공정시스템 공학 기술의 현황 소개

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화학공학과

Contents

1. On-Line Process Identification Methods for PID automatic tuning
2. Advanced Control and Estimation System for Wastewater Treatment Process
3. Multivariate Statistical Process Monitoring
4. Planning/Scheduling, Supply Chain Management

PART I.

Process Identification for automatic tuning of PID controller

Why PID Controllers ?

- Simple and intuitive
- Robustness
- Familiar to operators
- Extrapolation-Disturbance rejection

PID controller

- Proportional-Integral-Derivative (PID) Controllers:

$$u(t) = k_c(y_s(t) - y(t)) + \frac{k_c}{\tau_i}\int_0^t (y_s(t) - y(t))dt + k_c\tau_d \frac{d(y_s(t) - y(t))}{dt}$$

1. Proportional (P) Part : $u_P(t) = k_c(y_s(t) - y(t))$
2. Integral (I) Part : $u_I(t) = \frac{k_c}{\tau_i}\int_0^t (y_s(t) - y(t))dt$
3. Derivative (D) Part : $u_D(t) = k_c\tau_d \frac{d(y_s(t) - y(t))}{dt}$

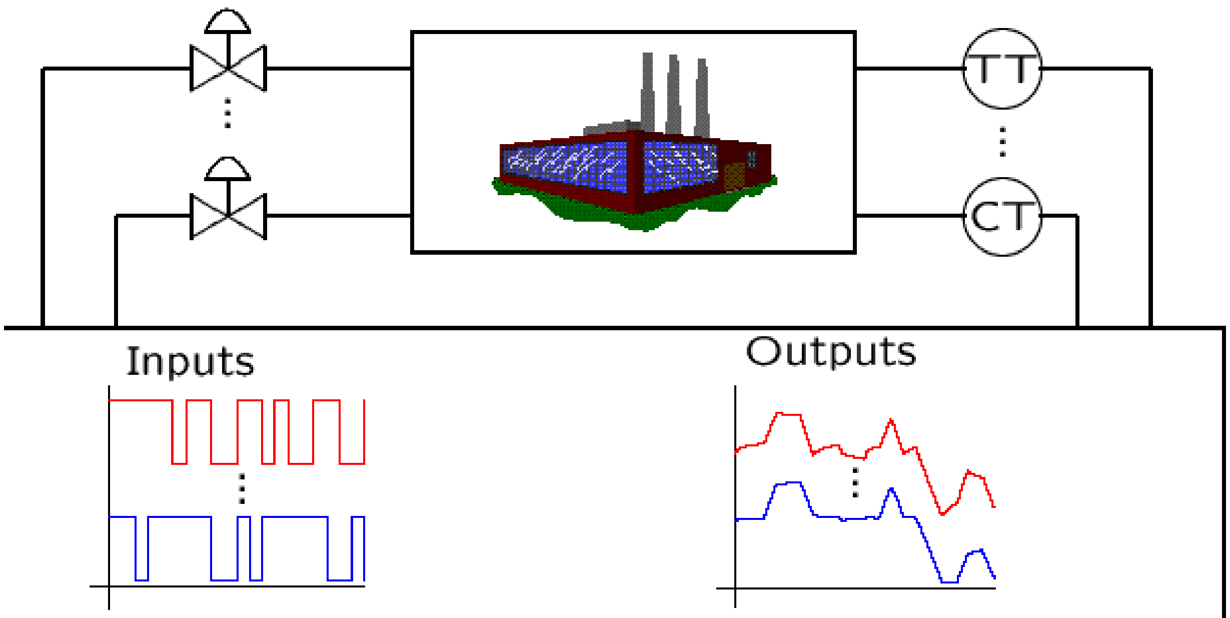
PID Autotuning Method

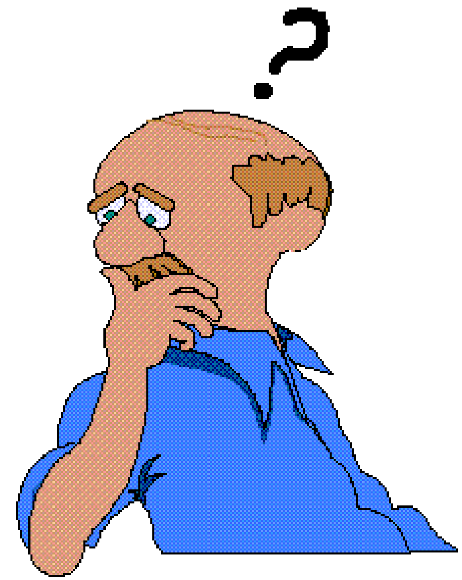
- Automatic tuning (autotuning) of PID controller is determining the PID tuning parameters (k_c, τ_i, τ_d)

- Bad tuning parameters deteriorate the performance of PID controller

- Prior to automatic tuning step, process dynamics should be known

Process Identification



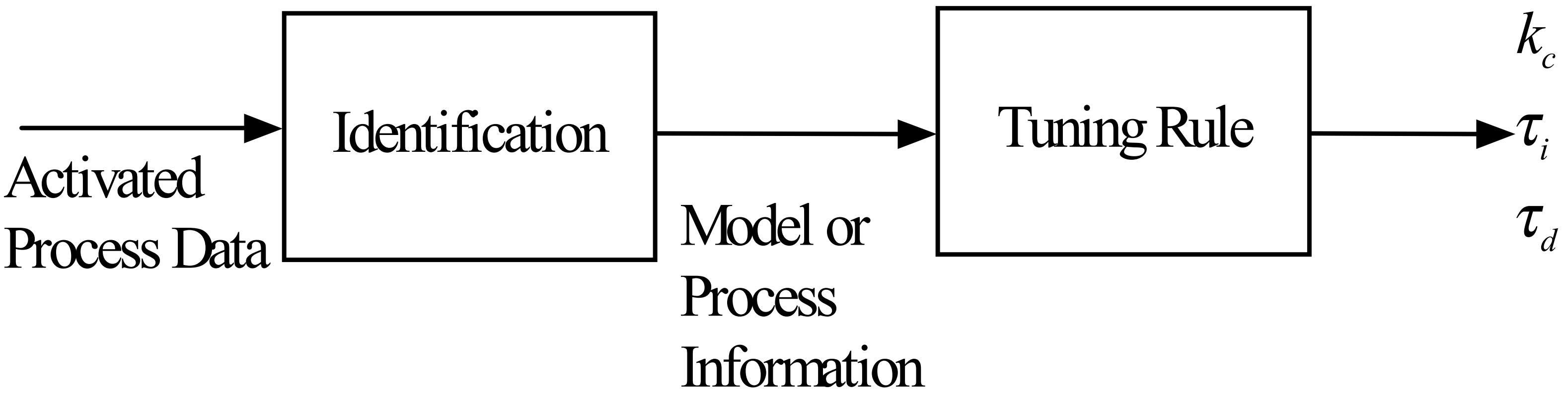


- Building a dynamic model using data obtained from the plant.

Good Identification Method ?

- Accuracy
- Simplicity
- Amount of Information
- Availability
- Robustness to Unexpected Effects

PID tuning procedures



1. **Activate the process**
2. **Make process model (process dynamics)**
3. **Calculate PID parameters using tuning rules**

***Autotuning**: automatic determination of step1-step3*

Examples

- Continuous Cycling Method (ultimate frequency data)
  - ⇒ Z-N tuning method
  - ⇒ PID parameters

- Process Reaction Curve Method (FOPTD model)
  - ⇒ C-C,IMC, ITAE-1, Z-N tuning method
  - ⇒ PID parameters

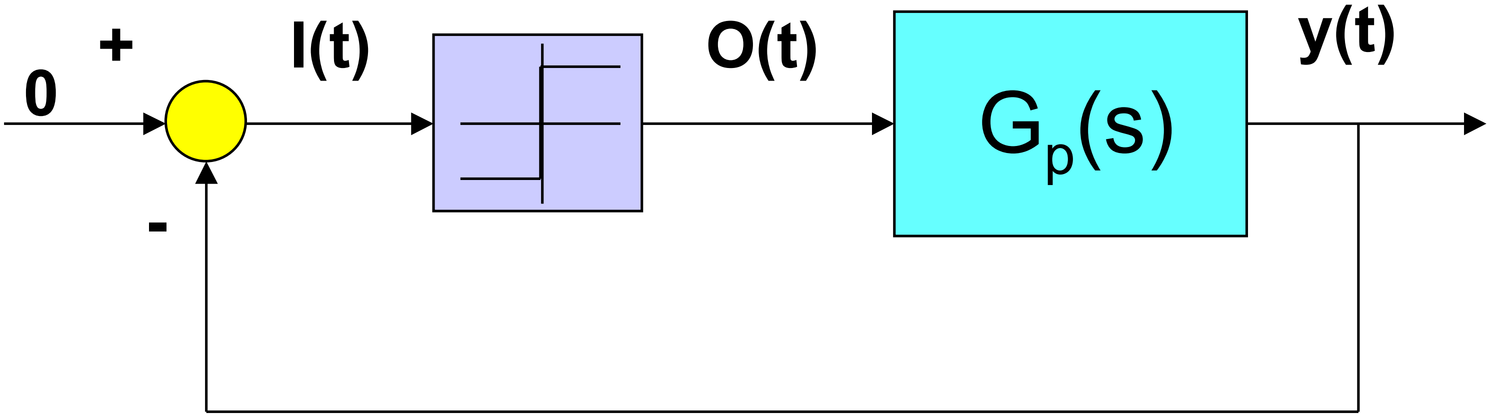
History of Continuous-time Process Identification Methods

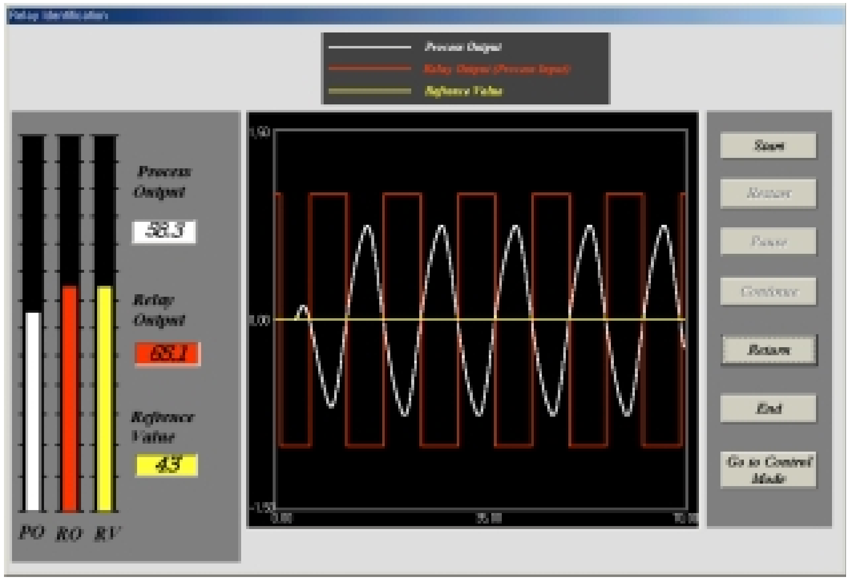
- **Test Signal Generator**
  - **P Controller**
    - FOPTD
    - SOPTD
  - **Relay**
    - Ultimate freq.
    - Better accuracy
    - Zero freq.
    - Disturbance
    - Desired freq.
    - Exact freq.
    - All desired freq.
  - **Arbitrary**
    - IT,EWIT,FWIT
    - FWIT without IP

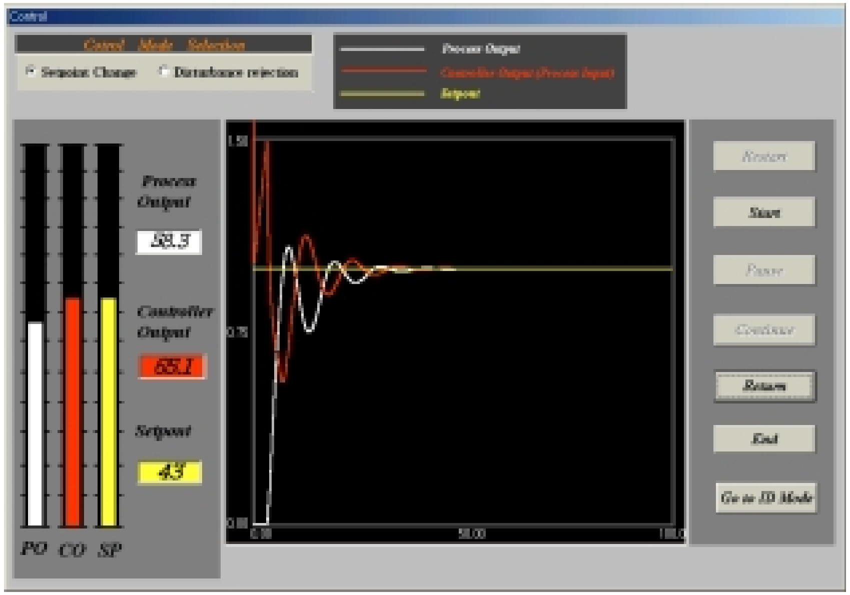
Original Relay Feedback Method

- Åström and Hägglund (1984)
- Ultimate frequency data
- Simple
- No prior information on the process

