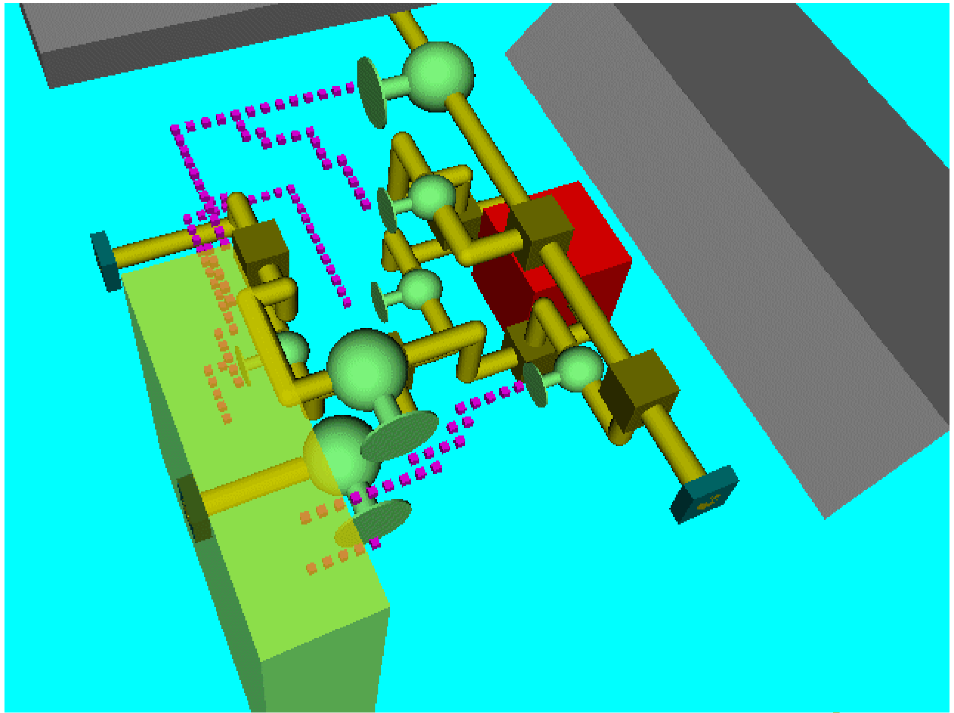


Automatic Designing System for Piping and Instruments Arrangement including Branches of Pipes

Hajime Kimura　(Kyushu University, Japan)

ICCAS2011 (September 20-22, 2011)

Overview

1. **Motivation and Purpose**

2. **Problem Formulation**

   ・Parameters： 1）Equipment's Locations and directions　　2）Piping Routes

   　Consider piping T-branches as equipments

   ・A new evaluation algorithm for Valve Operability → later

3. **Multi-Objective Genetic Algorithm (MOGA)**

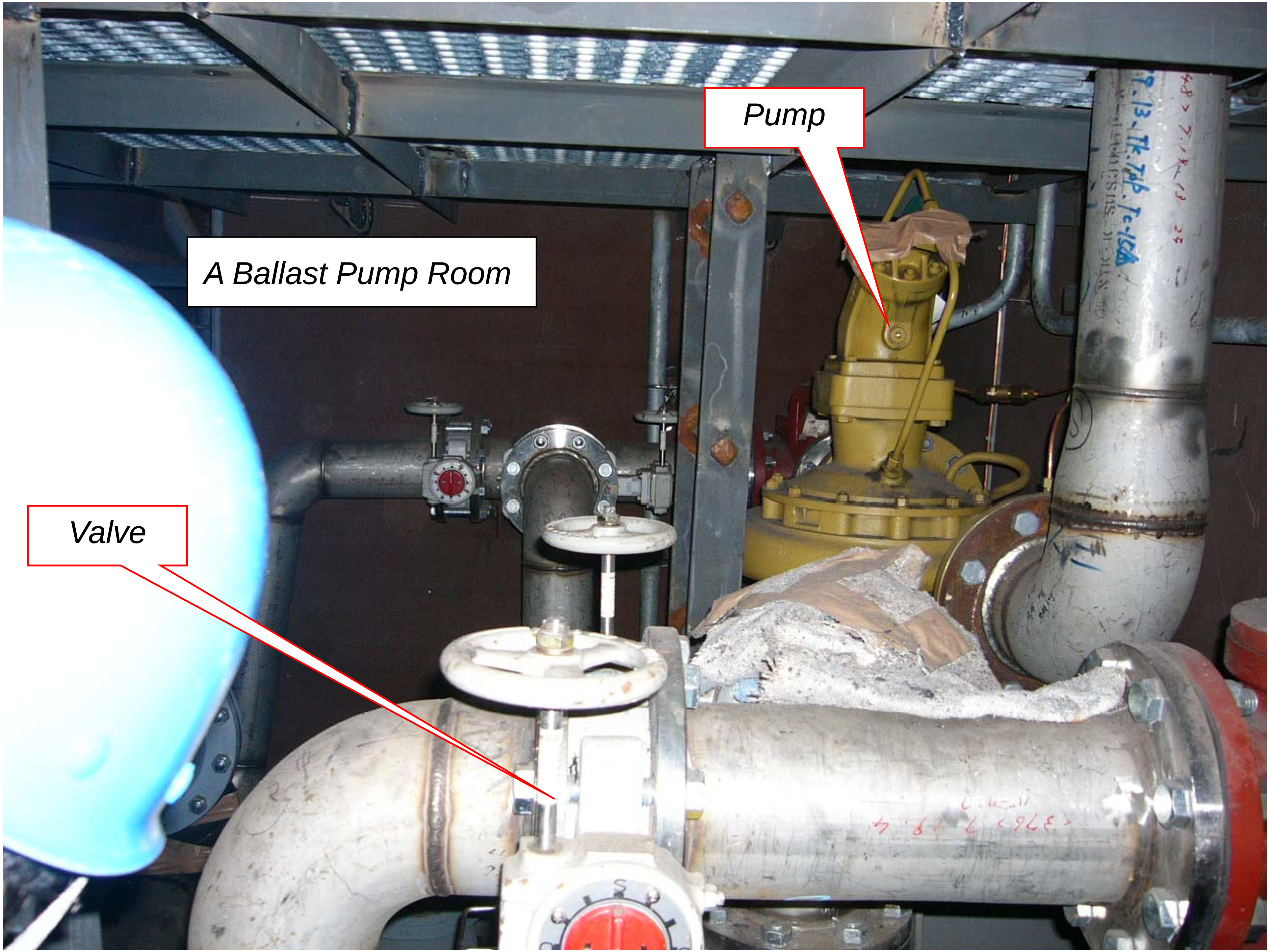
   ・Coding of the piping arrangement design

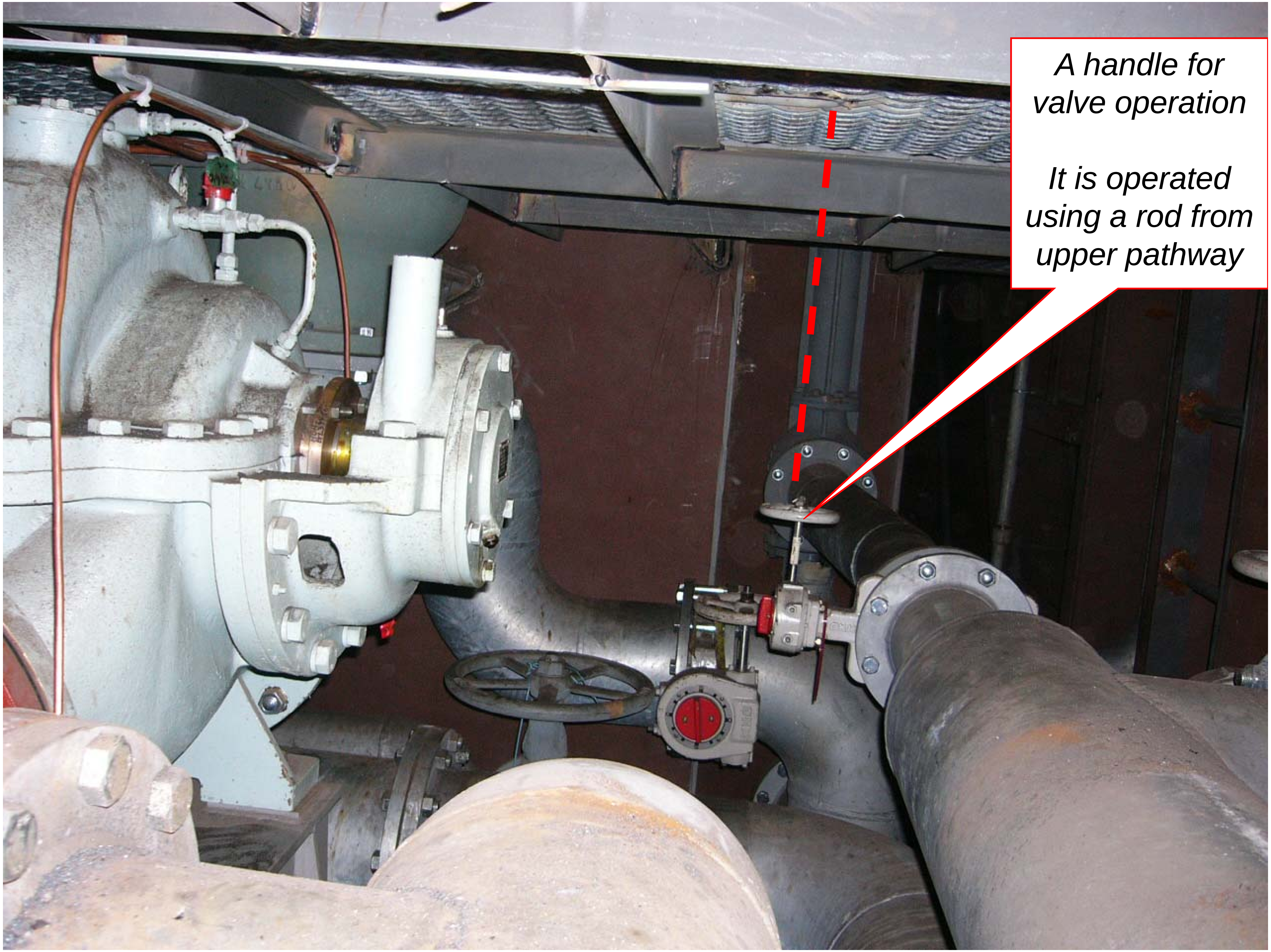
   ・Crossover operation

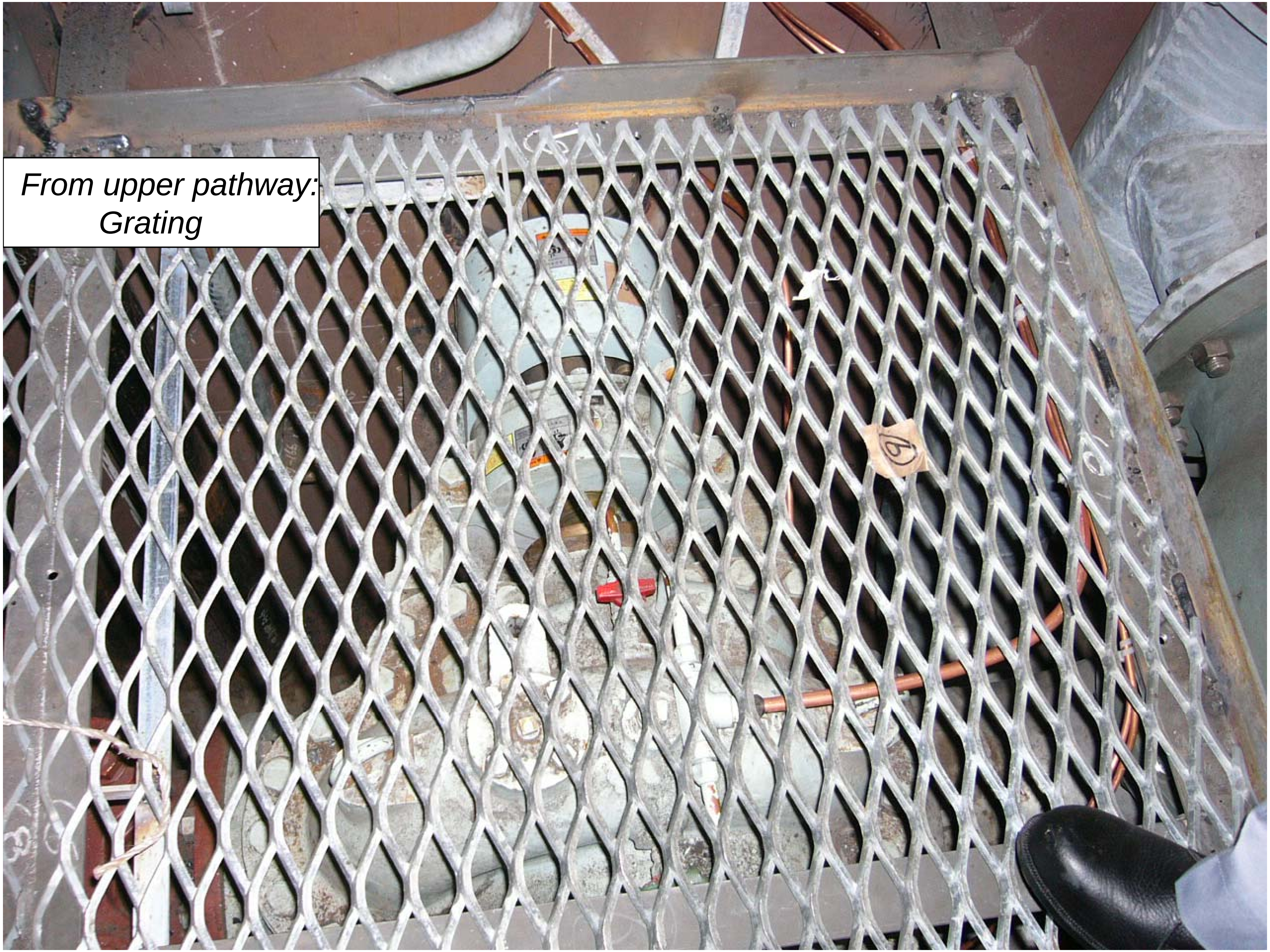
   ・Self-organization equipment arrangement method

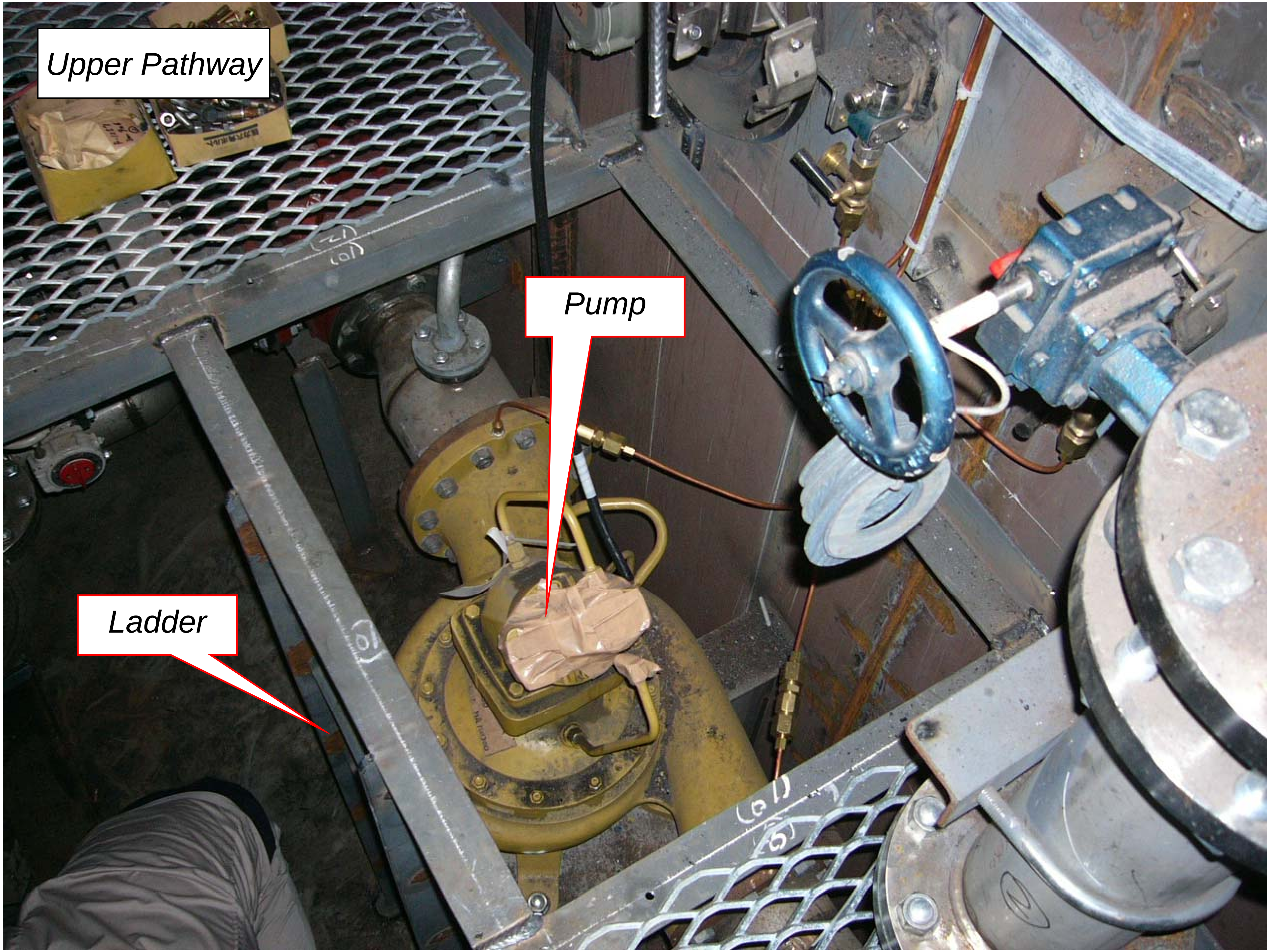
4. **Experiments**

5. **Conclusions and Future Works**


Pump
A Ballast Pump Room
Valve


A handle for valve operation
It is operated using a rod from upper pathway


From upper pathway:
Grating


Upper Pathway
Pump
Ladder

Motivation

But…

Pipe Arrangement

3D-CAD contributes designing efficiency

Needs sophisticated skills

~~Automatic design~~

Why？

Motivation

But…

Pipe Arrangement — 3D-CAD contributes designing efficiency →
- Needs sophisticated skills
- ~~Automatic design~~

Why？

[Reason 1] Problems in designing algorithms

-Poor Performance

-It is no use that the algorithm gives only one solution!

Answer

1) Reconsideration of the problem formulation

→ 2) Show plural solutions

Designer selects one of them as he needs.

Genetic algorithm

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[Reason 2] Obscurity of the Design Criteria

-Not only to arrange shortest pipes between equipments!

ex.) Easy to operate valves, easy for maintenance, etc.

Answer → 1) Define numerical evaluation for all items

2) Formulate as a multi-objective optimization

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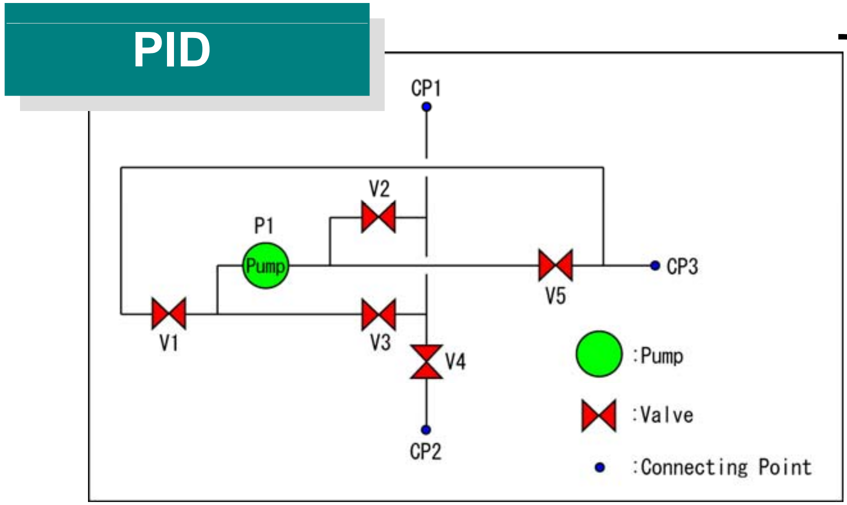
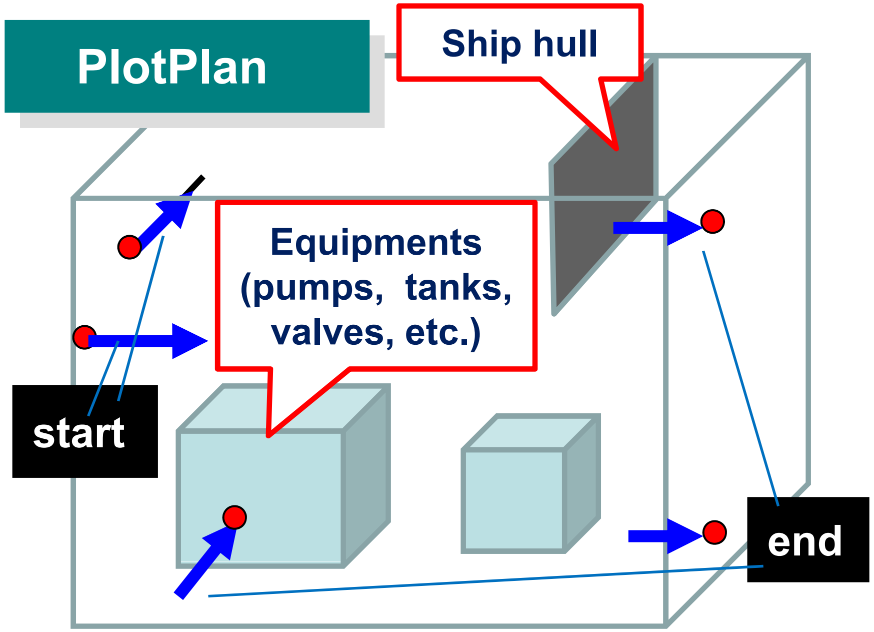
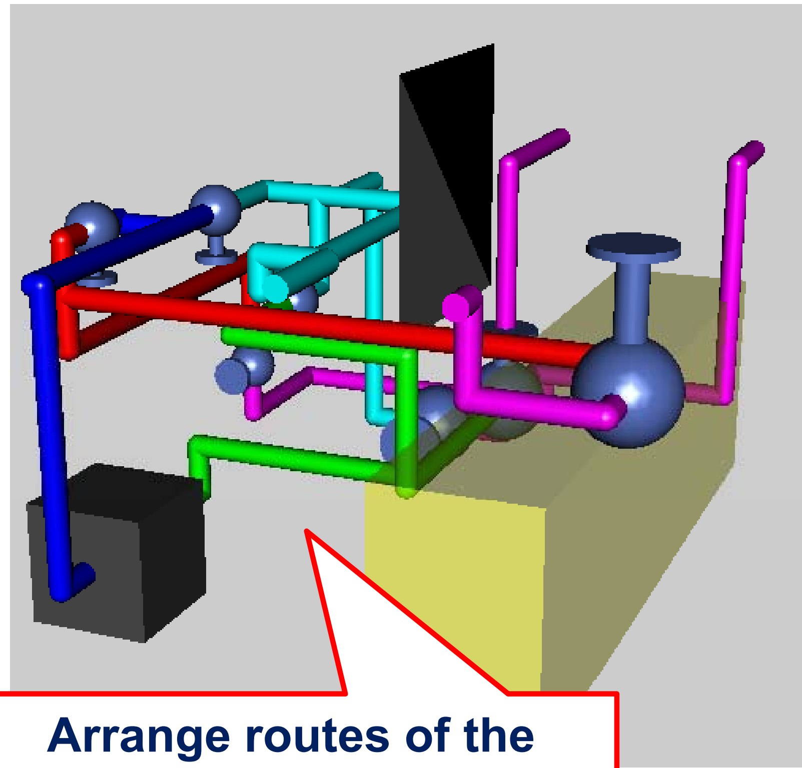
Piping and Instruments Arrangement Problem







Arrange routes of the pipes, the locations of the branches and the valves

Constraint: T-branches, etc･･･
Objective Function: Cost, Operability

For practical reasons, 90° elbows are used.

