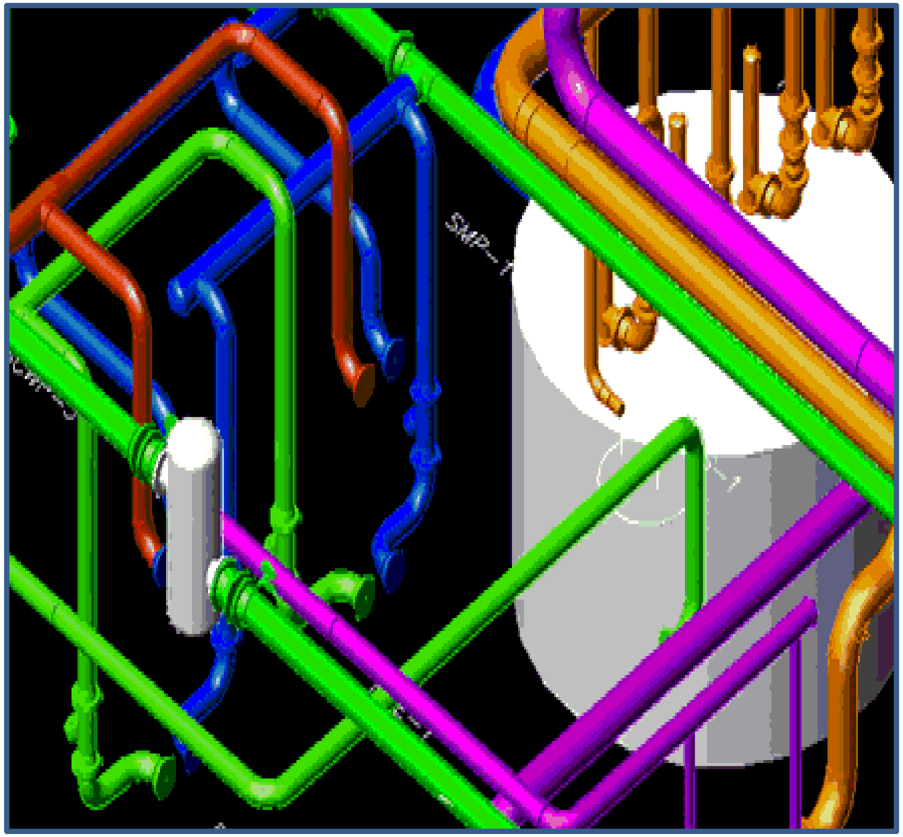
Experiences of skilled designers

Automatic Design System



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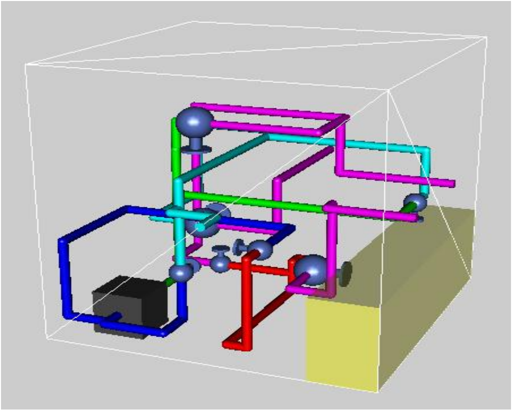
Purpose

Previous Researches



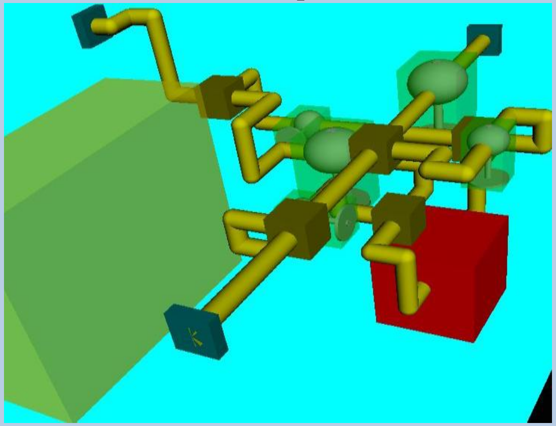
Problems are …

x Optimization of piping routes

x Searching of piping routes

x Constraints

Our Proposal



We try for …

◆ Solving these problems

◆ High performance system

◆ Full automatic design

Previous Research

Approach by Asmara and Nienhuis

- **Looking on the pipe arrangement problem as <u>a routing problem</u> in a directed and weighted graph**

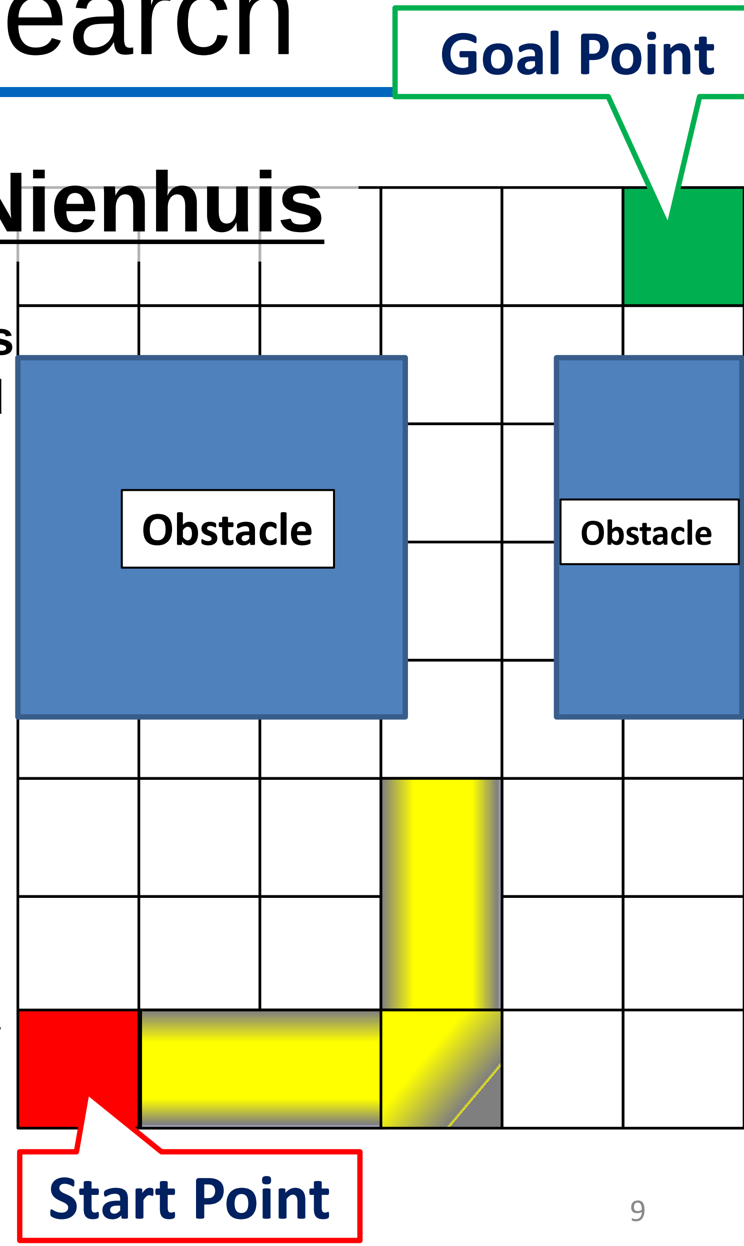
Solved by “**Dijkstra’s method**”

Disadvantage is …

- The mesh size is restricted to be larger than a pipe’s diameter

Especially in large pipe’s diameter

Strong Constraint!



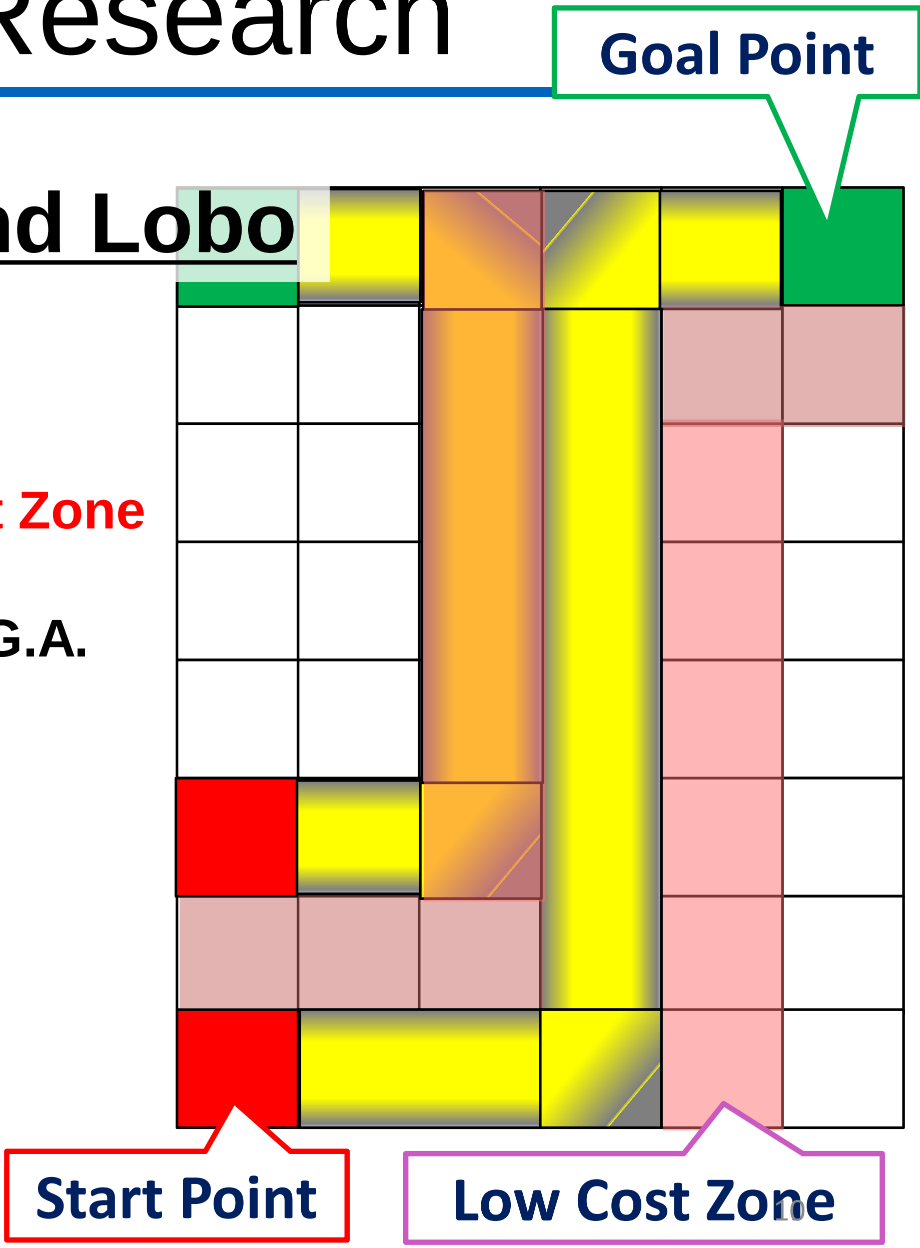
Previous Research

Approach by Martins and Lobo

- To set cost value in each cell
- To set area for pipes : Low Cost Zone
- Routing algorithm is based on G.A.

Disadvantages are…

- Uncertainty of optimal routing
- The mesh size is restricted



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- Outline of Pipe-rack Area and Aisle Space
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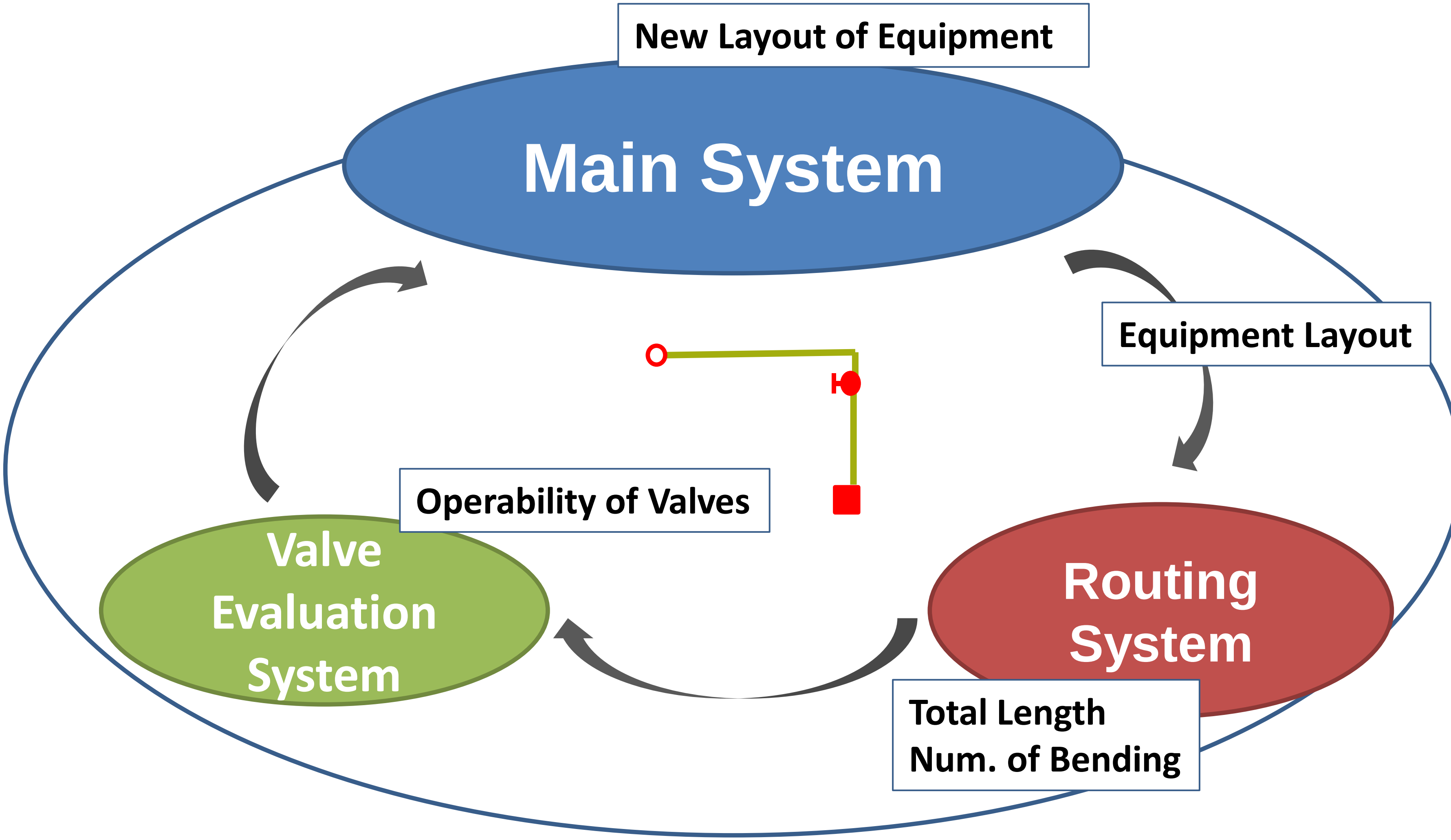
Approach


New Layout of Equipment
Main System
Equipment Layout
Operability of Valves
Valve Evaluation System
Routing System
Total Length
Num. of Bending

Approach of Routing

Problems of Previous Researches

- Uncertainty of the route with minimum costs
- Demanding of the mesh size on the diameter

Our Approach

◆ Using "Dijkstra's method"

◆ Improvement the routing algorithm

◆ Using not only elbows but "bends"

Approach of Routing

Problems of Previous Researches

- Uncertainty of the route with minimum costs

- Demanding of the mesh size on the diameter

Our Approach

- **Using "Dijkstra's method"**
- **Improvement the routing algorithm**
- **Using not only elbows but "bends"**

Approach of Routing

Problems of Previous Researches

- Uncertainty of the route with minimum costs

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Our Approach

◆ Using “Dijkstra’s method”

variable mesh size!