Block Diagram for Ideal Relay Feedback



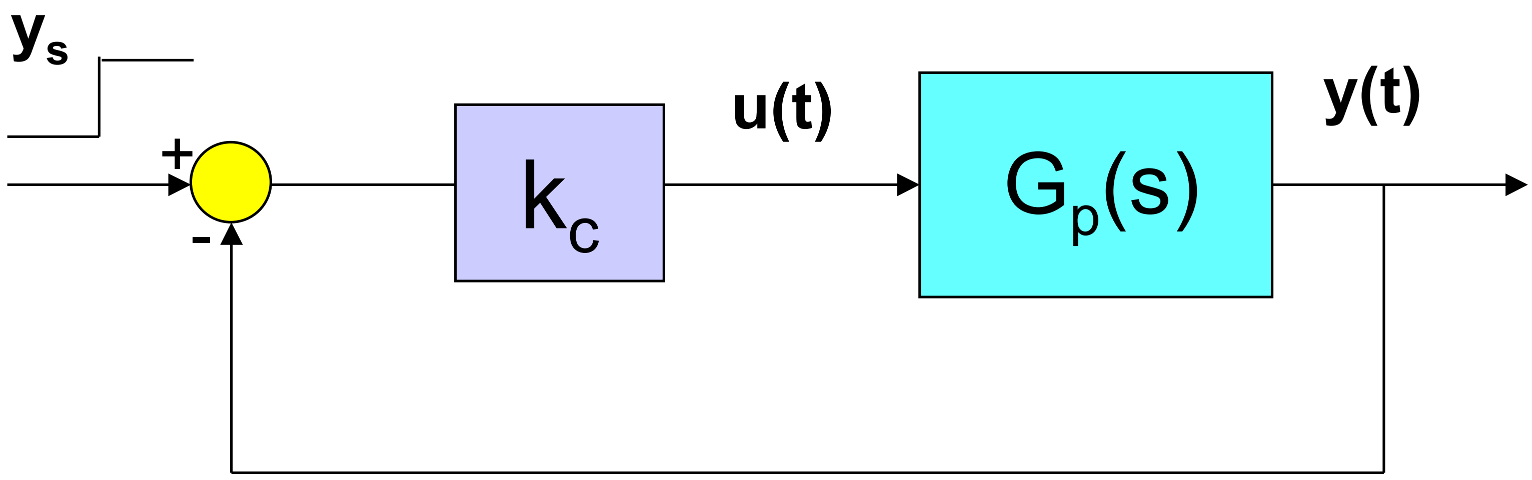

Process Output
Relay Output
Refrence Value
58.3
65.1
43
PO RO RV
Start
Return
End
Go to Control Mode

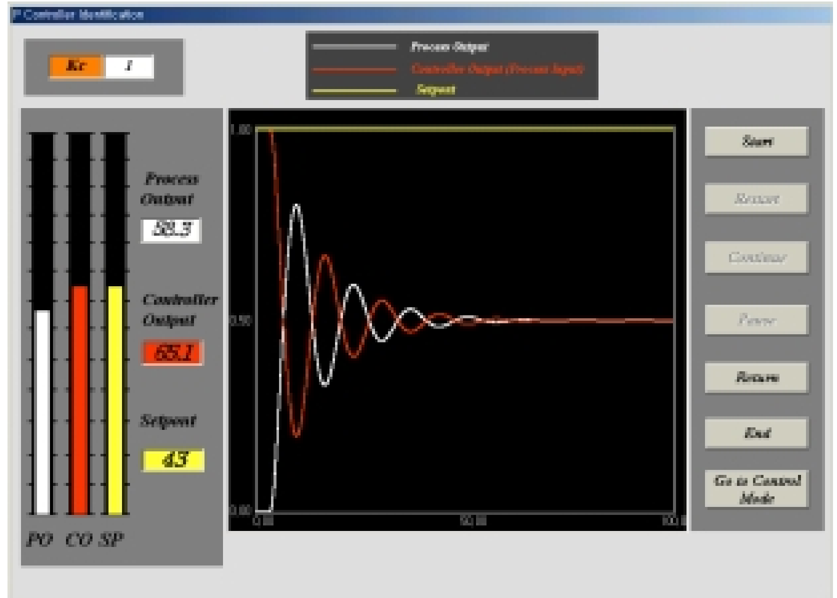

Control
Control Mode Selection
Process Output
Controller Output
Setpoint
58.3
65.1
43
PO CO SP
Start
Return
End
Go to ID Mode

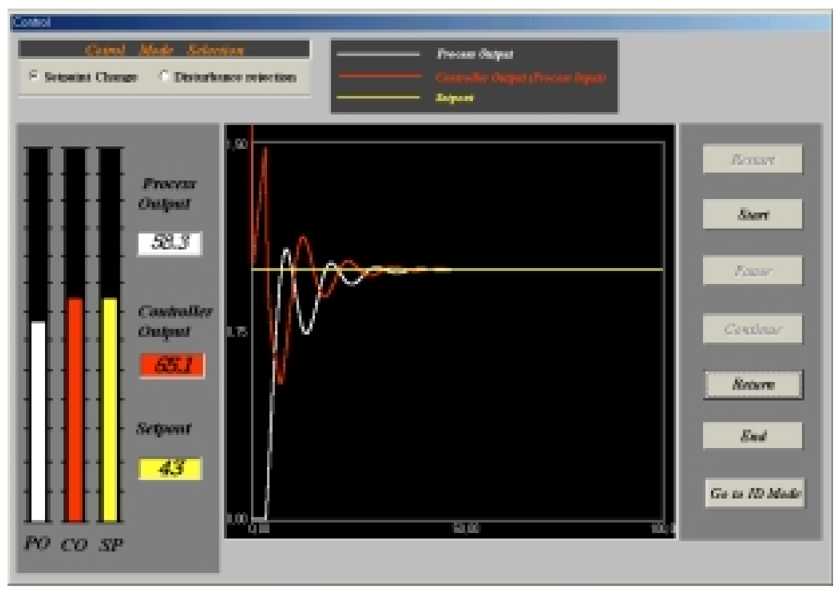
Original P Control Method

- Yuwana and Seborg (1982)
- First order plus time delay model
- Prior information on the process to determine the gain of the P controller

Block Diagram for P Controller




Process Output
58.3
Controller Output
65.1
Setpoint
43
PO CO SP
Start
Return
End
Go to Control Mode


Process Output
58.3
Controller Output
65.1
Setpoint
43
PO CO SP
Start
Return
End
Go to ID Mode

General Approaches for General Linear Time-invariant Model

- Transform the linear **differential** equation model to the **algebraic** equation model (**transformation method**)
- Obtain high-order model parameters using least square method
- Model reduction step for PID tuning rules
- Merits : **Any** test signal generator, **good** accuracy, various **weighting**

Summary

- On-line process identification method for automatic tuning of the PID controller
  - Relay Feedback, P-controller, Transformation methods
- Process identification shows good modeling performance and can be applied almost all processes.
- Autotuning gives good control performances for both the servo problem and regulatory problem.

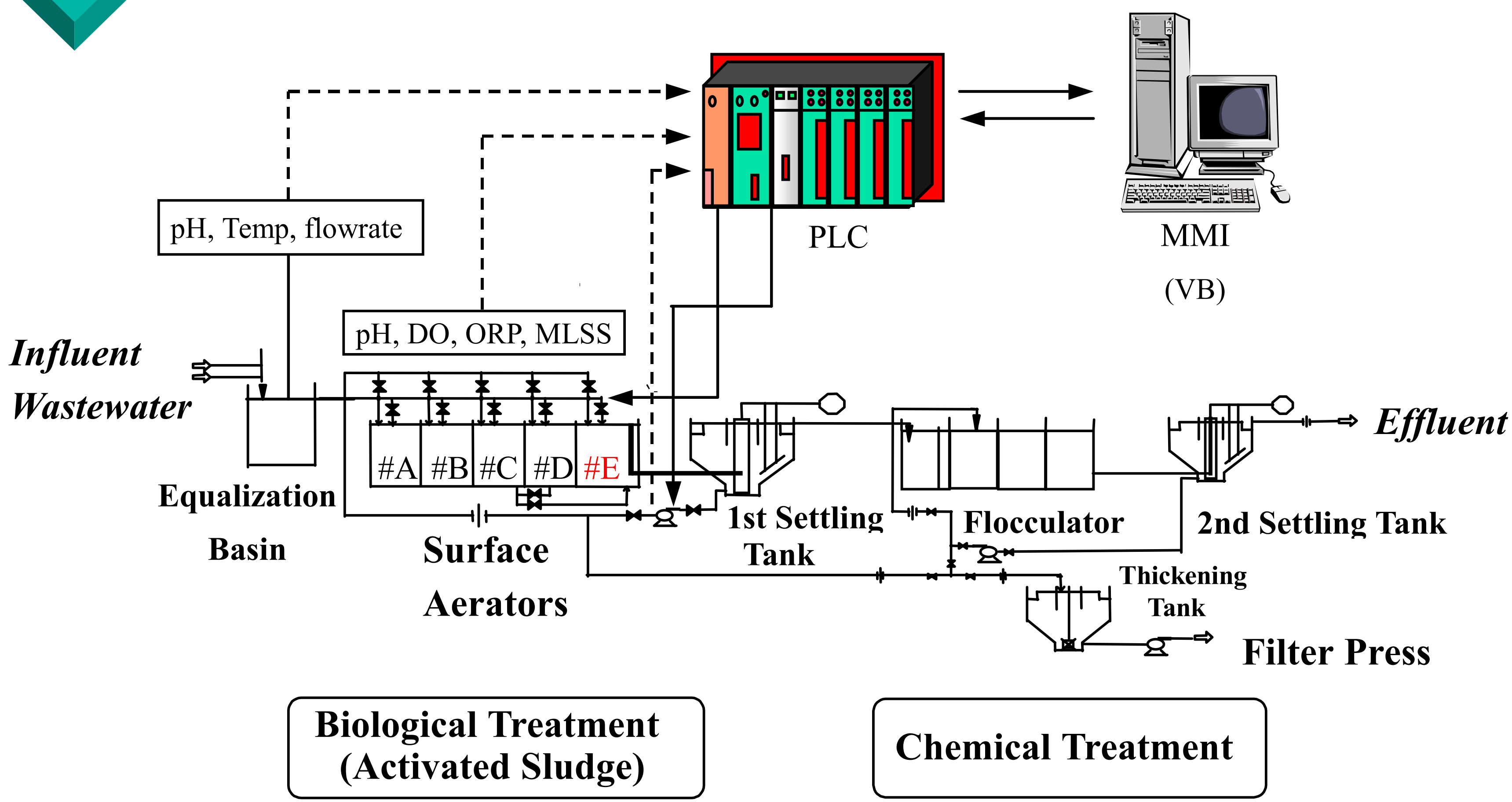
PART II.