Problem Formulation [Conventional]

Piping and Instruments Diagram

PID → **Pipeline FROM – TO List**

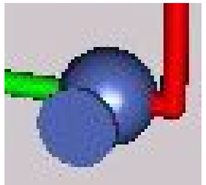
Plot Plan → **Equipment Dim. & Loc.**

Equipment arrangement list

Given

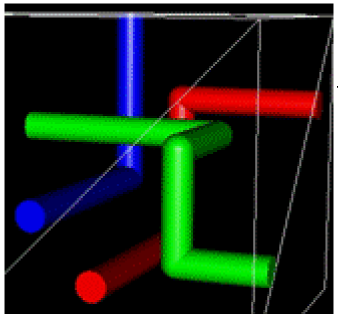
Search Space

- Parameters for VALVES



locations
directions

- Parameters for Pipes



locations
directions
branches → patterns
locations

Minimize **Valve Operationality (cost)** **and** **Cost of Materials**

Problem Formulation [Conventional]

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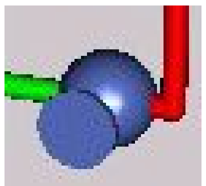
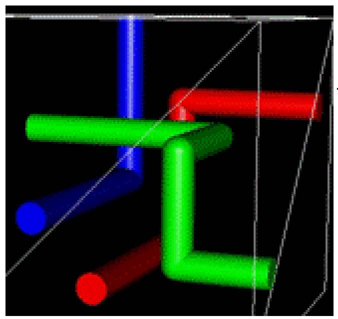


locations
directions

- Parameters for Pipes

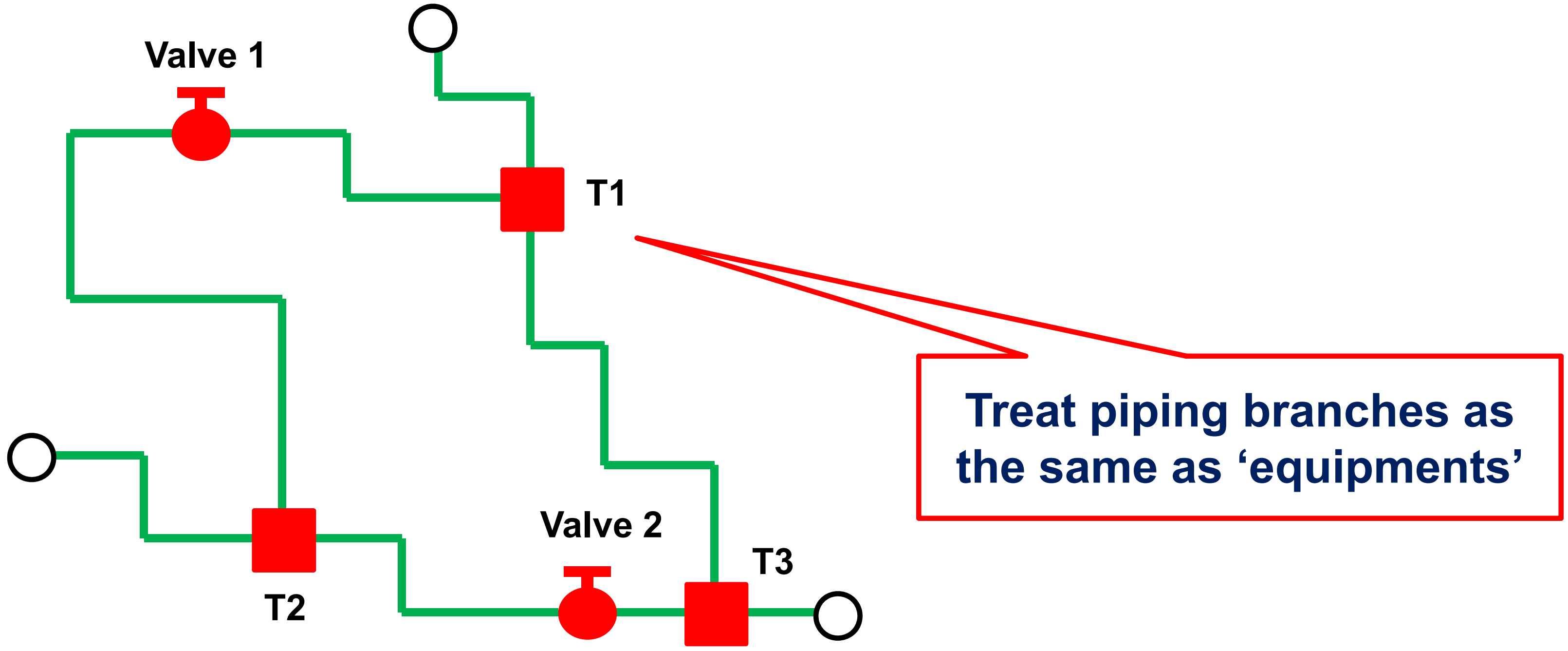


locations
directions
branches → patterns, locations

Including branches in piping makes the arrangement problem complicated!

Minimize **Valve Operationality (cost)** **and** **Co Mat**

A New Problem Formulation



Parameters to search:

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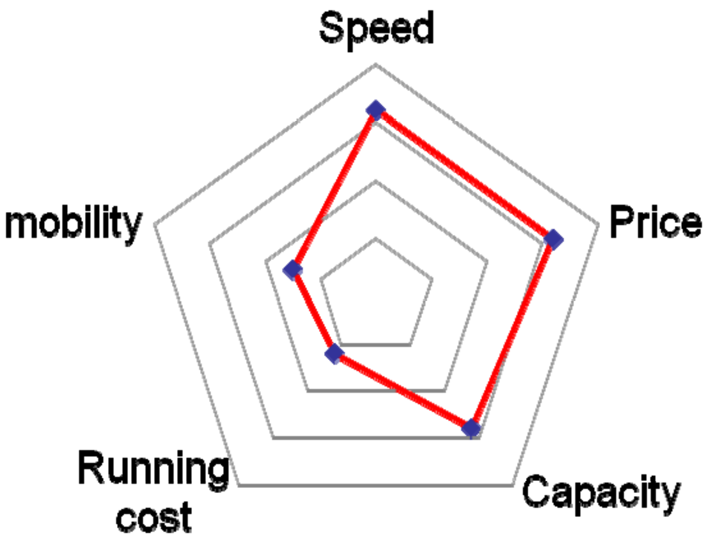
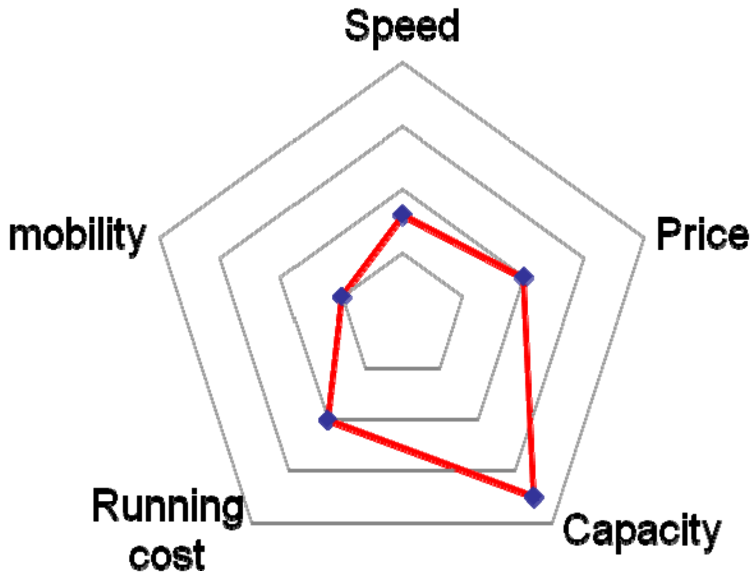
What is “multi-objective optimization”?



Ship A

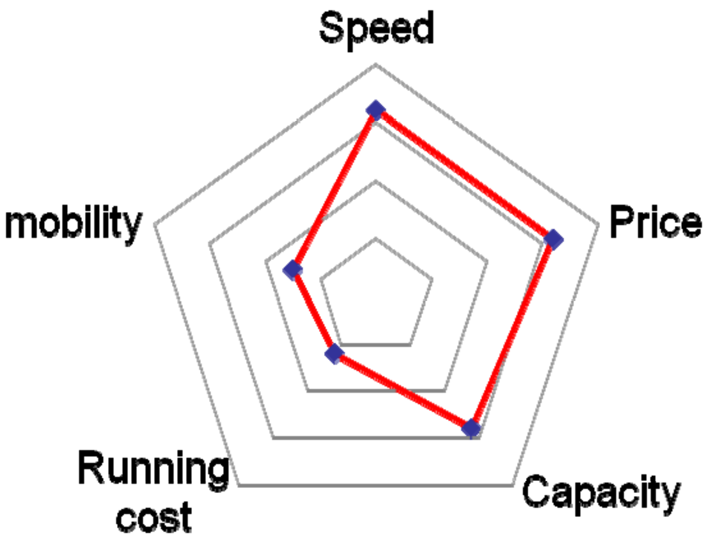


Ship B

Which solution should we choose?

Designers encounter with similar situations too often

What is “multi-objective optimization”?



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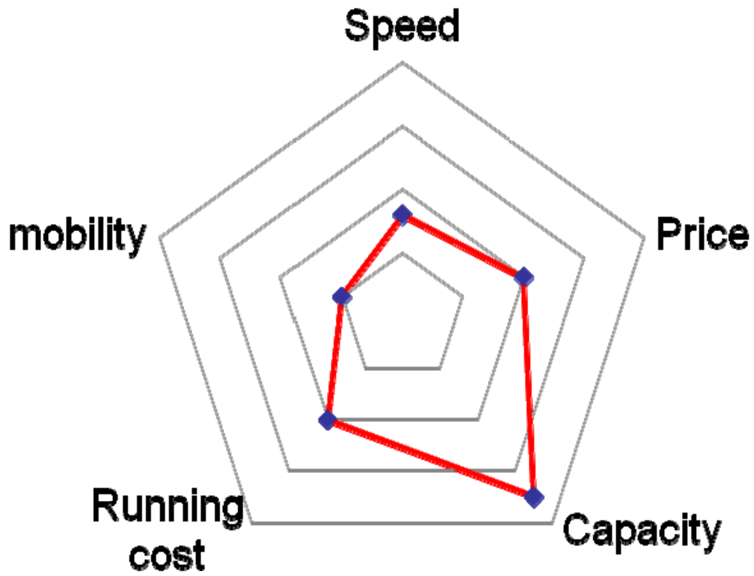

Ship B

Which solution should we choose?

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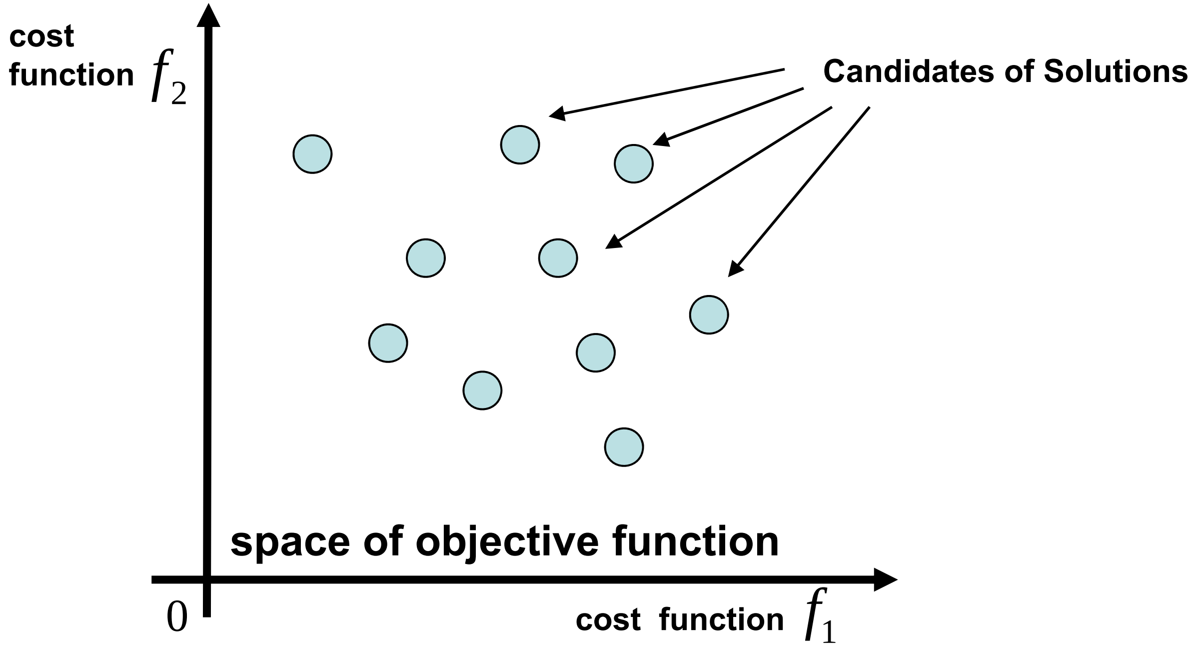
Evaluation is not scalar → **Multi-Objective Optimization**

What is “multi-objective optimization”?



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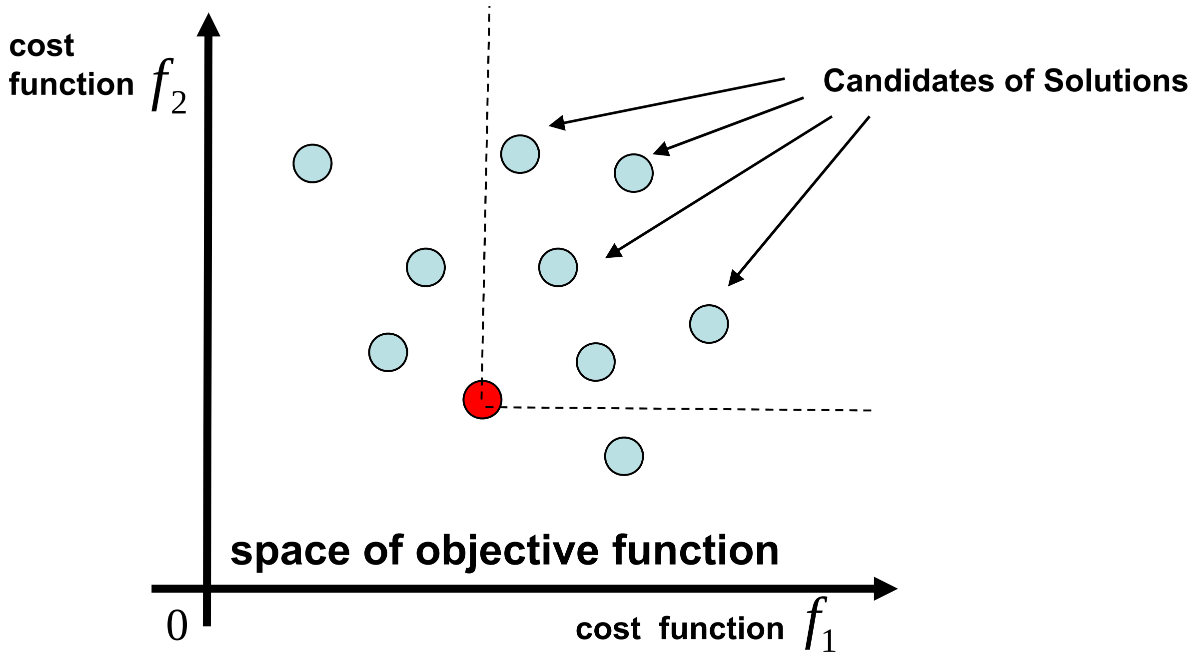

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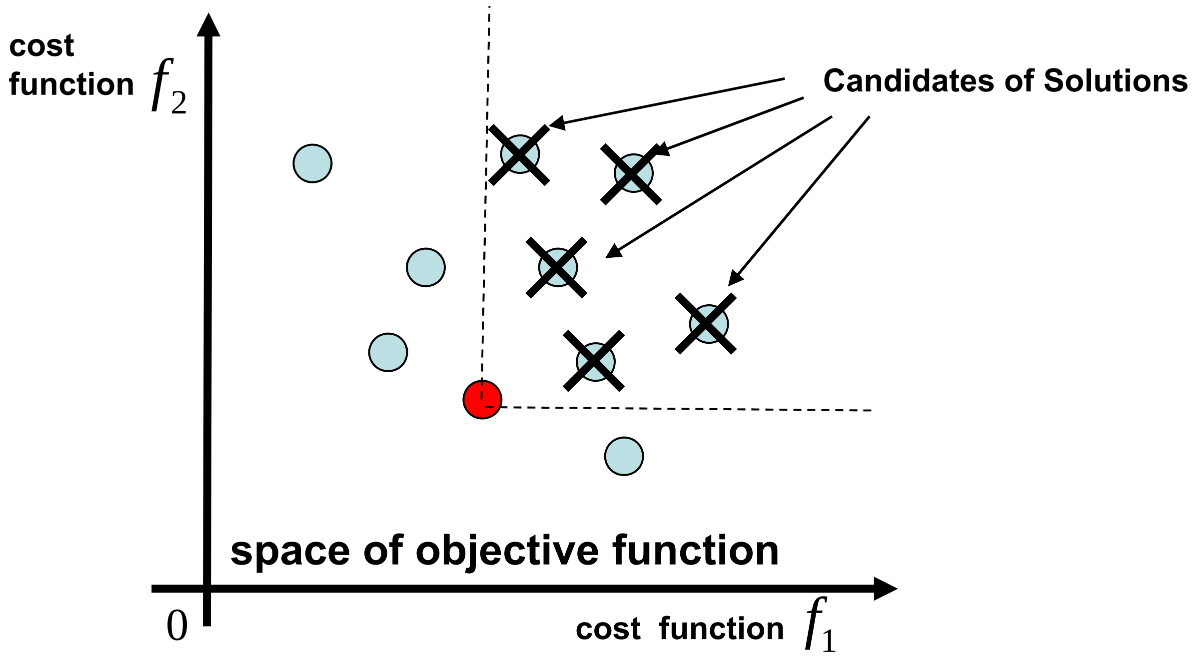

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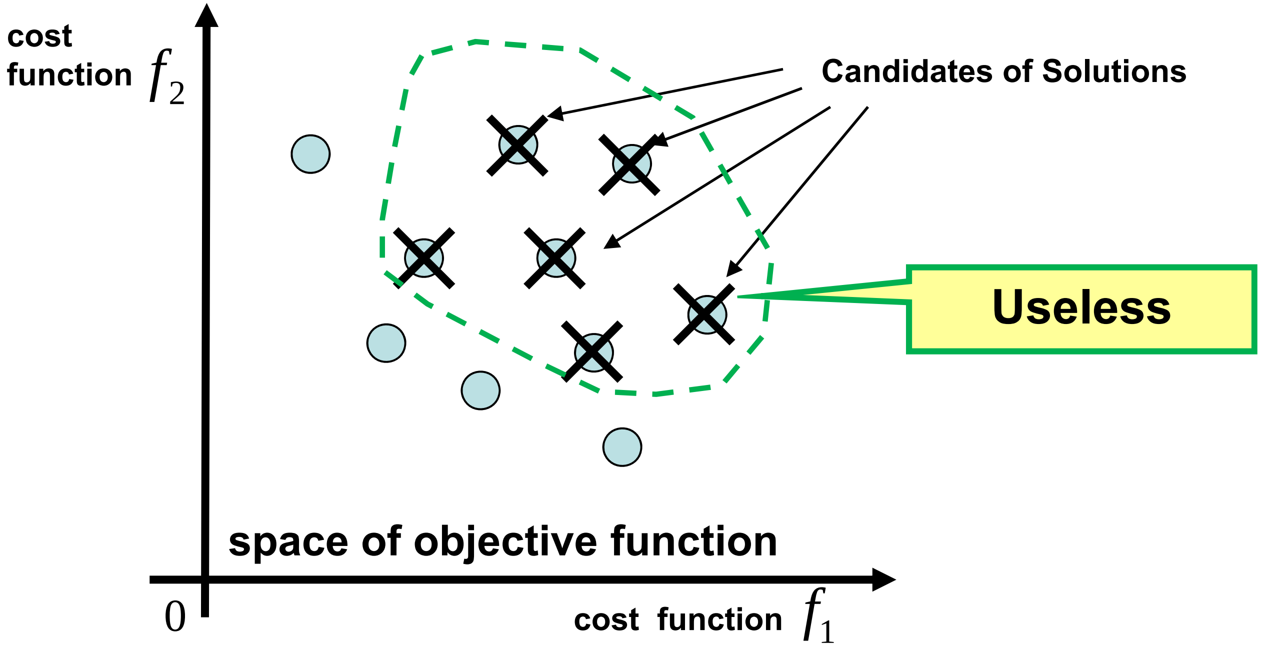

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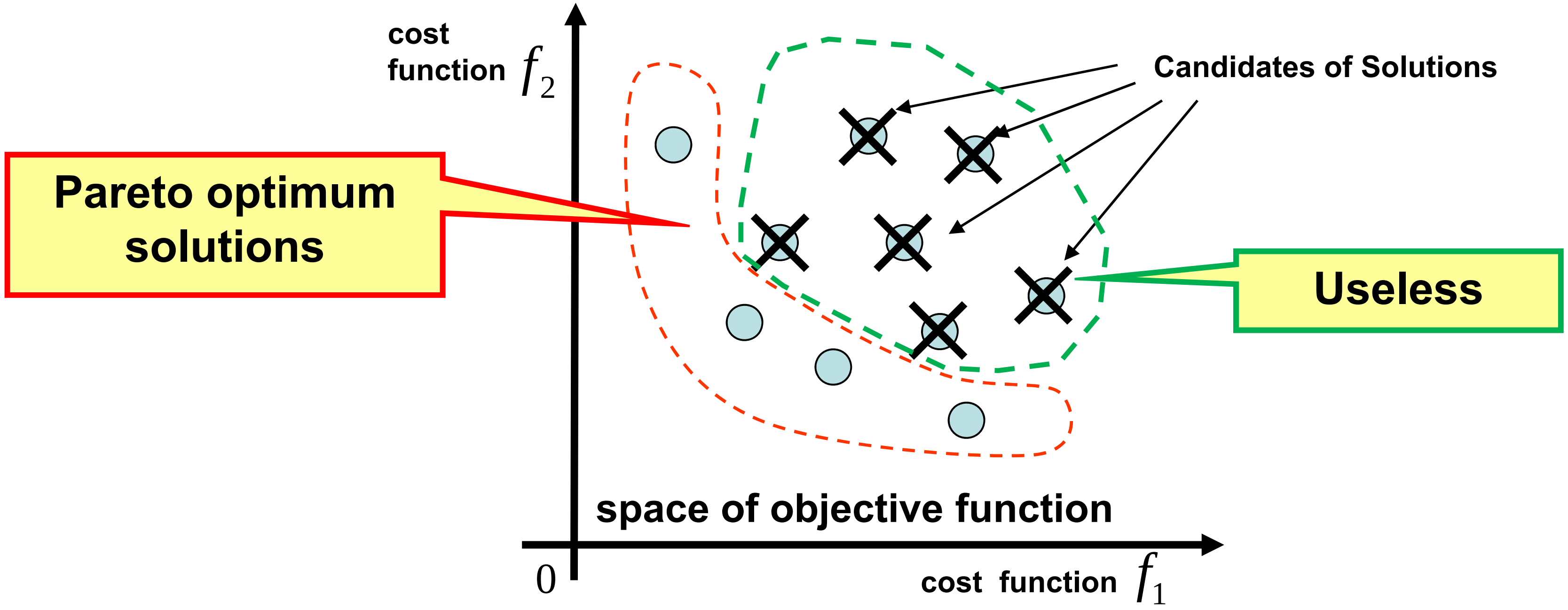

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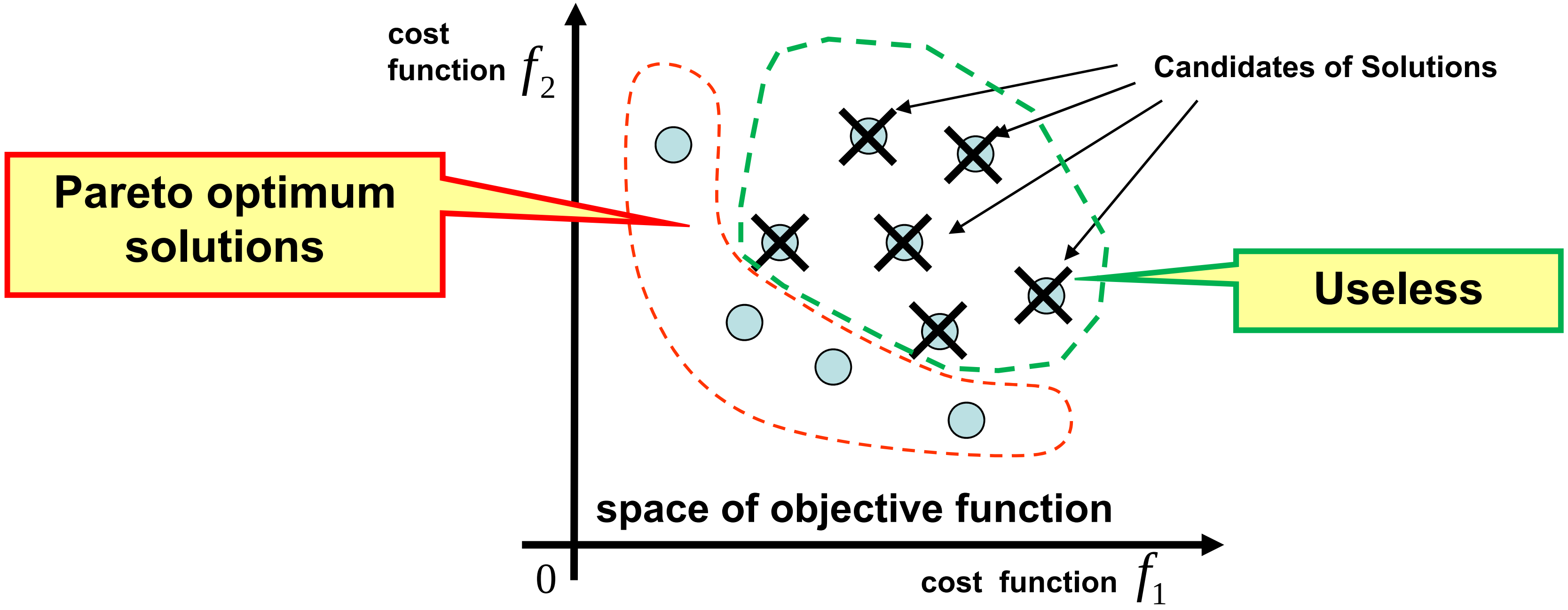


1) Eliminate useless dominated solutions

2) Many optimum solutions would exist.
Finding all the <u>Pareto optimum solutions</u> is important.
Do not worry about choosing one of them.