◆ Improvement the routing algorithm

◆ Using not only elbows but “bends”

Approach of Routing

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Our Approach

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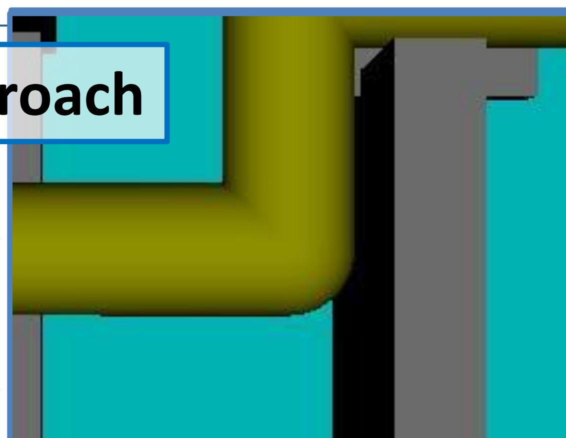
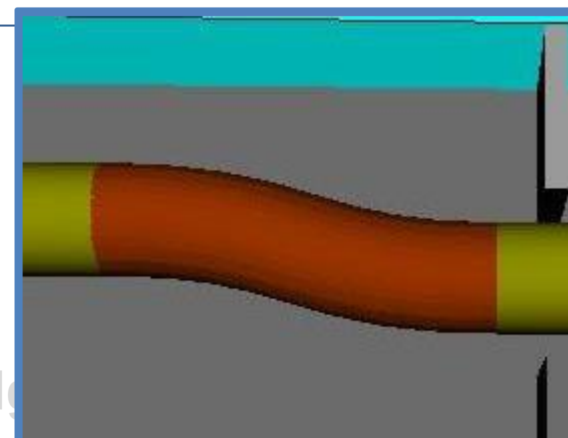
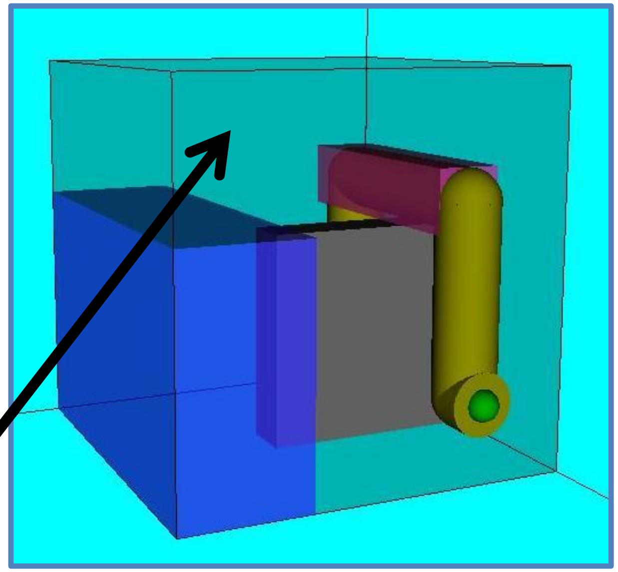
◆ ing al





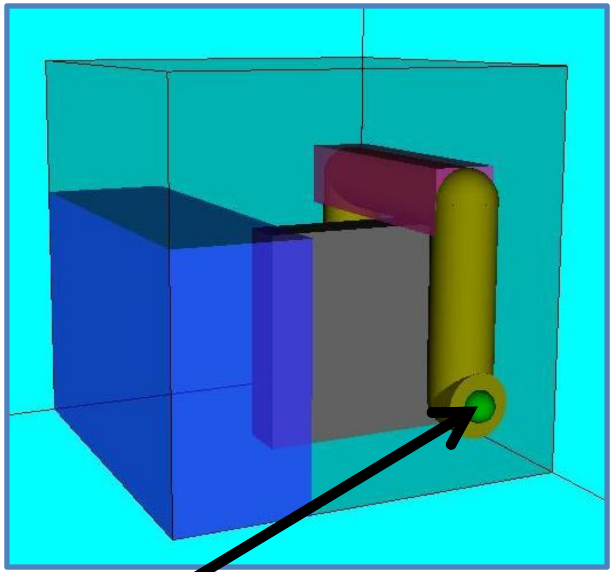
◆ **Using not only elbows but “bends”**

Approach



- **Design Space** : Box for pipe arrangement
- **Start and Goal** : Coordinates and vectors
- **Target Pipeline** : Pipes not including any branches

Approach



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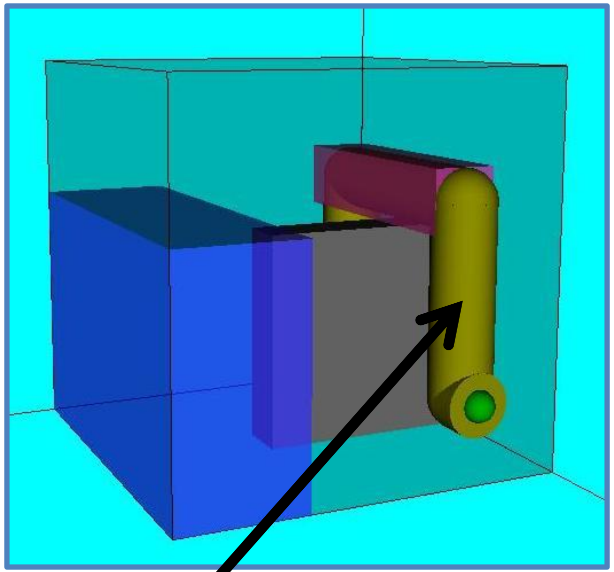

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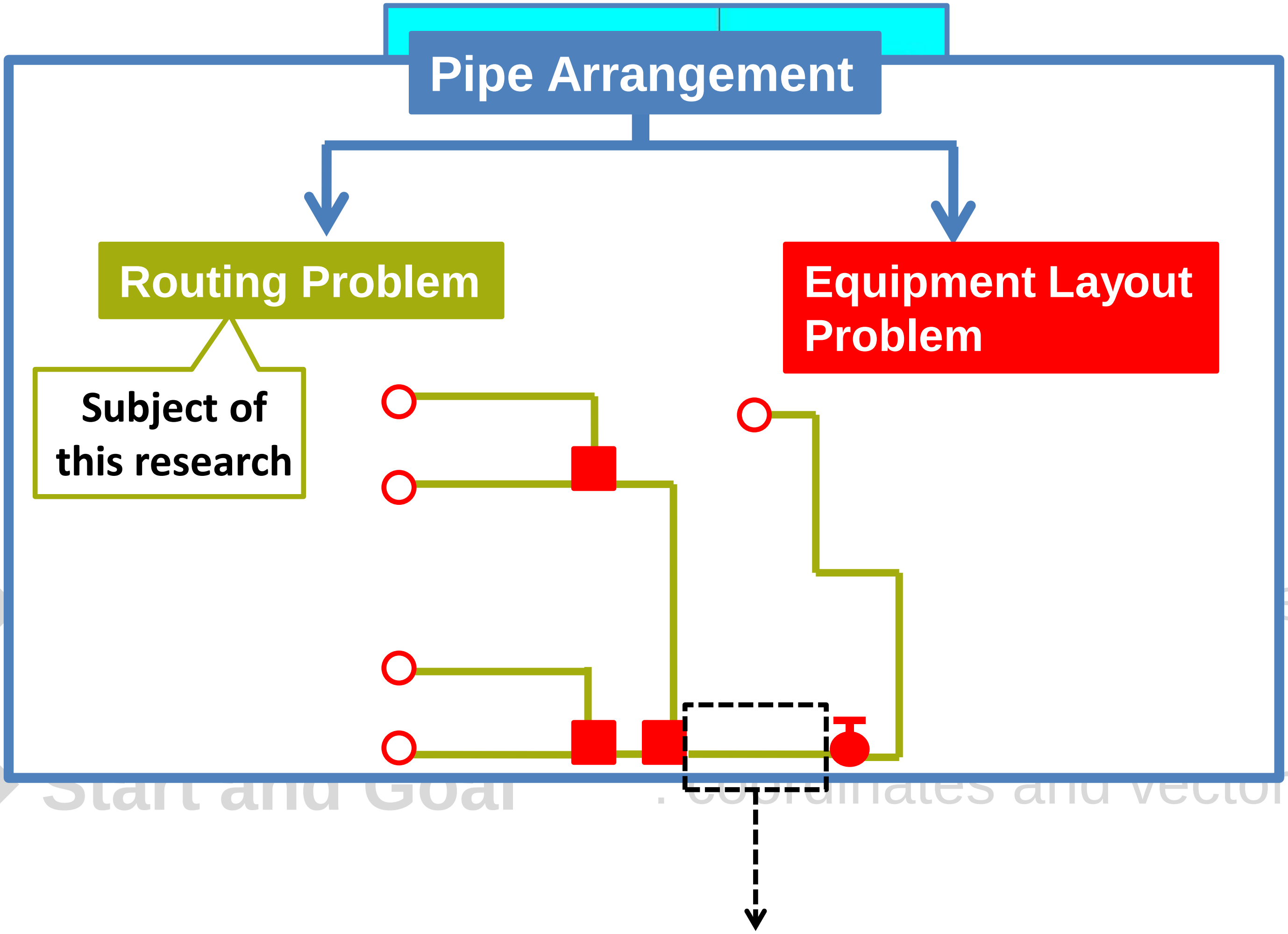
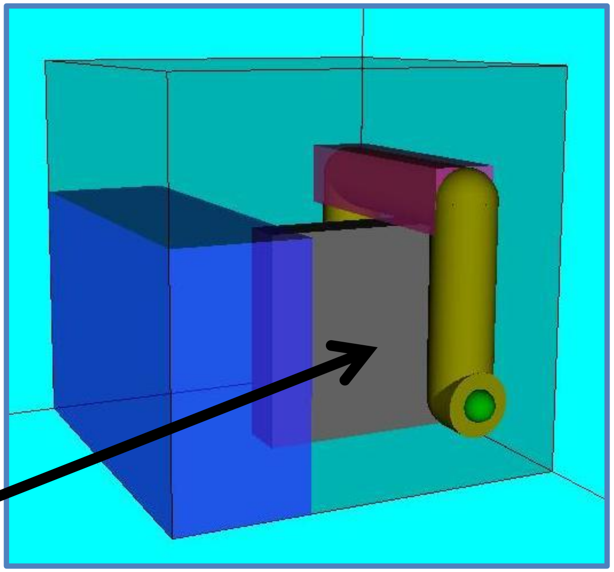


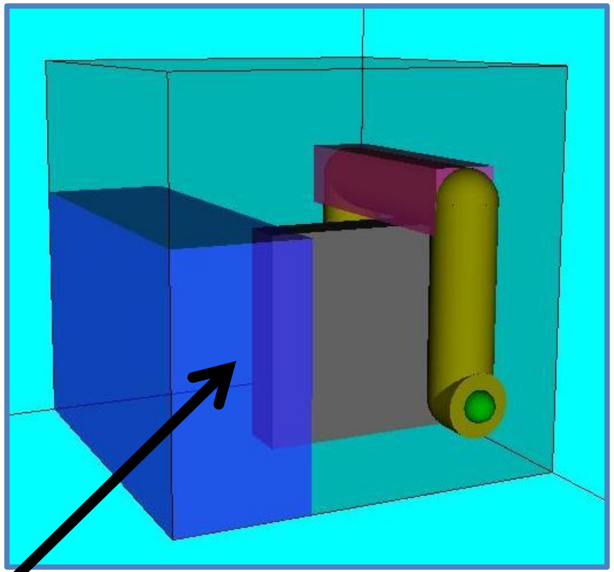
◆ **Target Pipeline** : Pipes not including any branches

Approach



- **Obstacle** : Structures and equipments in ships
- **Aisle Space** : Space for passages
- **Pipe-rack Area** : Space for pipelines

Approach



◆ **Obstacle** : Structures and equipments in ships

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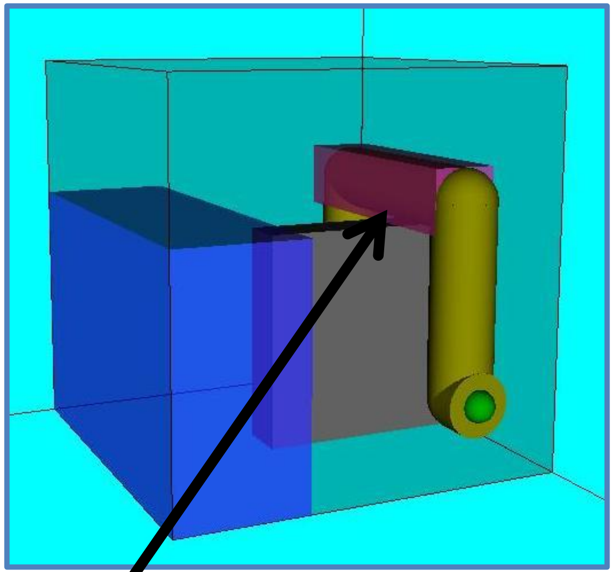
◆ **Pipe-rack Area** : Space for pipelines

Approach



◆ **Obstacle** : Structures and equipments in ships

◆ **Aisle Space** : Space for passages

◆ **Pipe-rack Area** : Space for pipelines

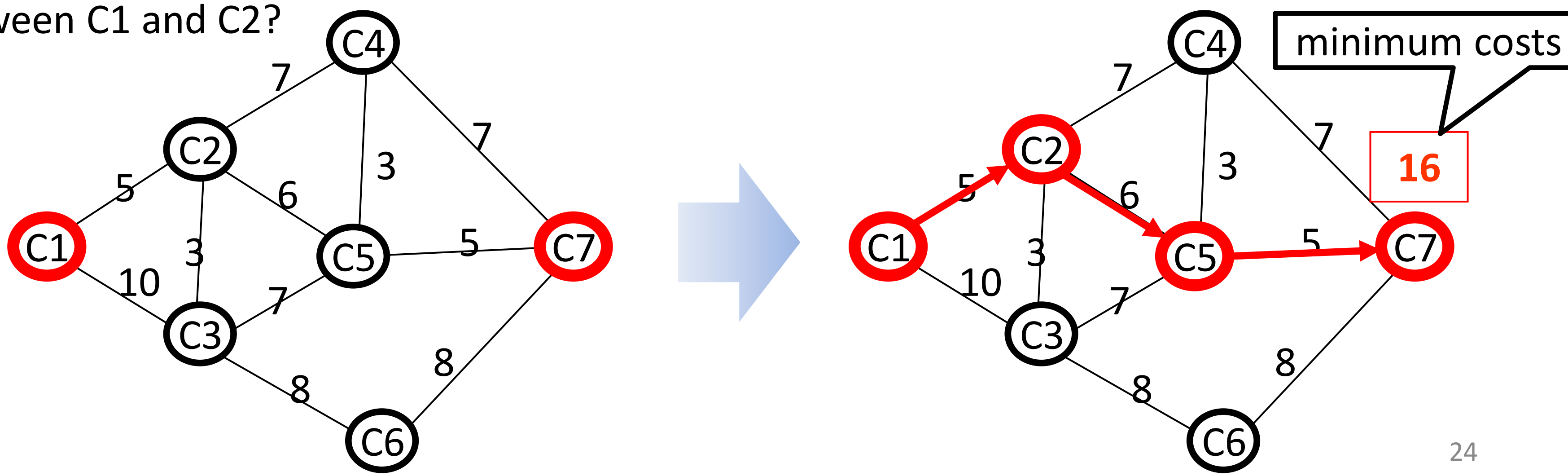
Dijkstra’s Method

This method can …

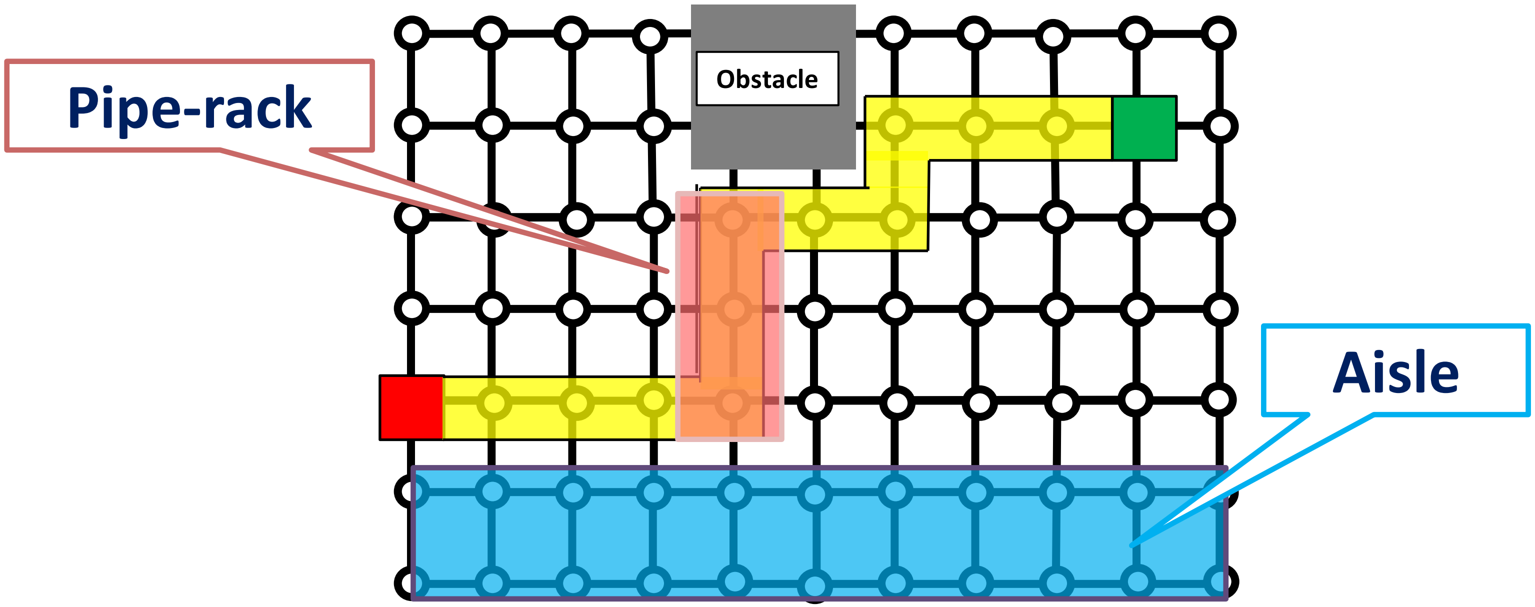
- **Find the shortest path in a directed and weighted graph**
- **Guarantee a path with minimum costs**

Where is the path with minimum costs between C1 and C2?