Advanced Control and Estimation for Wasterwater Treatment Process

Contents

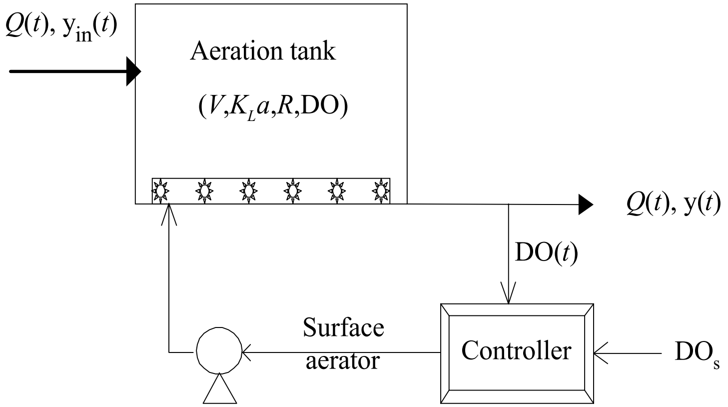
- **Configuration of cokes wastewater treatment plant**
- **Characteristics of dissolved oxygen (DO) control**
- **Simple DO set-point decision algorithm**
- **Experiment results**
- **Face chart monitoring and Decision supporting system**
- **Summary**

Configuration of cokes wastewater treatment plant (POSCO)



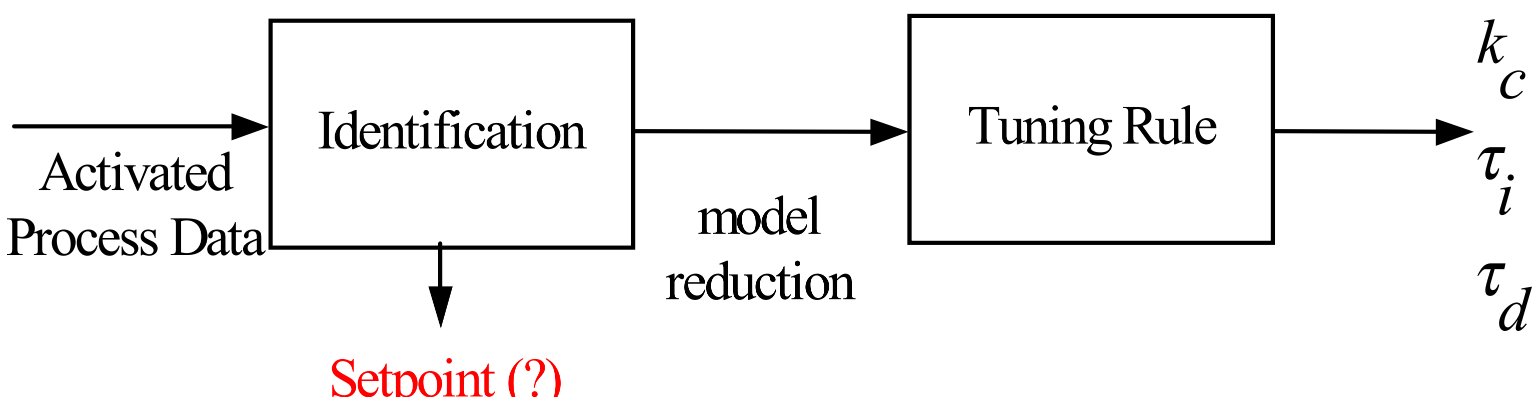
Characteristics of DO control

- DO control in the WWTP has been the most critical factor in the viewpoint of the **operation cost** and **effluent quality**.
- It is difficult to control with **fixed gain PID** controllers
  - Nonlinear, bilinear and time varying disturbance.
- There are motivation of an autotuning method and setpoint decision rule suitable to the **varying operating condition.**



Autotuning method using integral transformation

- Identification using integral transformation (Sung & Lee, 1998).
  - It does not require the specific signal generator.
  - It can use **arbitrary activation signal**.
  - It use **least square** method of high order model estimation.
  - Follow **model reduction step** (FOPTD, SOPTD) for tuning

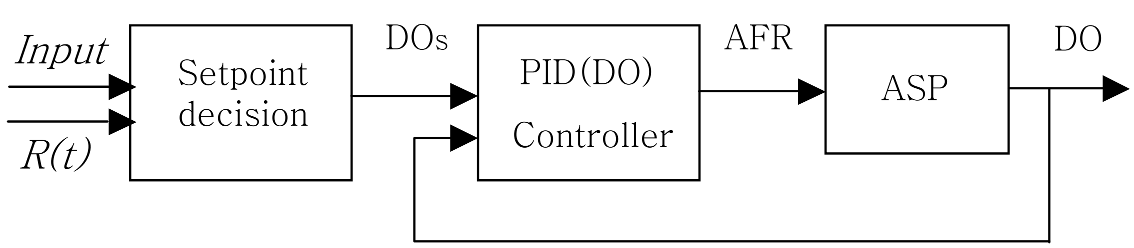


Simple DO set-point decision

- There have been **few guidelines** for the proper DO setpoint decision rule until now.
  - ✓ Respiration rate is the **indicator** of biological operating status
  - ✓ Respiration rate can be estimated simultaneously during auto-tuning using Kalman filter approach.
  - ✓ DO set point is determined in inverse proportion to the respiration rate.

➢ Suggestion : **"the higher respiration rate, the lower DO set point."**

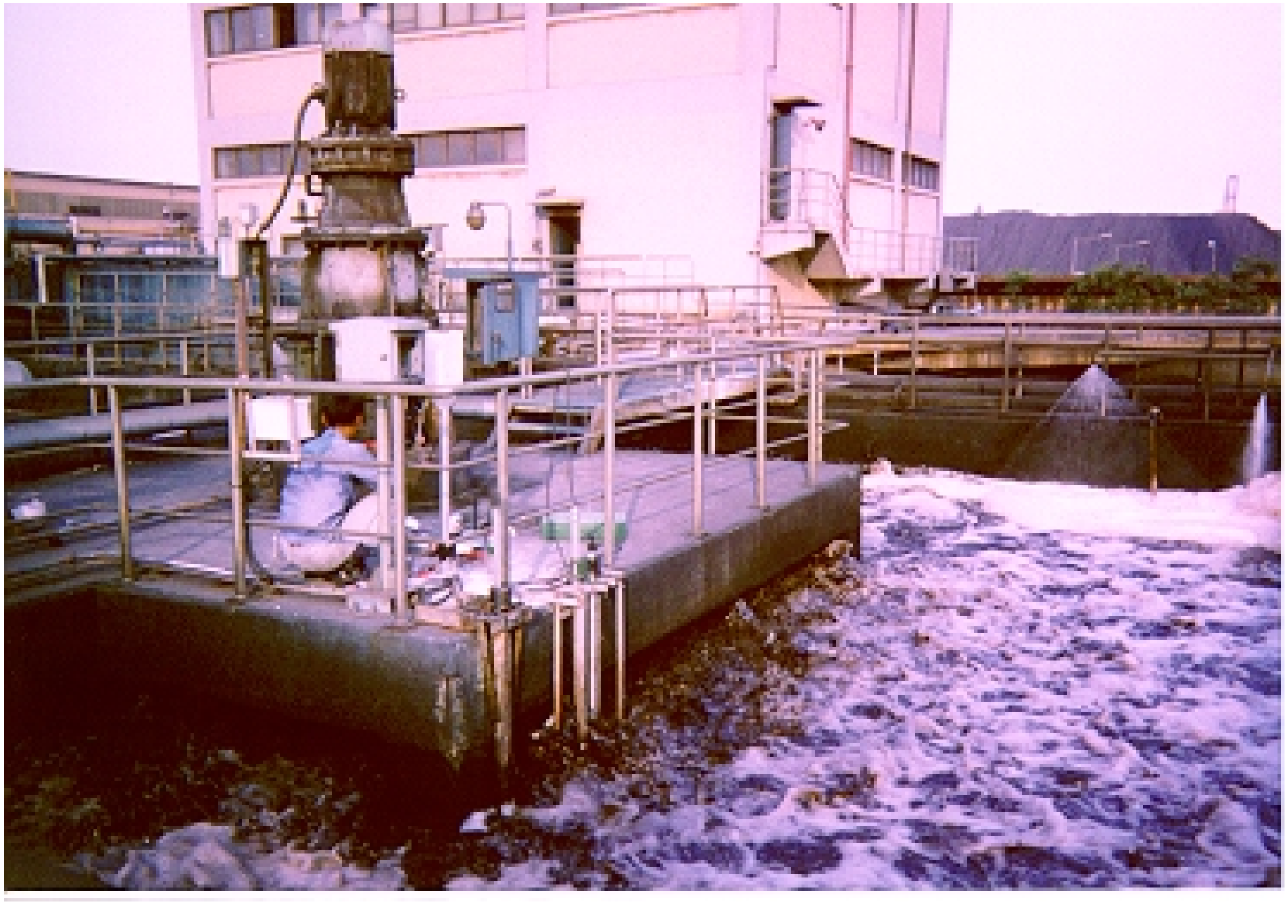
$$DO_s = -a \cdot \hat{R}(t) + b$$



Experimental condition

- We chose the **simple PID setpoint change** as the activation signal **without any mode change**.
  - We increased the DO set point from **1.6** to **2.0** mg/l during one hour for the identification.
  - The tested aeration basin was the final aeration basin which is the most important one.
- PID autotuning method
  - Process output : DO concentration
  - Control input : surface aerator RPM
  - Tuning rules : ITAE disturbance rejection

Aeration Tank-Surface Aerator

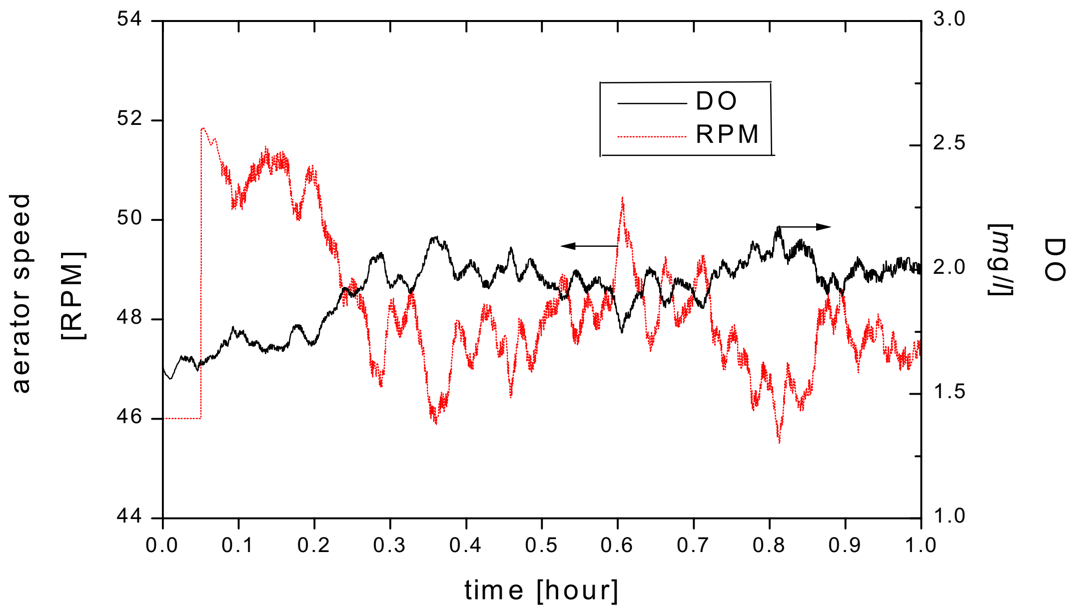


Settling Tank

Manipulated variables

Inverter **Control Valve**

Identification results with the transformation method



$$G_p(s) = \frac{-0.000012\,s^3 + 0.00098\,s^2 - 0.001s + 0.196}{-0.000003\,s^4 + 0.001s^3 - 0.0016\,s^2 + 0.325s + 1}$$