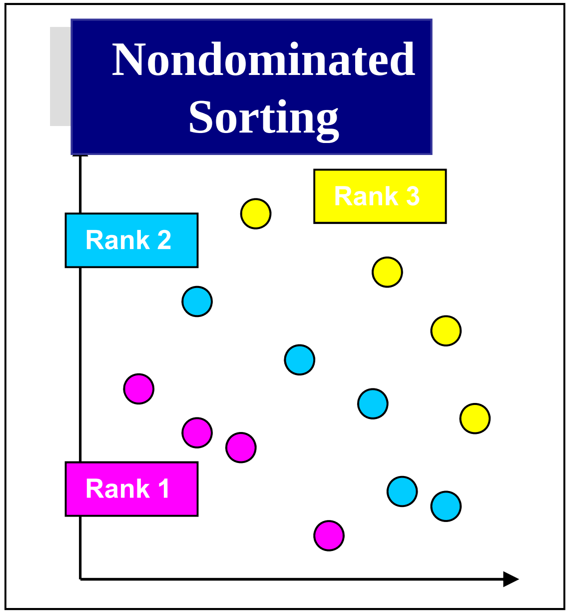
NSGA-Ⅱ

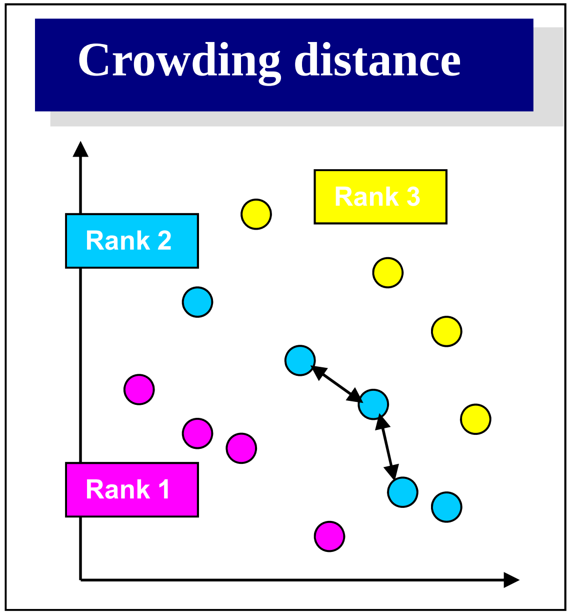
NSGA-Ⅱ： Nondominated Sorting Genetic Algorithms Ⅱ

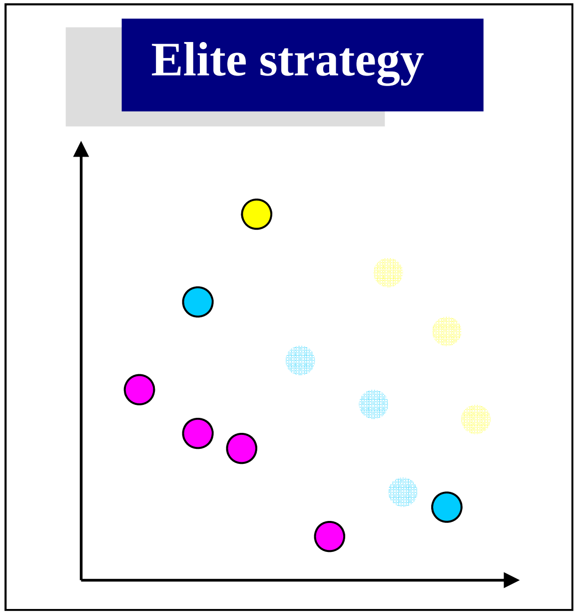
Multi-objective Genetic algorithm

1. Efficient calculation in Nondominated Sorting
2. Crowding distance
3. Elite strategy

Reference
Kalyanmoy Deb:
A Fast and Elitist Multiobjective Genetic Algorithm: NSGA-Ⅱ,
IEEE Transactions on Evolutionary Computation, vol. 6, No. 2, (2002)







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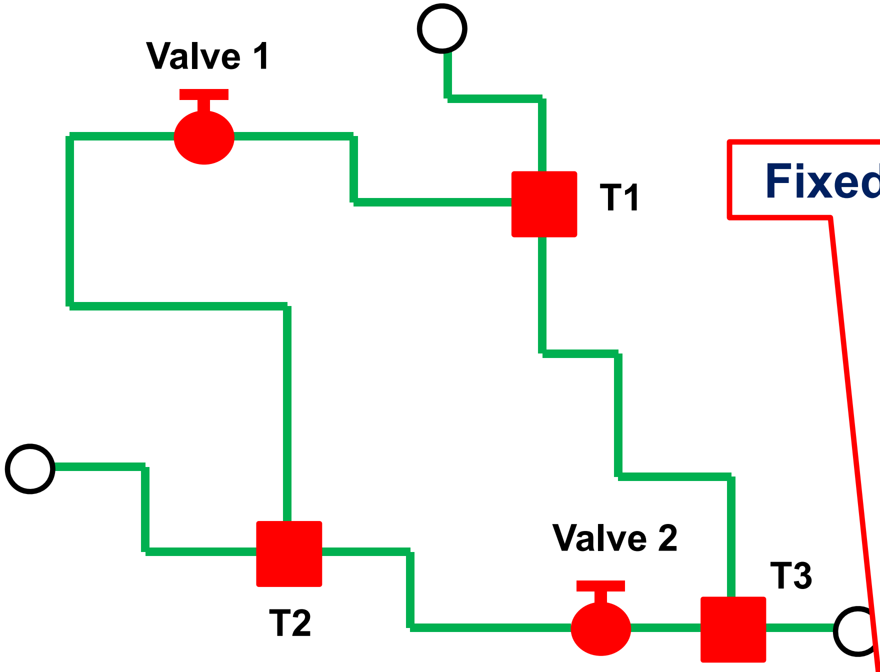
Coding For Genetic Algorithms



Fixed-length gene code

・Variable-length gene code
・Depends on the locations of the connected equipments

Parameters to search:

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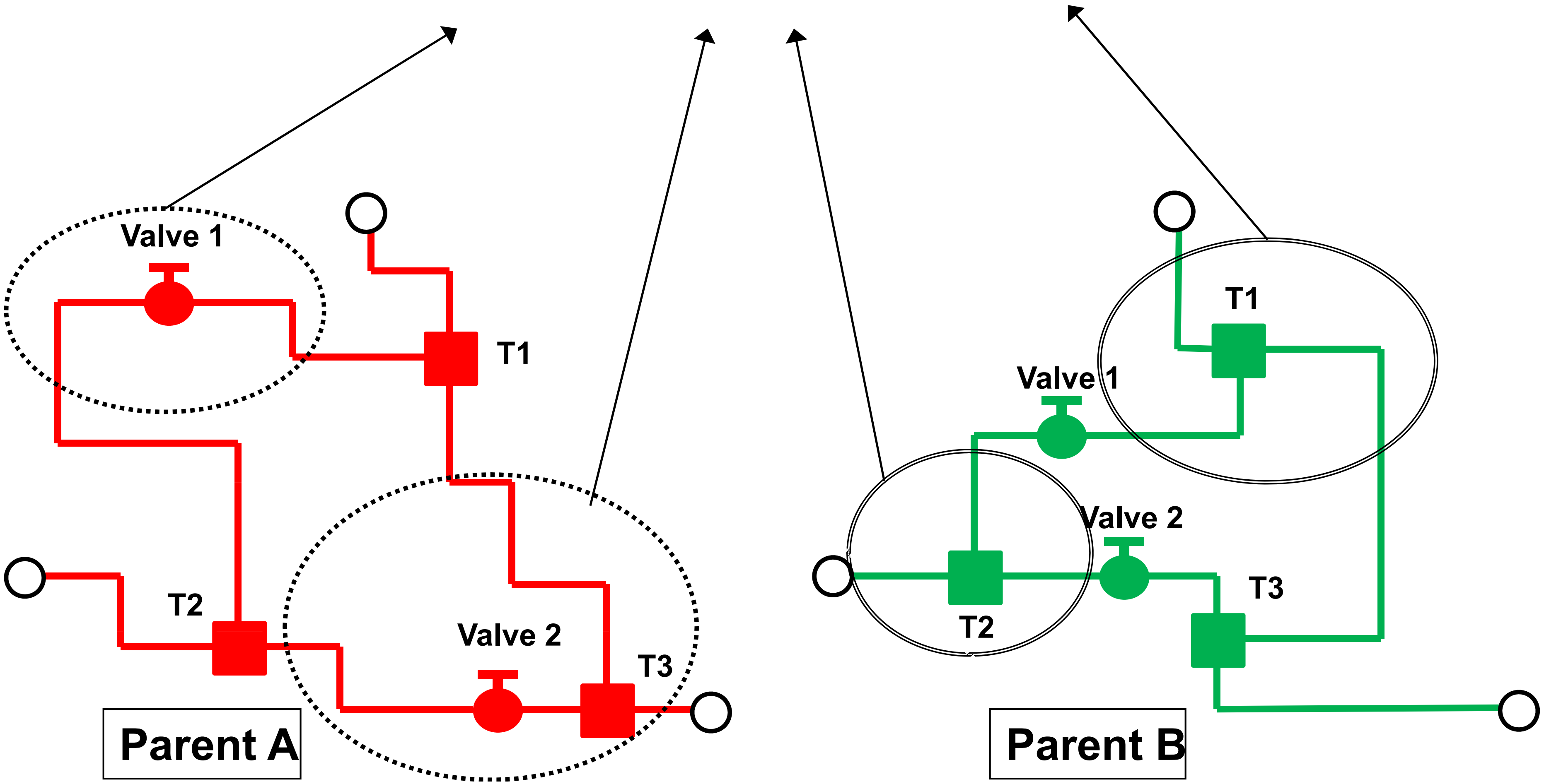
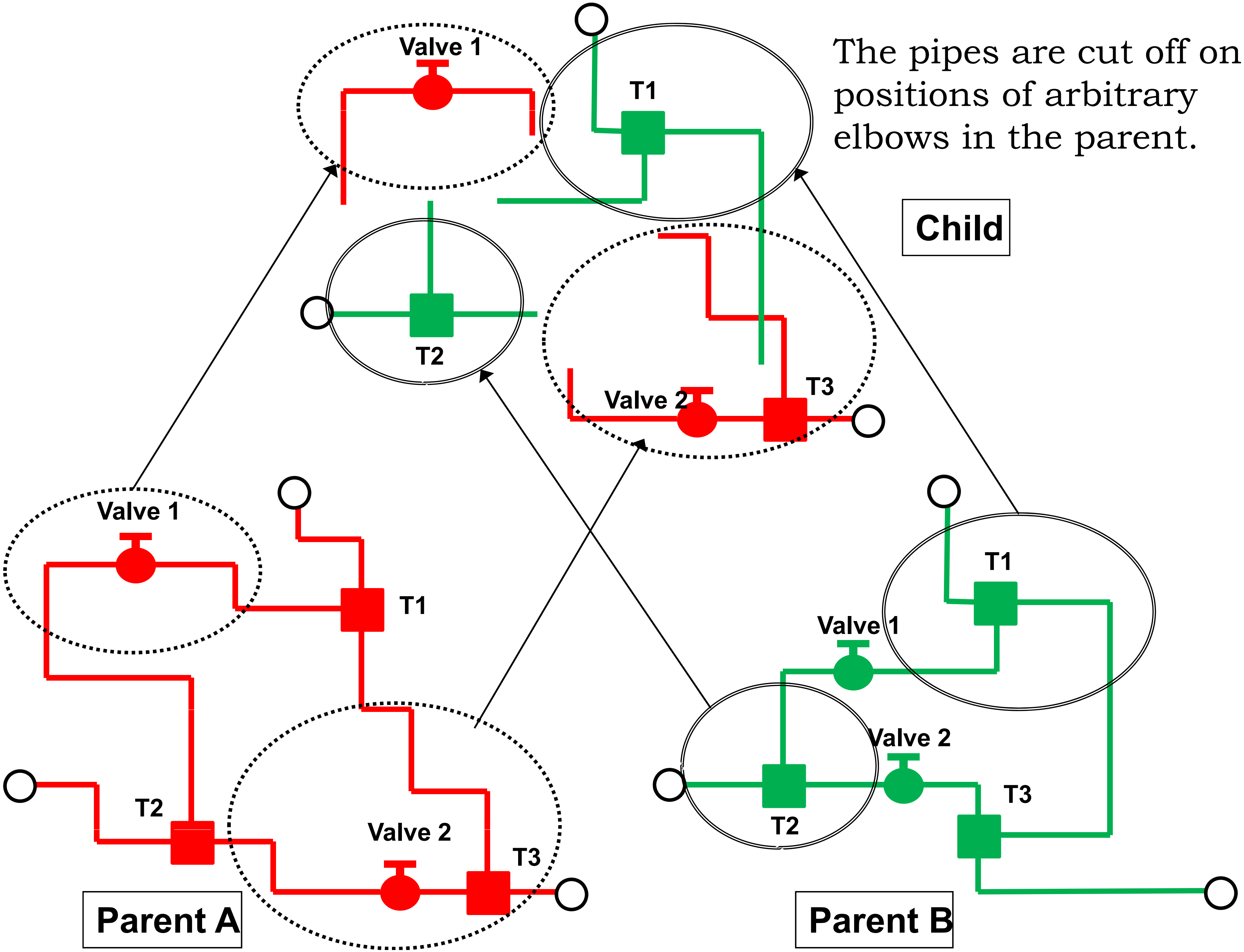
Crossover Operation in the Piping Arrangement

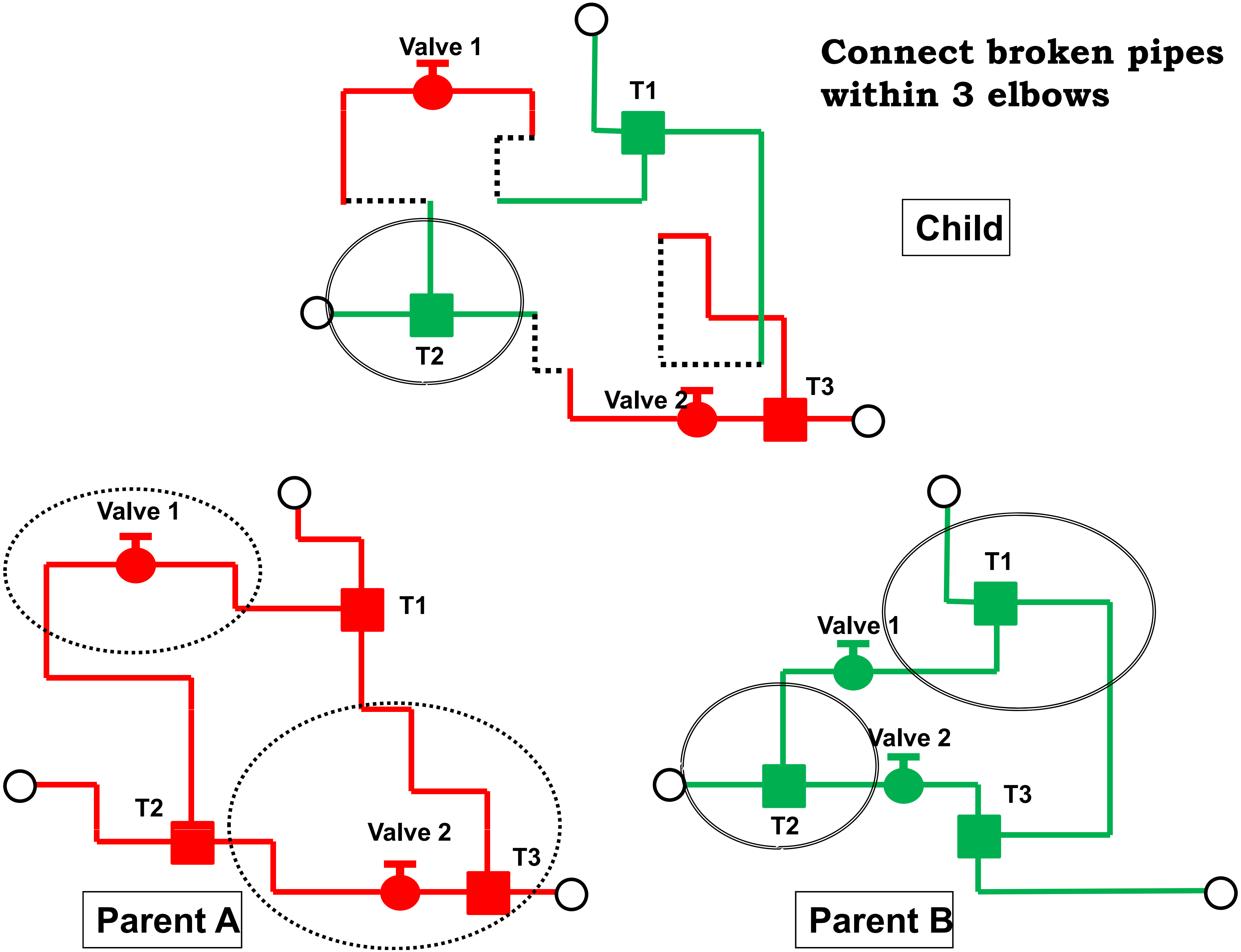
Prepare two solutions as parents
Select locations and directions of equipments
with connected pipes



The pipes are cut off on positions of arbitrary elbows in the parent.



Connect broken pipes within 3 elbows



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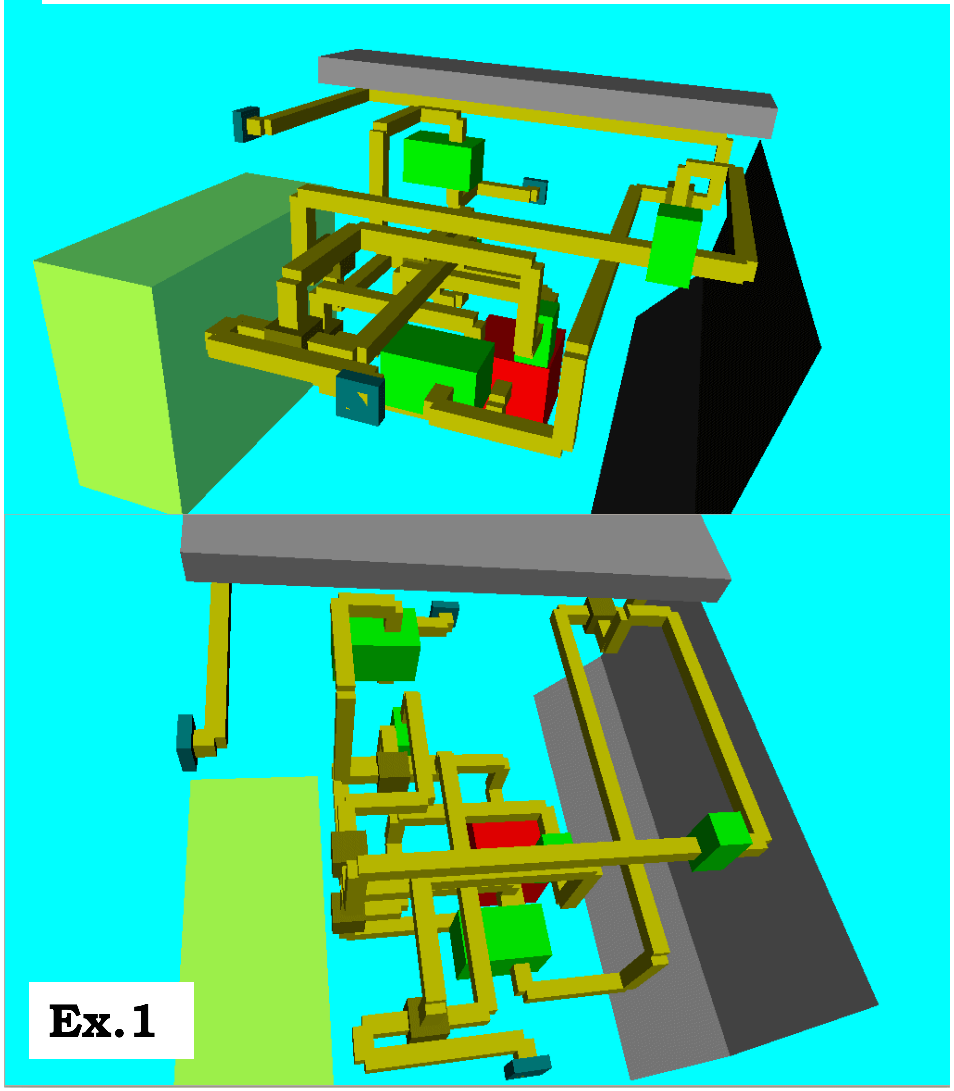
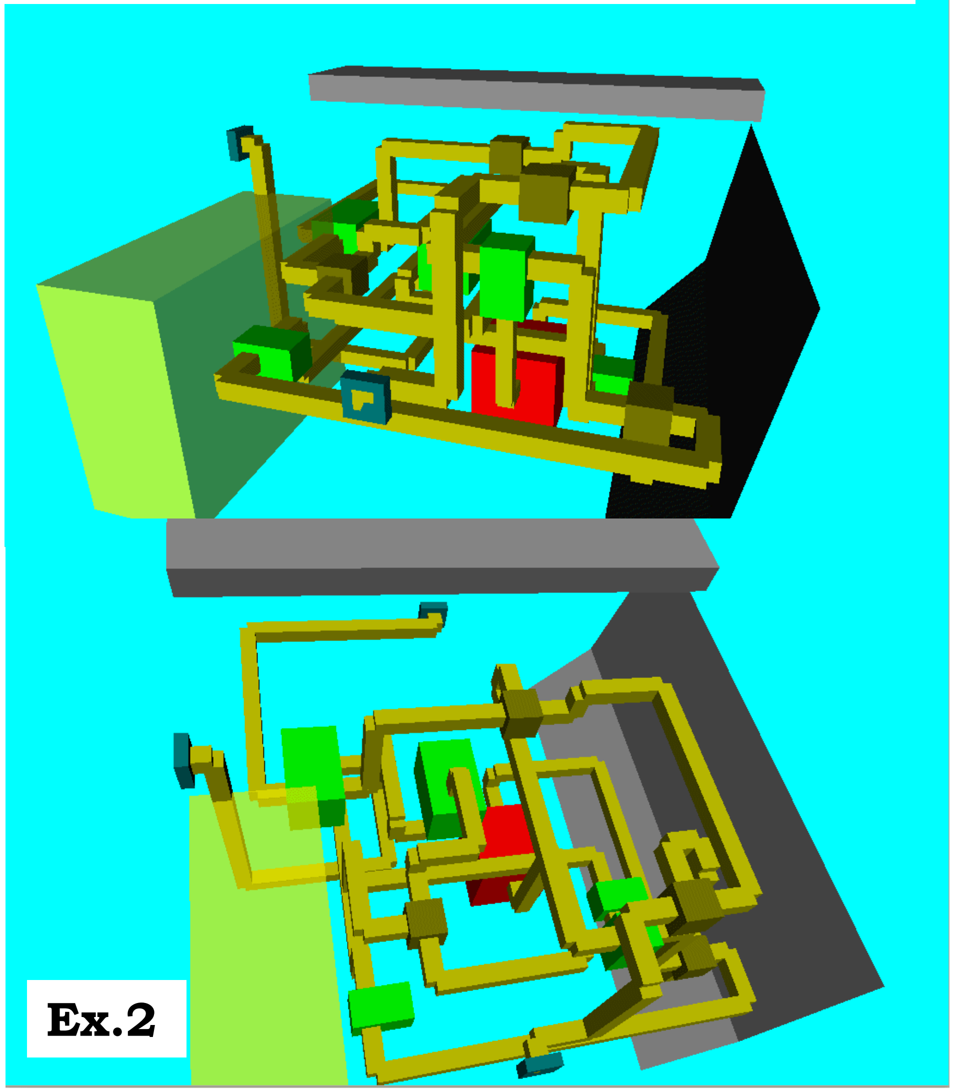
To use Genetic Algorithms,
feasible initial solution candidates are needed.