The answer is …



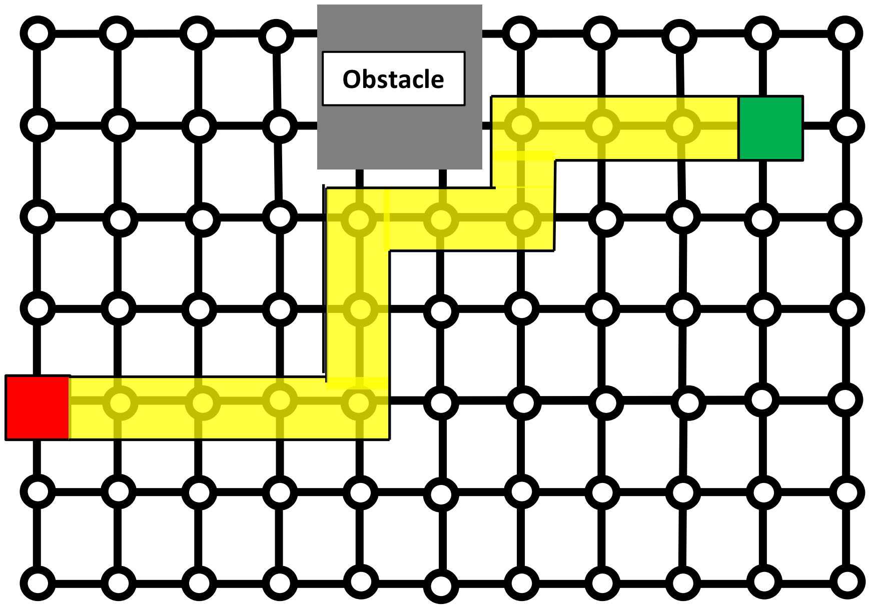
Design Objectives



Sum Up

- To minimize the total length of pipes
- To minimize the number of elbows and bends
- To avoid aisles as possible
- To pass through pipe-rack areas as possible

Design Objectives



Cost of 1 Mesh = 1

Cost of Elbows = 0.1

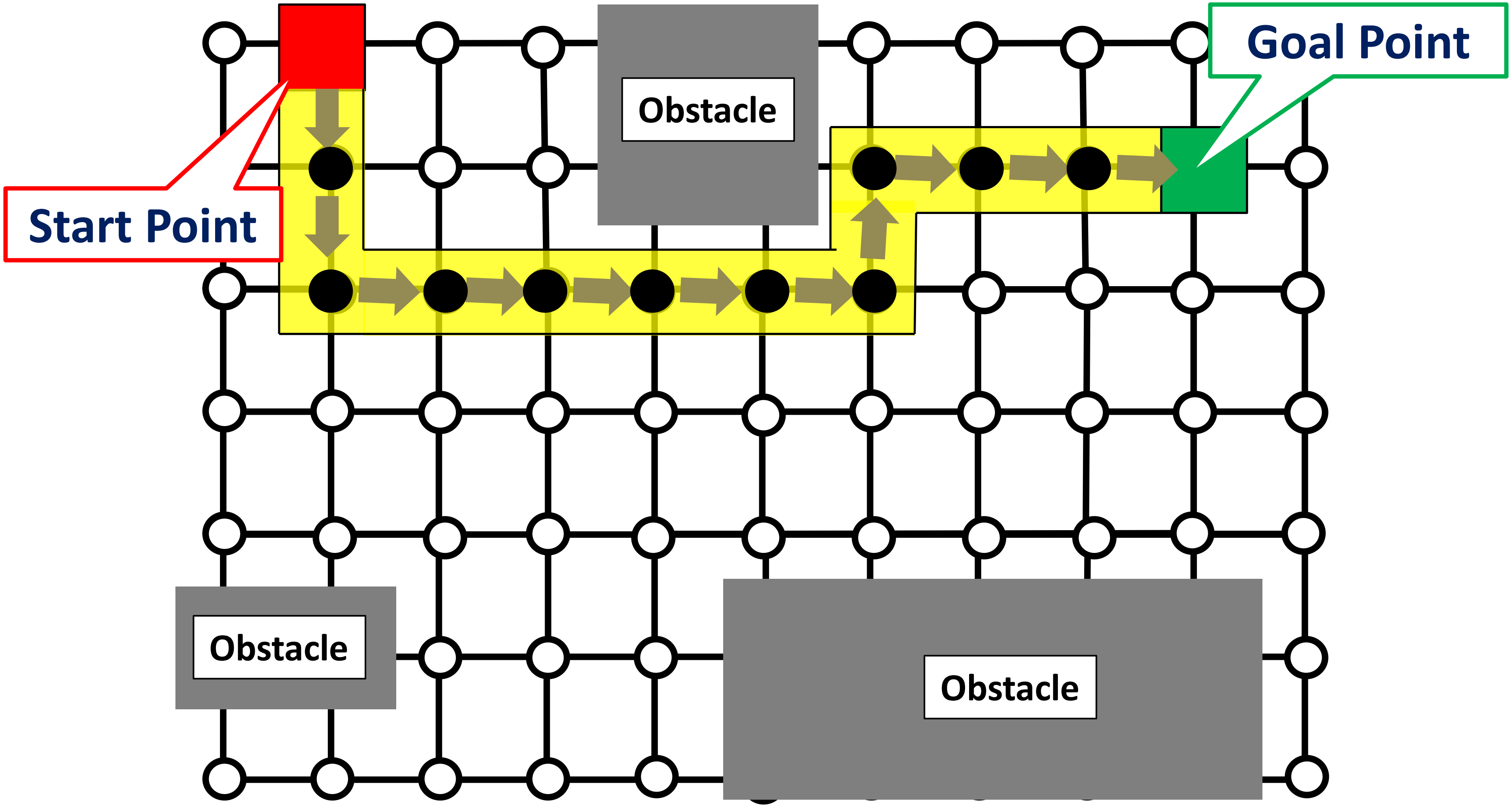
Total Costs = Cost of Total Length +

Cost of Elbows and Bends

$$= 12 + 0.1 \times 4$$

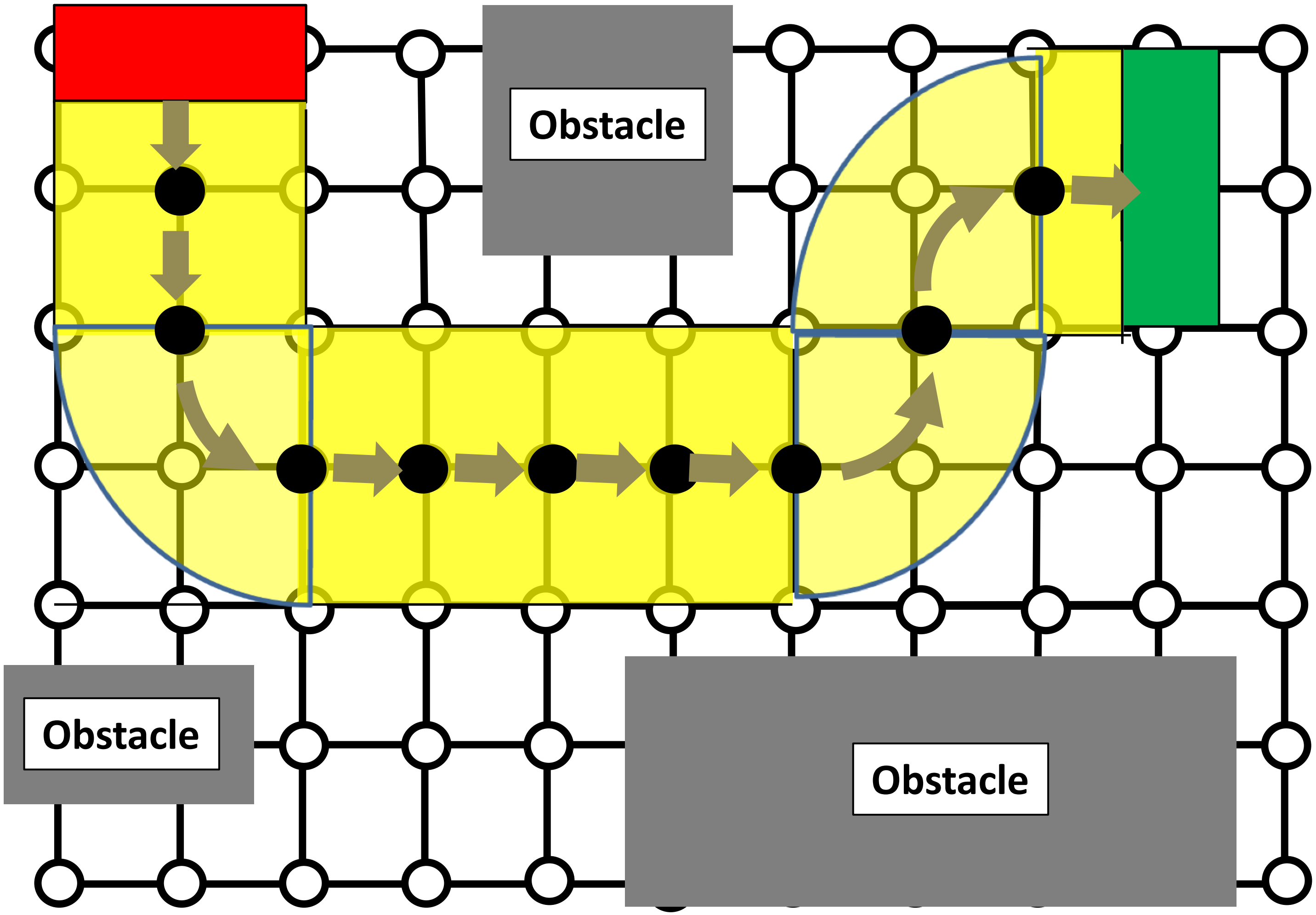
$$= 12.4$$

Routing Algorithm



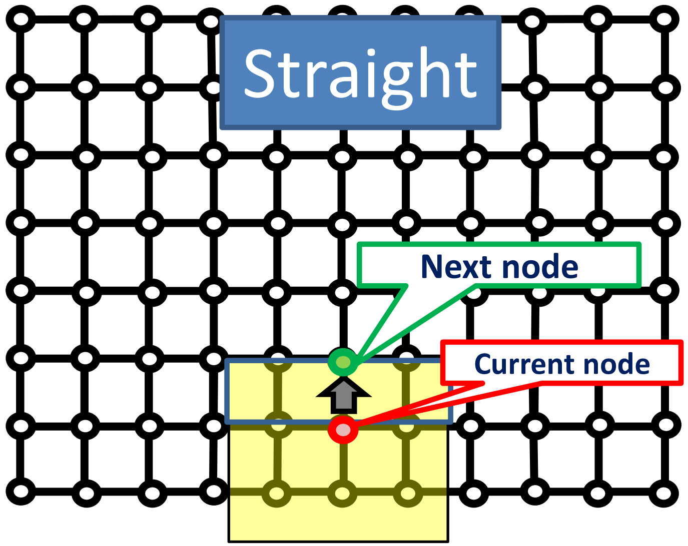
Pipe's Diameter < Mesh Size

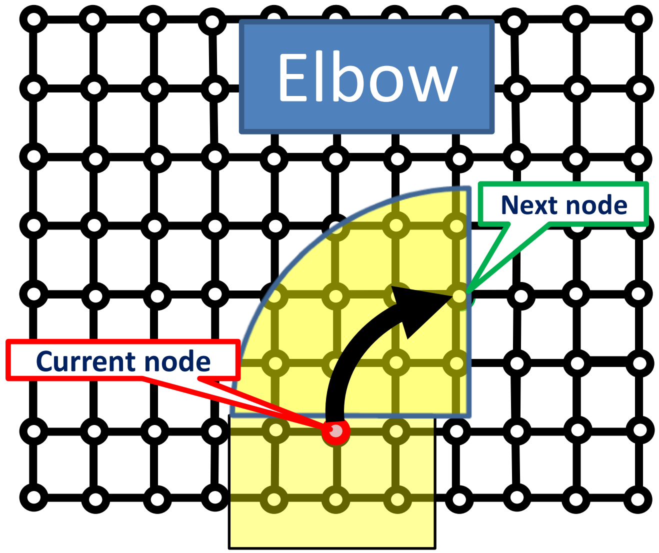
Routing Algorithm

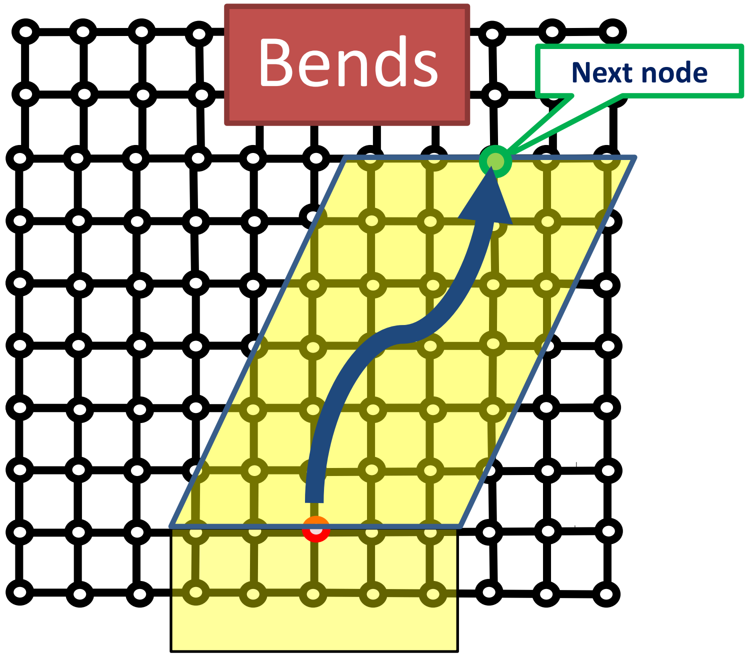


Pipe's Diameter > Mesh Size

Searching of Straight Pipes







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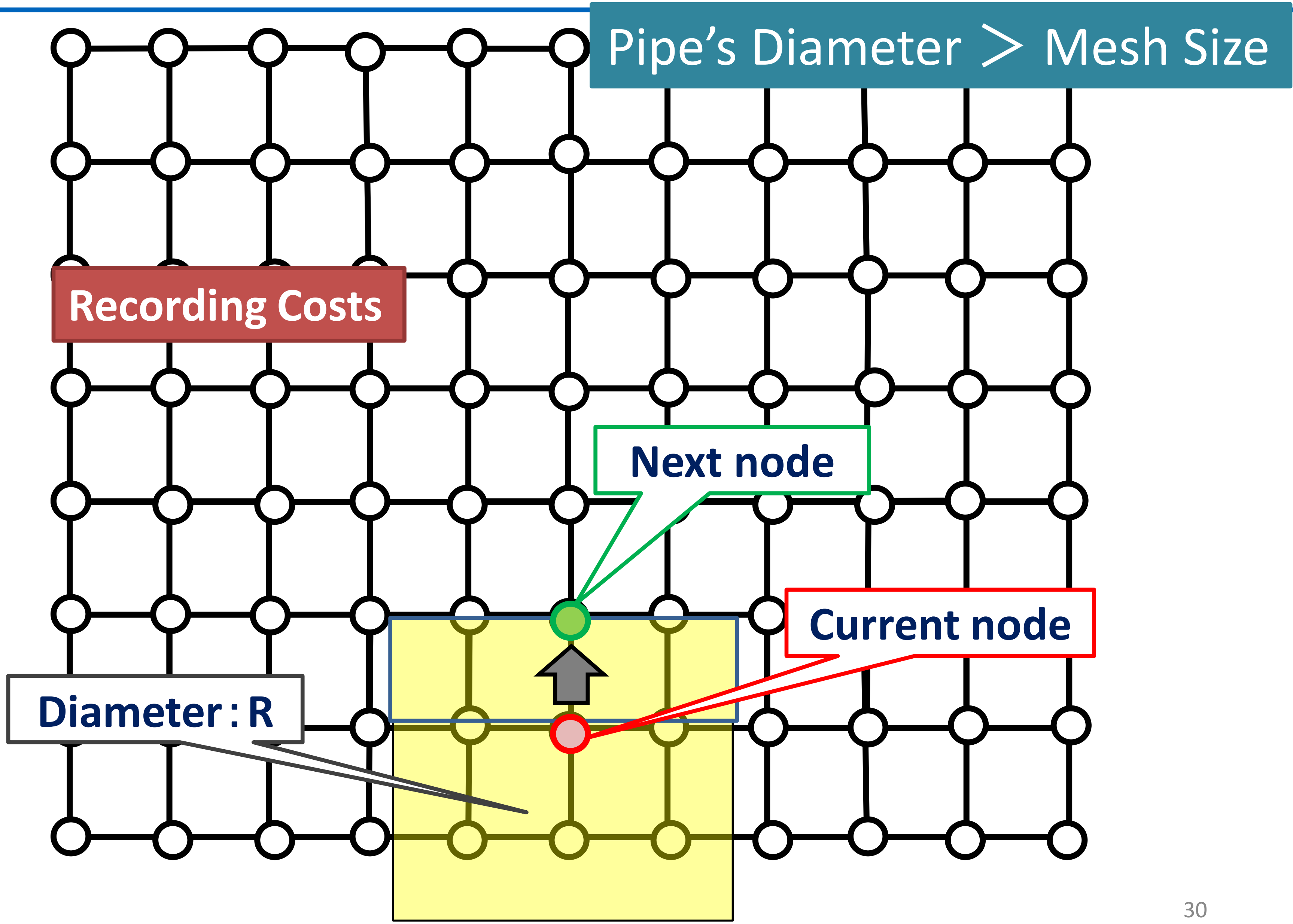
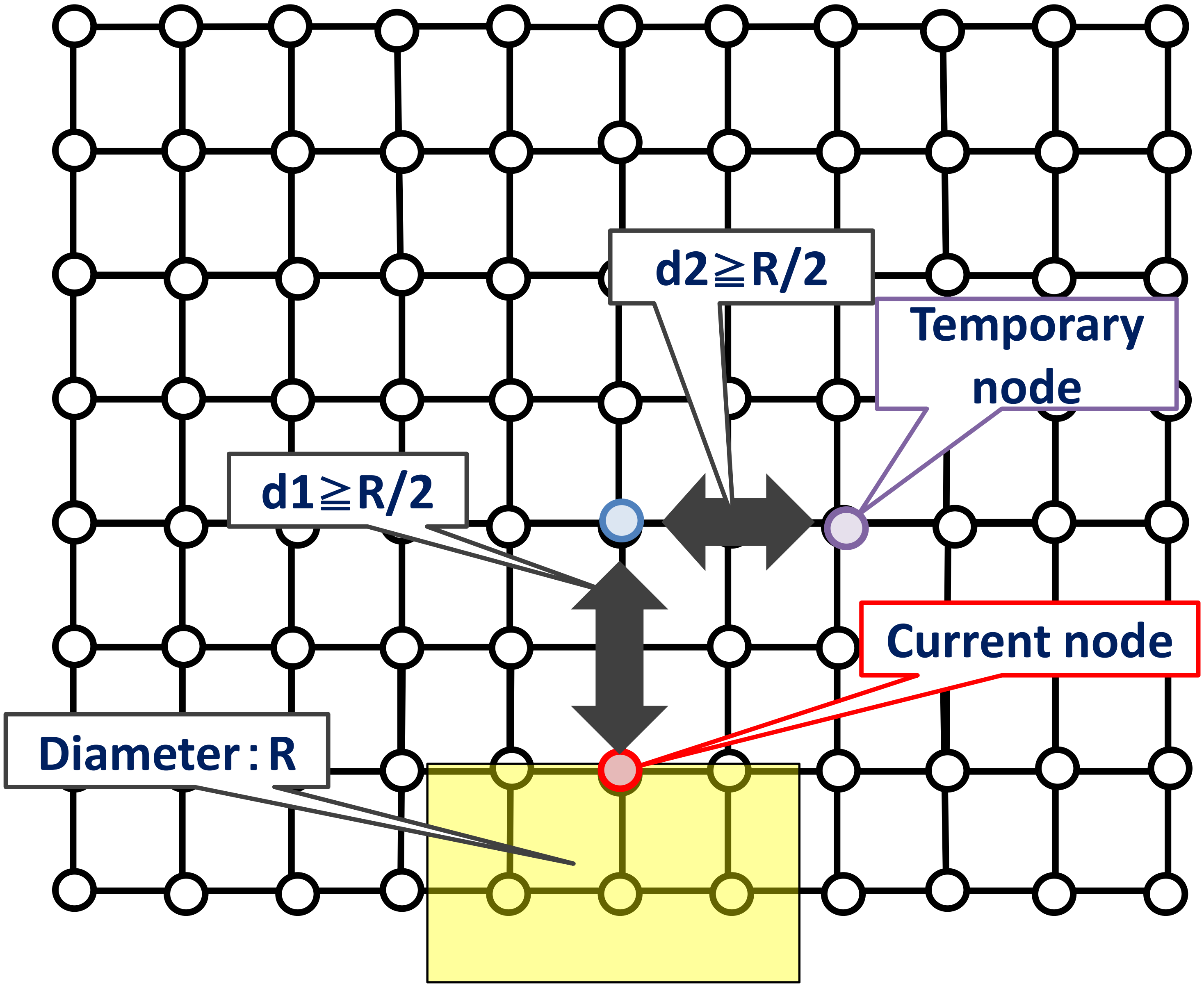