$$G_{F\,OPTD}(s) \cong \frac{0.2e^{-0.19s}}{0.35s + 1}$$

Comparison of step response of real and model

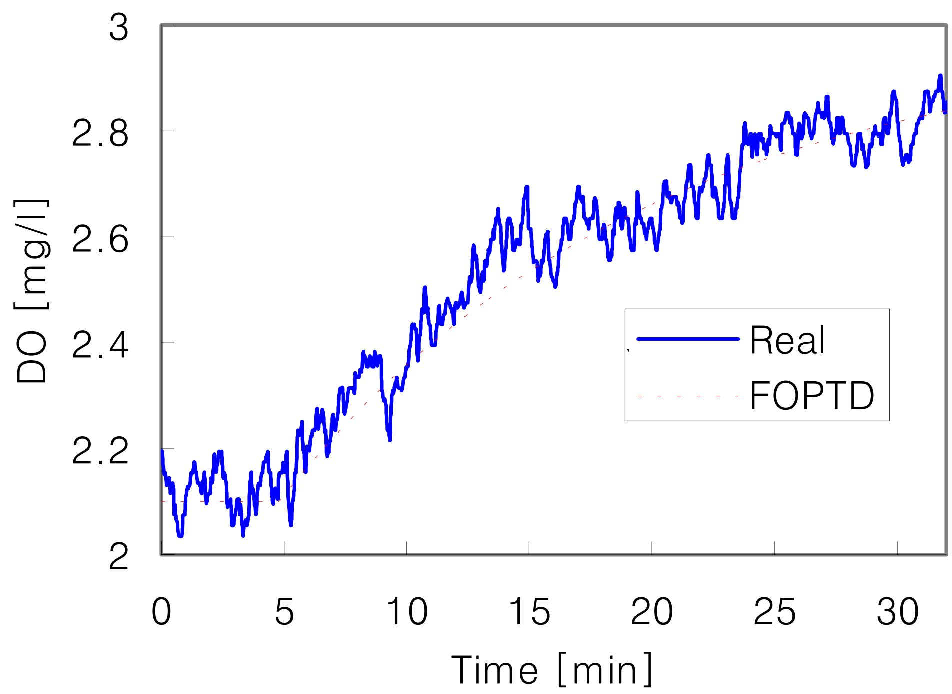
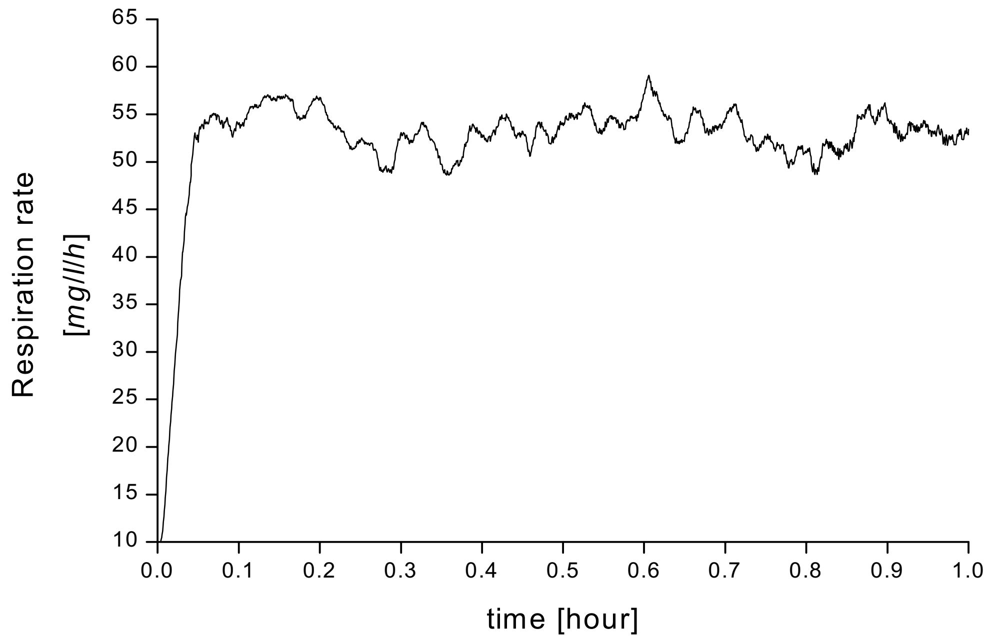


Figure. Step response of real and model using step input.

Respiration rate estimation during the identification phase



$$DO_s = -0.025\,\hat{R}(t) + 2.75$$

$$\hat{R}(t) = 54\,mg/l/h$$

$$DO_s = 1.4\,mg/l$$

Figure. The estimated respiration rate and DO setpoint decision rule during the identification phase.

Experimental results of autotuning and setpoint decision rule

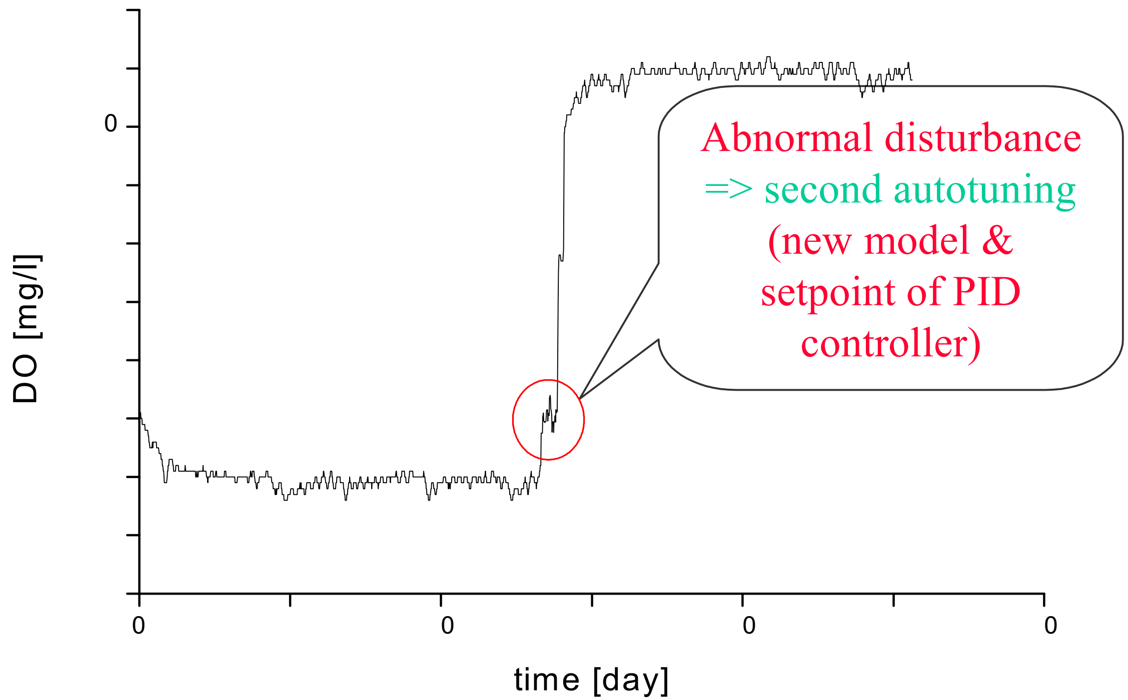
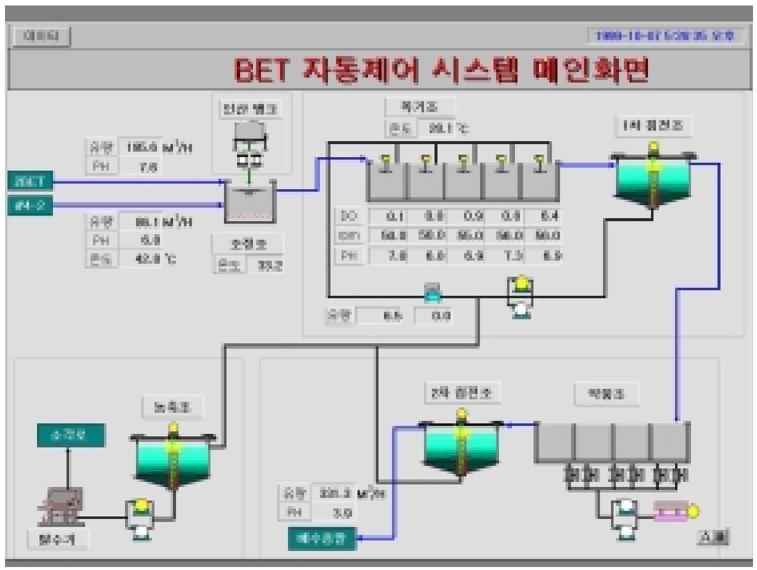
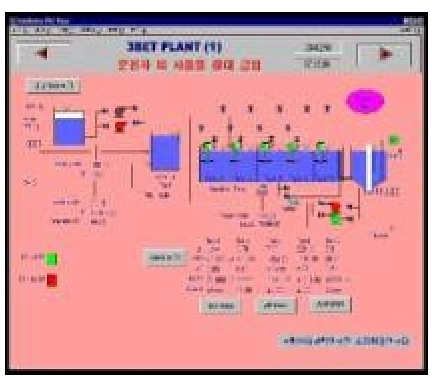
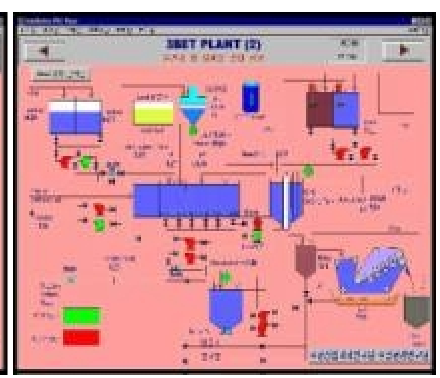


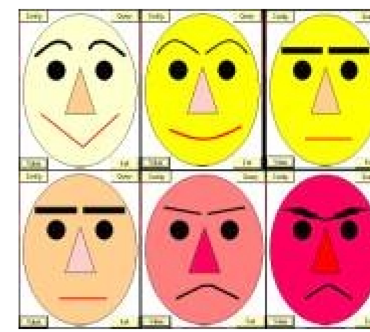
Figure. DO control results using the autotuning and setpoint decision rule during 26 days.