However, if we generate initial populations by random equipment arrangement...





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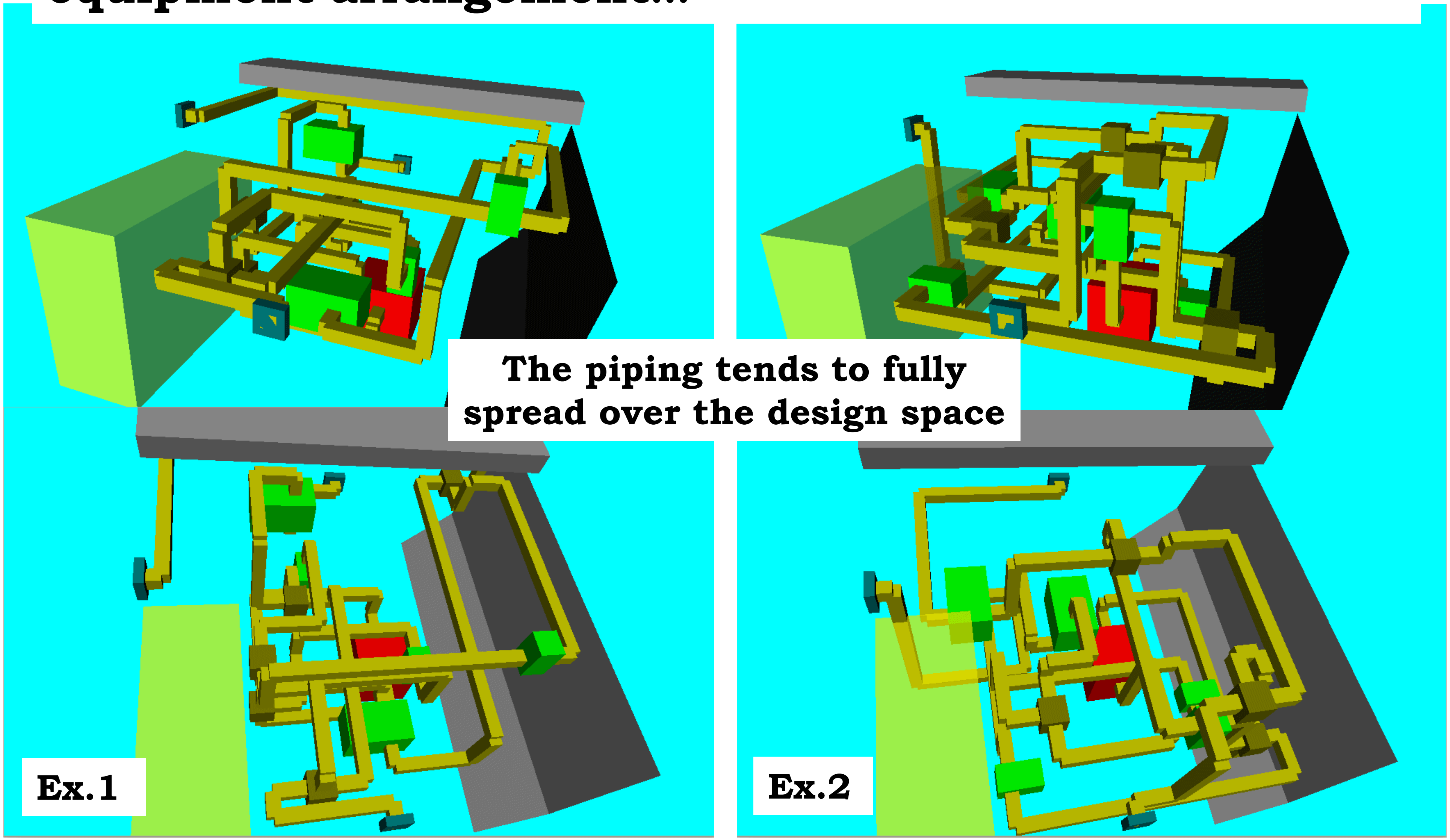

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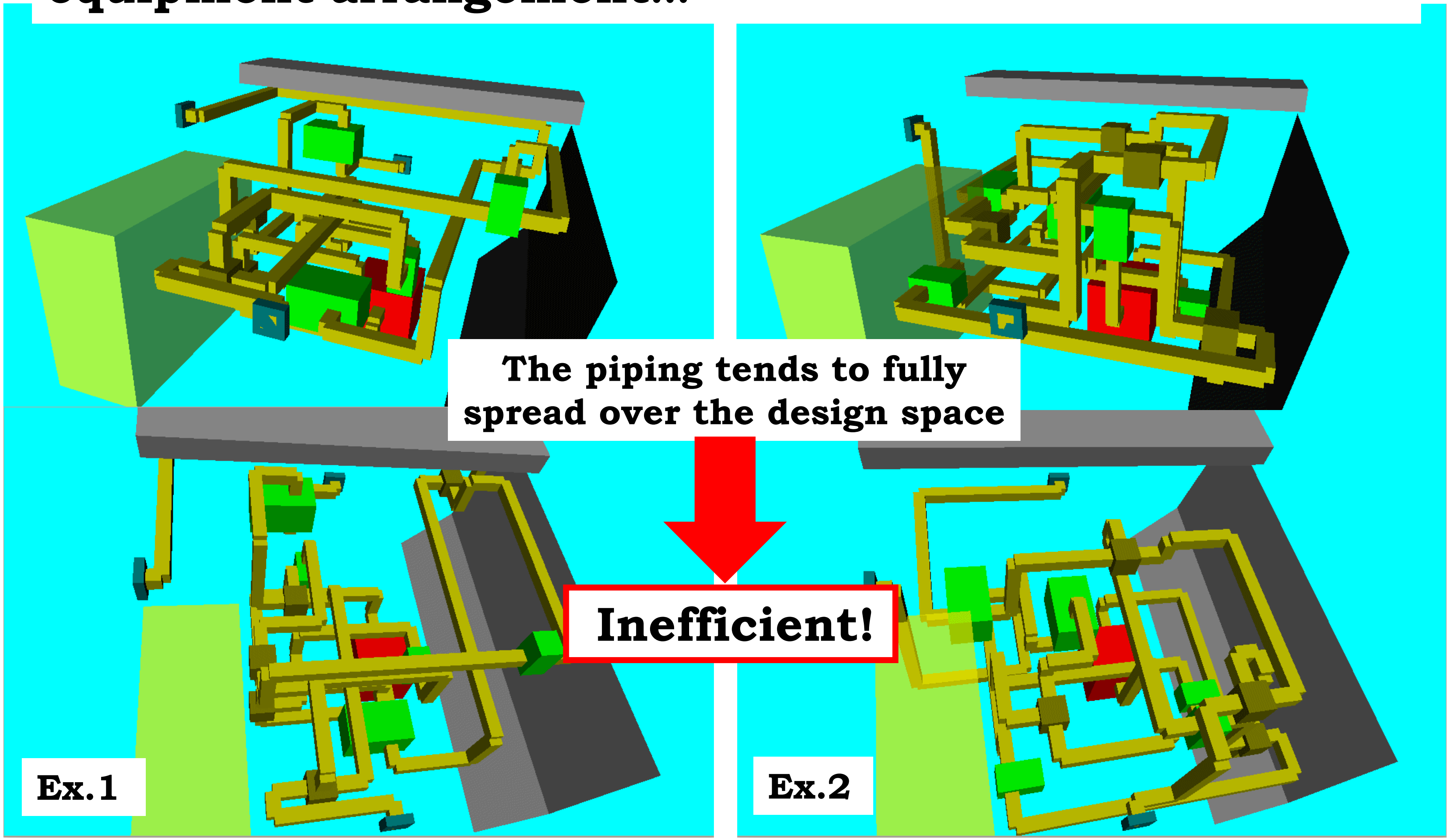
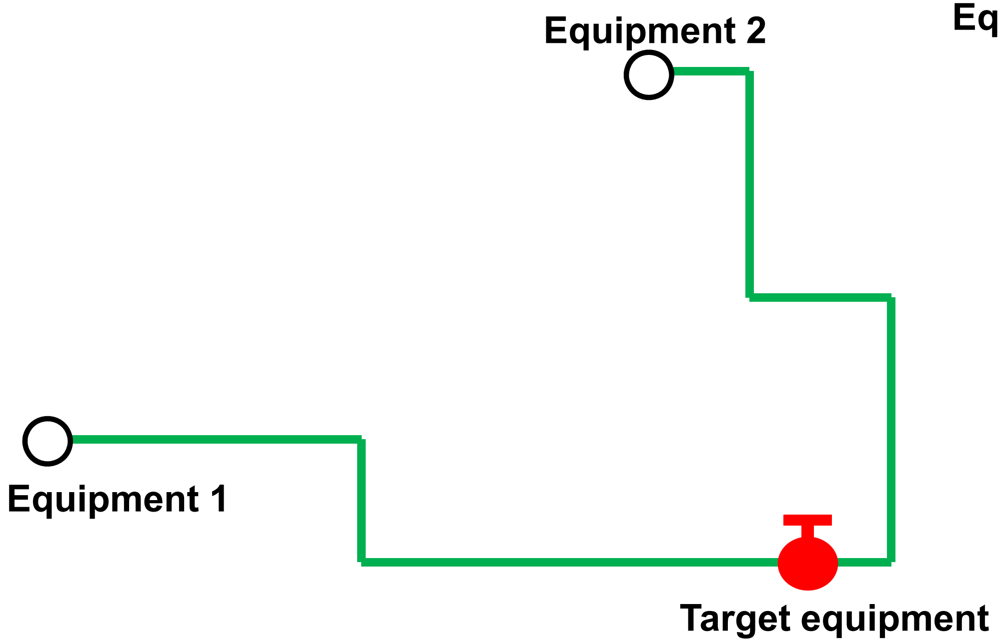
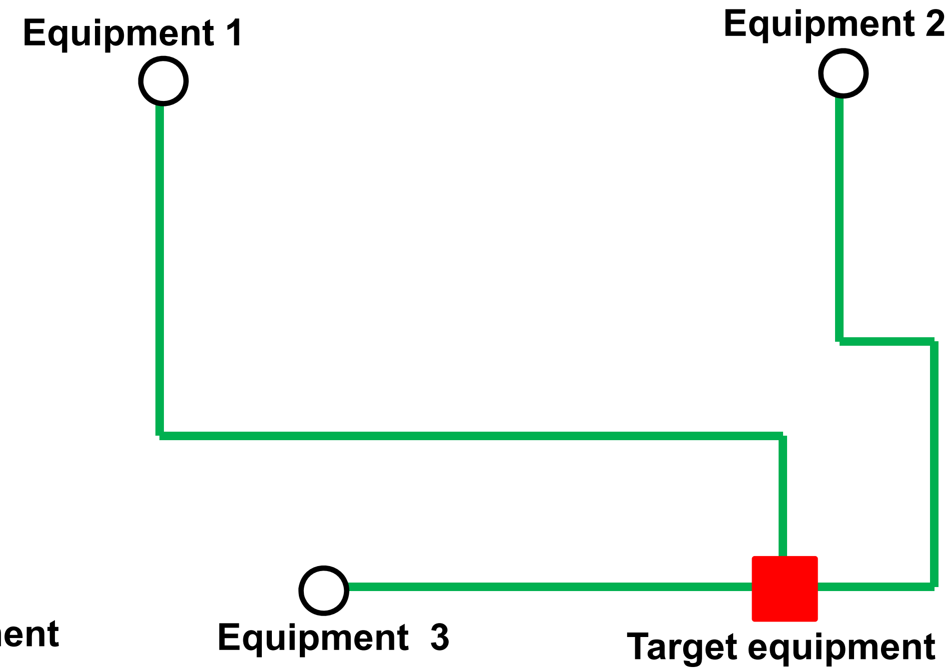


Generating good initial populations:
Self-organization Equipment Arrangement



(a) Target has two destinations



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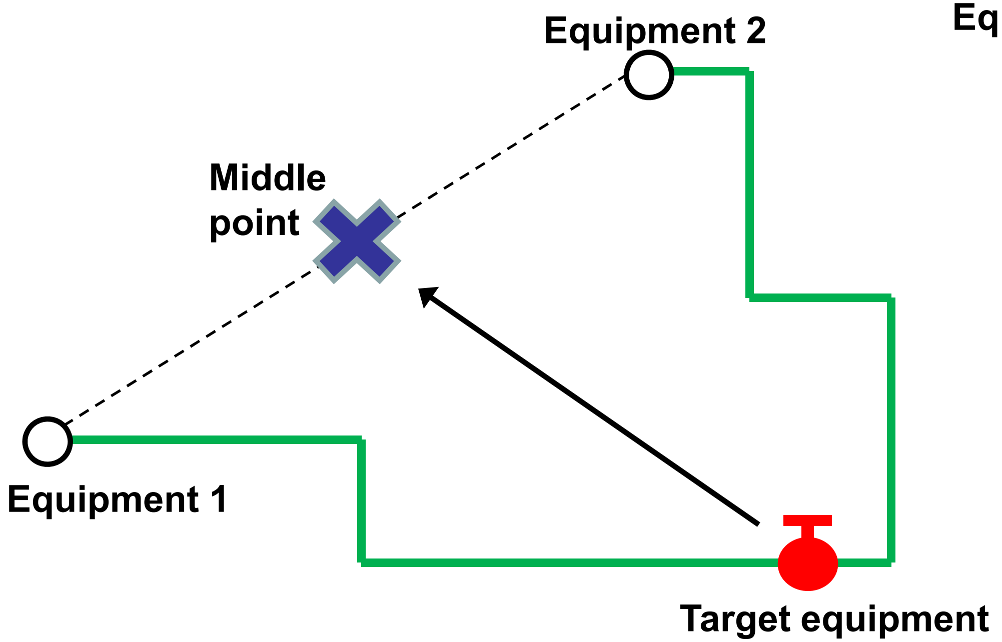

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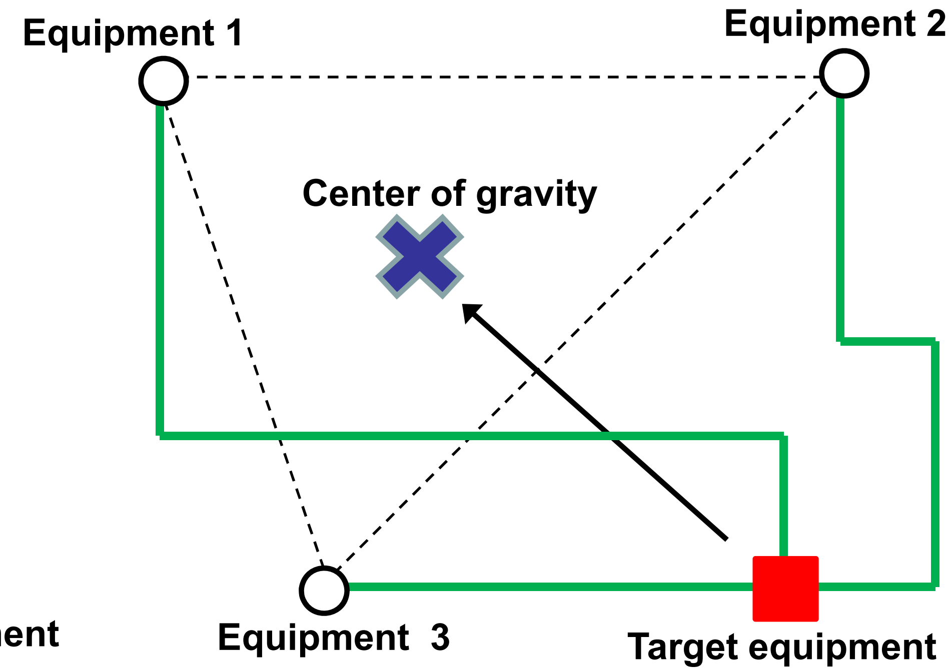

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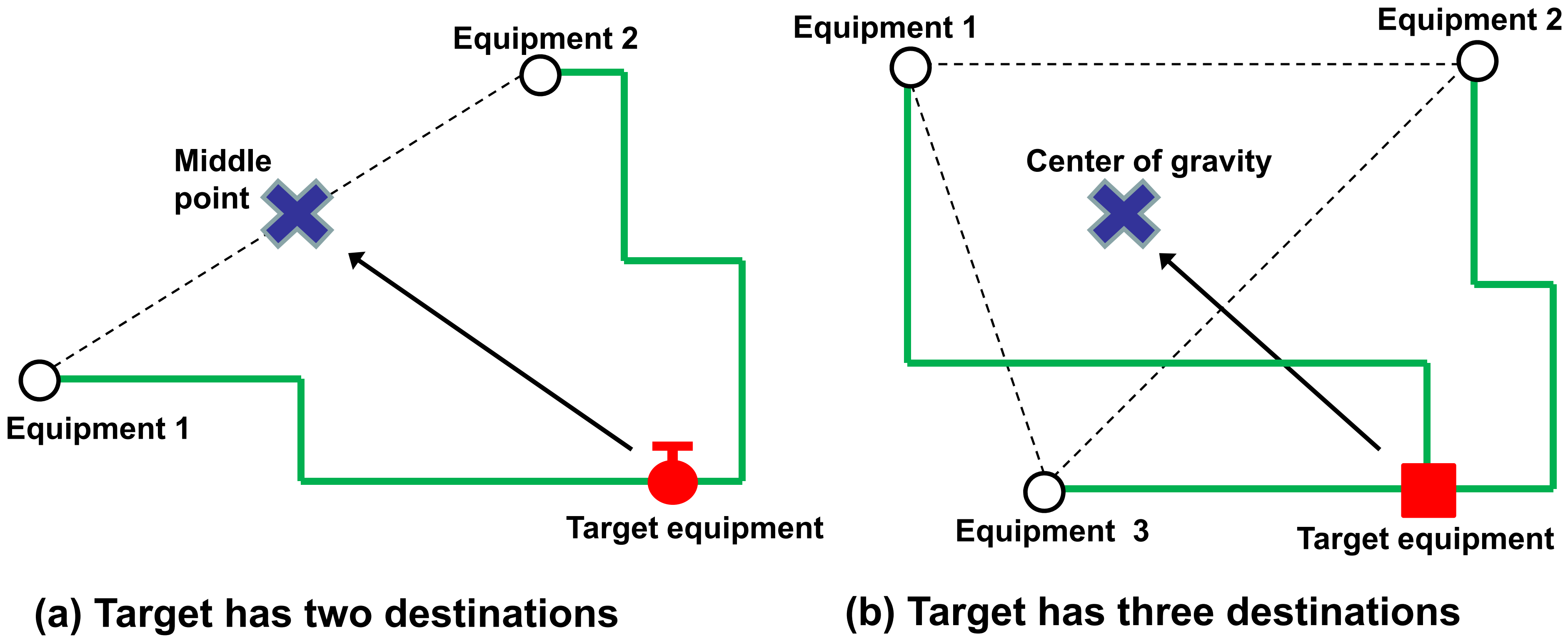
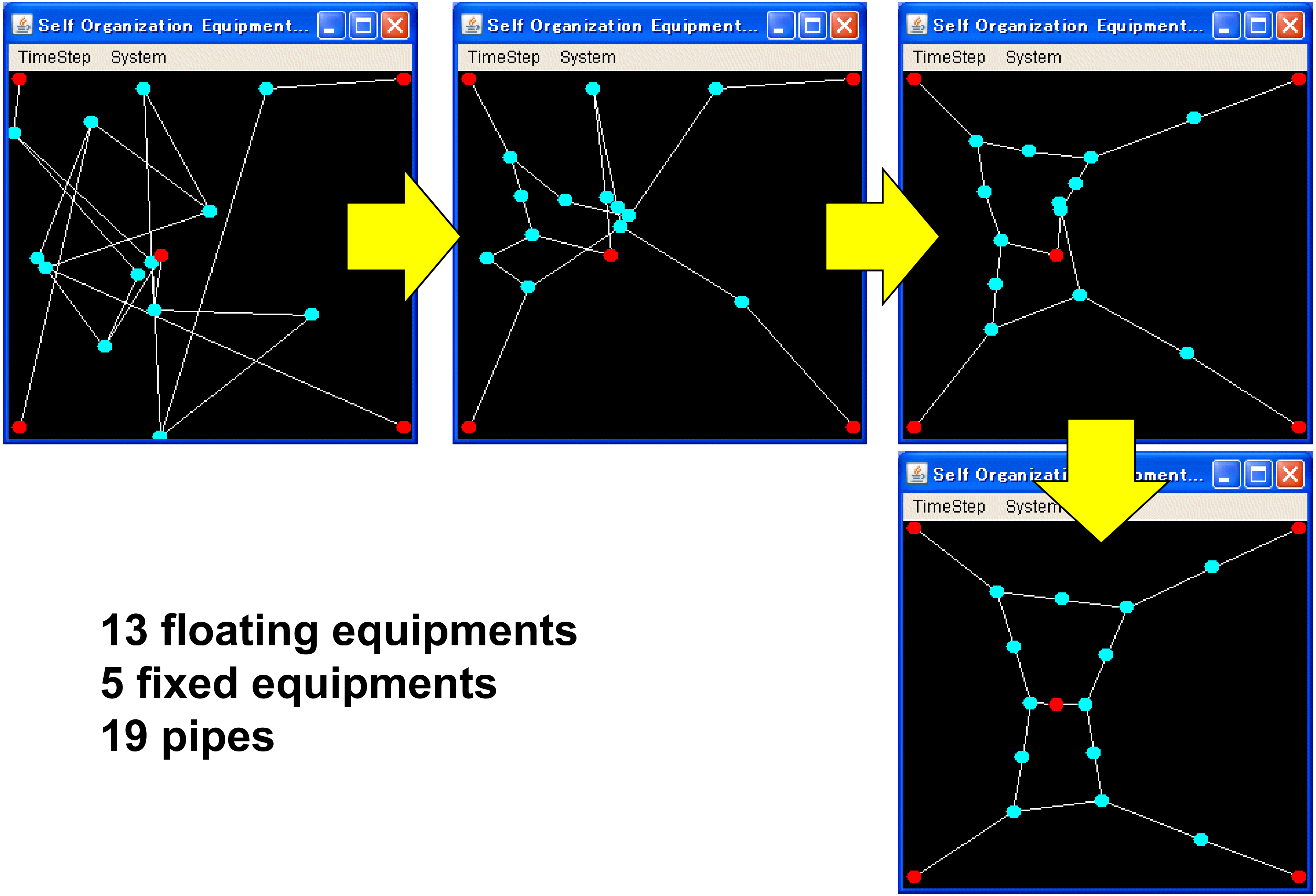


Repeat these operations at all equipments in random order

→ The equipments form into connected order.