Searching of Elbows



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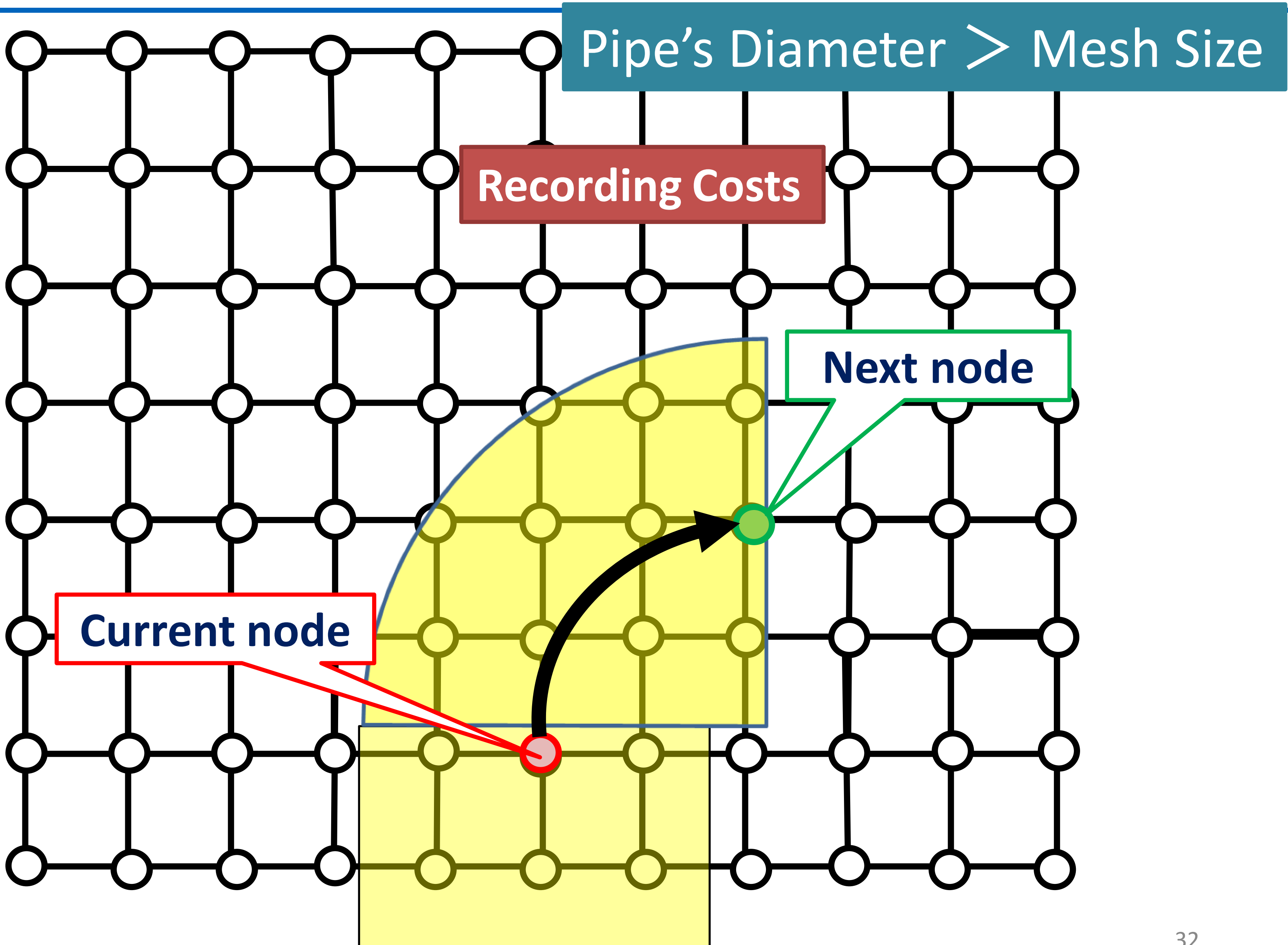
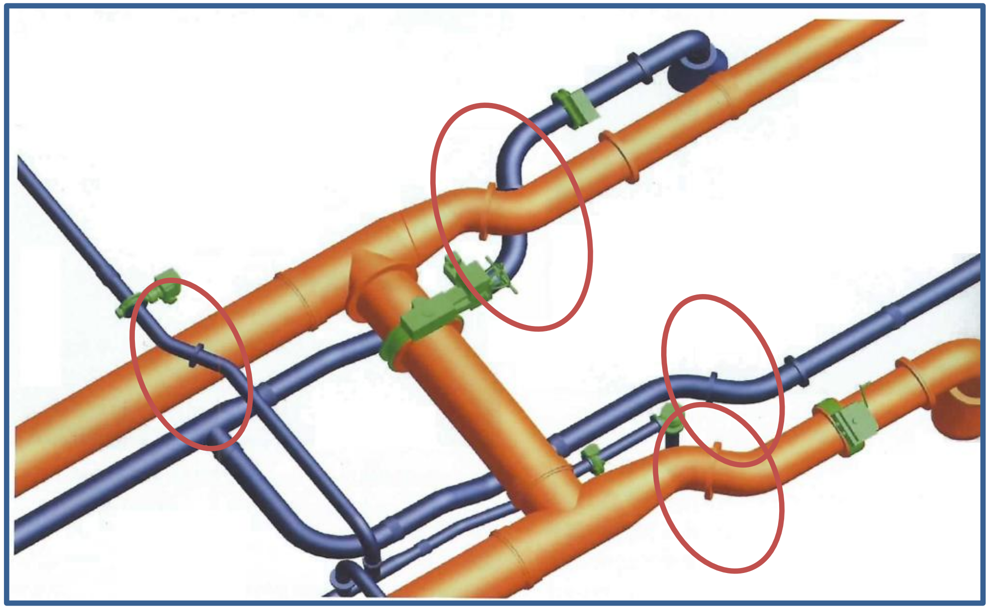


Outline of Bends

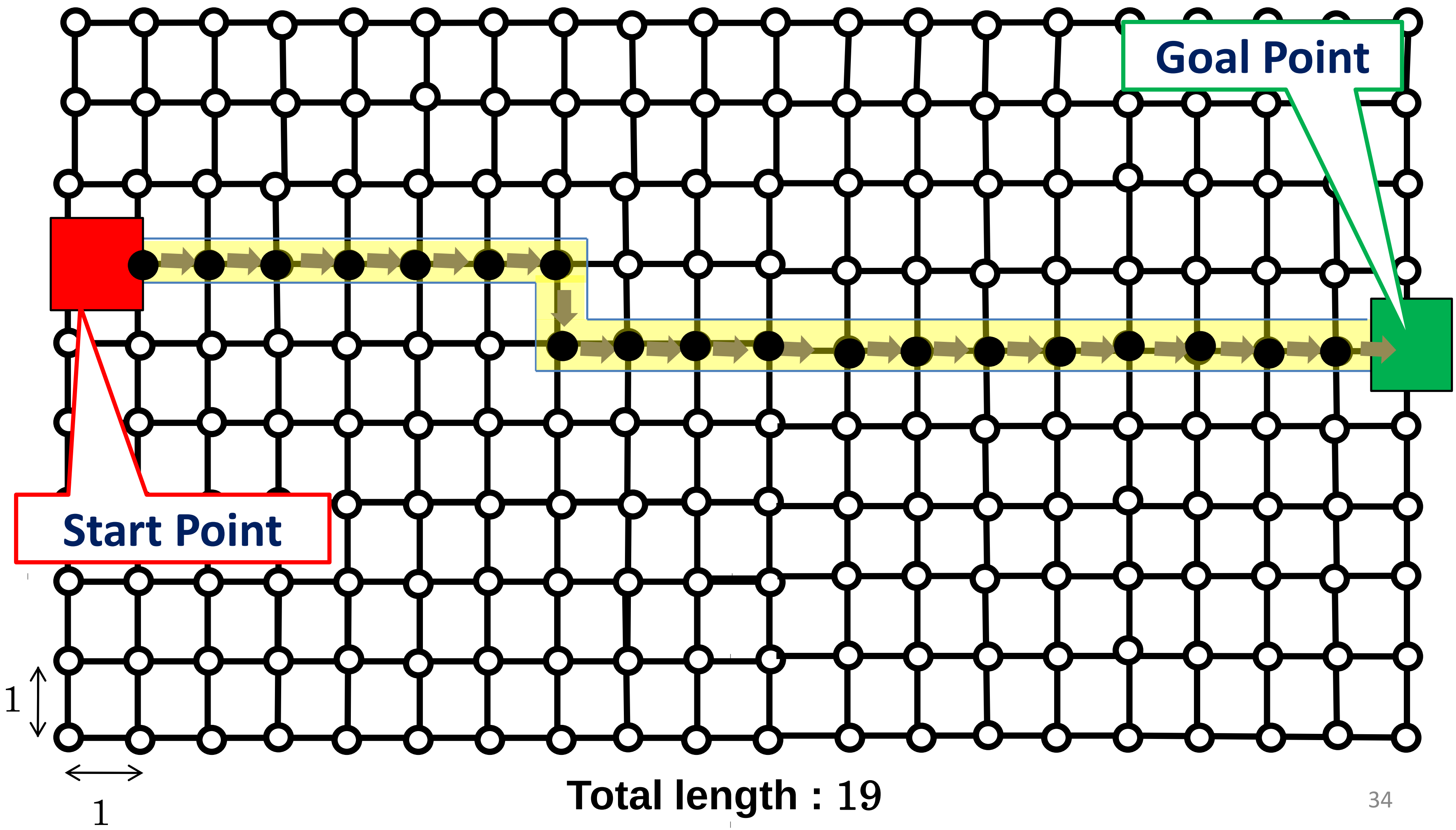
"Bends" are …

- ◆ **Pipe parts to take the form of gentle S-shape**
- ◆ **Connectors for gaps within the pipe's diameter**



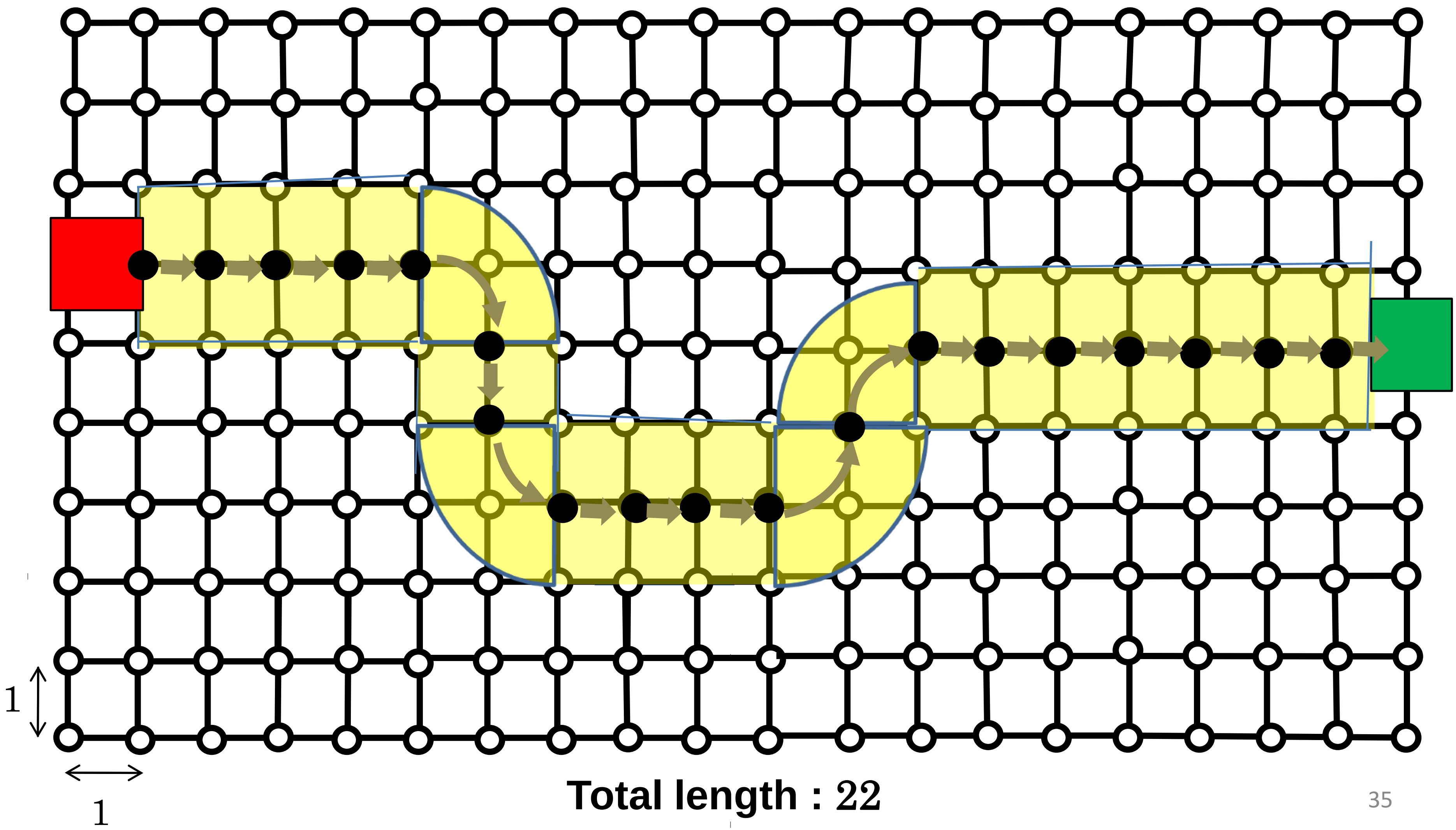
from "NAMURA TECHNICAL REVIEW No.13, 2010"