Face chart monitoring method

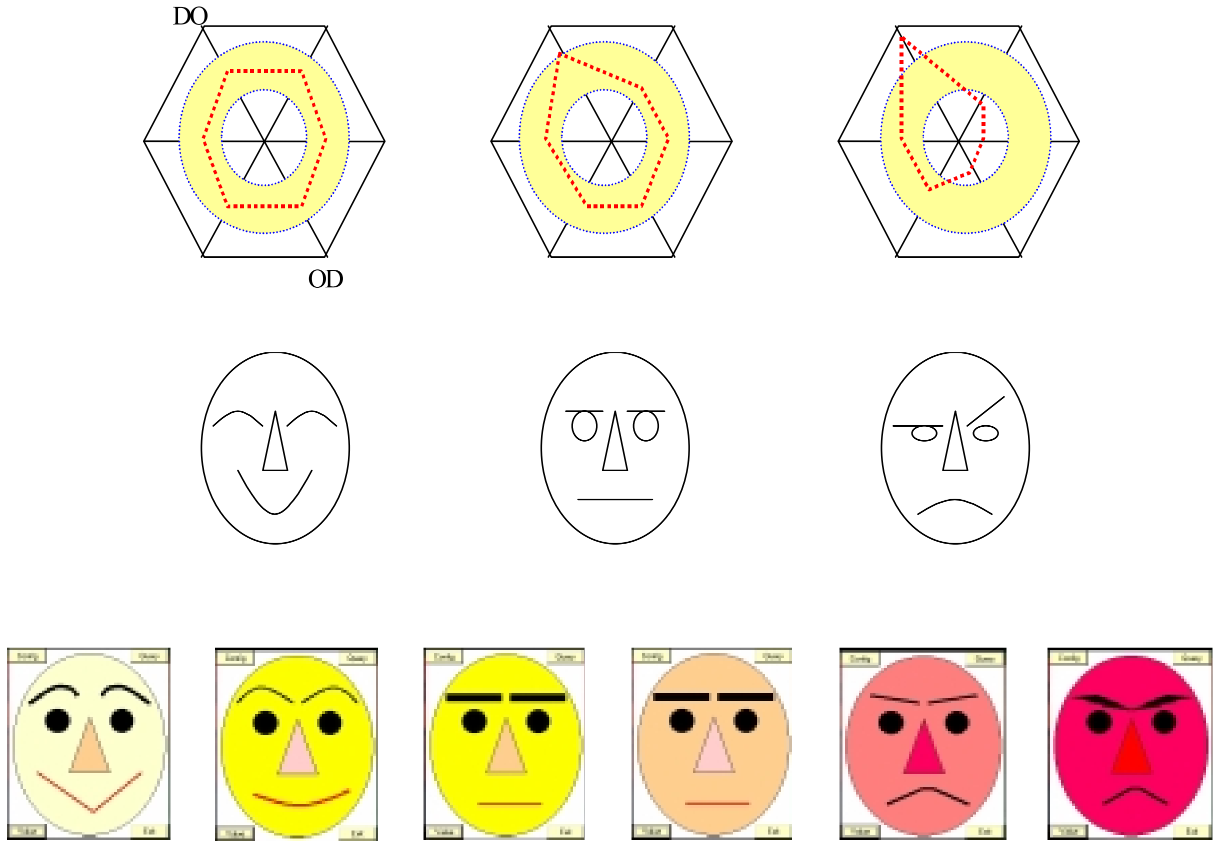




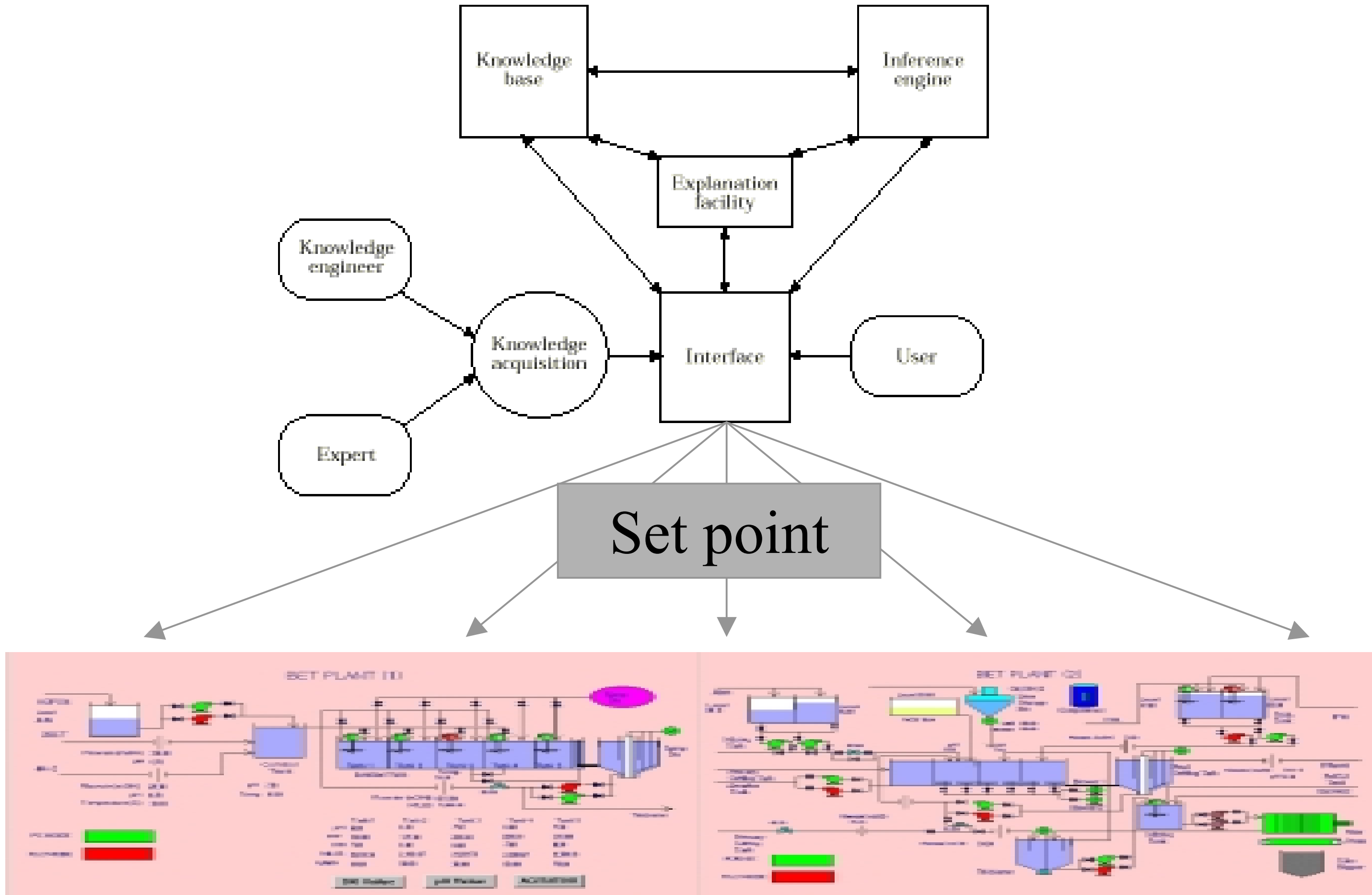




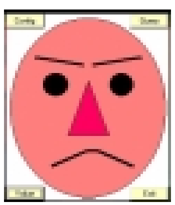
Face chart : Data conceptualize

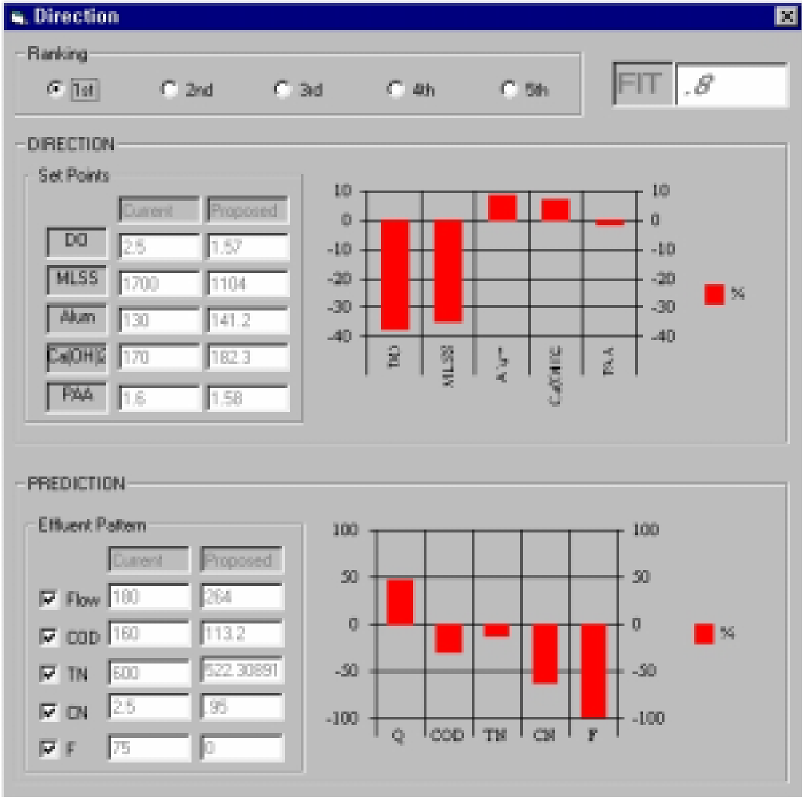


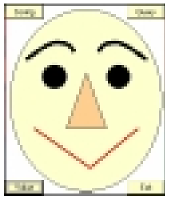
Decision Supporting System



Decision Support Direction







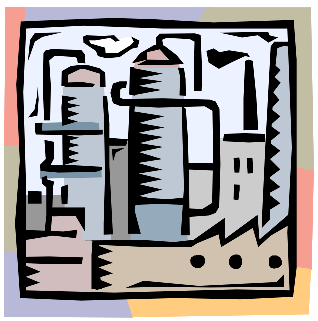
Summary

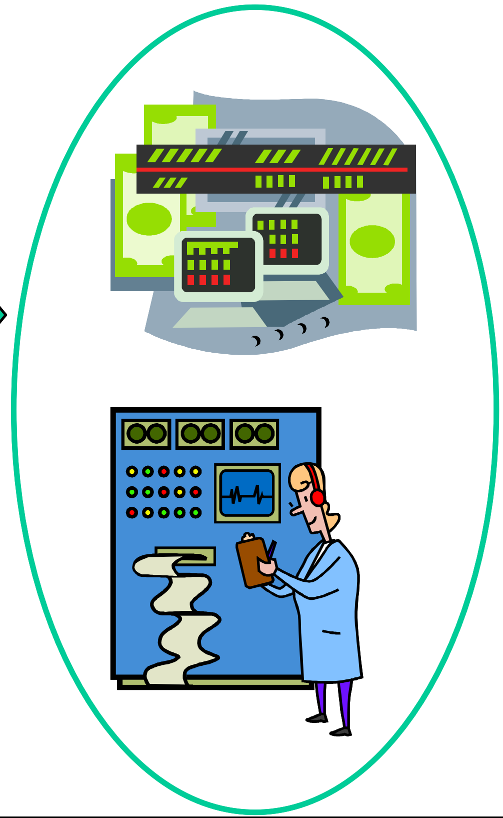
- Implementation of PID autotuning, advanced control and estimation system
- We achieved the **overall improvement of effluent quality**
- We have reduced **10 %** of **the electric power cost**.
- Integrated management system of control, supervisory control and decision support system

PART III.

Multivariate Statistical Process Mo itori a ata a al sis

Process Monitoring



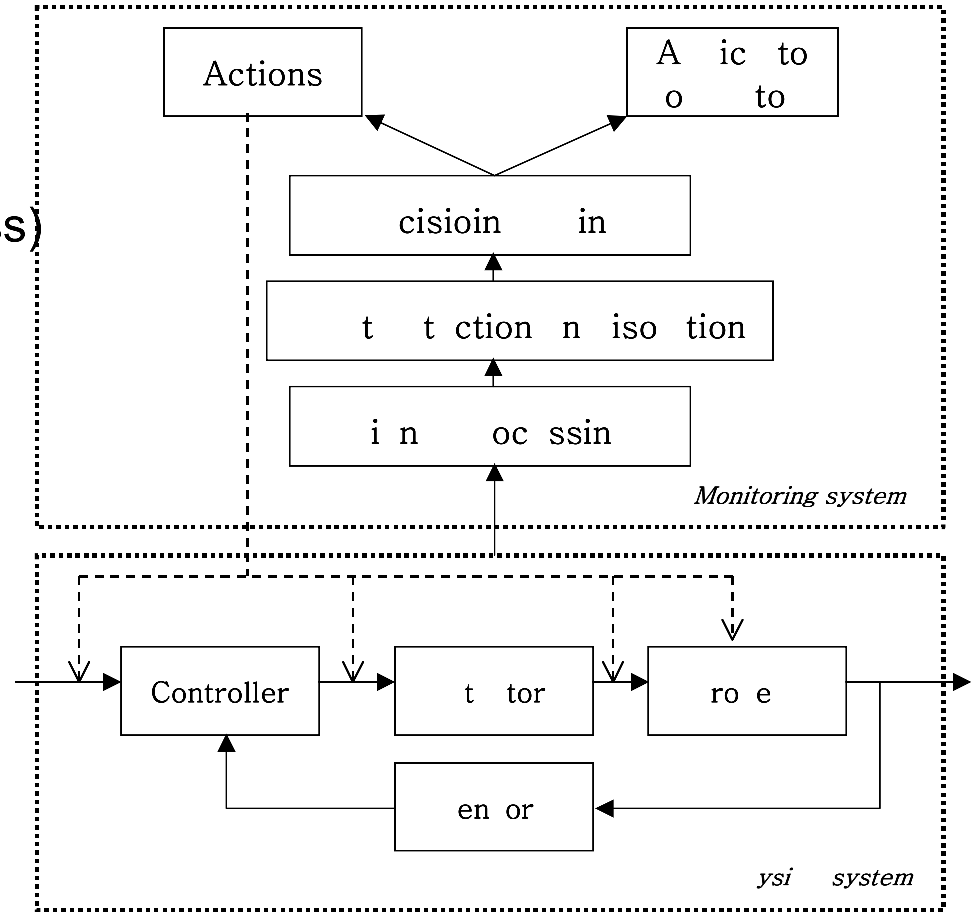


n en ineer has a chance t st the r em ef re it r ws int a f ma a

Effective maintenance starts with an ear etecti n f eve in r ems

Monitoring system

- Monitoring Objects
  -
  - (Actuator, Sensor,Process)
    etect on
    so at on
    a nos s
- Monitoring Methods
  - Stat st ca et o
    P A, P S)
  - Art c a nte ence
    , u , A)
  - ata ana s s
    c uster n an c ass cat on)



Conventional Monitoring

- Univariate process monitoring
  - Looking at one variable at a time (OVAT)
  - Realized by calculating univariate control charts for a few quality related key variables
    - Ex. Shewart chart, CUSUM chart, EWMA chart
- Limits of conventional monitoring
  - Dimensional overload
    → Too many observed variables
  - Data redundancy (collinearity)
    → False monitoring conclusions !!

A comparison of univariate and multivariate monitoring techniques

Univariate process monitoring	Multivariate process monitoring
A traditional way of monitoring	More recently introduced and implemented
Simple but often **misleading interpretations**	Almost as simple
	The higher the number of variables, the bigger can be the advantage over the univariate approach
Both the monitoring and the visualization are the more difficult to conduct	Both the tasks are easy to perform even for tens of variables
Many variables results in as many control charts	
Assume that variable are free of errors. In addition, **noise is not always considered**.	Systematic intercorrelation structures are used to model systematic variations and to **remove both the noise and the errors**
Small simultaneous change in several variables are not necessarily observed	**Incresed sensitivity**. Even small but yet important changes can be visualized.