Demo

Self-organization



13 floating equipments
5 fixed equipments
19 pipes

Demo

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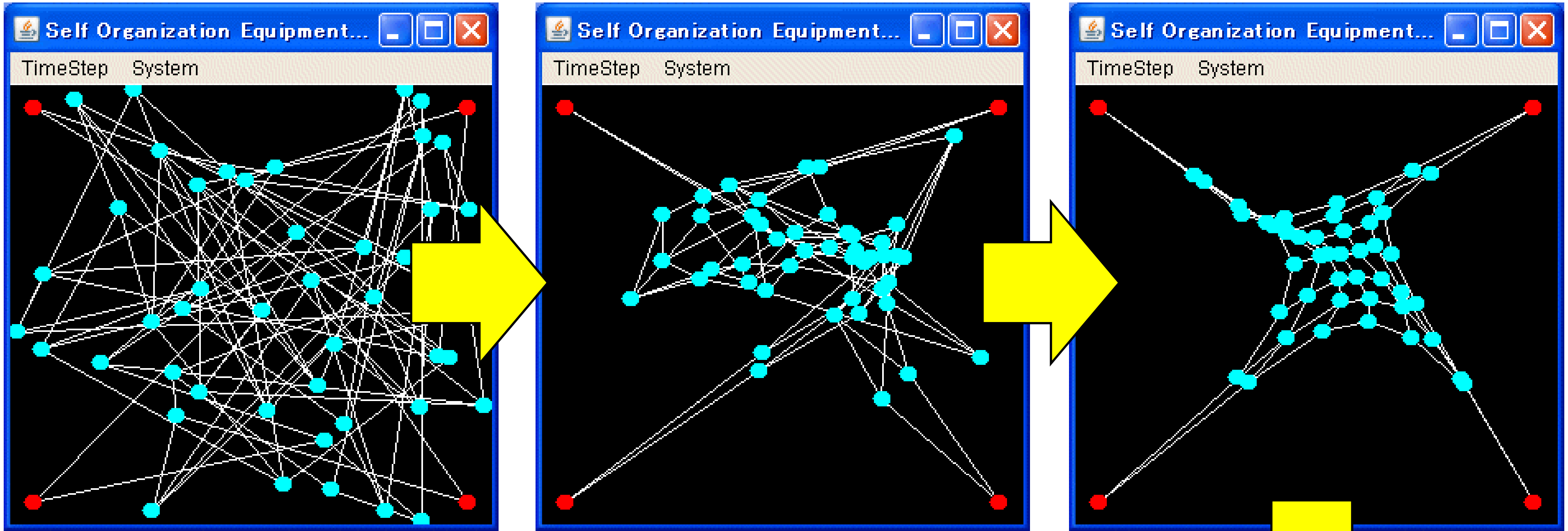

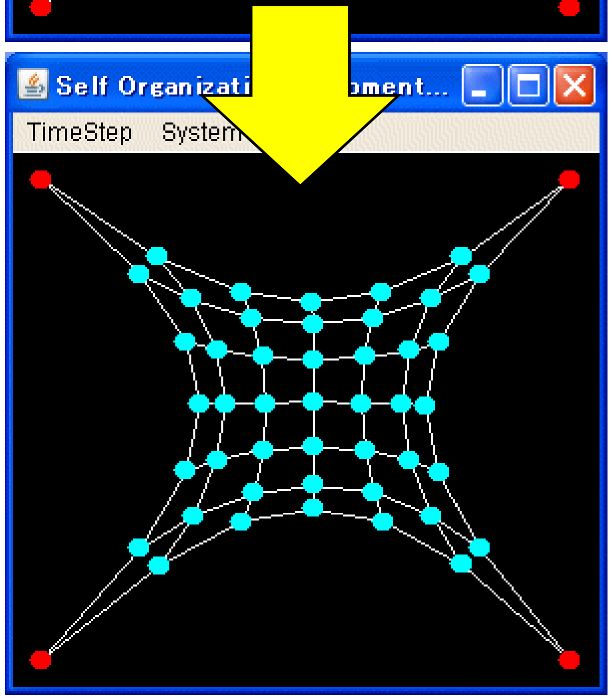

32 floating equipments
4 fixed equipments
72 pipes

Generating good initial populations:
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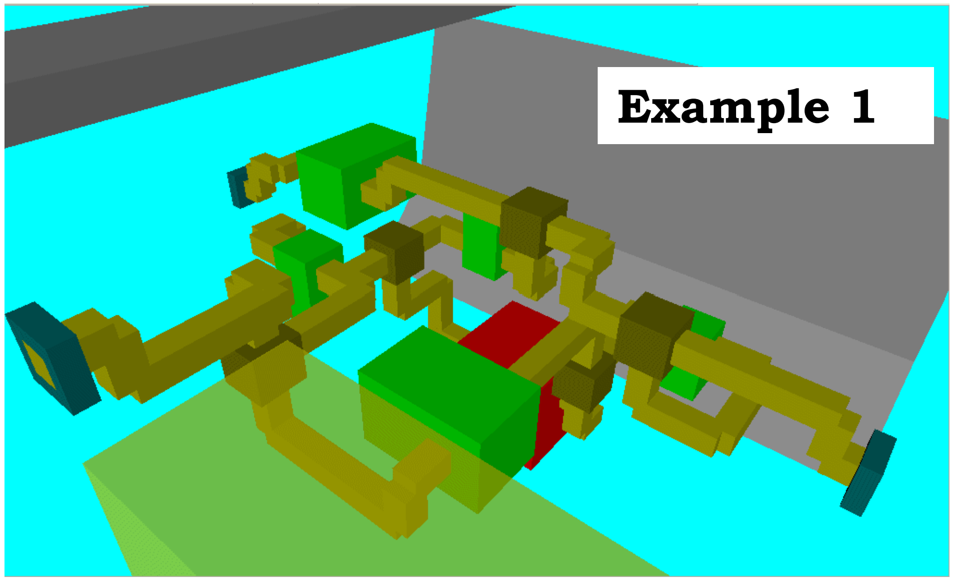

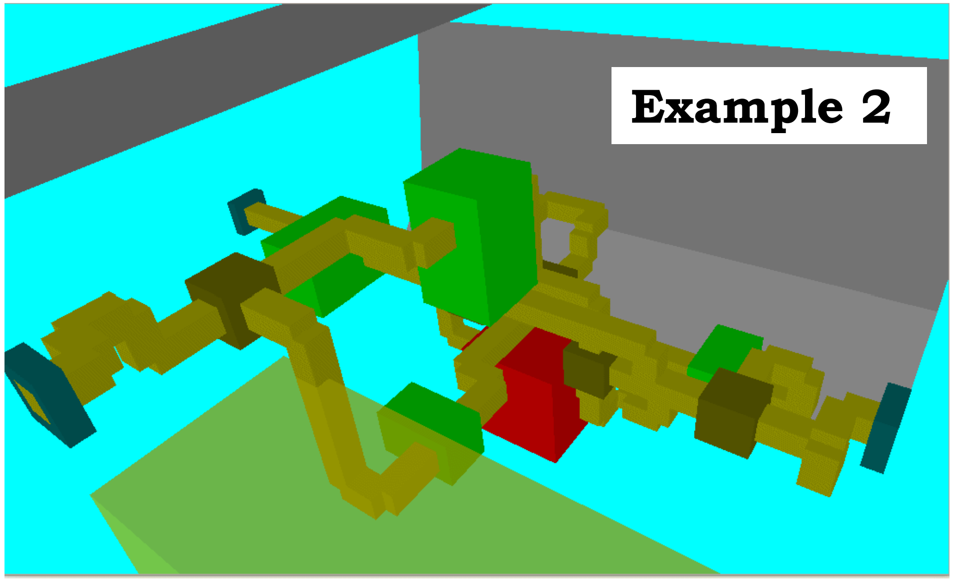

Feature: Various solutions are found when the order of the operation is different.

Problems: It cannot take care of 'valve operability', or etc..
→ **Use Genetic Algorithms**

It cannot draw pipelines if there are too many obstacles
→ **Make use of Dijkstra method** (on going)

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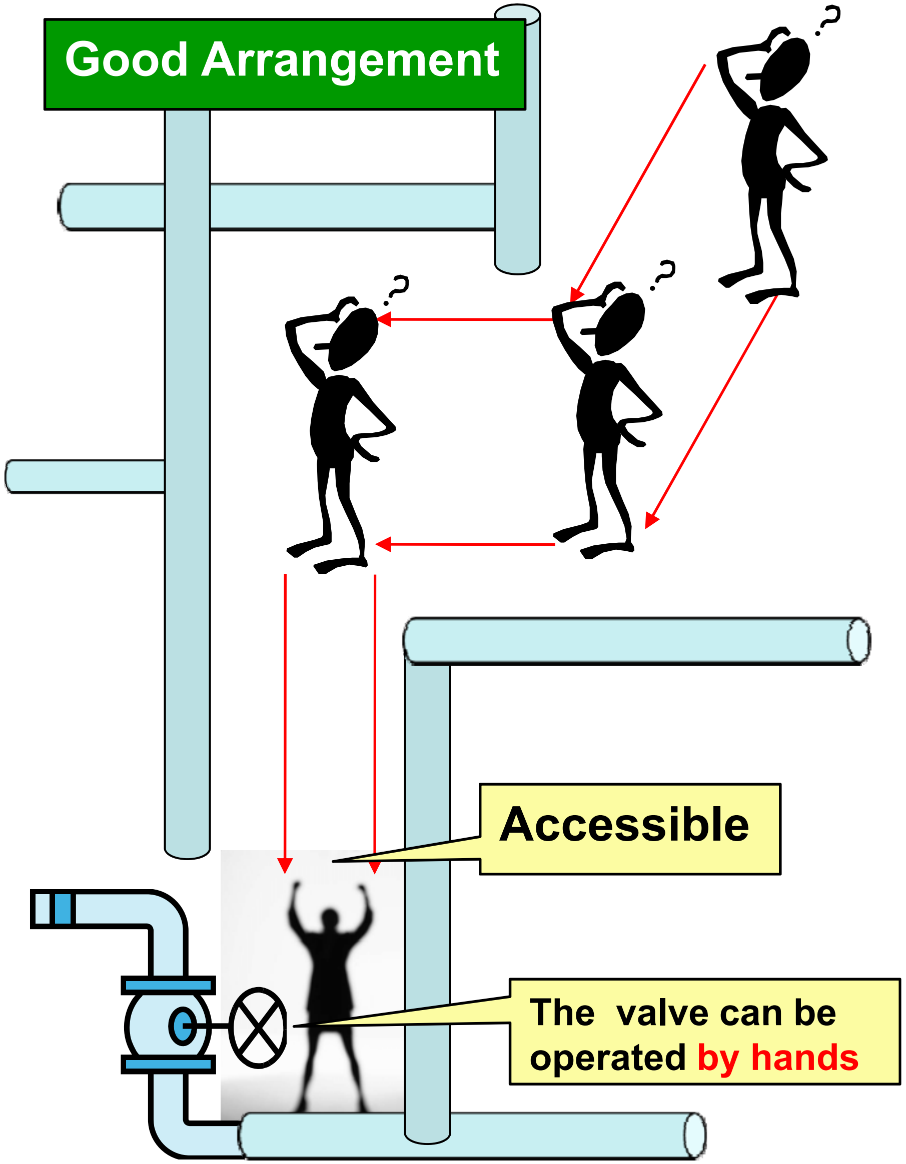
Valve Operability

Evaluation of the space from pathways to valves



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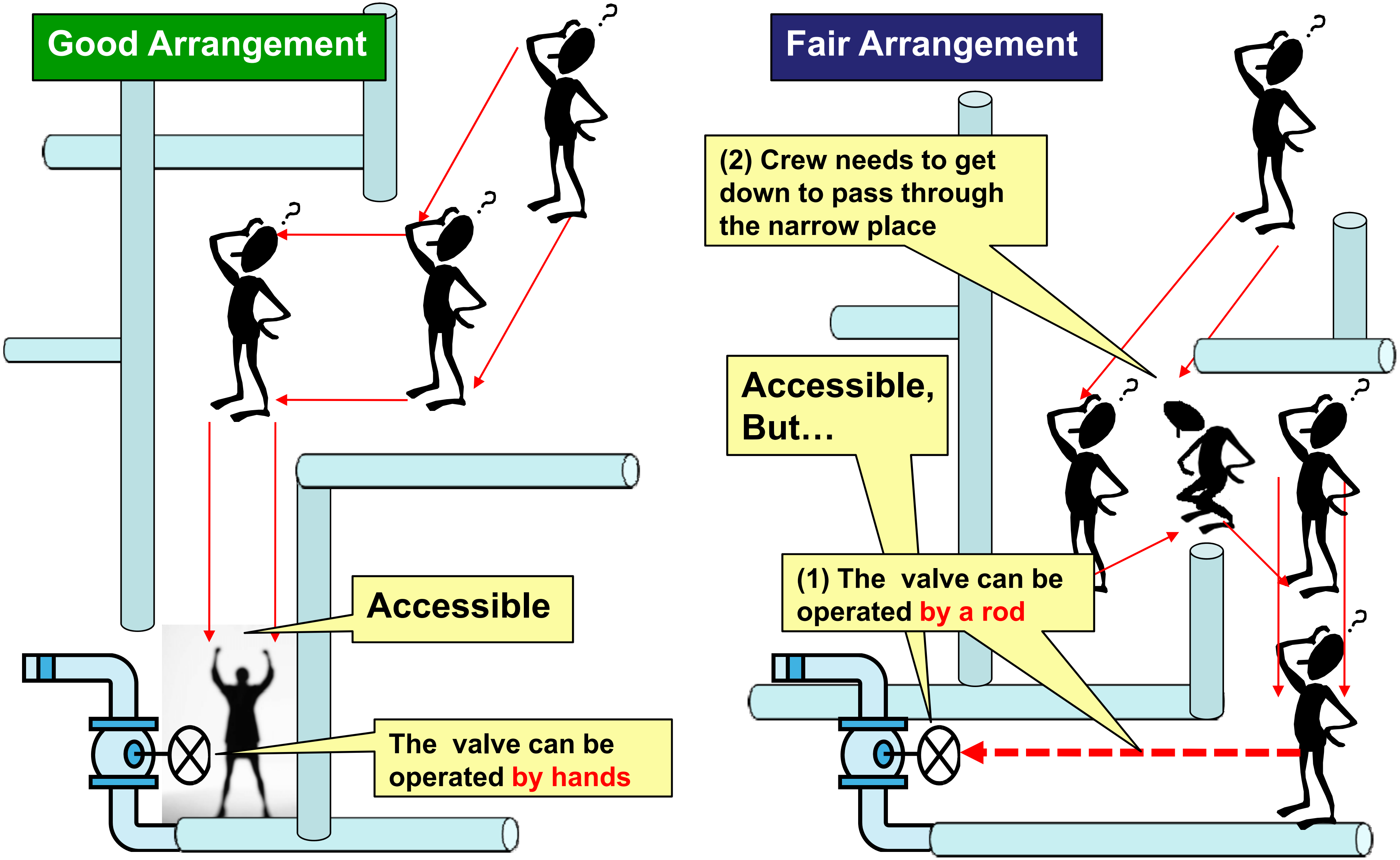

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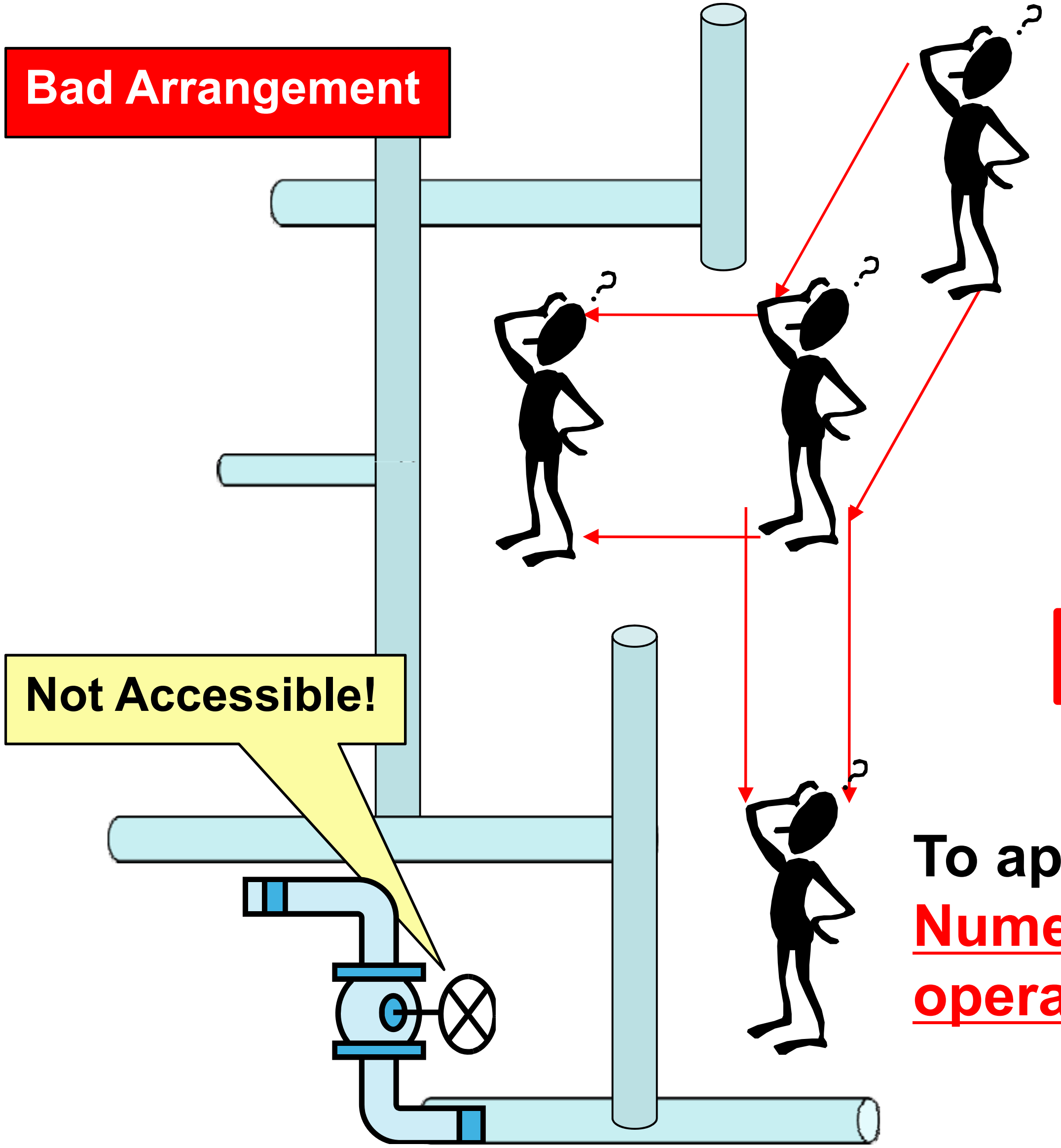
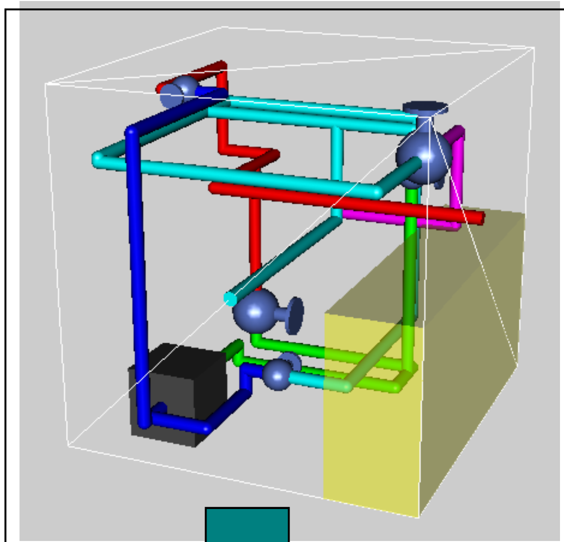


All pipes and valves must be arranged not only to put without interference each other but also to make space from pathways to valves so that crew can access the valves.

Implicit and Obscure so far!

To apply optimization algorithms, <u>Numerical evaluation for the valve operationality</u> is needed.

Evaluation Algorithm for Valve Operability



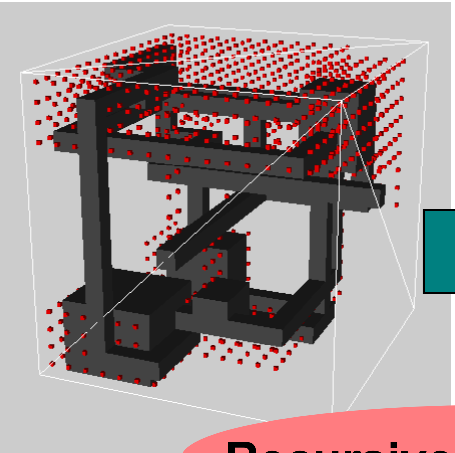
Accessibility

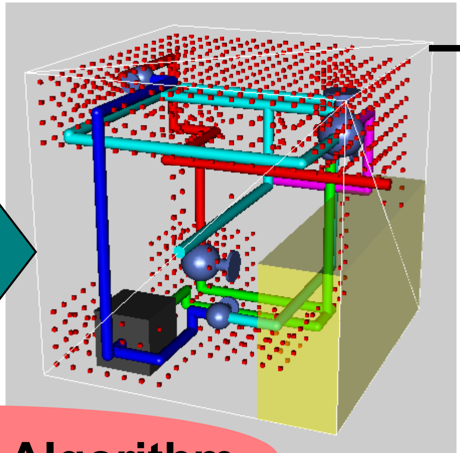
Crew can move to a position where the valve can be operated by hands or by some tools.

Possibility of Valve Handling

The valve can be operated by hands.