Outline of Bends



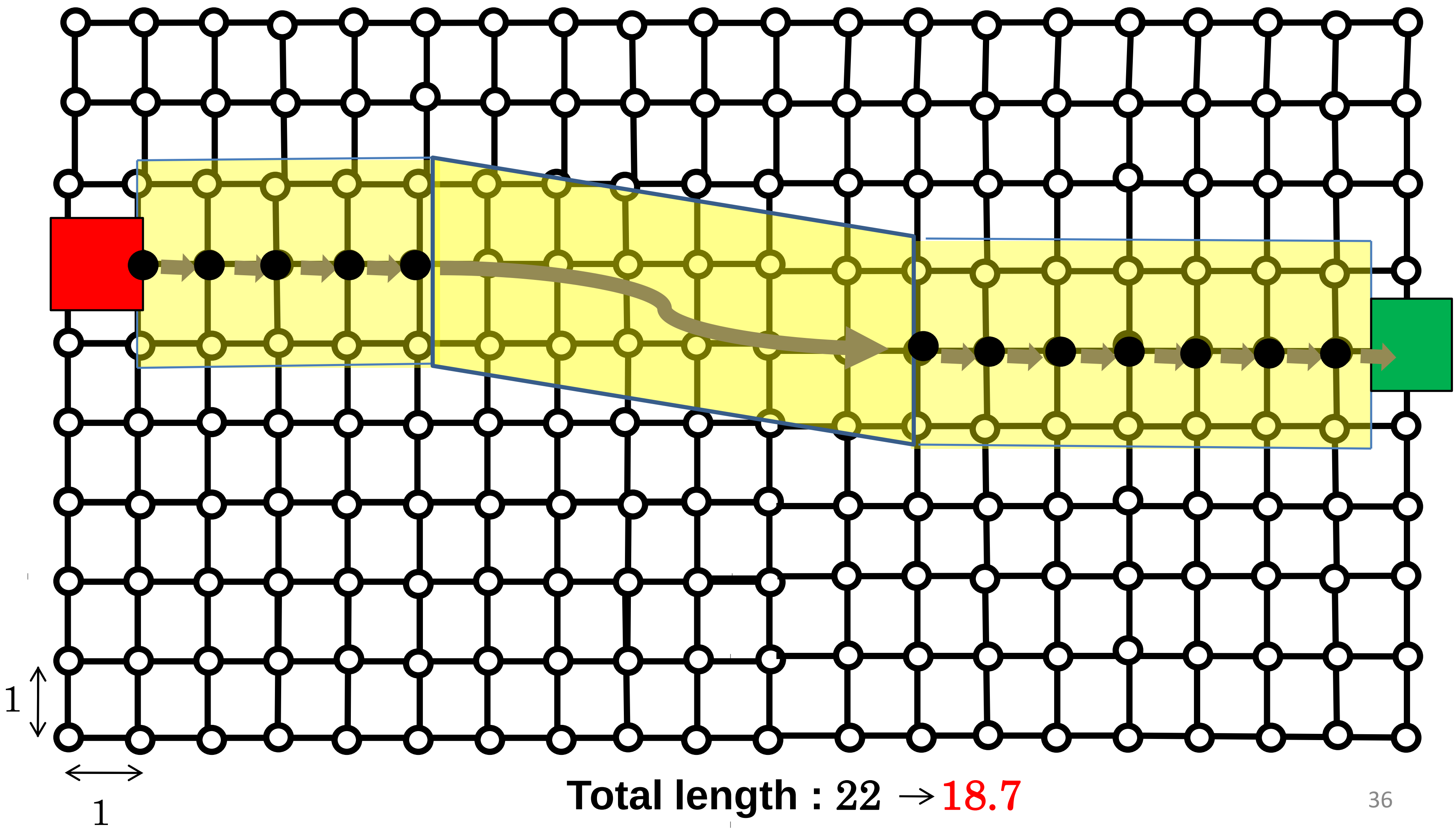
Total length : 19

Outline of Bends



Total length : 22

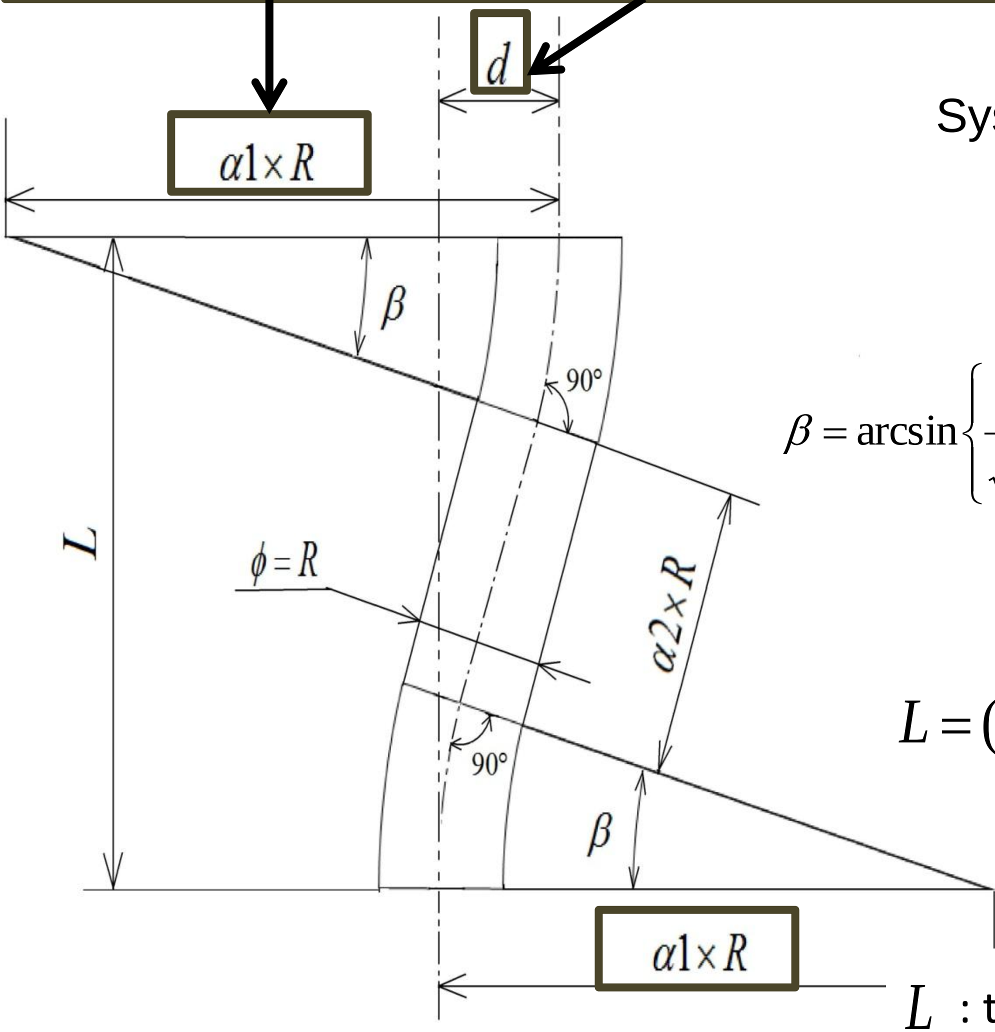
Outline of Bends



Total length : $22 \rightarrow$ 18.7

Searching of Bends

Constraints of Bending Machine



System user sets a value of $\alpha 1, \alpha 2, d$

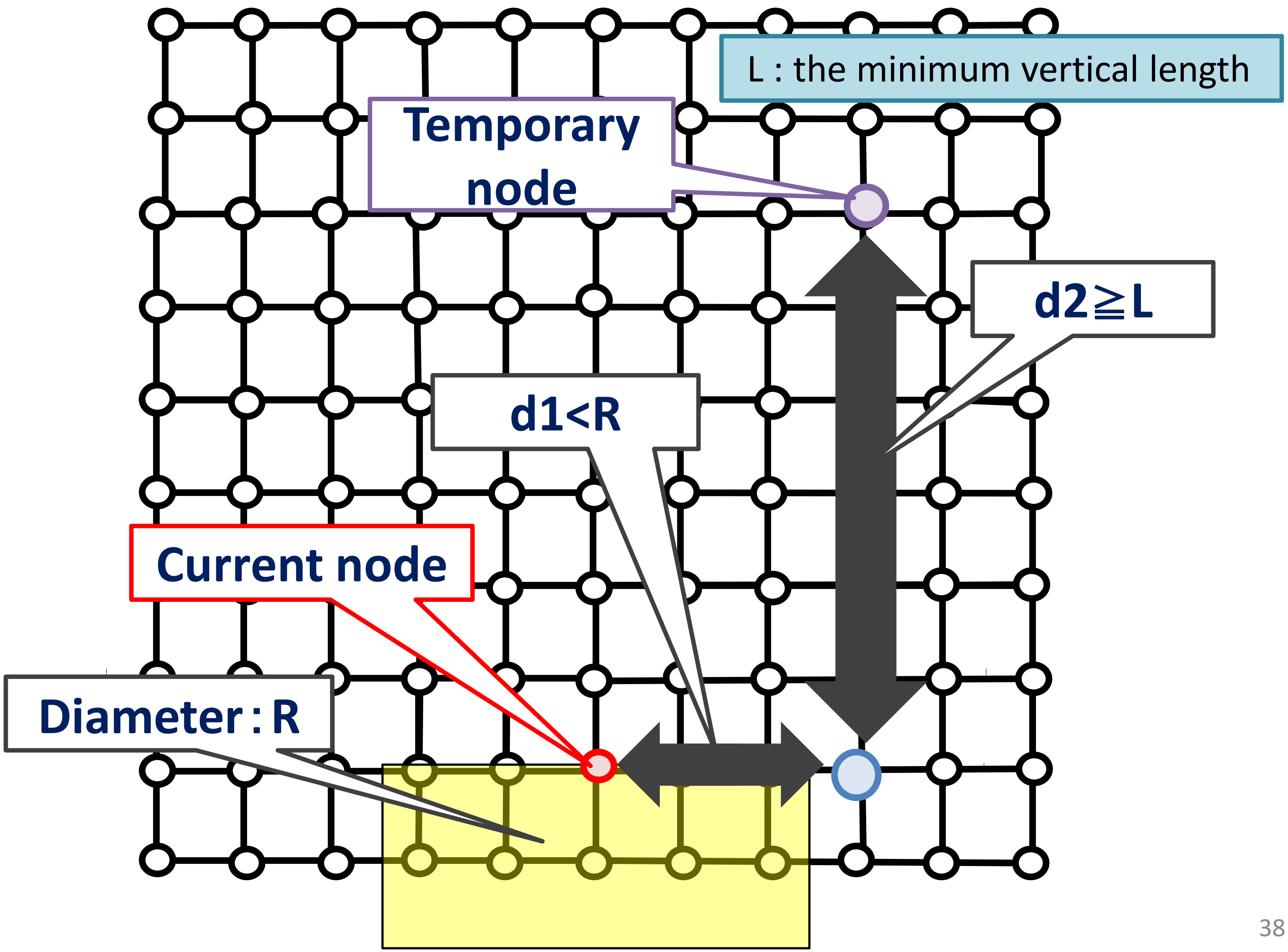
ex. $\alpha 1 = 5, \alpha 2 = 0, d < R$

$$\beta = \arcsin\left\{\frac{d - 2\times\alpha 1\times R}{\sqrt{(2\times\alpha 1)^2 + (\alpha 2)^2}}\right\} + \arcsin\left\{\frac{2\times\alpha 1}{\sqrt{(2\times\alpha 1)^2 + (\alpha 2)^2}}\right\}$$

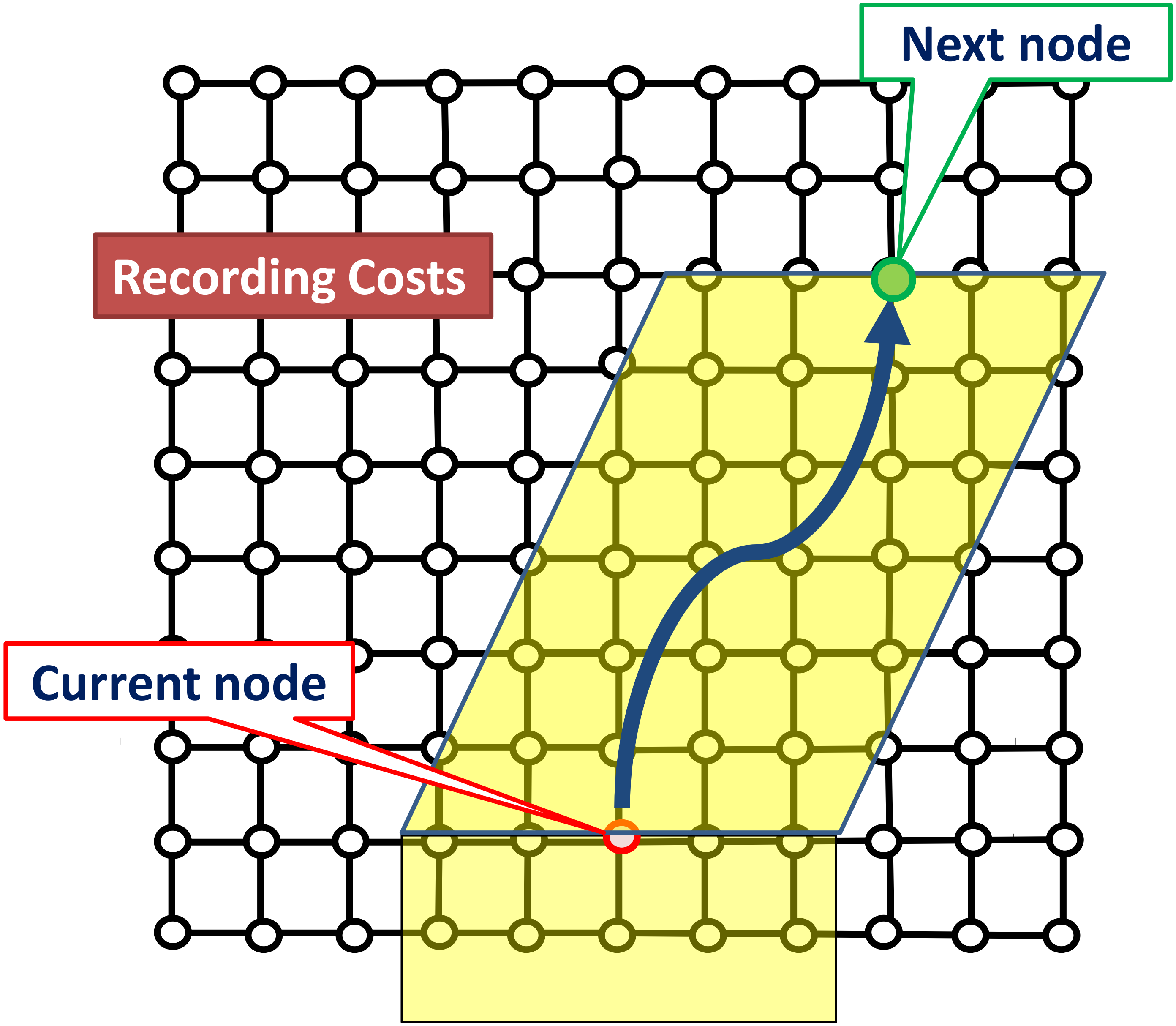
$$\boxed{L = (2\times\alpha 1\times R\times\sin\beta) + (\alpha 2\times R\times\cos\beta)}$$

L : the minimum vertical length of the bend

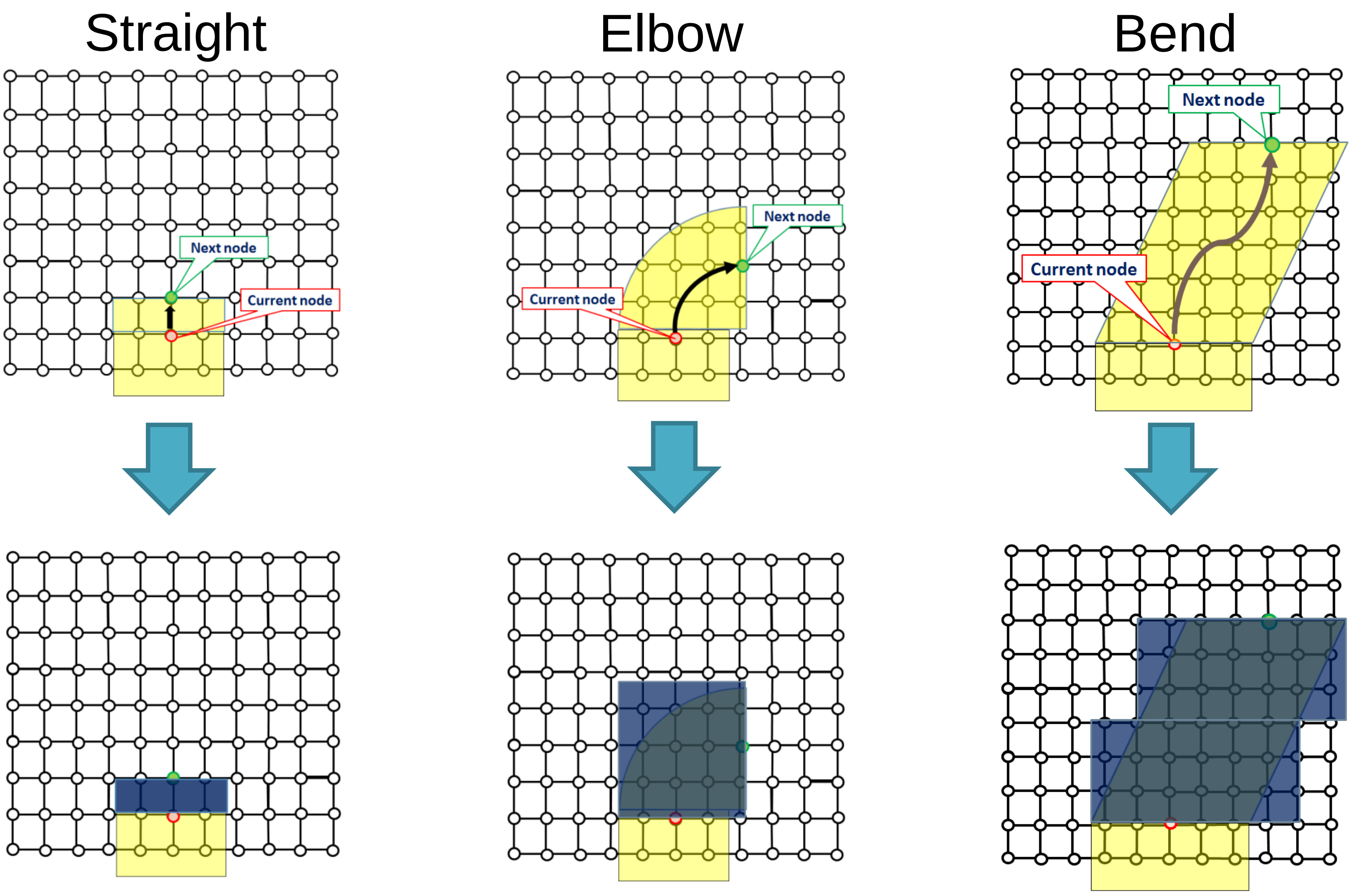
Searching of Bends



Searching of Bends



Interference Check



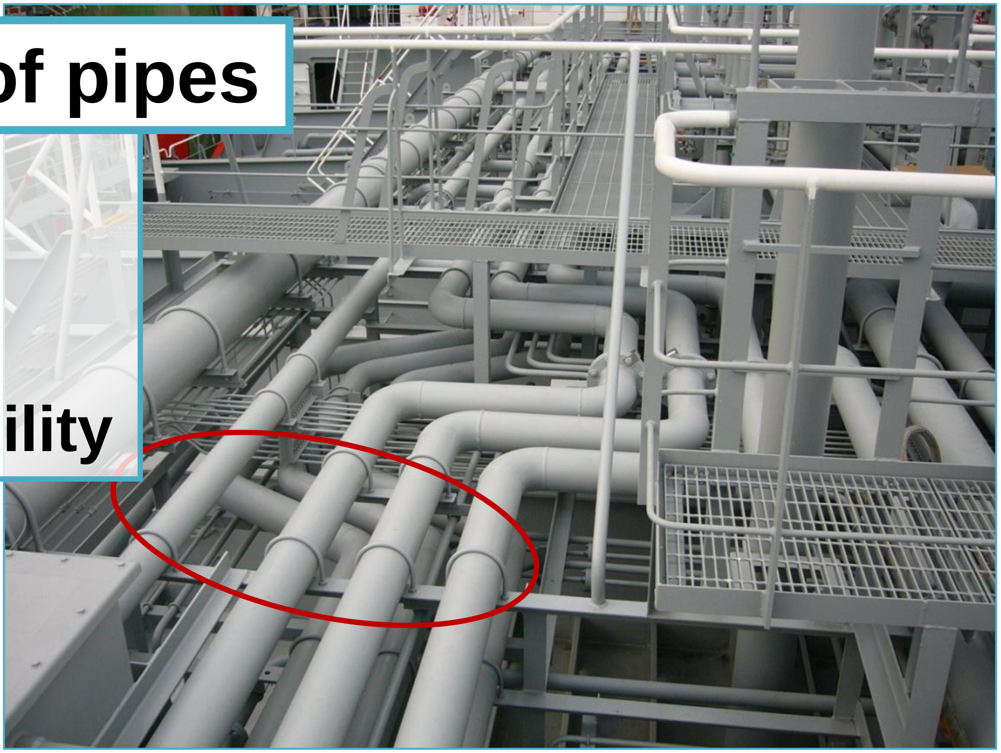
Check coordinates of circumscribed boxes