Multivariate Statistical Process Monitoring (MSPM)

- Two main categories of fault detection and diagnosis (FDD)
  – Model-based method: mathematical representation of the process
  – Model-free method: simple limit checking of plant measurements, etc.
- Extension of univariate monitoring techniques
  – Consider the interactions between variables
  – Extract the necessary information about the behavior of the process among many variables

Summary of MSPM

1) Multivariate data

Focusing on certain scales while removing others, *e.g.*, drift correction
• MRA-PLS (Publication VII)

2) Projection of the data onto Multivariate PLS model

Focusing on certain scales by scrutinizing latent variable models
• PLS-MRA (Publication VI)

3) Visualization of and learning from the data
• biplots
• multivariate control charts

Fuzzy and possibilistic clustering, *i.e.*, at the same time an object can belong to different classes. (Publication V)

4) Detection of the problem
• multivariate control charts

5) Isolation of the problem
• biplots
• multivariate control charts

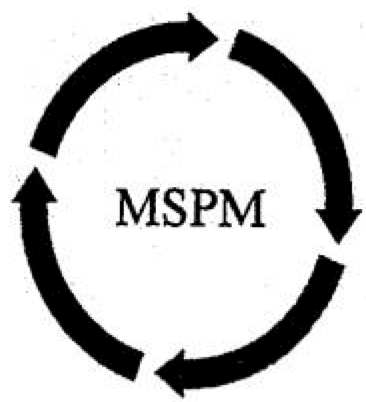
6) Identification of the variables
• variable contributions

Identifying and visualization of variables
• contribution maps (Publication II)

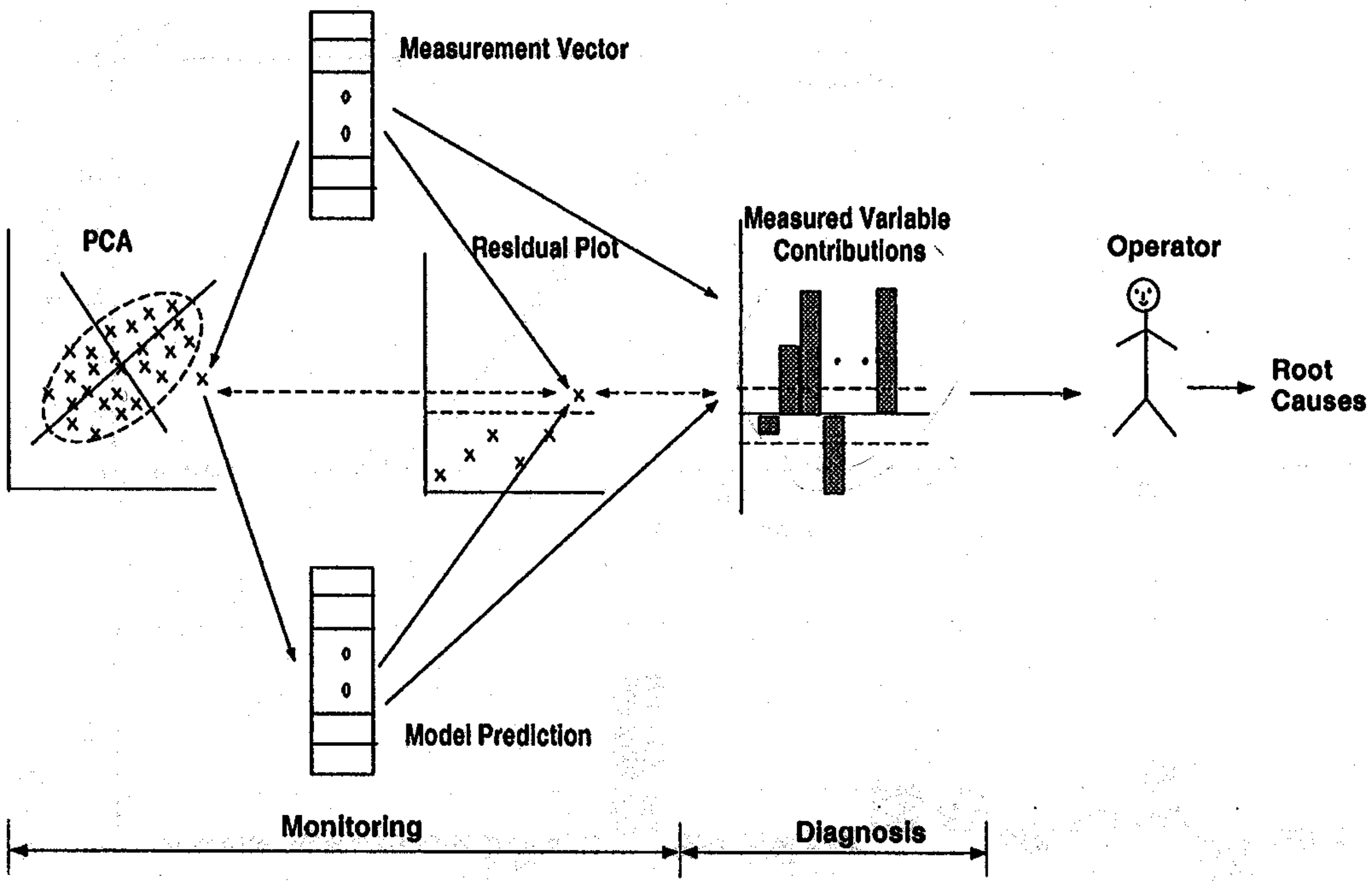
7) Visualization of the variables
• trends

Visualization of the variables
• parallel coordinates (Publication II)

8) Confirmation of the conclusions
• checking the original data

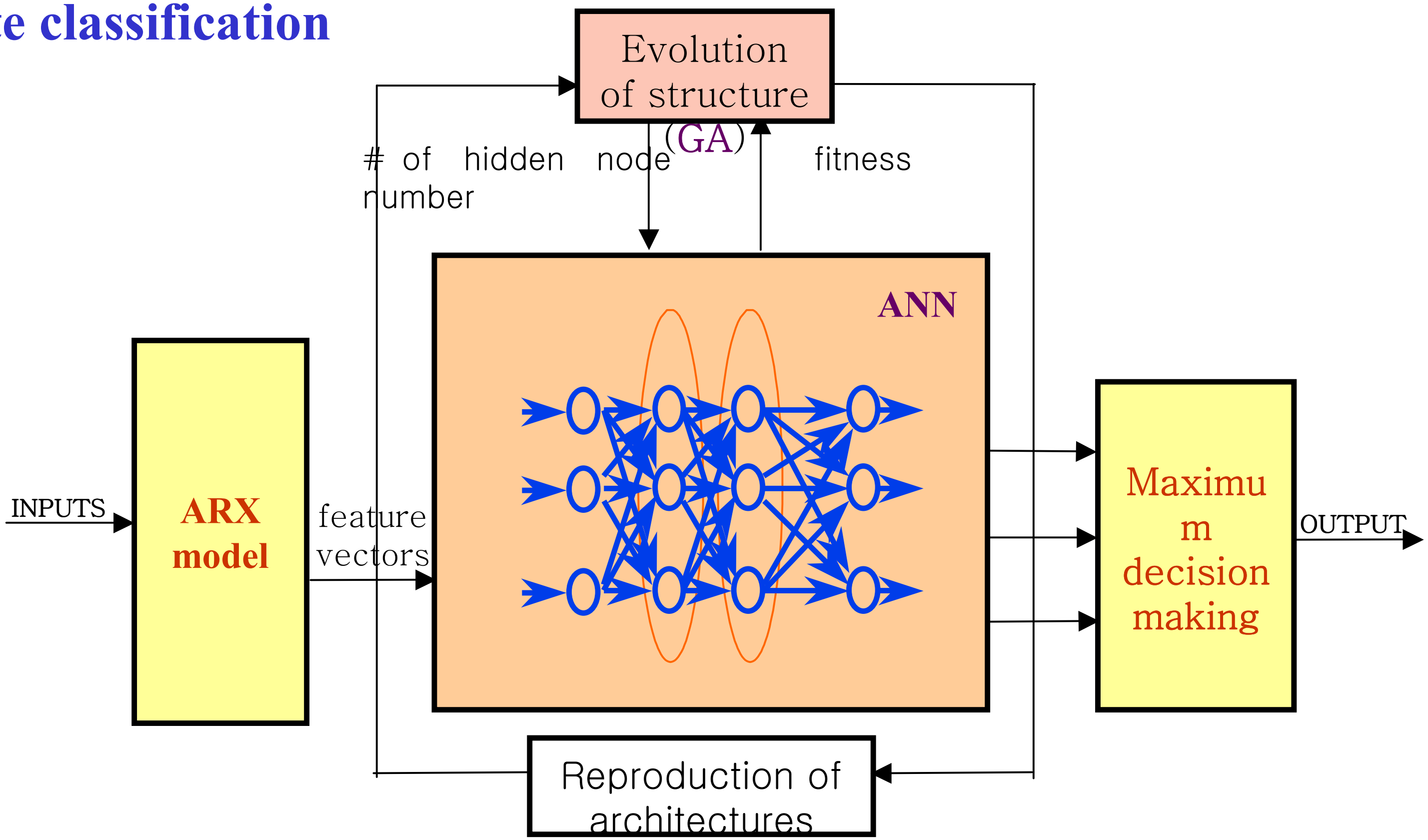


Application1:Multivariate Process Monitoring using PCA



Application2: Air Pollution Monitoring using Artificial Neural Networks(1)

•**Prediction** of conc. of **SO_x** using amount of **COG, BFG, LDG, Oil** and **State classification**



Application2: Air Pollution Monitoring using Artificial Neural Networks(2)

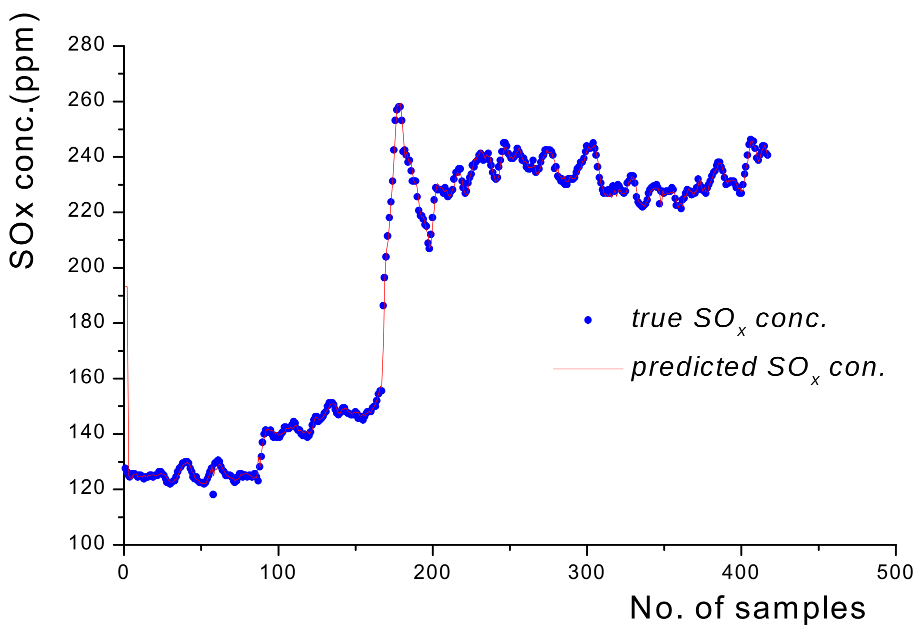
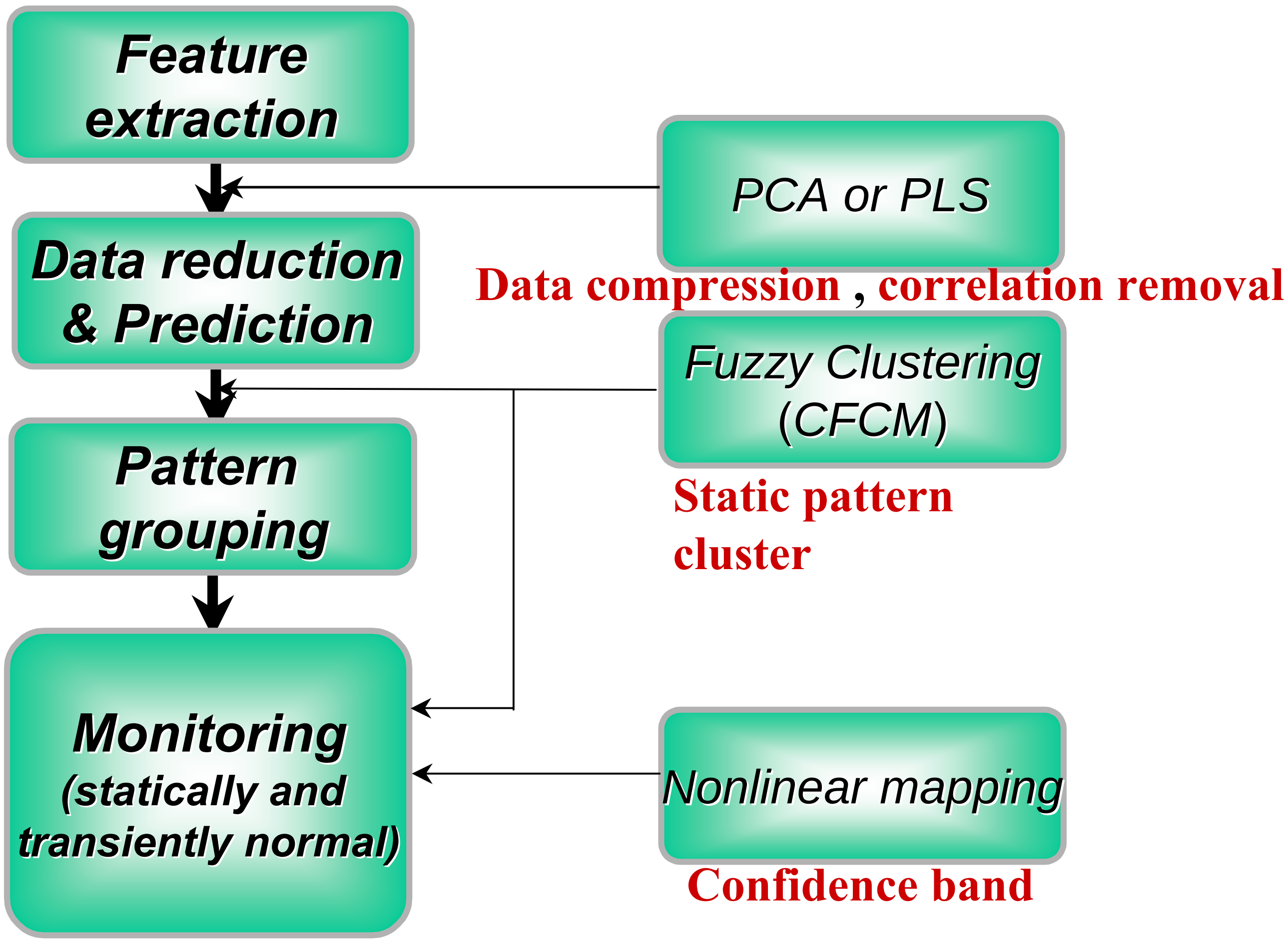