The design space is partitioned into **regular grids,** and recognize accessible segments

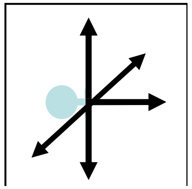




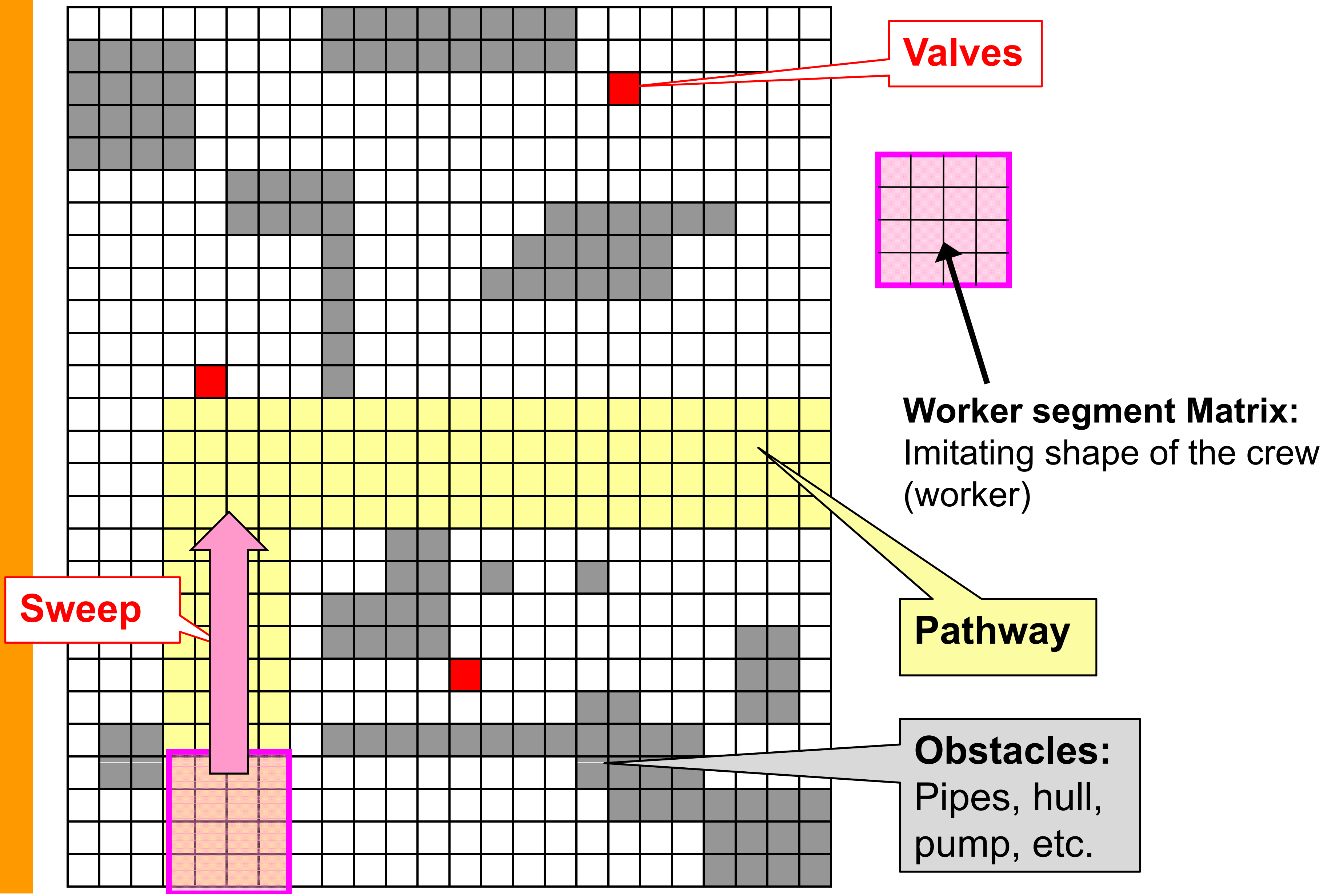
Recursive Fill Algorithm

Evaluation

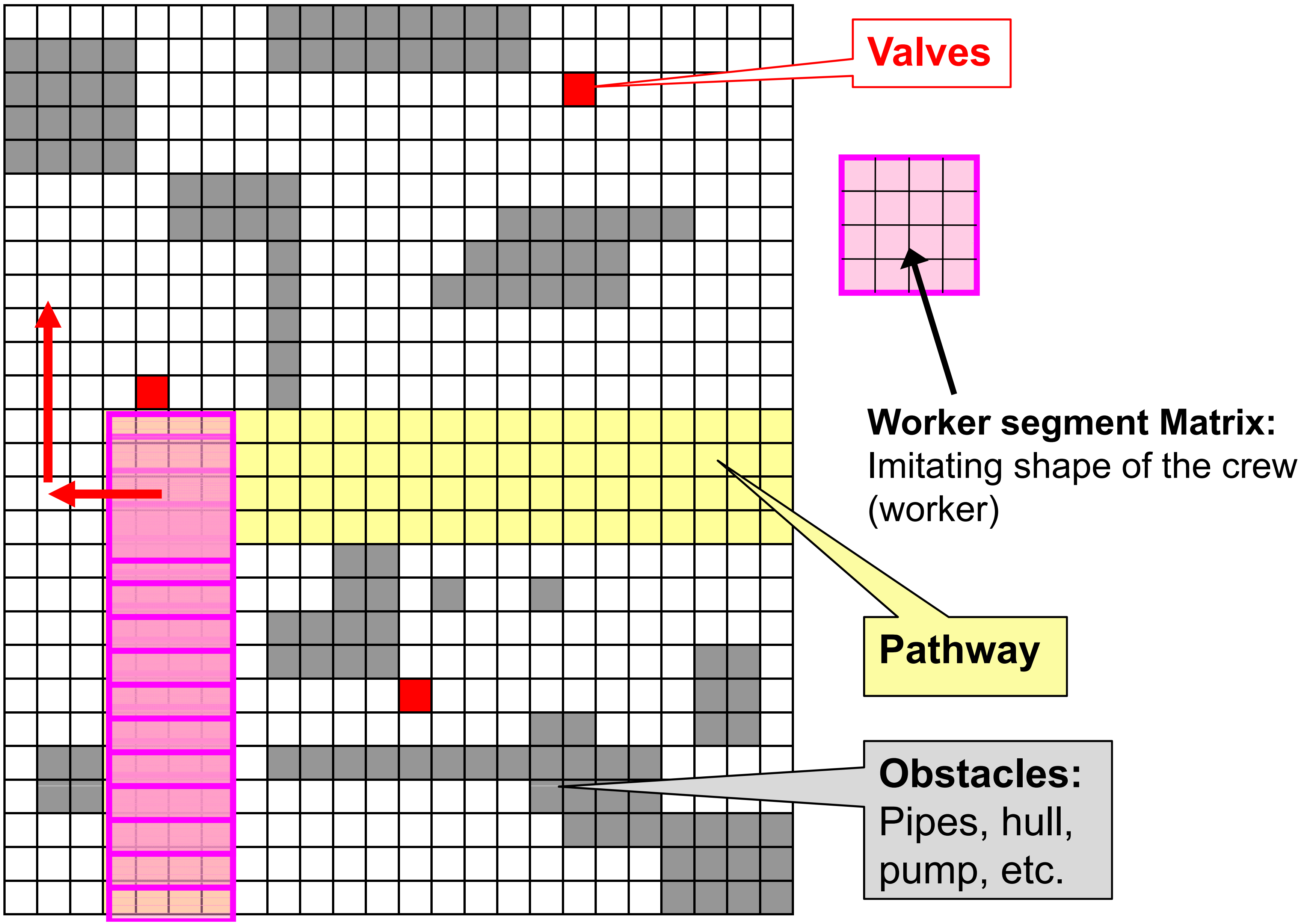
Valve operability is calculated in this grid space by summing up the minimum distance from each valve to accessible segments that are located in the direction of the axis of the valve's handle or four directions perpendicular to that axis.



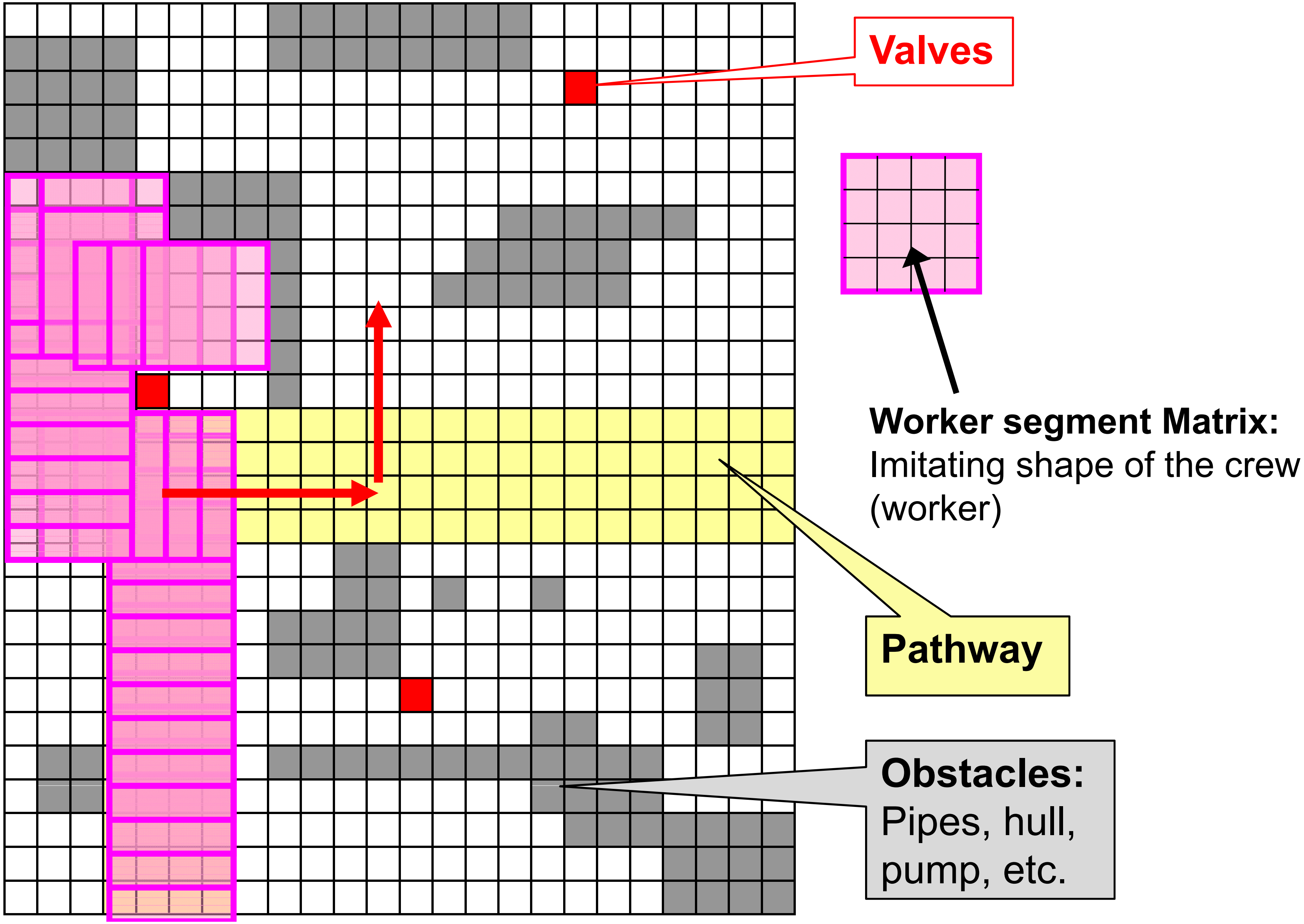
Finding Accessible Segments: Recursive Fill Algorithm



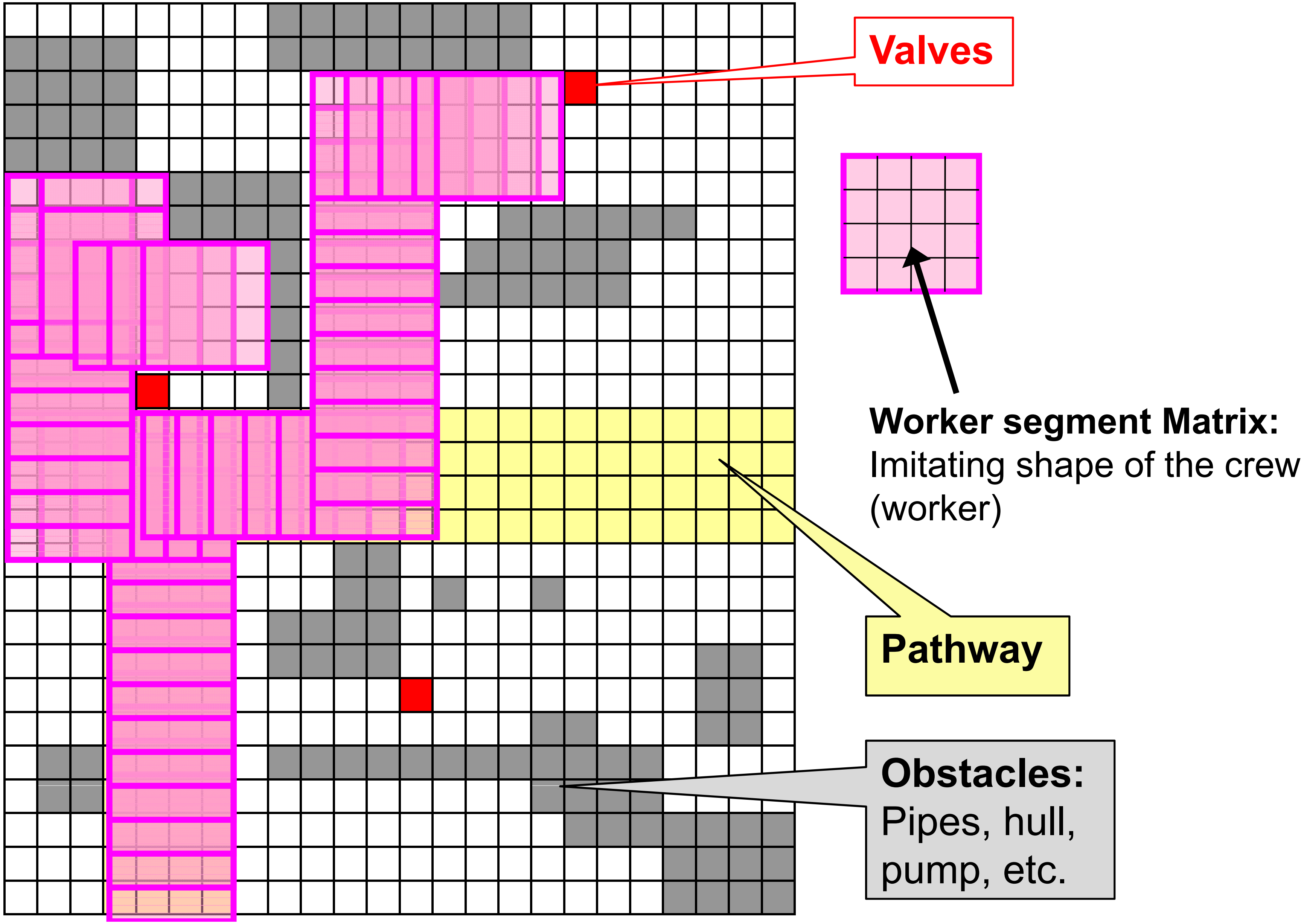
Finding Accessible Segments: Recursive Fill Algorithm



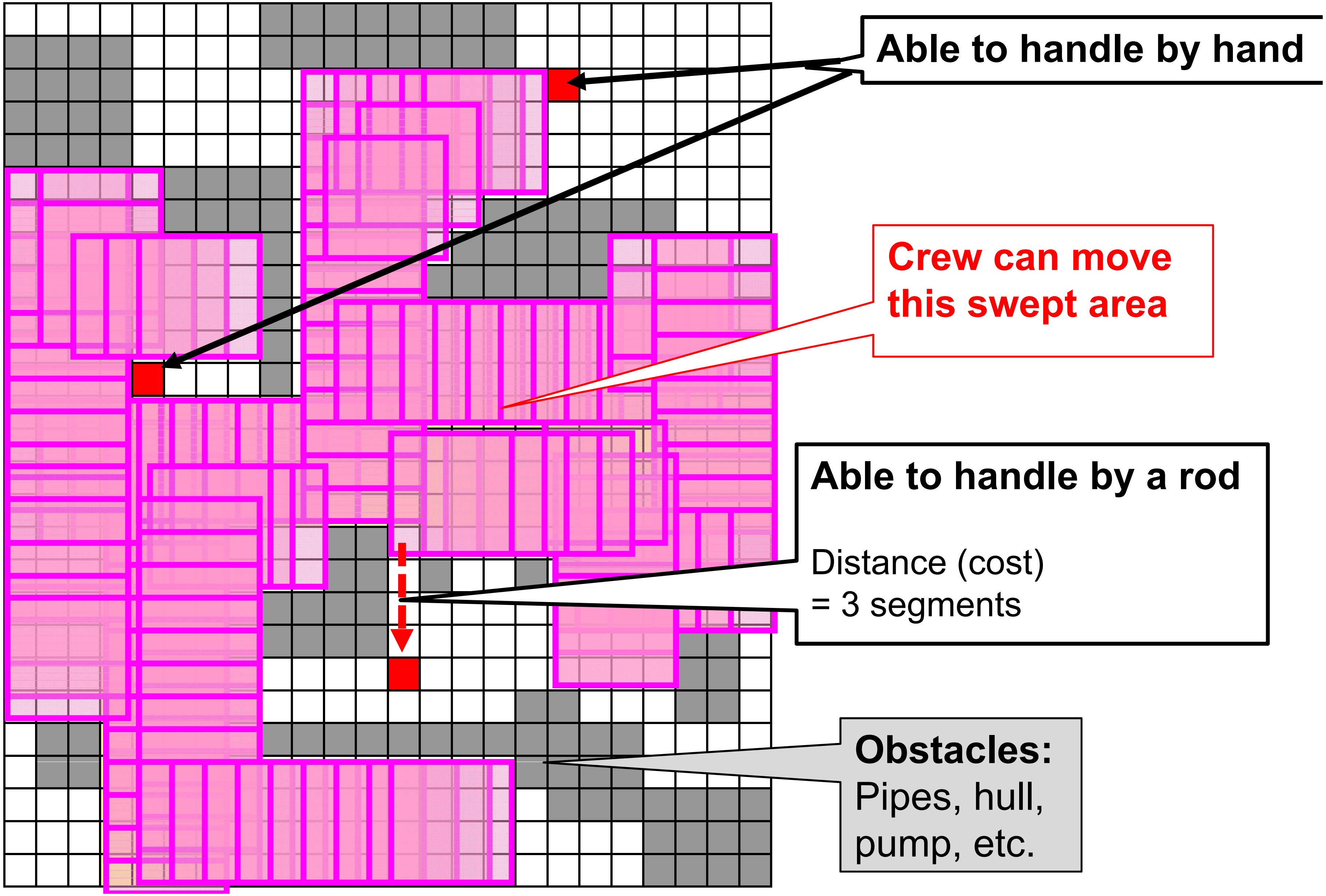
Finding Accessible Segments: Recursive Fill Algorithm

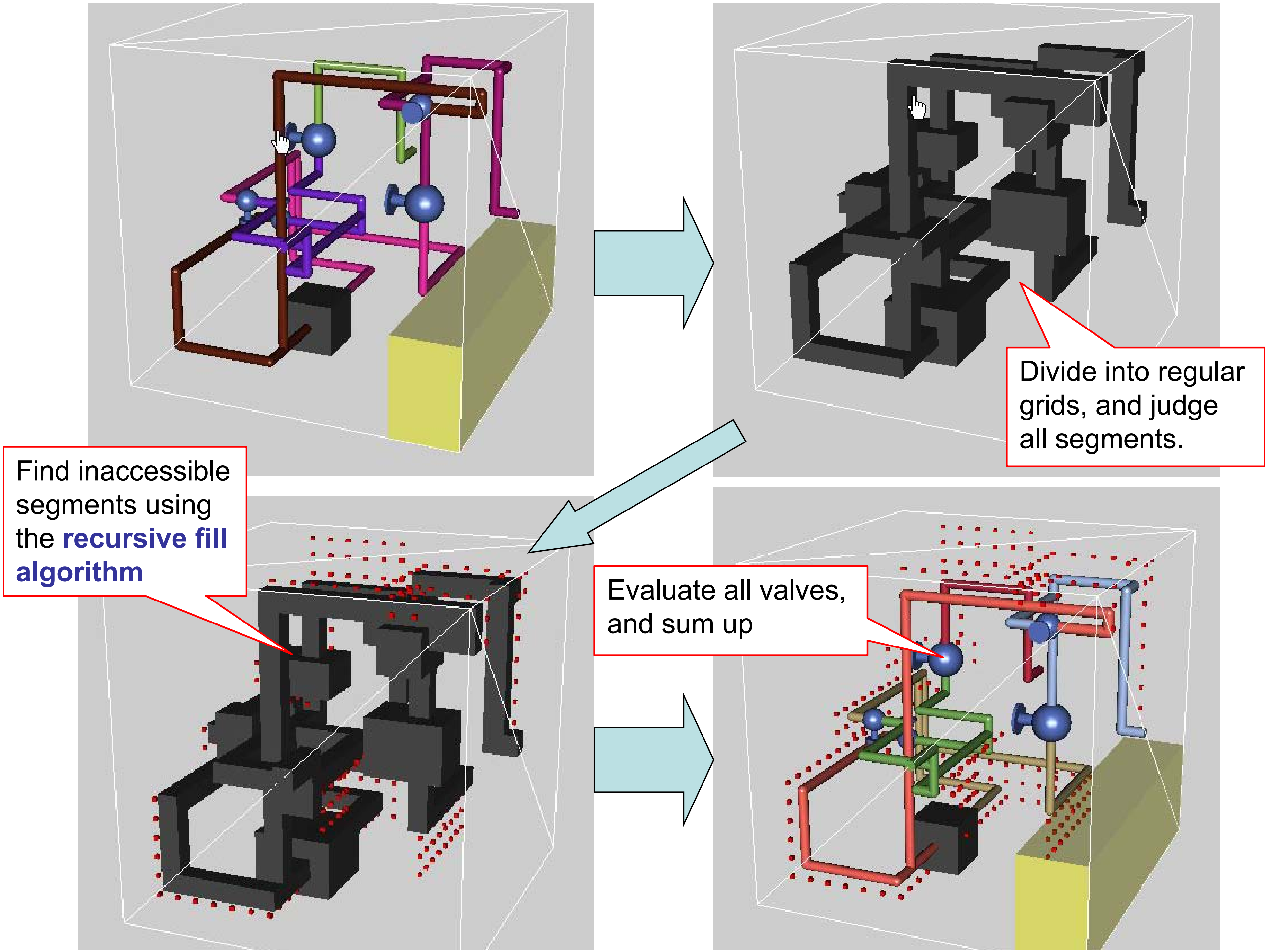


Finding Accessible Segments: Recursive Fill Algorithm

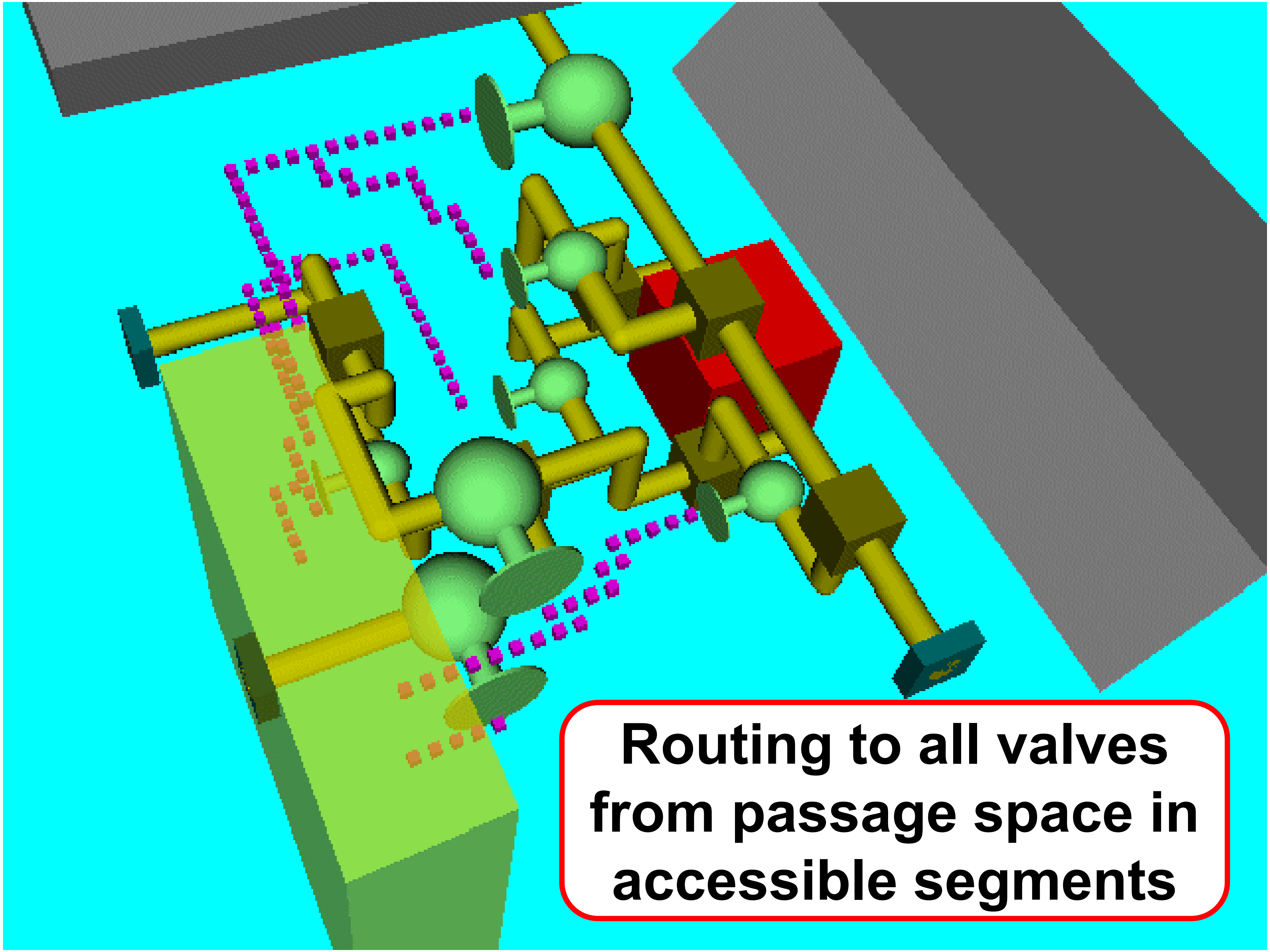


Finding Accessible Segments: Recursive Fill Algorithm





Divide into regular grids, and judge all segments.
Find inaccessible segments using the **recursive fill algorithm**
Evaluate all valves, and sum up



Routing to all valves from passage space in accessible segments

Features of the Evaluation Algorithm

Accessible

1. Crew can move to a position where the valve can be operated by hands. → **Good** **Cost = 0**

2. Crew can move to a position where the valve can be operated by a rod, but cannot be operated by hands. → **Fair** **Cost = distance**

Inaccessible

Crew cannot move to a position where the valve can be operated because obstacles surround valves. → **Bad** **Cost = 10000**

Summing over all valves

Expert's Obscure or Implicit Criterion of

Valve-Operability is clearly numerically defined.