Pipe-rack Area

Pipe-rack : Supporter of pipes

Objectives…

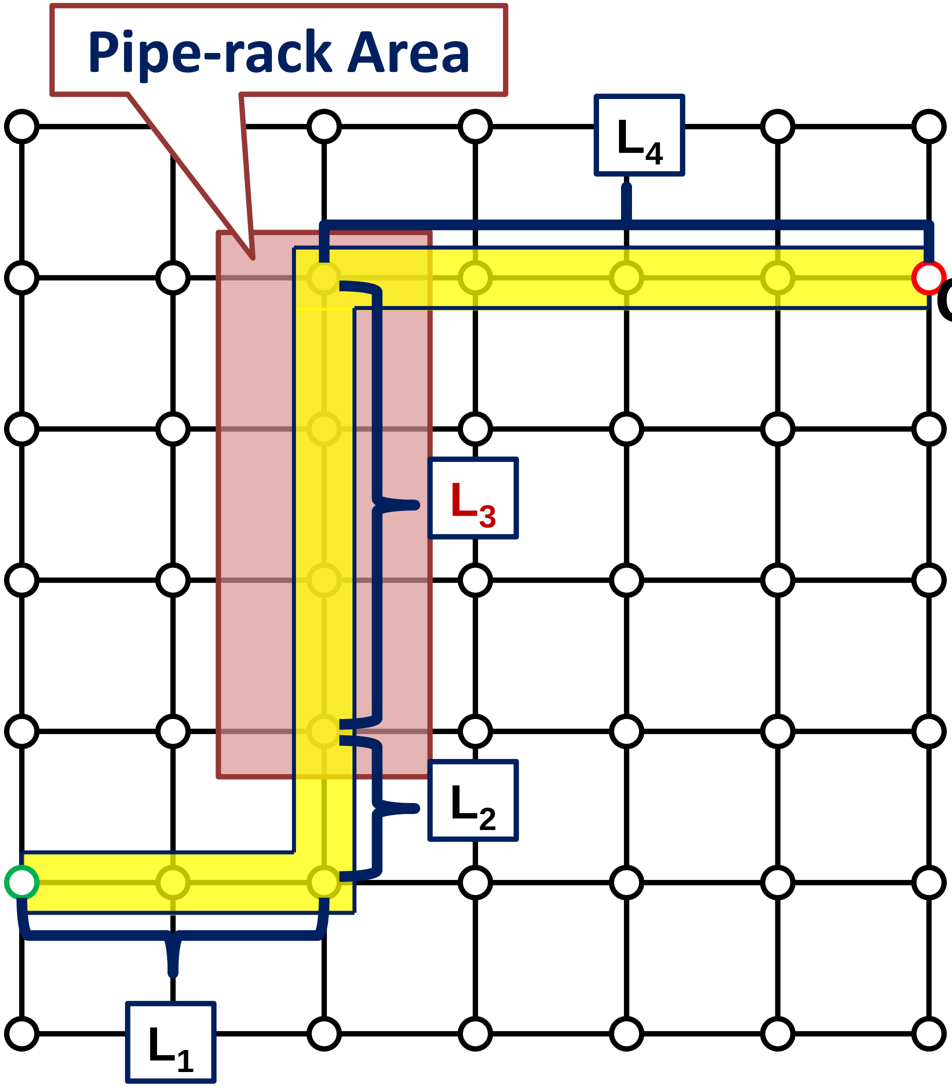
- **To bundle pipes**
- **To progress workability**
- **To progress maintainability**



In the routing system…

Cost Discounting Area

Pipe-rack Area



Total Cost : C_{total}

Cost of an Elbow : C_E

Length of Pipe : $L_1 \sim L_4$

Discount Rate : $V_D < 1$

Diameter : R

$$C_{Total} = (L_1+L_2+L_3 \times V_D+L_4 + (1+V_D) \times C_E) \times R$$

Experiments

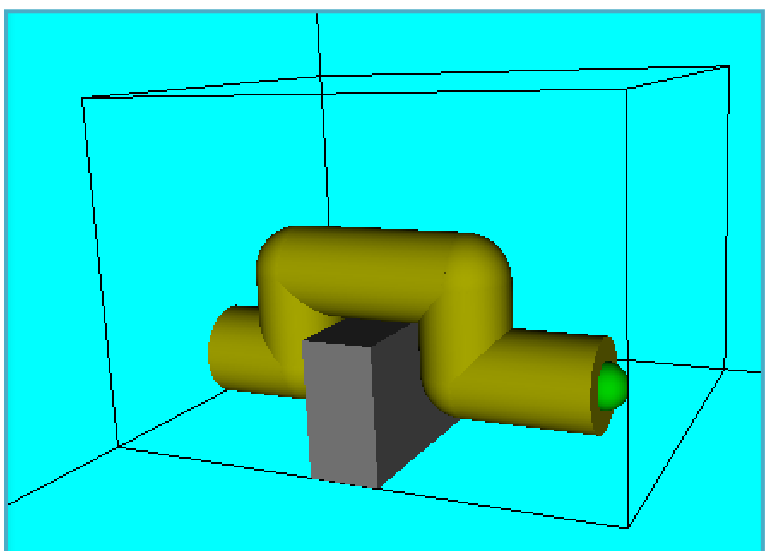
Design Space : Size X 3.0m, Size Y 2.5m, Size Z 2.0m

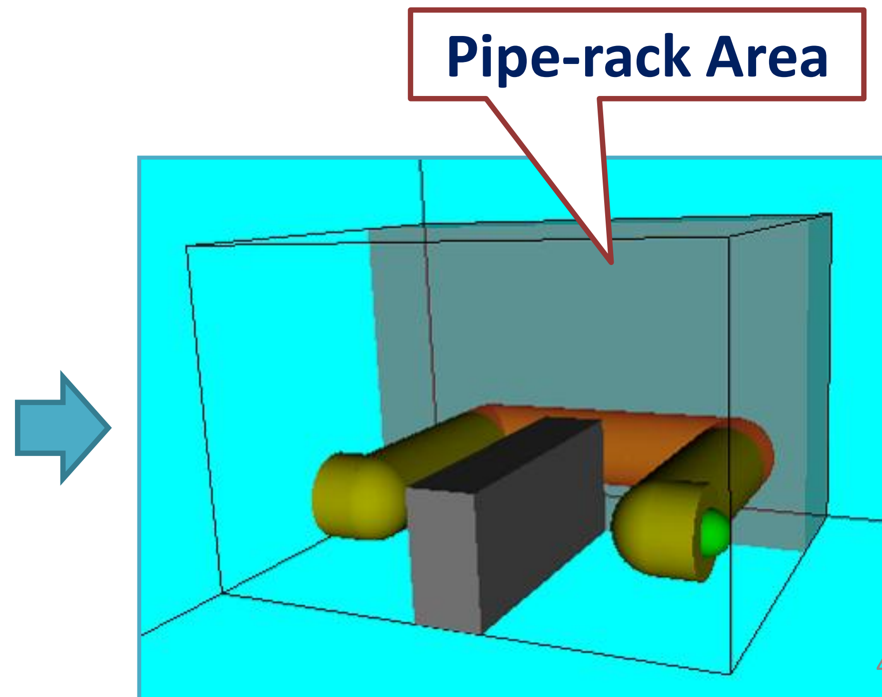
Mesh Size : Size X 0.25m, Size Y 0.25m, Size Z 0.25m

Start Point : (0.5m, 2.0m, 0.5m), x+

Goal Point : (2.75m, 2.0m, 0.5m), x-

Discount Rate : 0.3



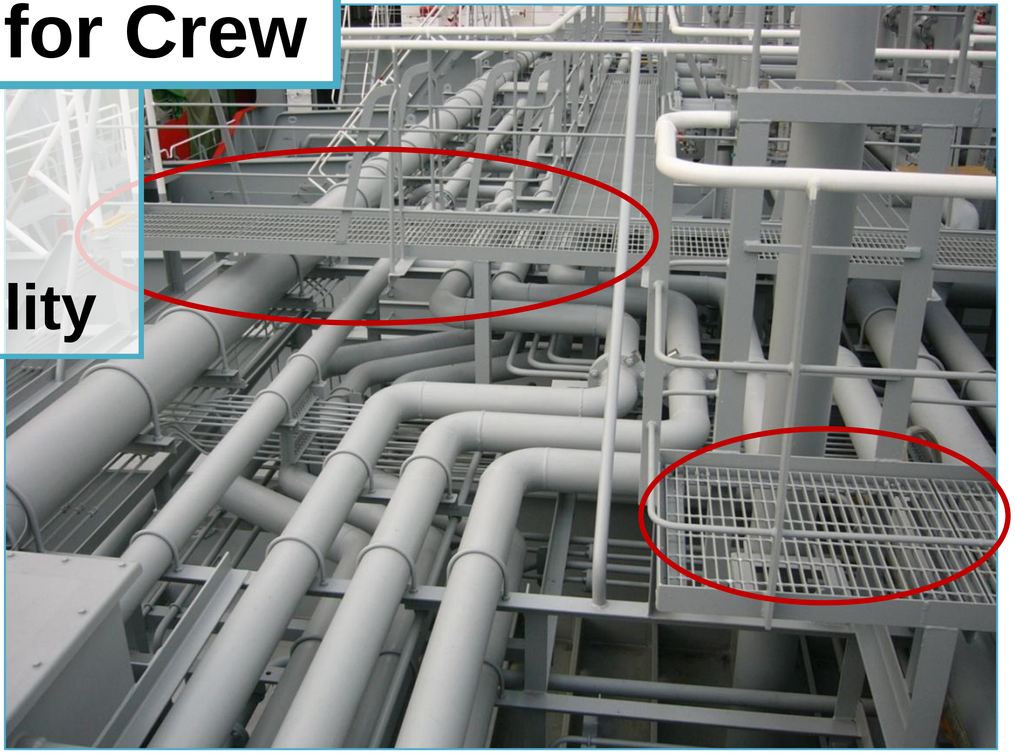


Aisle Space

Aisle Space : Passage for Crew

Objective…

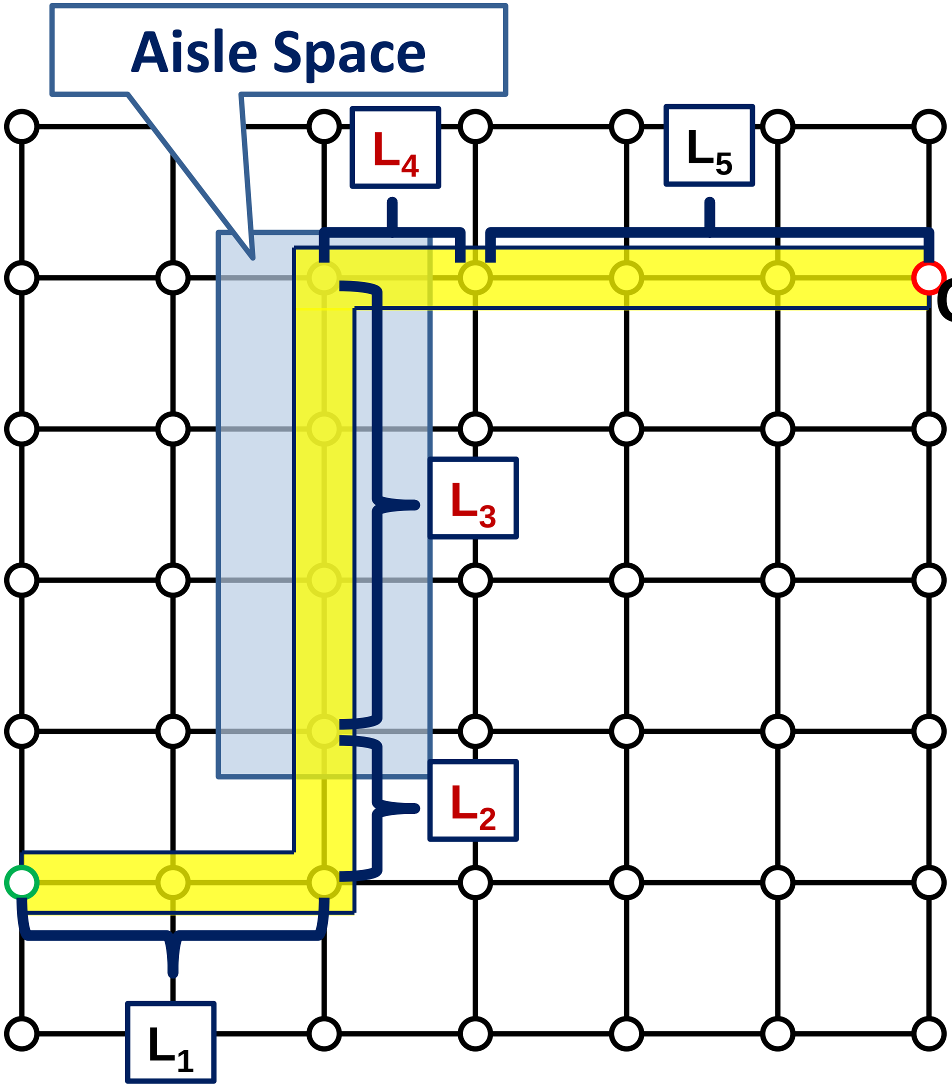
- ◆ **To improve safety**
- ◆ **To progress maintainability**



In the routing system…

Cost Increasing Area

Aisle Space



Total Cost : C_{total}

Cost of an Elbow : C_E

Length of Pipe : $L_1 \sim L_5$

Extra Rate : $V_P > 1$

Diameter : R

$$C_{Total} = (L_1 + (L_2 + L_3 + L_4) \times V_P + L_5 + (1 + V_P) \times C_E) \times R$$

Aisle Space

Experiment

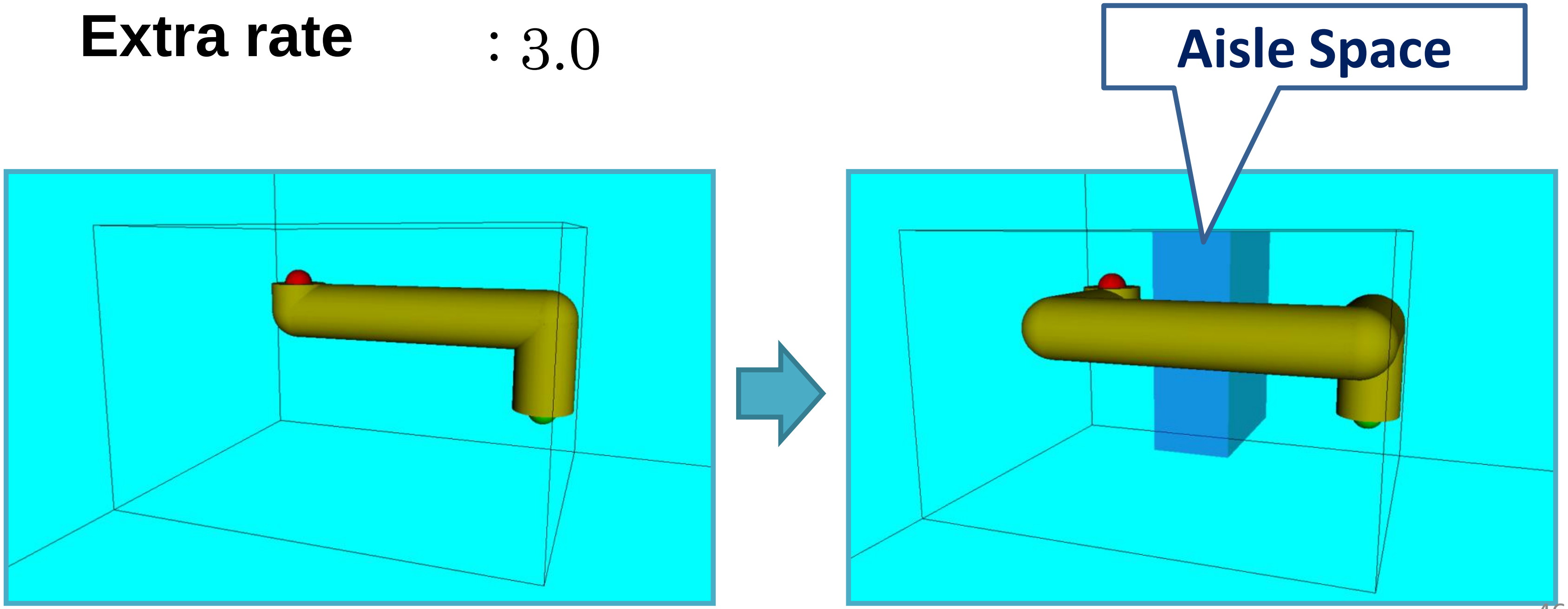
Design Space : Size X 3.0m, Size Y 2.5m, Size Z 2.0m

Mesh Size : Size X 0.25m, Size Y 0.25m, Size Z 0.25m

Start Point : (0.5m, 0.5m, 1.5m), z-

Goal Point : (2.75m, 0.5m, 0.5m), z+

Extra rate : 3.0



Simulations

Objective

To verify the useful of the algorithm through drawing pipes in a part of a ballast pomp room