Figure. SOx prediction

		Predicted		
		Low	Transient	High
True	Low	155	0	9
	Transient	3	9	11
	High	5	0	226

Table. Confusion matrix of test data set

Application3: Air Pollution Monitoring using Partial Least Squares(PLS) and Clustering (1)



Application3: Air Pollution Monitoring using Partial Least Squares(PLS) and Clustering (2)

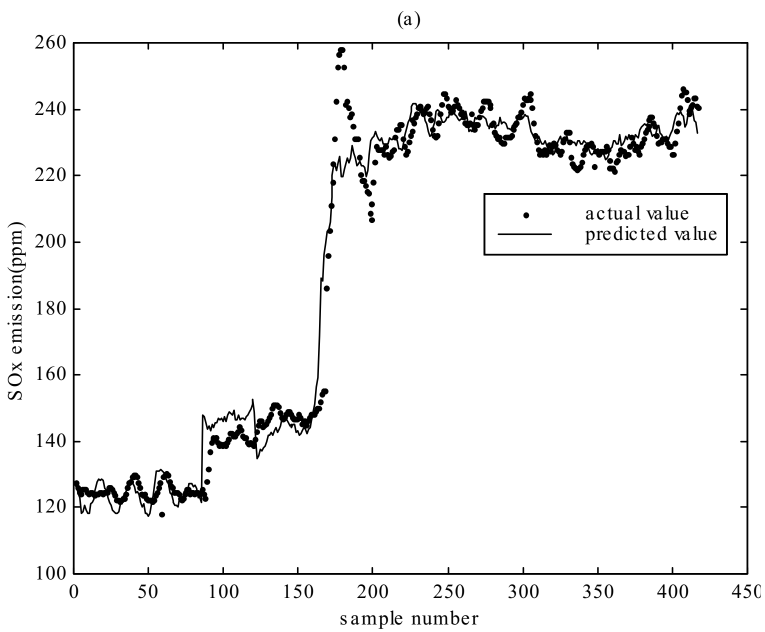


Figure. Real and prediction values of $\mathbf{SO_x}$ emission using PLS

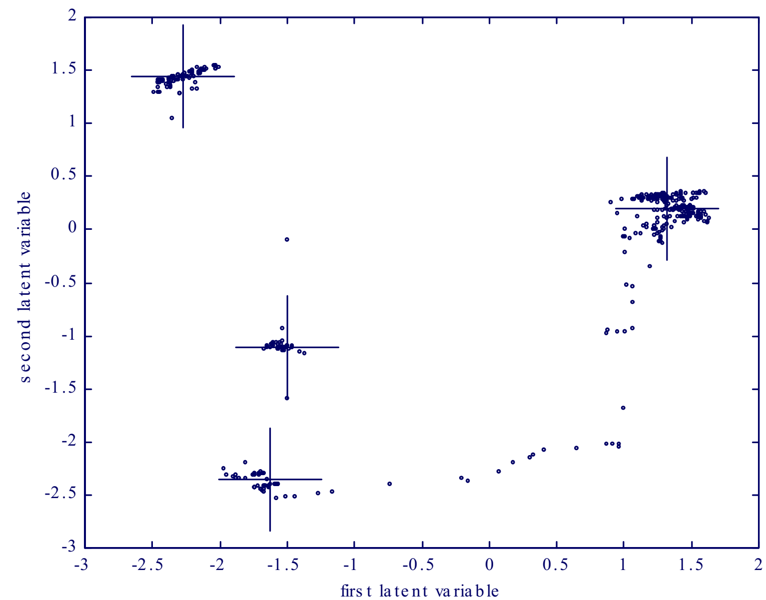
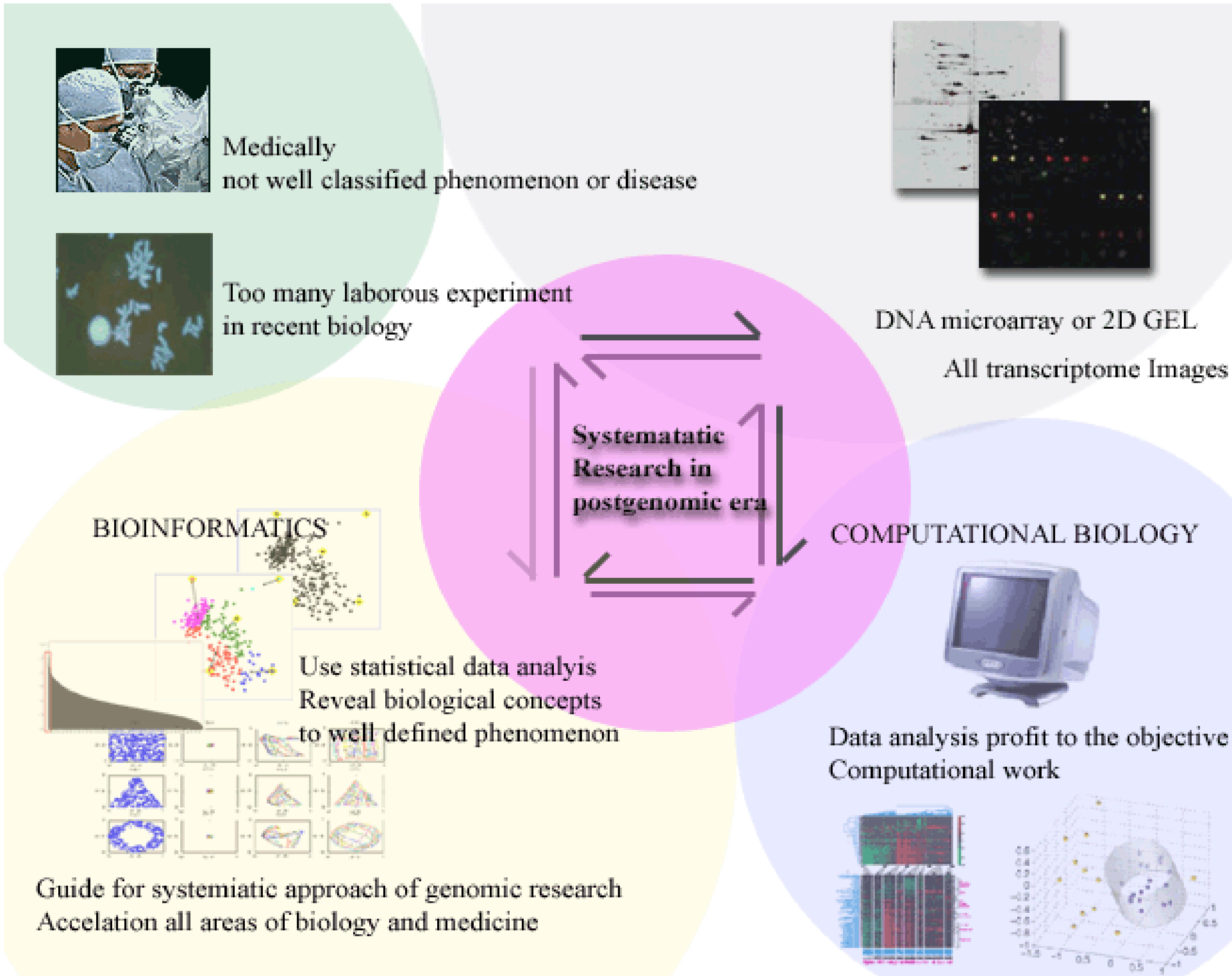
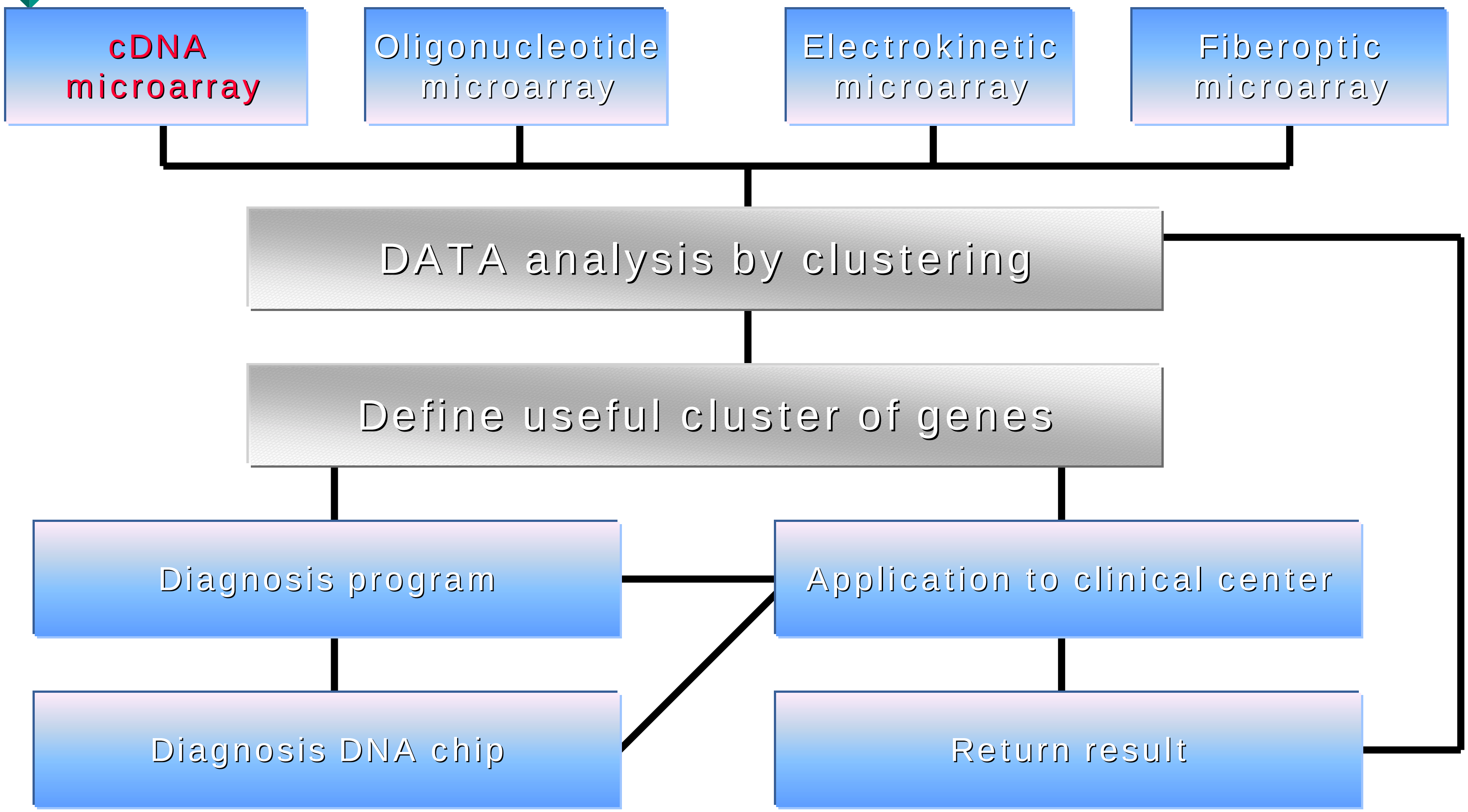