Material Cost

Material Cost Function

$$f\_material = \sum_{k=1}^{n_p} W_k L_k D_k$$

W_k : **Weight of the kth pipe**

L_k : **Length of the kth pipe**

D_k : **Diameter of the kth pipe**

n_p : Number of pipes

Overview

1. **Motivation and Purpose**

2. **Problem Formulation**

・Parameters： 1）Equipment's Locations and directions 2）Piping Routes

Consider piping T-branches as equipments

・A new evaluation algorithm for Valve Operability → later

3. **Multi-Objective Optimization Algorithm (MOGA)**

・Coding of the piping arrangement design

・Crossover operation

・Self-organization equipment arrangement method

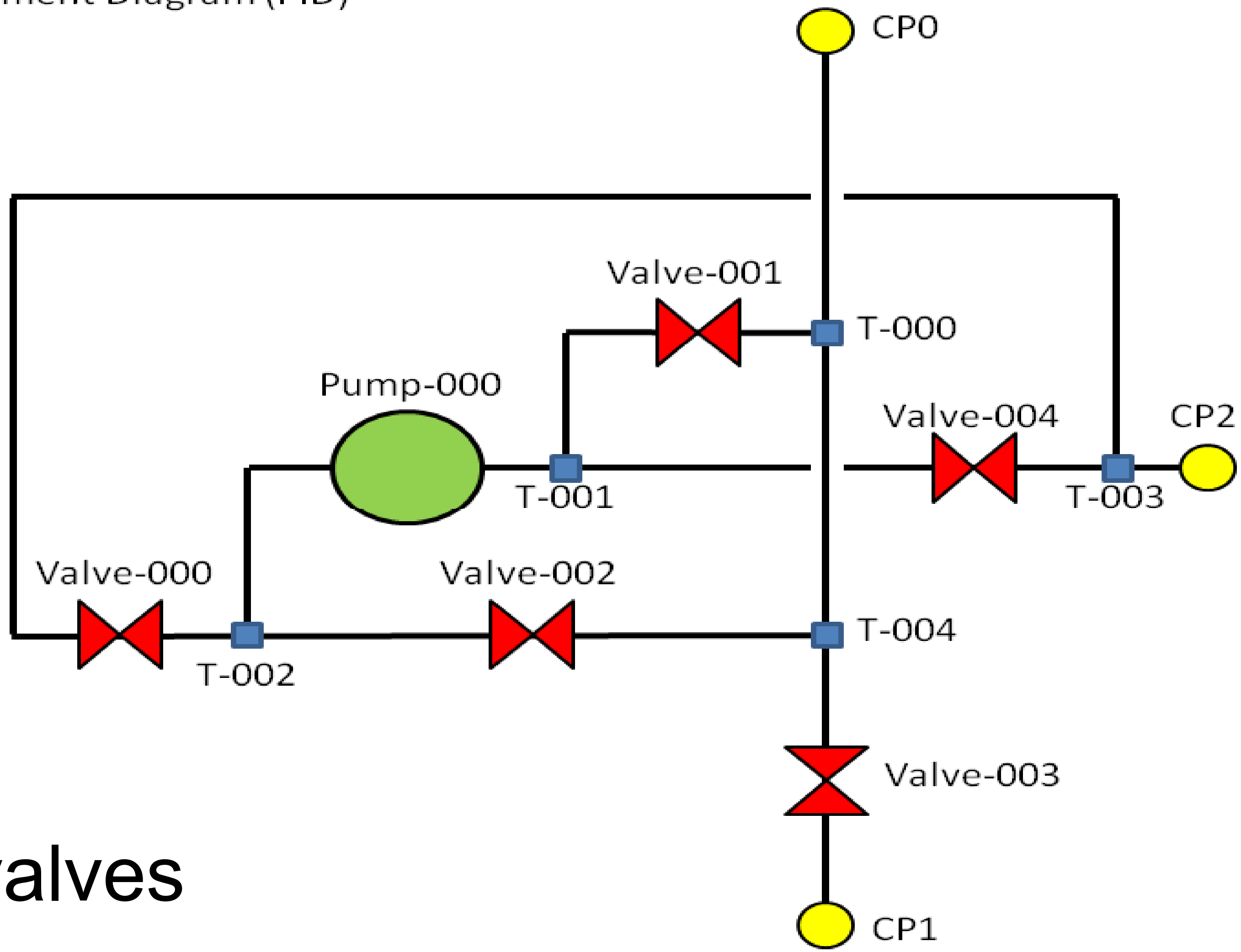
4. **Experiments**

(1) 5 valves (2) 7valves

5. **Conclusions and Future Works**

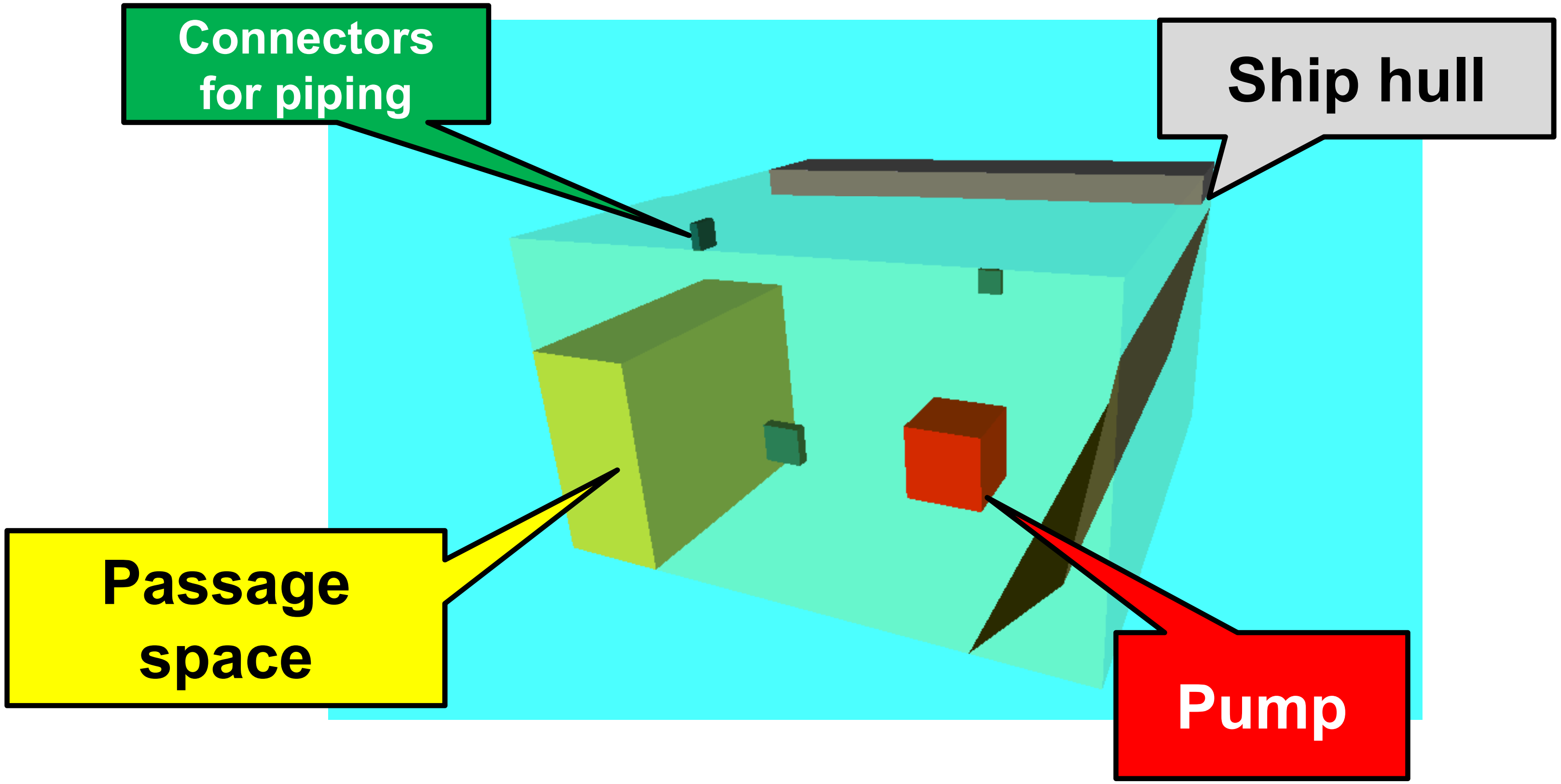
Simulation Setting (PID)

Piping and instrument Diagram (PID)



Five valves

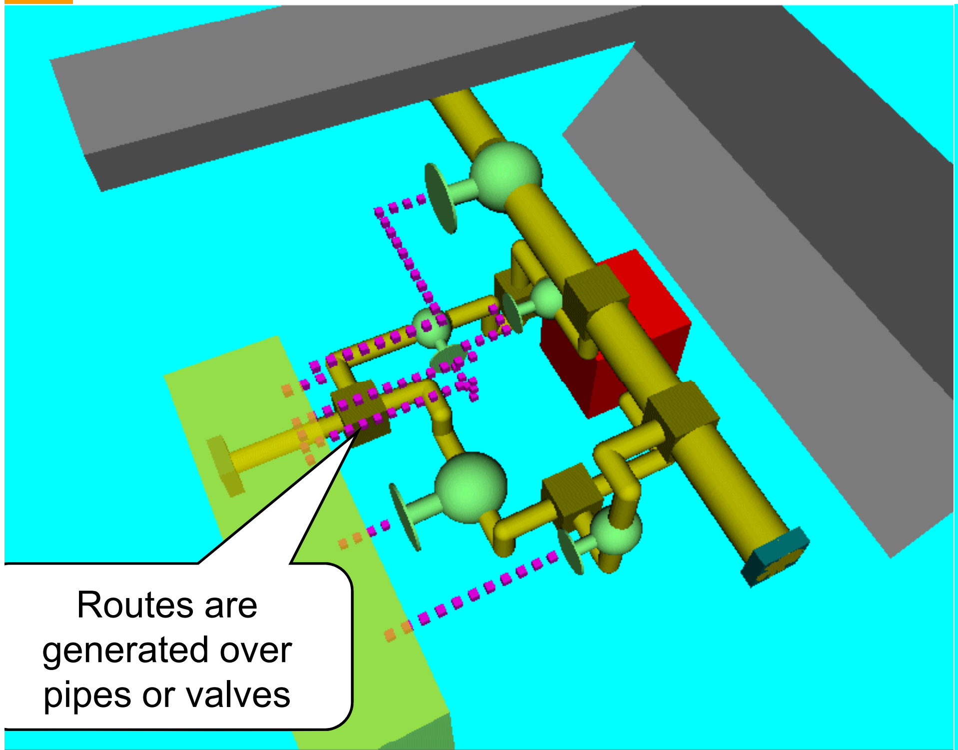
Simulation Setting（Geometrical conditions）

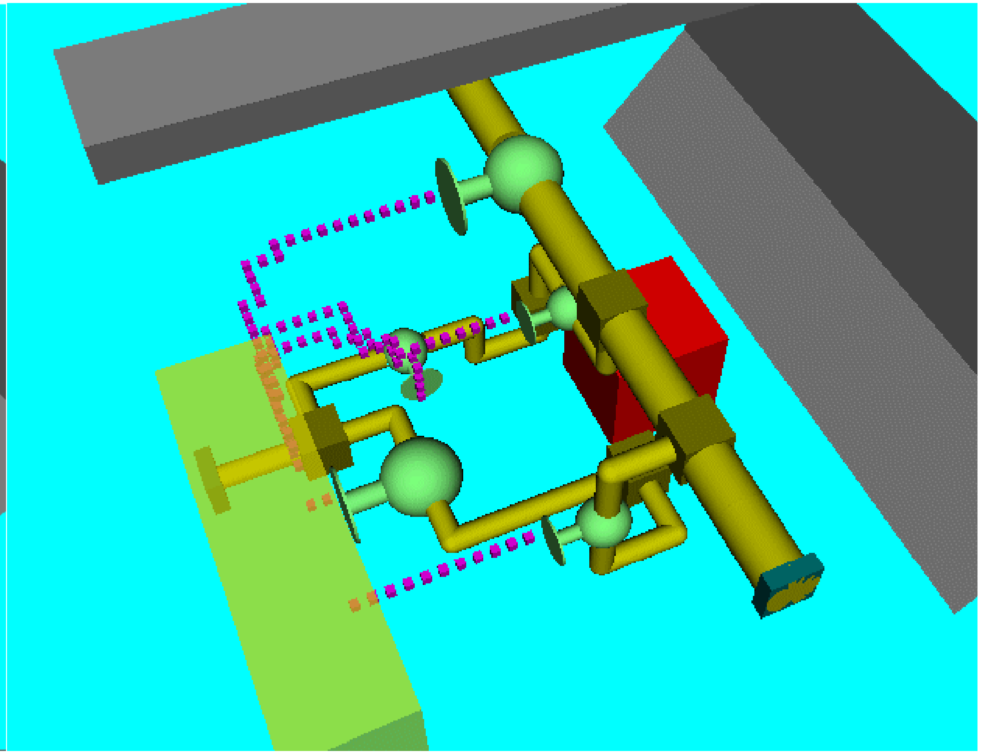


Design space is 5m×5m×2m

Results (5 valves)

Number of evaluate solutions: 20000 times
Calculation time: 10 days by Intel Core2Quad 2.664GHz





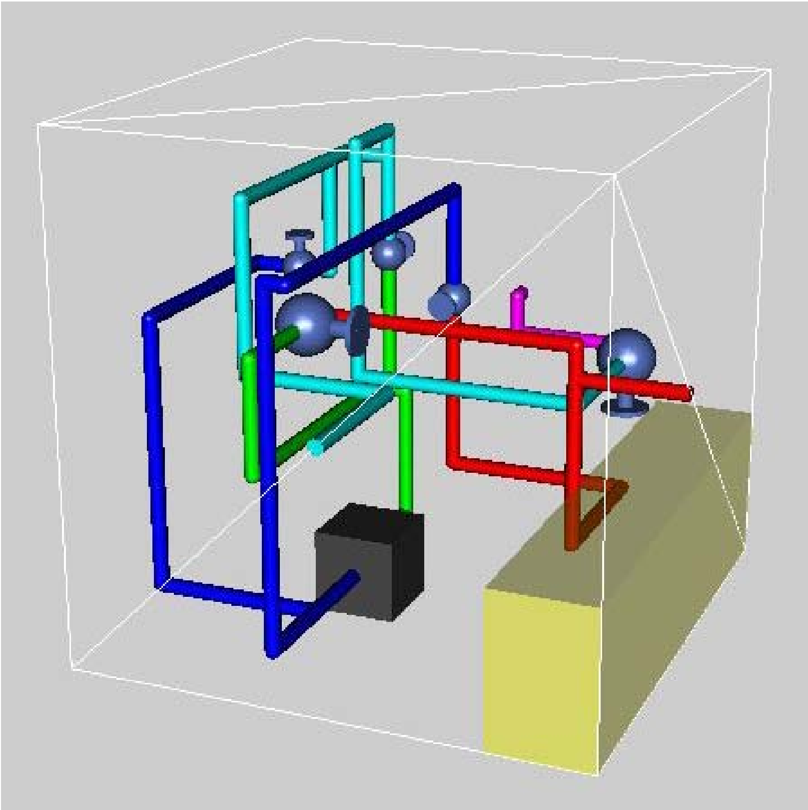
Material Cost = 2.67
Number of elbows = 18
Cost of Valve Operability = 140.6

Material Cost = 2.595
Number of Elbows = 13
Cost of Valve Operability = 171.0

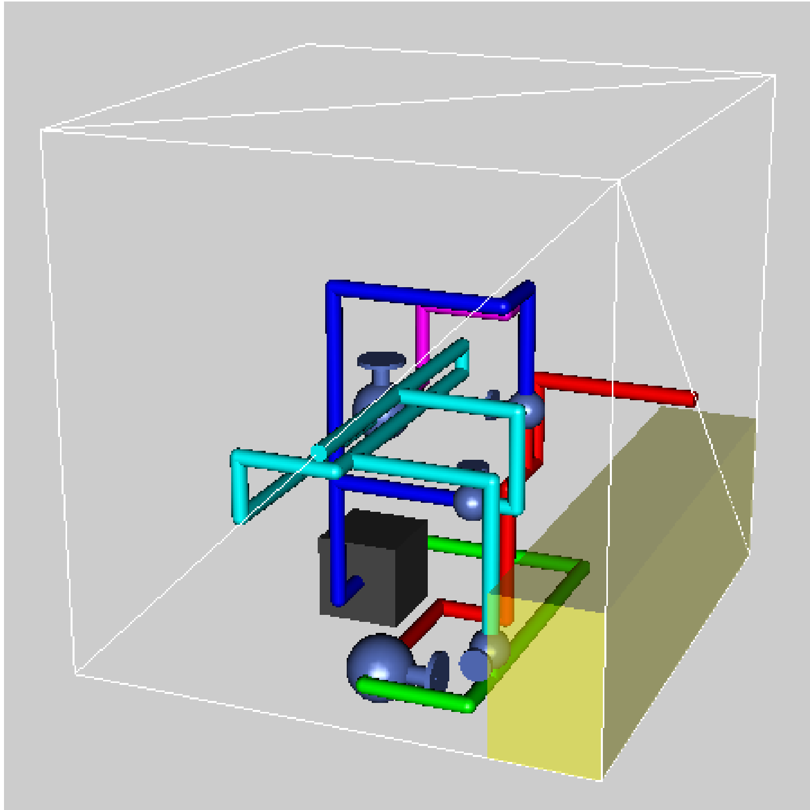
3-objective optimization


Grating

【Note】 Solutions in previous methods



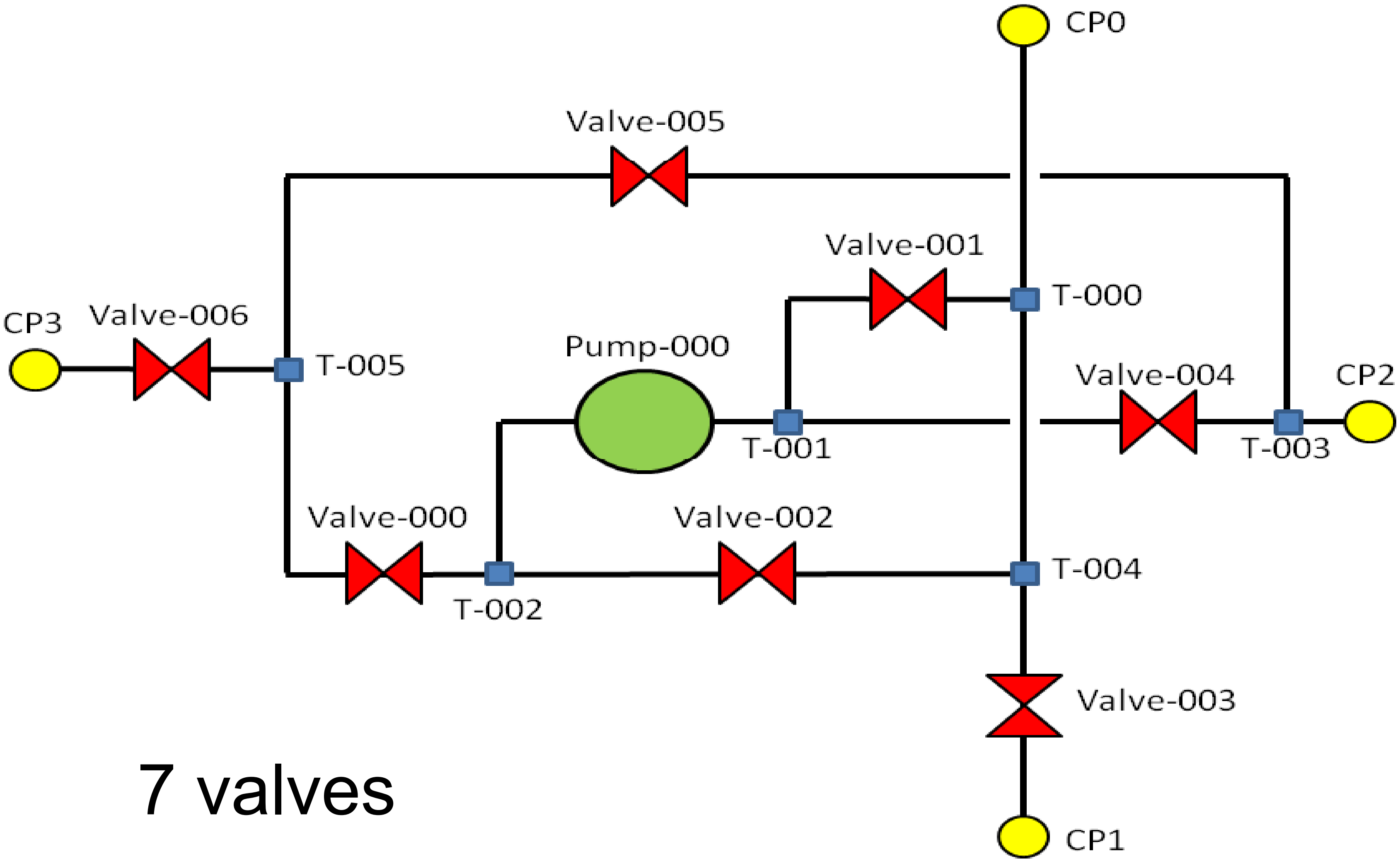
Material Cost = 8.12
Cost of Valve Operationality = 0



Material Cost = 5.50
Cost of Valve Operationality = 10001

Design space = 5m x 5m x 5m

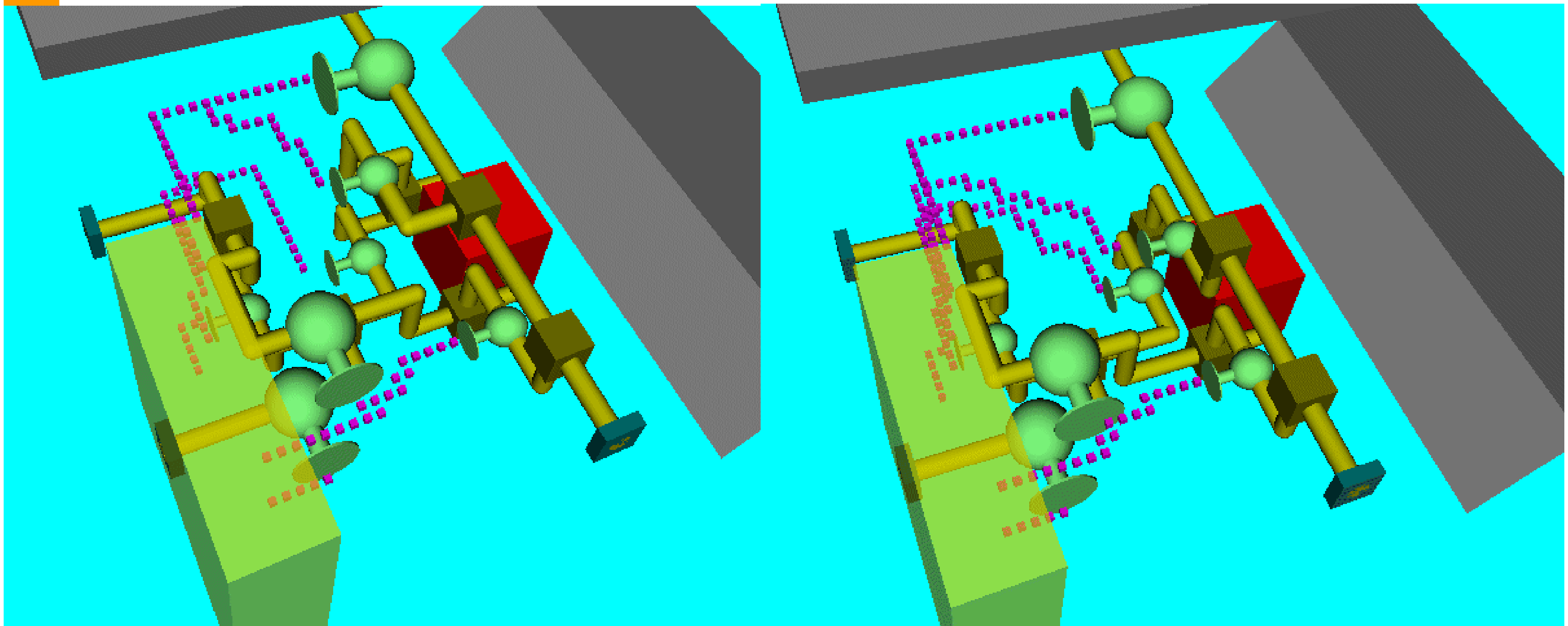
Simulation Setting（PID）



7 valves

Results（7 valves）

Number of evaluate solutions: 20000 times
Calculation time: 7 days by Intel Core2Quad 2.664GHz