Test Case Setting

Design Space : $\mathrm{Size\ X\ 8.0m,\ Size\ Y\ 12.0m,\ Size\ Z\ 4.0m}$

Mesh Size : $\mathrm{Size\ X\ 0.25m,\ Size\ Y\ 0.25m,\ Size\ Z\ 0.25m}$

Discount Rate of Pipe-rack Area : 0.5

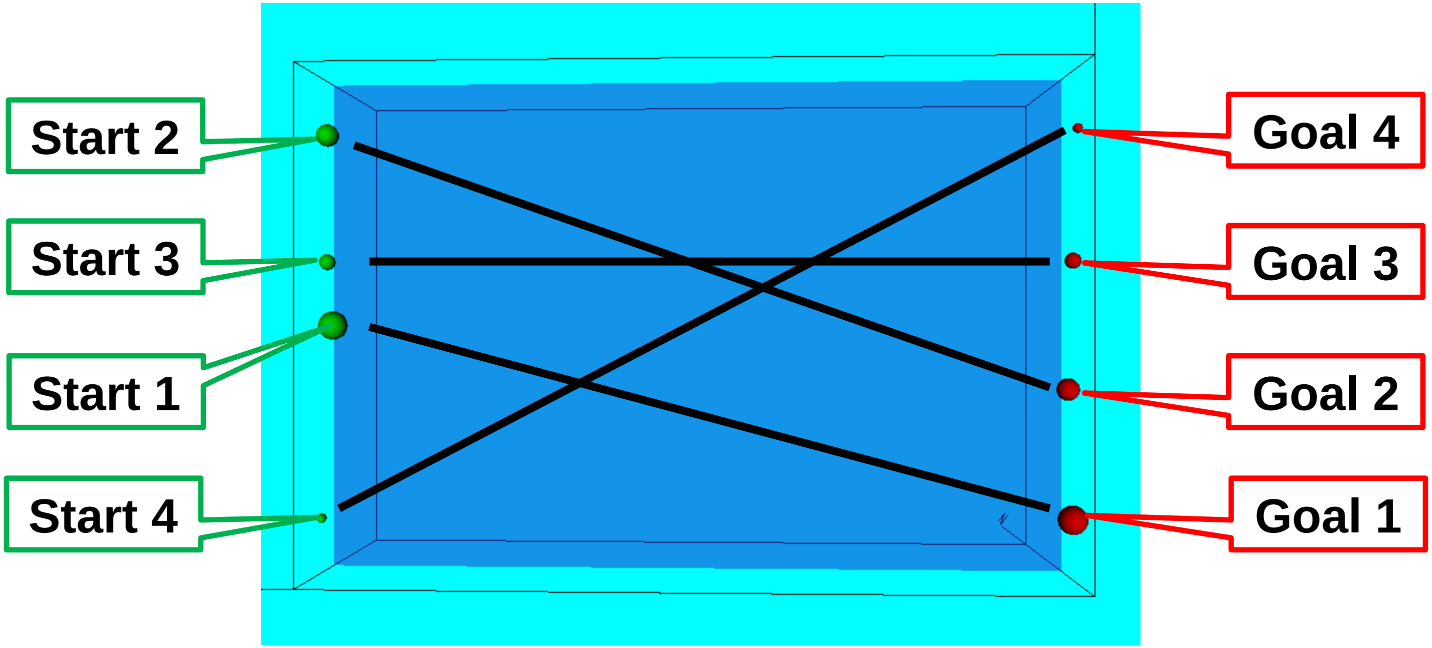
Extra Rate of Aisle Space : 2.0

S

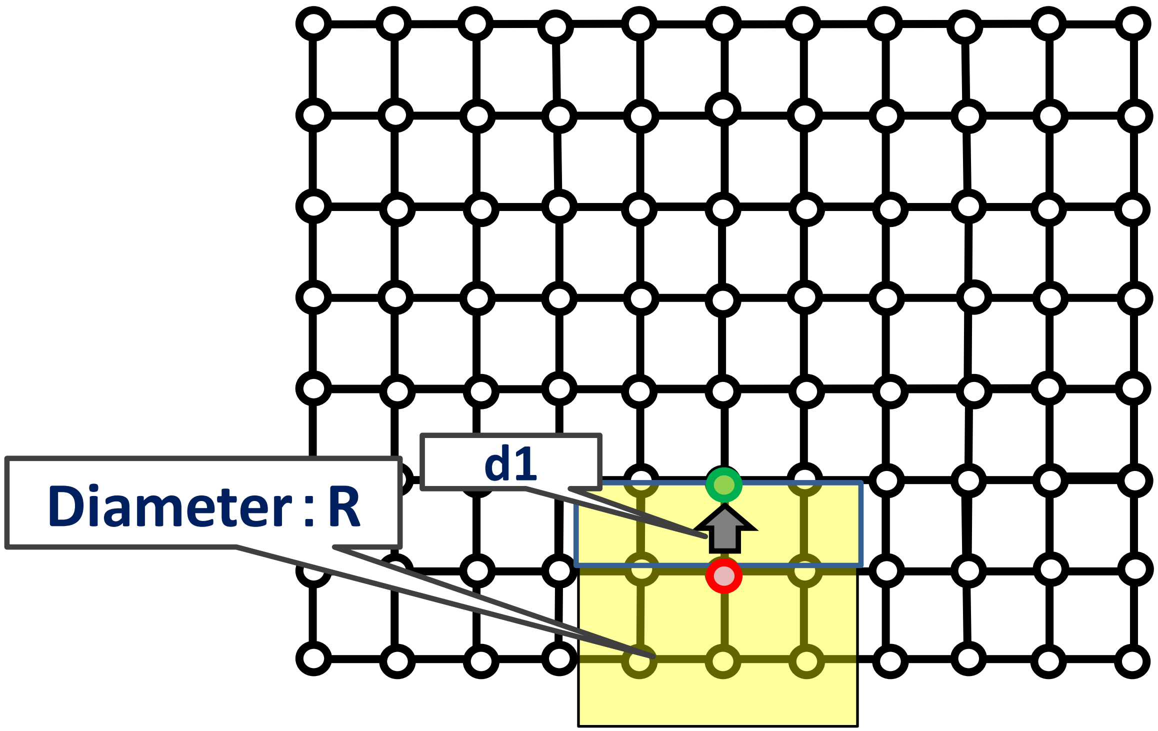
From the largest
To the thinnest

From the longest
To the shortest

Pipe No.	Diameter [m]	Length [m]	Order1	Order2
Pipe1	0.9	12.0	1	3
Pipe2	0.7	12.3	2	2
Pipe3	0.5	11.7	3	4
Pipe4	0.3	13.1	4	1

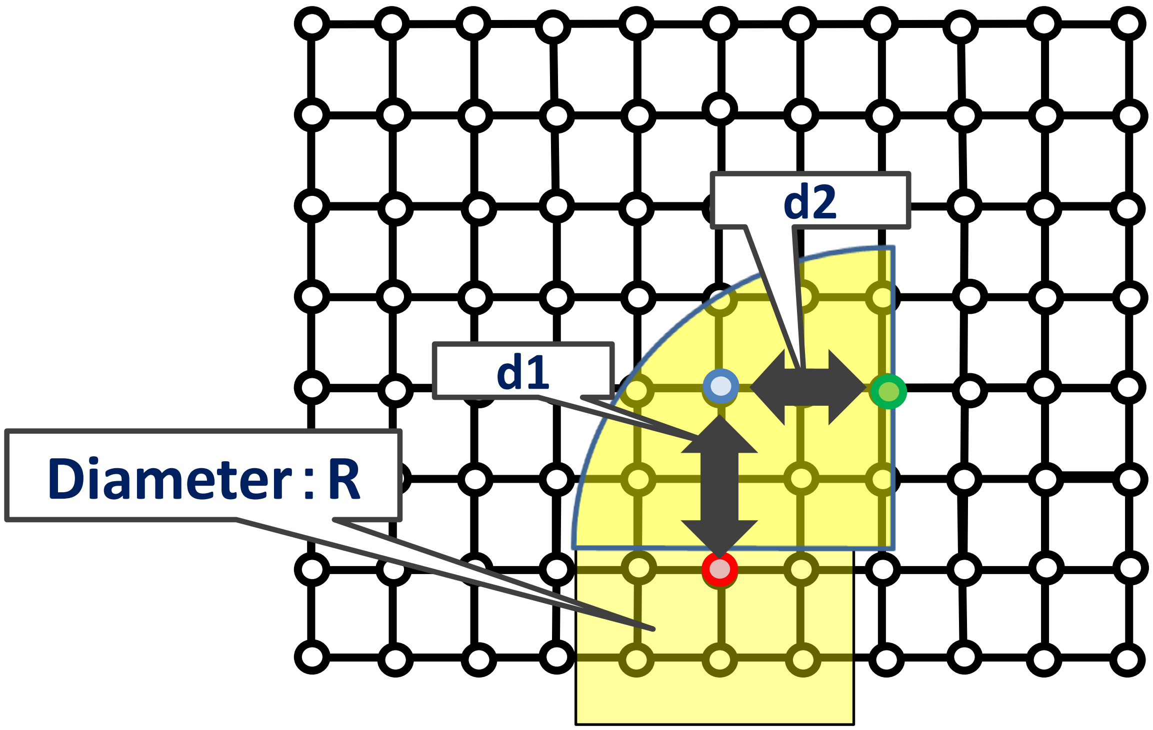


Experiments



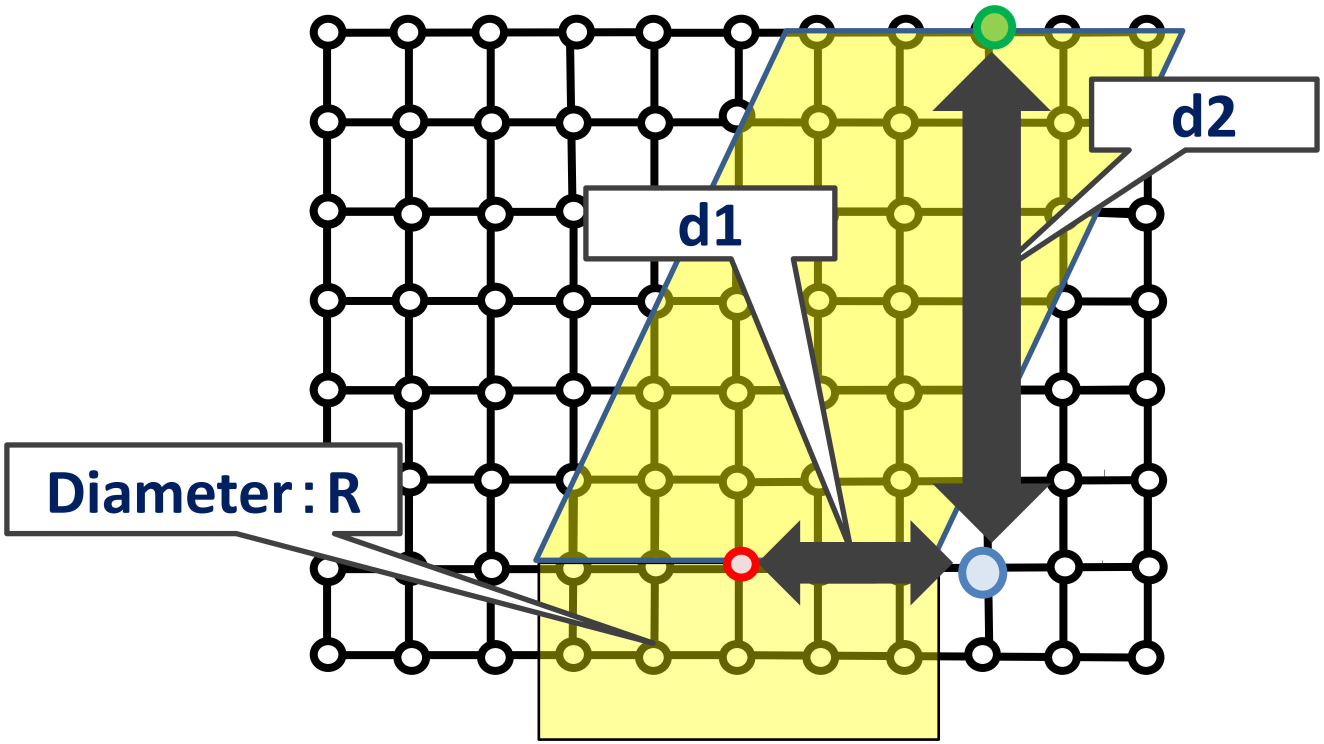
Cost of a Straight Pipe : $1 \times R$ per $1m$