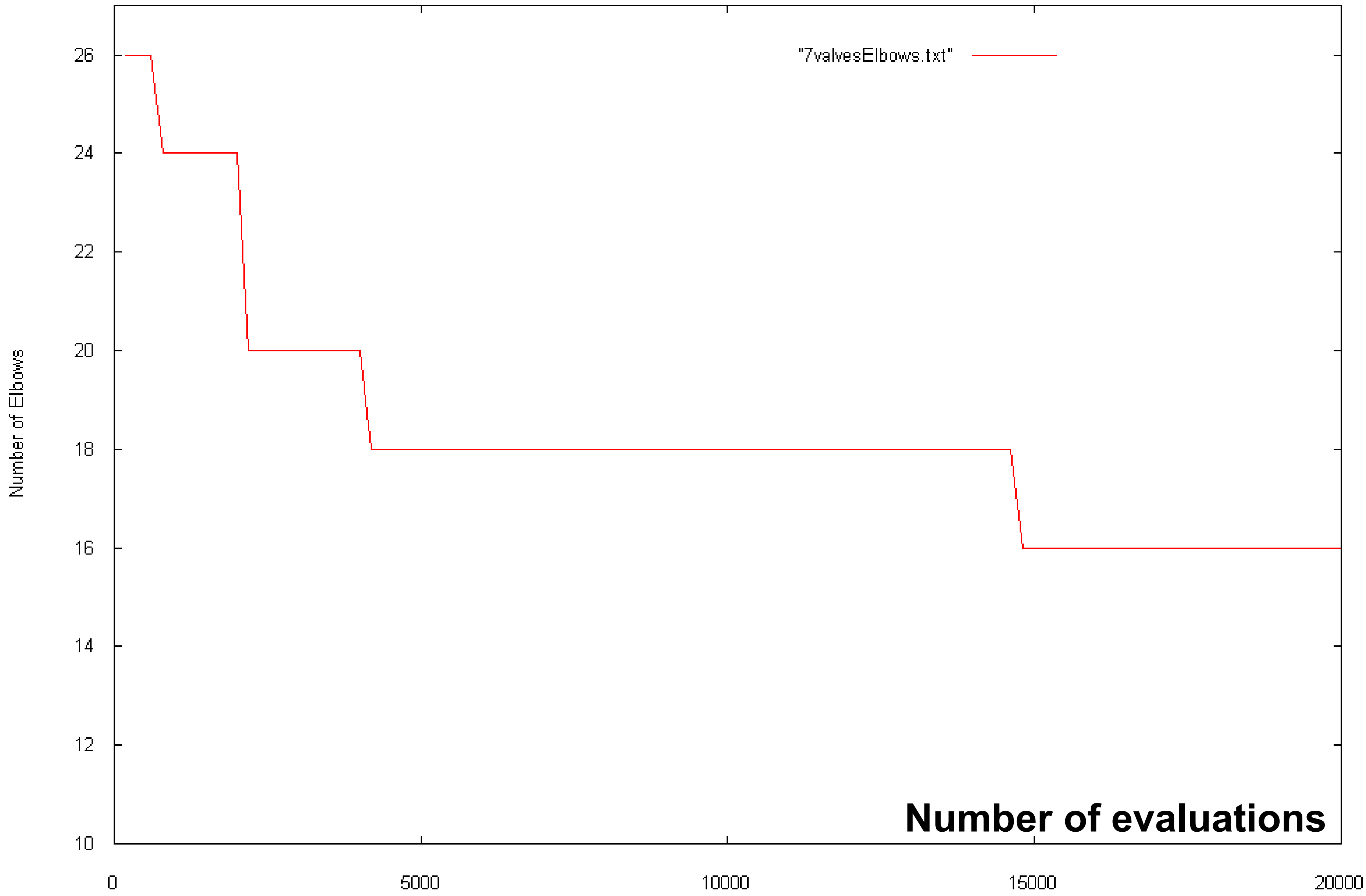


Material Cost = 2.7975
Number of elbows = 24
Cost of Valve Operability = 270.8

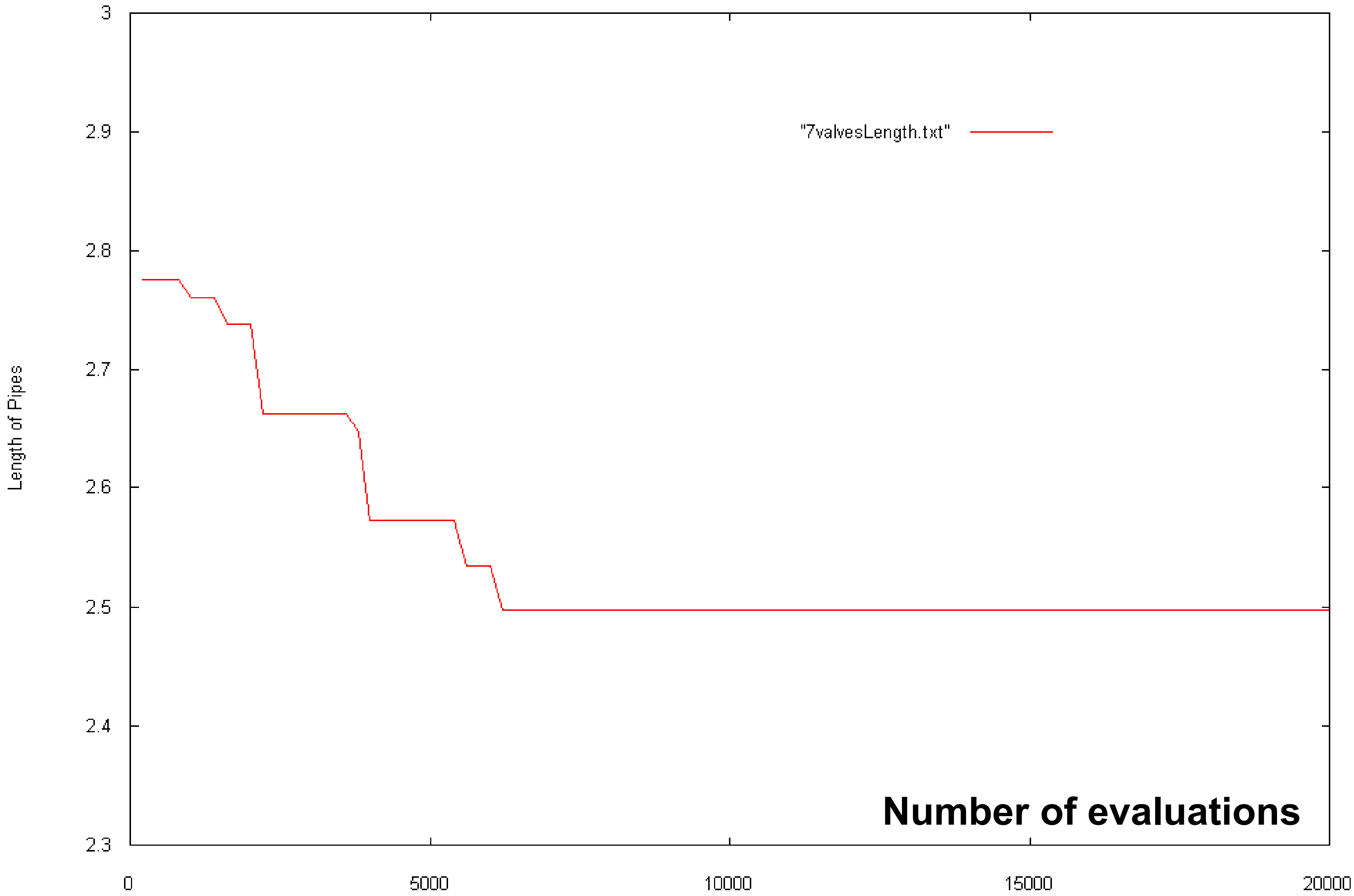
Material Cost = 2.6475
Number of Elbows = 22
Cost of Valve Operability = 286.0

3-objective optimization

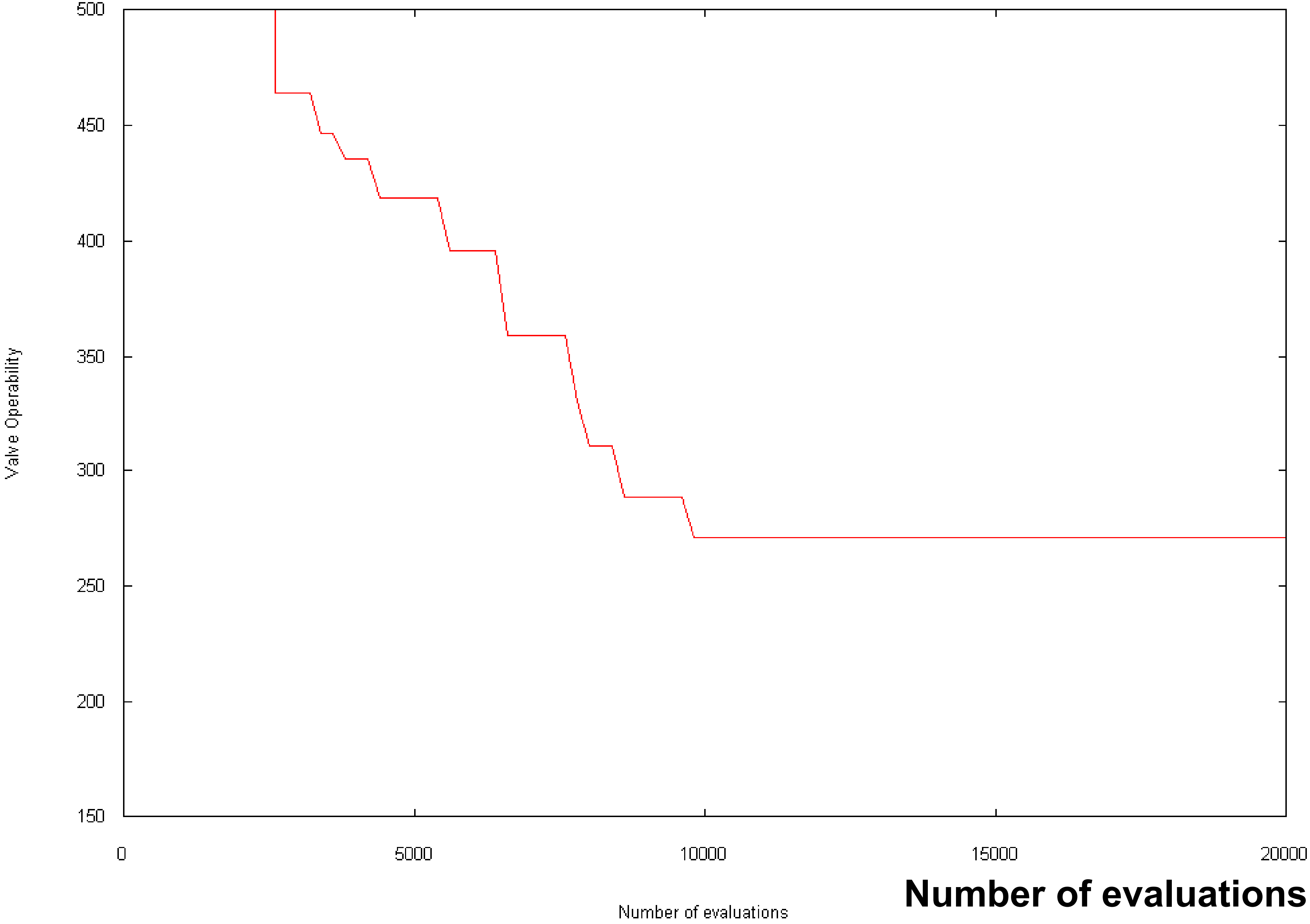
Best solution on number of elbows（7 valves）



Best solution on Material cost（7 valves）

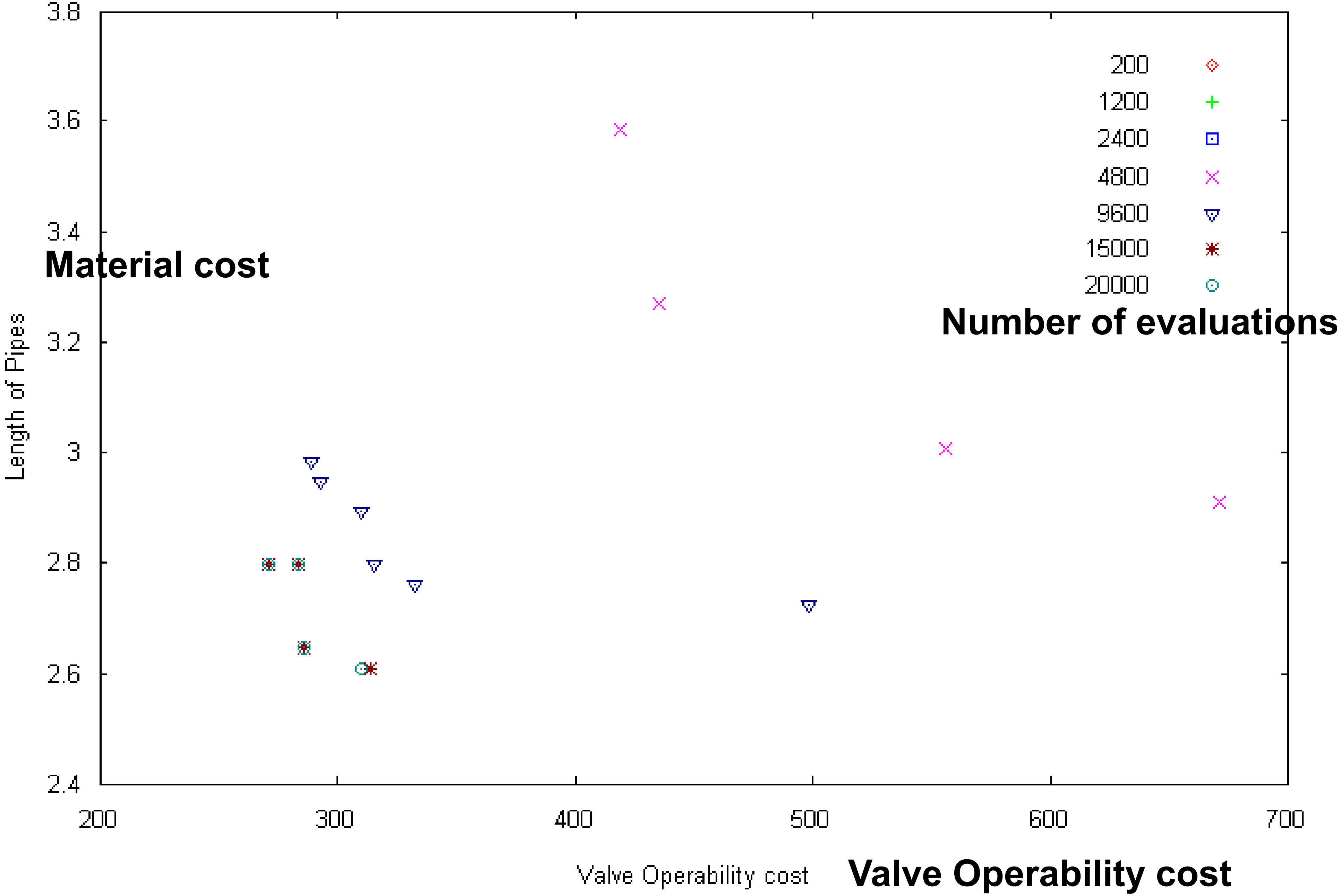


Best solution on Valve Operability Cost（7 valves）

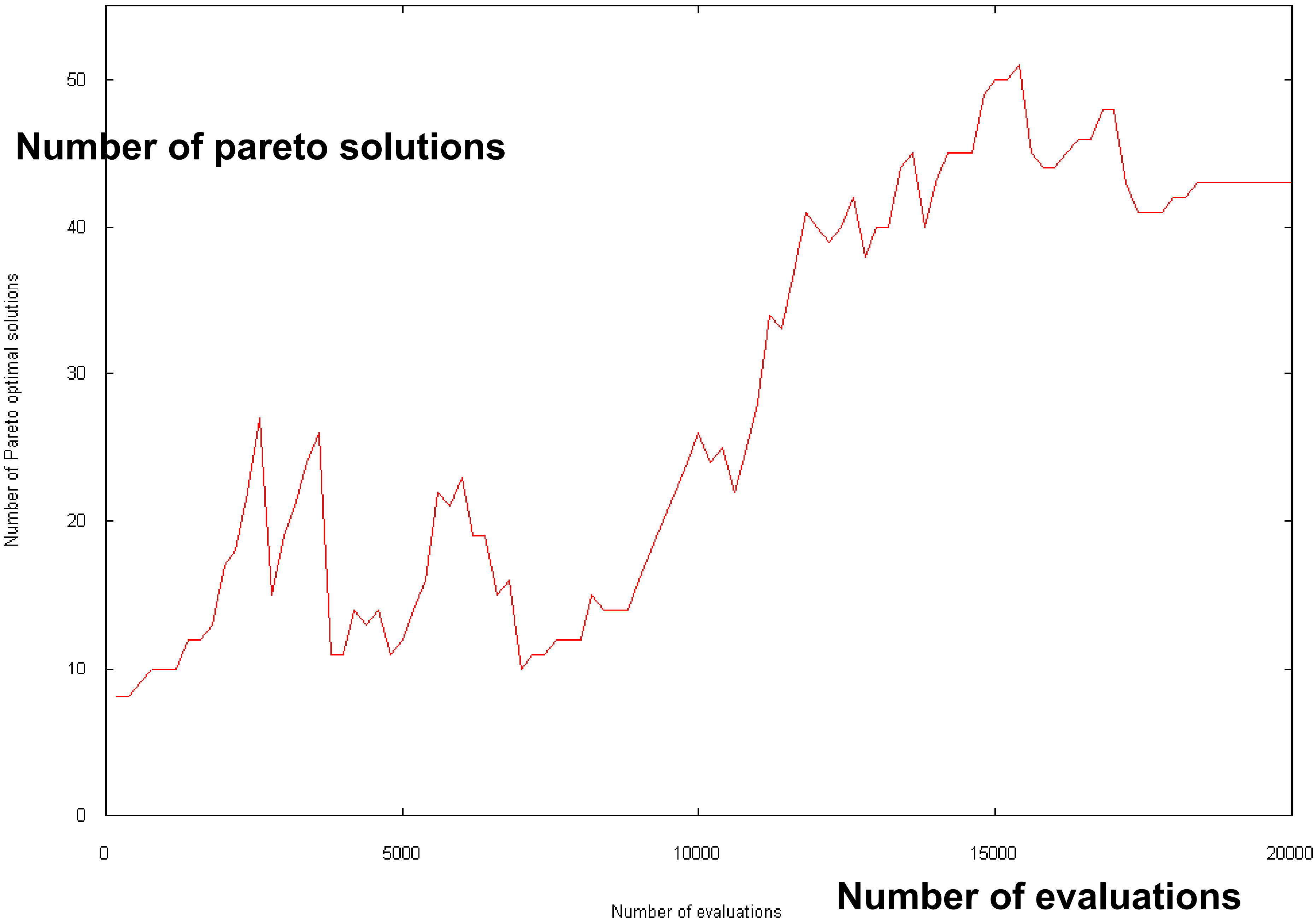


Number of evaluations

Pareto solutions in Material-ValveOperability space



Number of Pareto solutions （7 valves）



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Conclusions

Conclusions

1. Supposition in Automatic Pipe Arrangement :

Make obscure criteria to be clear

Treat as multi-objective problem

2. Valve Operability Evaluation Algorithm is proposed.

3. An Implementation of **Multi-objective GA for pipe arrangement** is proposed.

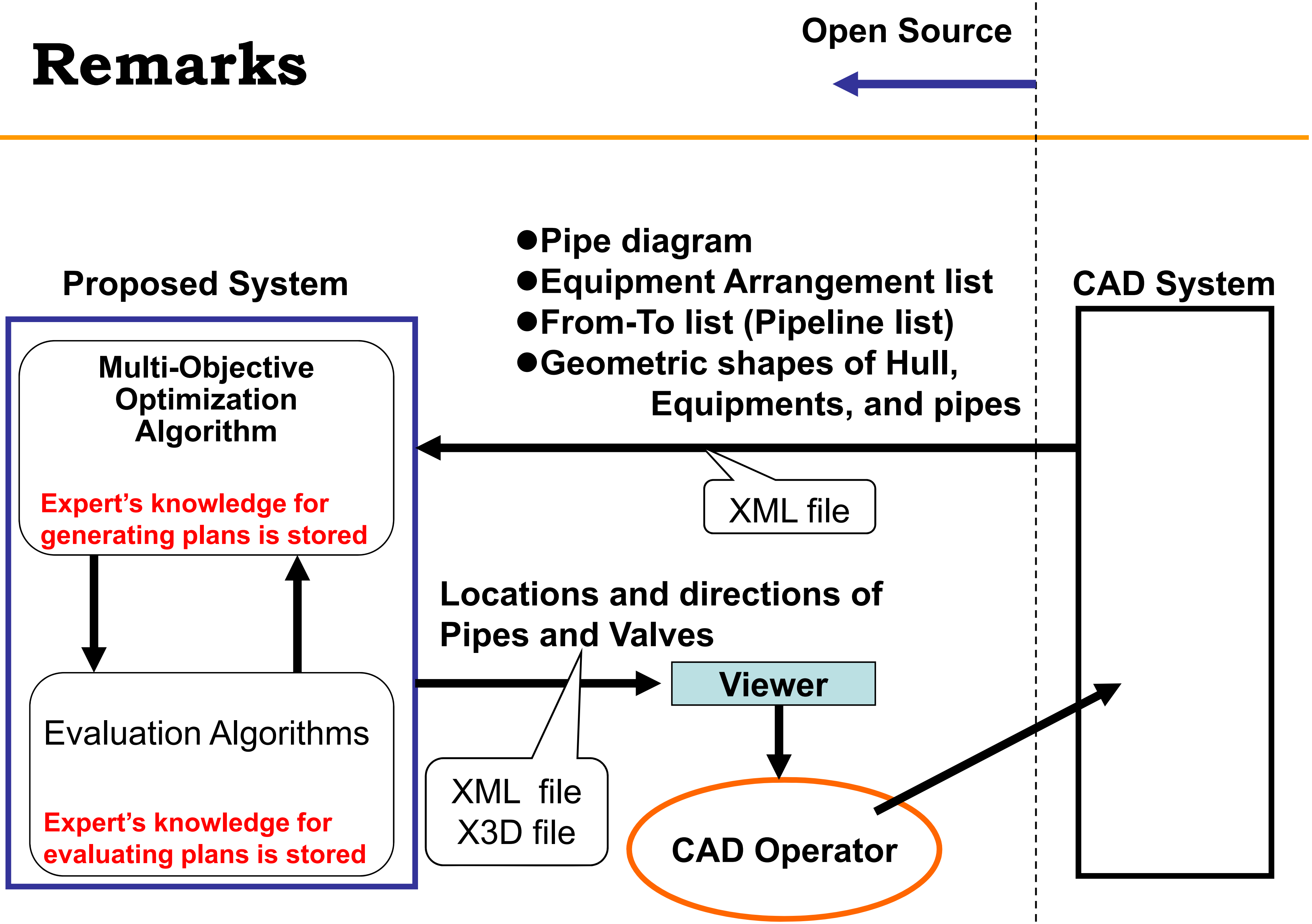
【A new GA for piping arrangement】

●**Problem formulation: Piping branches as equipments**
→ **Simplify the piping encoding**

●**A new Gene encoding** and **crossover operation** for GAs
→ **Simple and Intuitively appropriate**

●**Self-organization equipment arrangement**
to generate good initial populations

Remarks


Open Source
Proposed System
Multi-Objective
Optimization
Algorithm
Expert's knowledge for
generating plans is stored
Evaluation Algorithms
Expert's knowledge for
evaluating plans is stored
●Pipe diagram
●Equipment Arrangement list
●From-To list (Pipeline list)
●Geometric shapes of Hull,
Equipments, and pipes
XML file
CAD System
Locations and directions of
Pipes and Valves
Viewer
XML file
X3D file
CAD Operator