Experiments



Cost of a Elbow : $(d1 + d2 + 0.1) \times R$

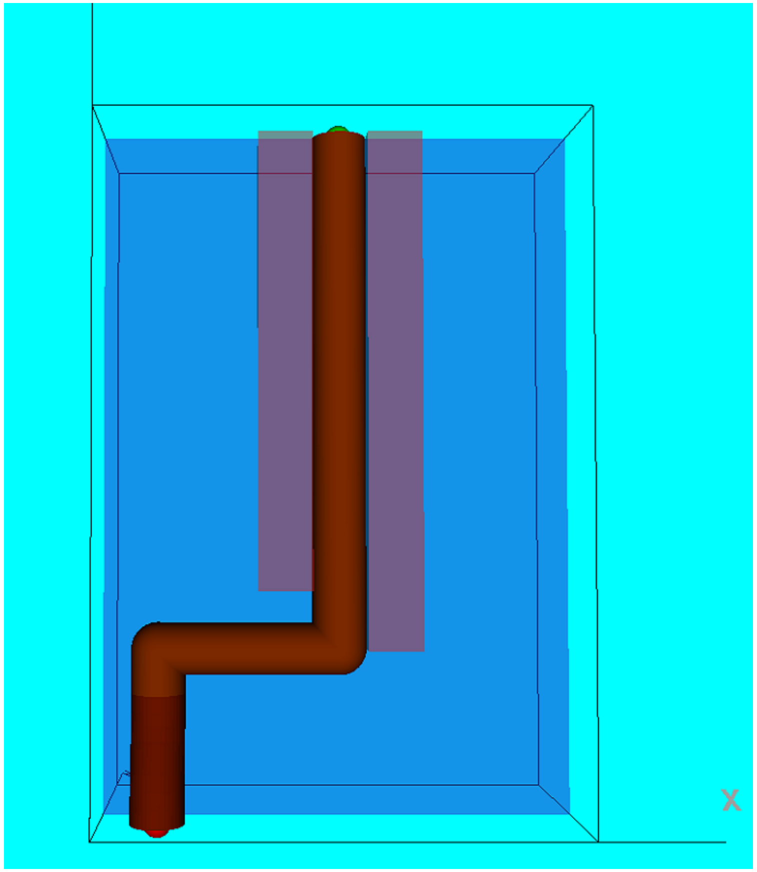
Experiments



Cost of a Bend : $(d1 + d2 + 0.3)$ x R

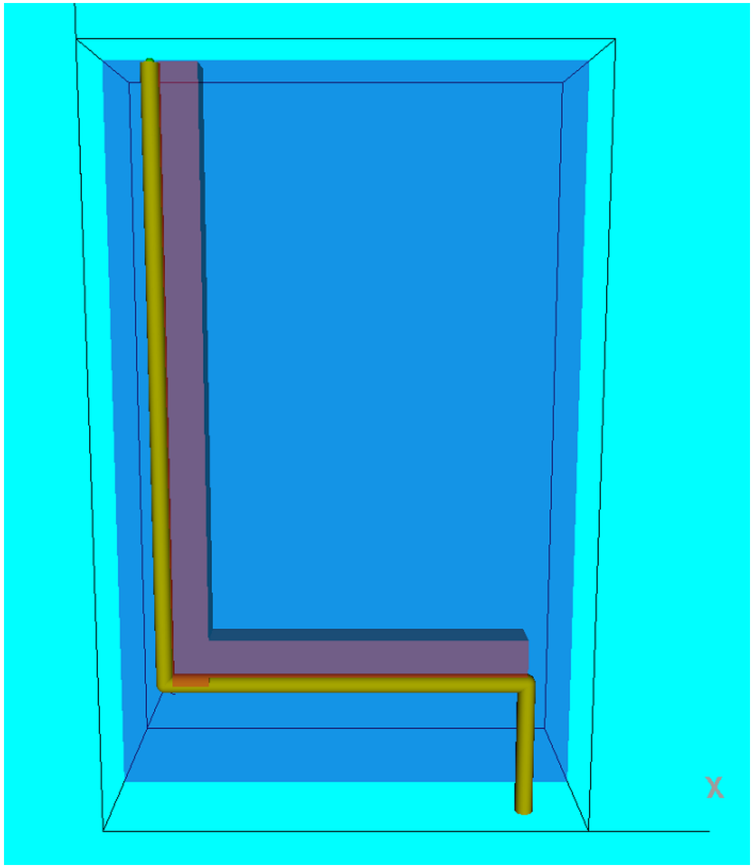
Results

Order1 : From the largest



Total Cost : 13.95

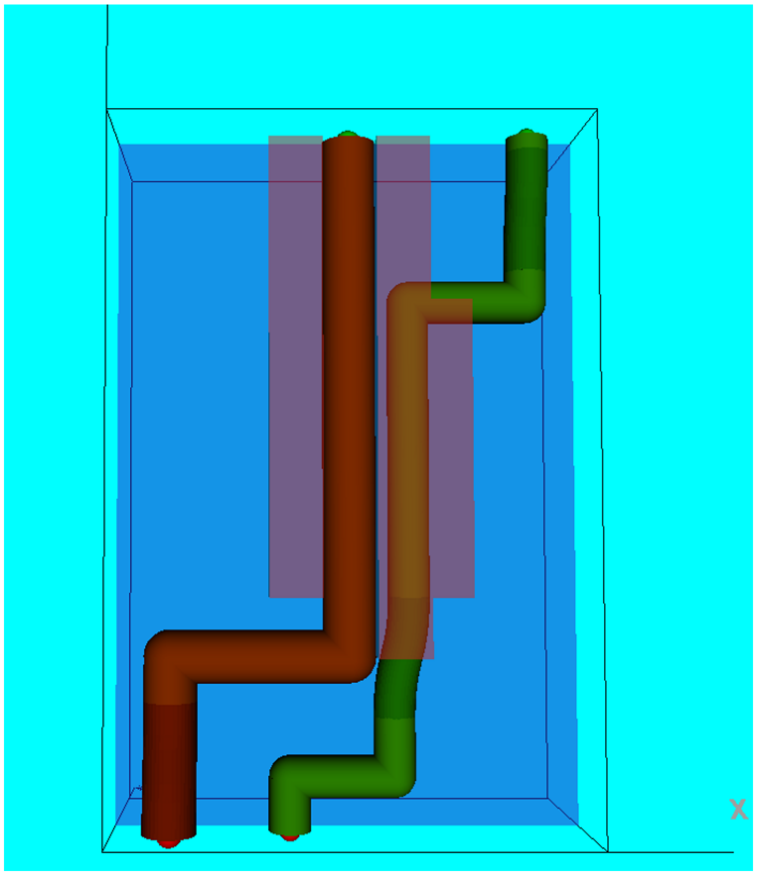
Order2 : From the longest



Total Cost : 5.4

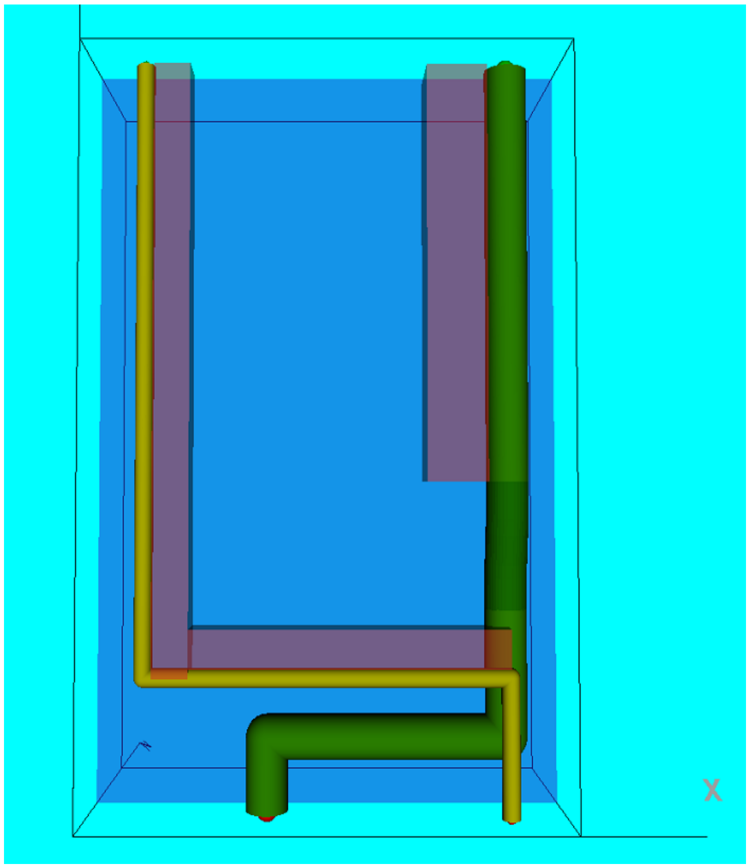
Results

Order1 : From the largest



Total Cost : 23.42

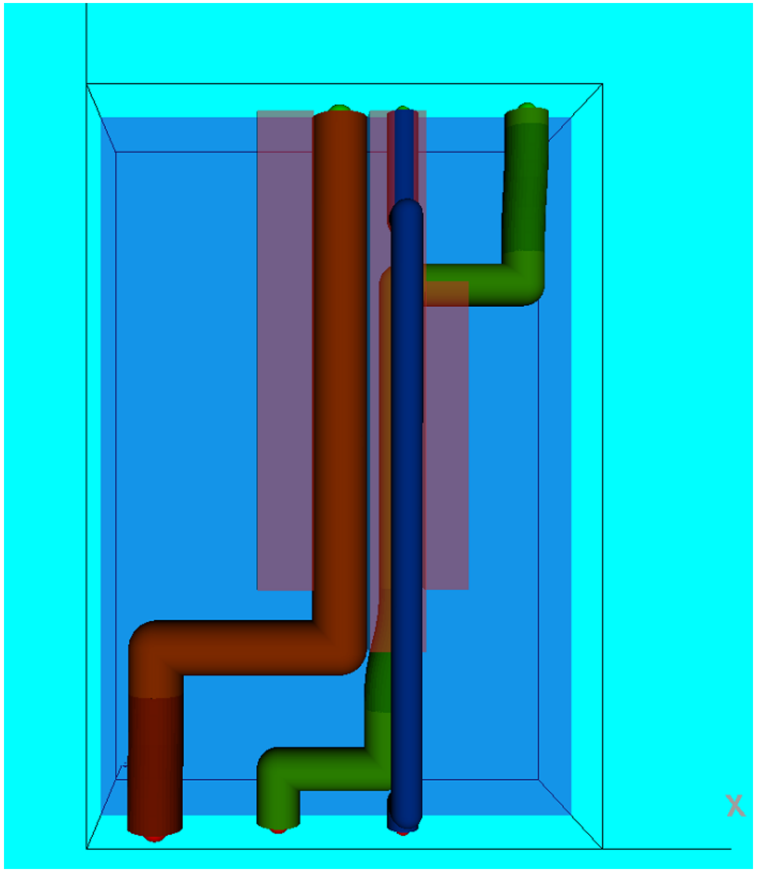
Order2 : From the longest



Total Cost : 11.90

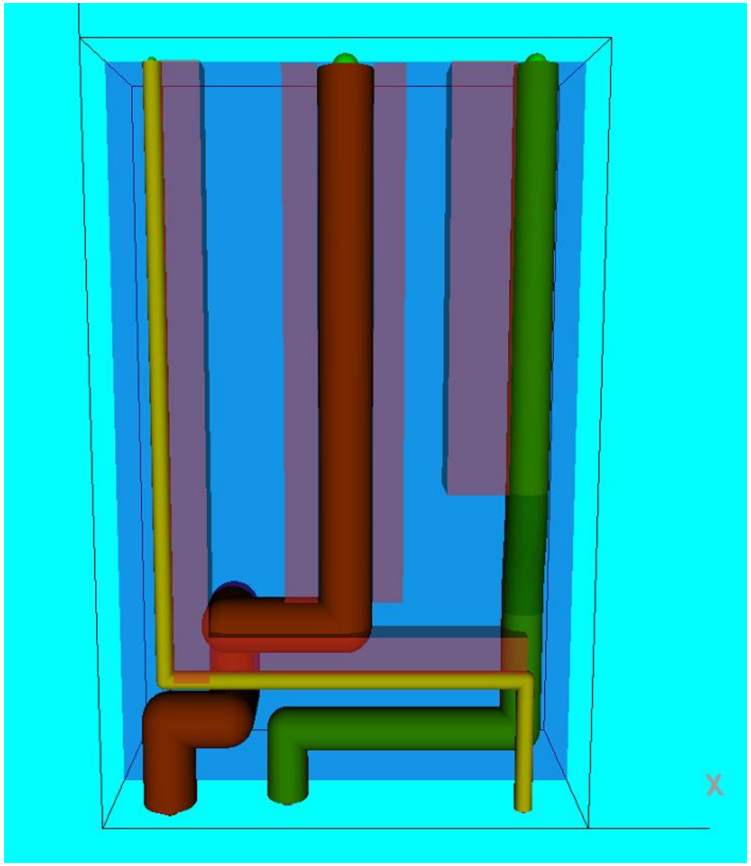
Results

Order1 : From the largest



Total Cost : 29.95

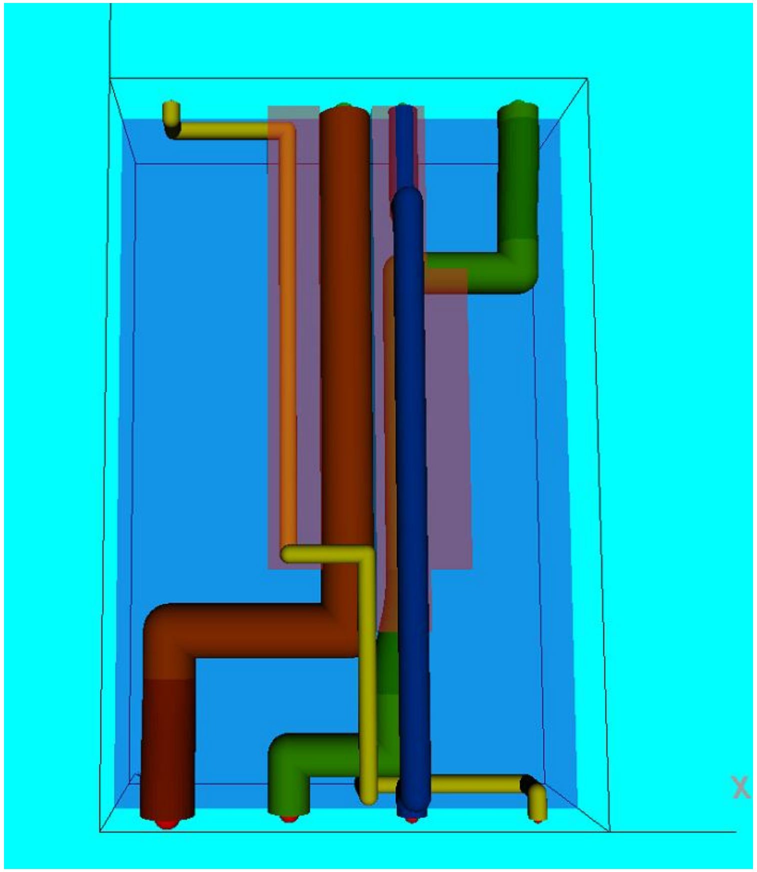
Order2 : From the longest



Total Cost : 30.08

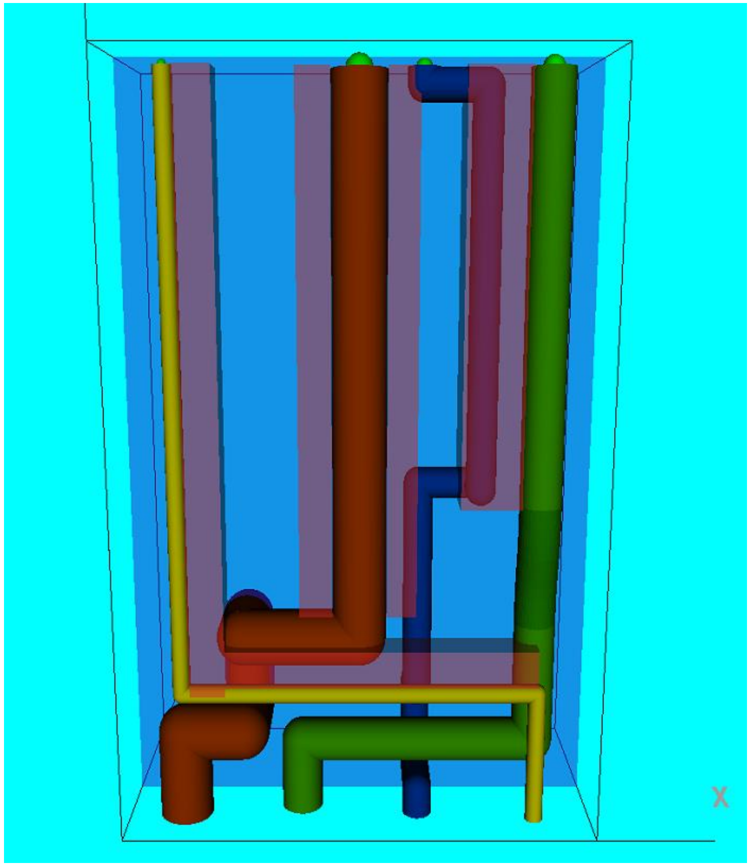
Results

Order1 : From the largest



Total Cost : 35.22

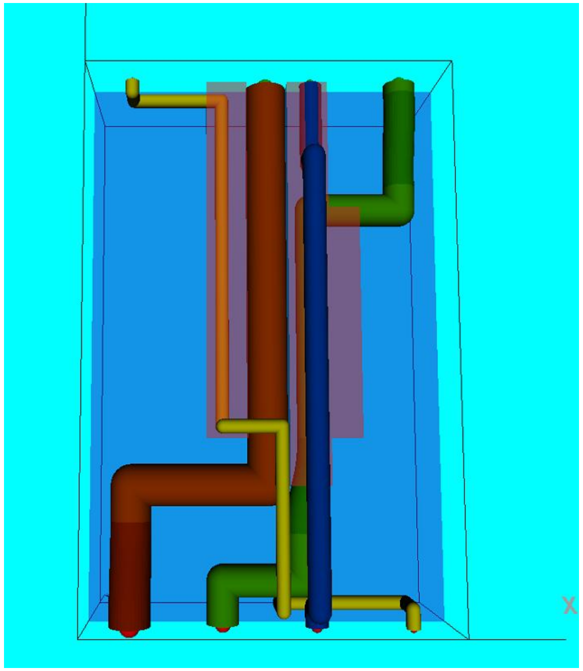
Order2 : From the longest

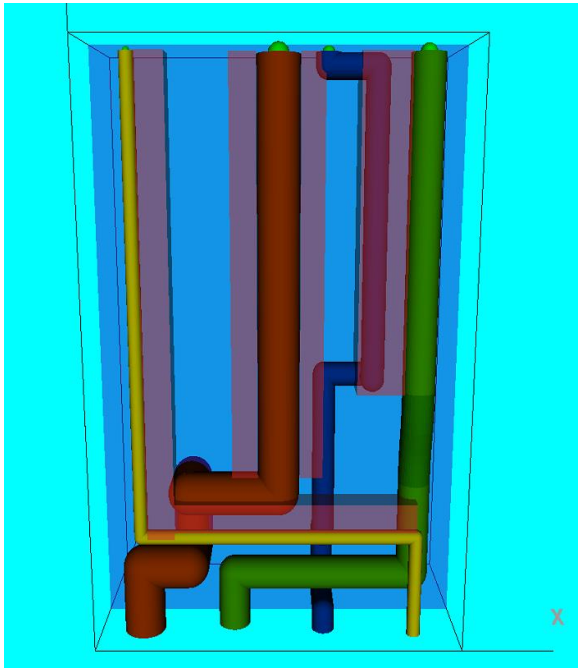


Total Cost : 37.78

Discussion

Order1 : From the largest **Order2 : From the longest**



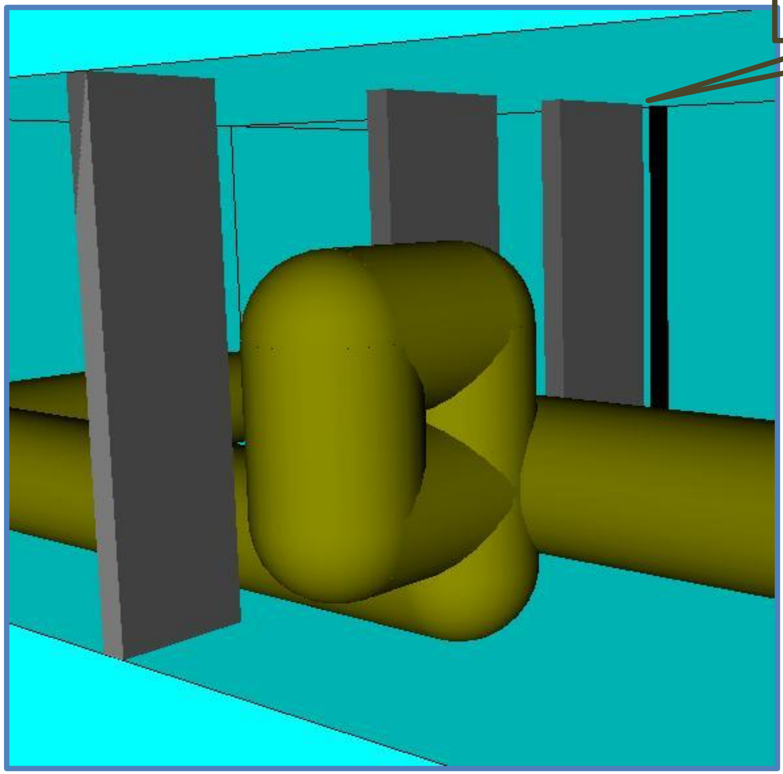


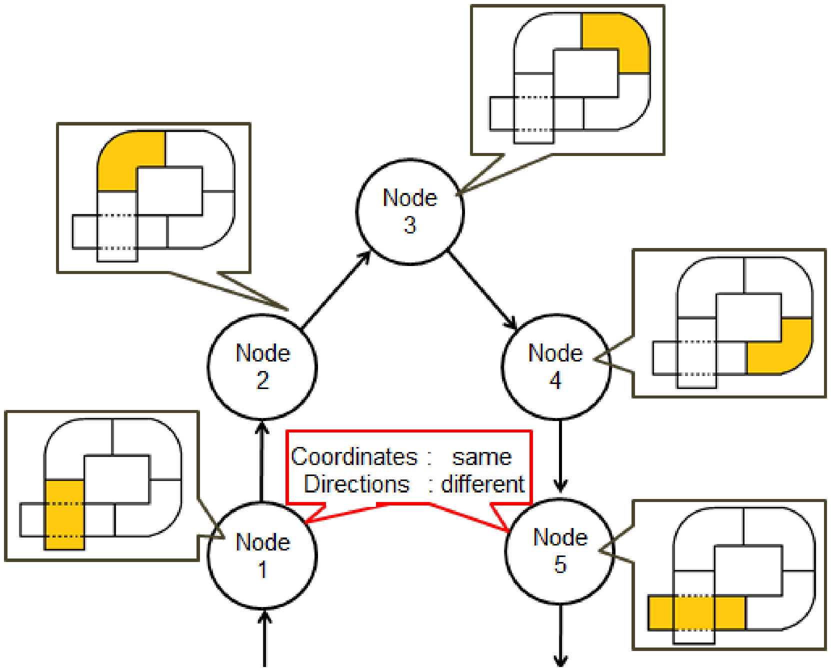
- The algorithm succeeded finding routes with bends.
- Simulated routes passed the pipe-rack area.
- Last design demands on the order of routing.
- The system often drew pipes those are difficult to assemble.

Discussion

As a result in other test case…

Especially in very narrow space





An obtained route interfered with itself!

Outline

1. Background and Purpose
- Previous Research

2. Routing Algorithm Including Bends
- Approach
- Outline of “Bends”
- Outline of Pipe-rack Area and Aisle Space
- Experiments

3. Conclusion and Challenges

Conclusions

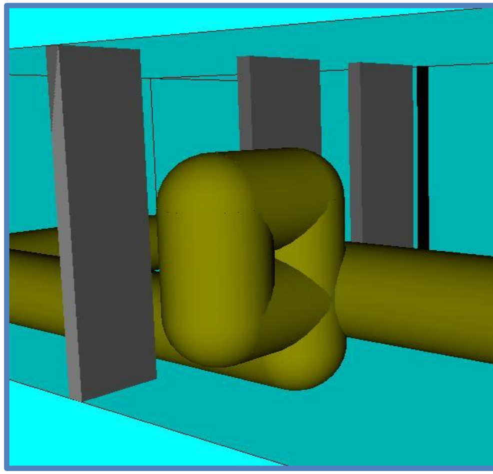
<u>Advantages of the algorithm</u>

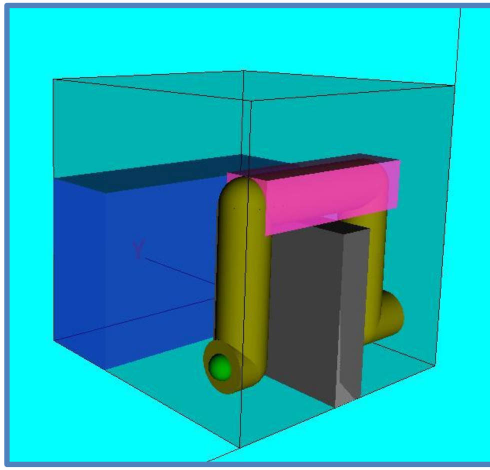
- **The mesh size is free.**
- **The algorithm generates practical designs with bends.**
- **The algorithm draws each pipe with <u>optimum costs</u>.**
- **The drawing pipes are considered <u>pipe-rack-area and aisle space</u>.**

Future Works

We need to …

- ◆ **Improve the routing algorithm**
- ◆ **Associate the routing system with the equipment layout system**
- ◆ **Make better the interference check algorithm**
- ◆ **Investigate best order of routing**





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