Figure. Clustering results (4 patterns +: cluster prototype)

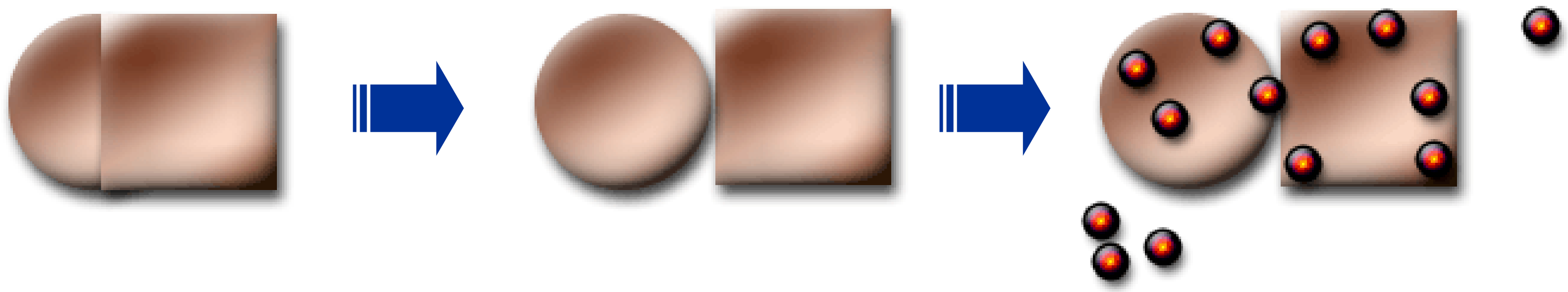
Application4 : Bioinformatics (1)



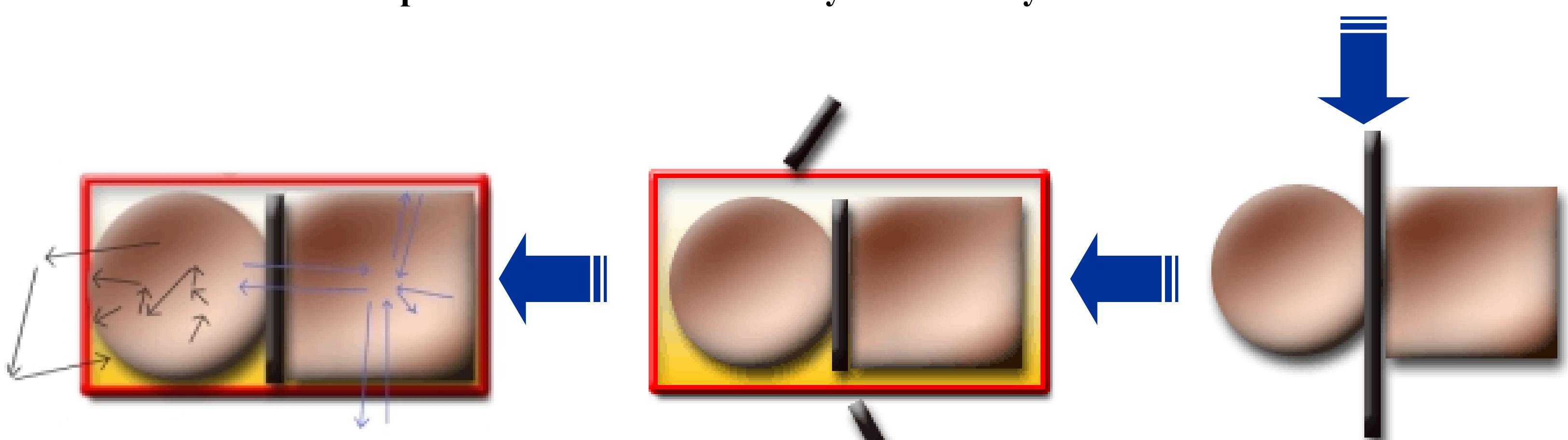
Application4 : Bioinformatics (2)



Application4:Bioinformatics (3)



Not well defined aspects | DNA microarray&Data analysis | Model test and outlier detect



Metabolic network analysis
Genetic network analysis

Useful genes selection
Construction biological axis

Useful gene selection
Construction statistical axis

Summary

- Constructing the monitoring systems based on multivariate techniques can gives us
  - more reliable monitoring
  - faster detection of process malfunction
  - more exact root cause finding
  - possibility of early remedy for anomaly
- New process monitoring using multivariate statistical techniques, artificial intelligence (neural network), and various data analysis.
- New application: bioinformatics

PART IV.

Planning/Scheduling, Supply Chain Management

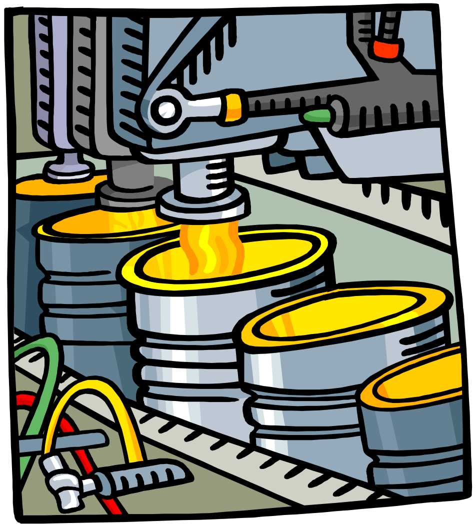
System Integration

Supply-Chain Management

Planning/Scheduling

Advanced Process Control

Planning/Scheduling



- Scheduling/Planning
  - the **process** of **organizing, choosing, and timing resource usage** to carry out all the activities in order to maximize profit or to minimize cost
  - necessary to produce
    - **the desired outputs**
    - **at the desired times**
  - while satisfying a large number of time and relationship constraints among the activities and the resources

Manual Works

- Difficulty in analyzing economic factors
- Needs of long time load of specified small manpower
- Difficulty in rapid change of the plan
- Obstacles of enterprise computerization due to non-standardized tasks and results
- Weakness of importance of planning task

Planning by Computerization

- **Objective**
  - Maximization of profit of minimization of cost
    - Cost of raw material, operation, inventory, safety stock or transportation etc.
- **Constraints**
  - Balance of inventory
  - Balance of production and distribution
  - Constraints in production planning

Solution of Automated Production Planning

- Heuristic methods
  - Finds good solution in short time
  - But, not complete rule
- Mathematical approach
  - Proper formulation gives optimum solution
- Approach though random search
  - SA / GA / EP

Real Plant Applications

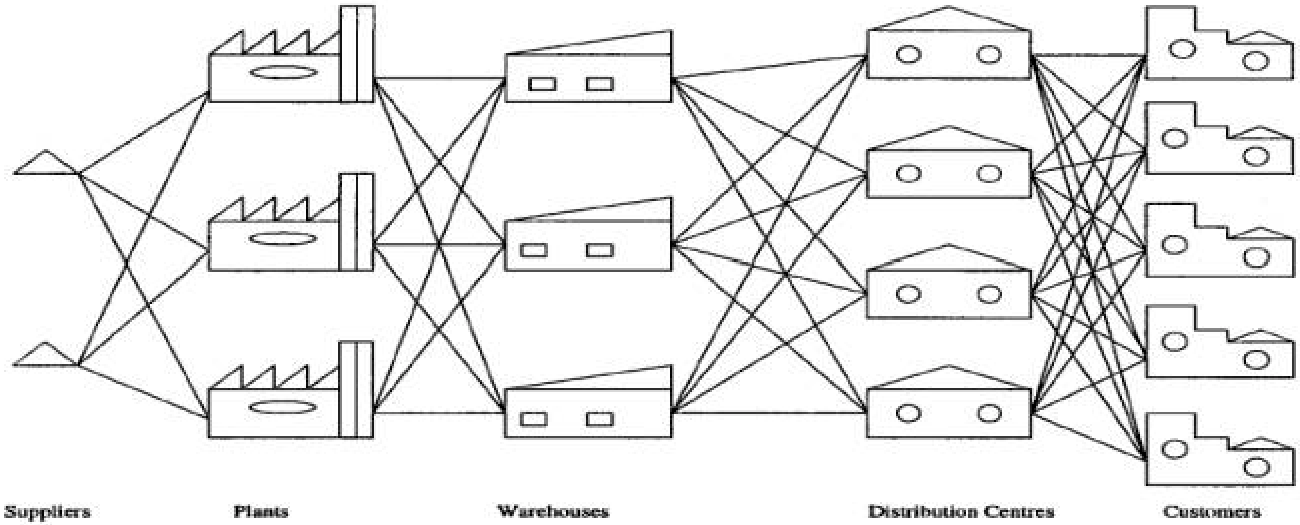
Problems		Characteristics
Refinery crude	Purchase	Ship scheduling, Property driven blending
	Feeding	Property driven blending, Block operation
	Blending	Property driven blending, Batch operation
Naphtha	Purchase	Ship scheduling, Property driven blending
	Cracker	Nonlinear yield, Block operation
Polymer process		Block operation, Sequence dependent costs

Expected Effect of Scheduling/Planning

- Example of the plant of synthetic resin
  - Increase of expected profit by 5%
  - Increase of profit by 1% compared to sale

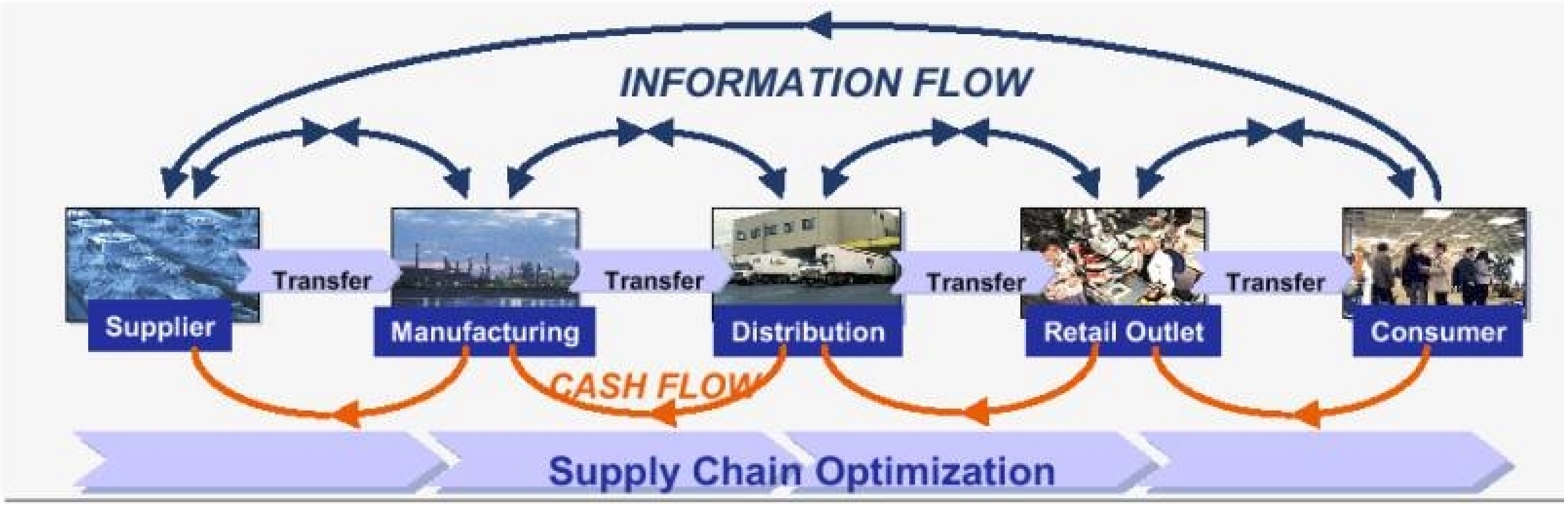
Supply Chain

- An interconnected set of linkages among suppliers of materials and services that spans the transformation processes that convert ideas and raw materials into finished goods and services for a firm's customers.

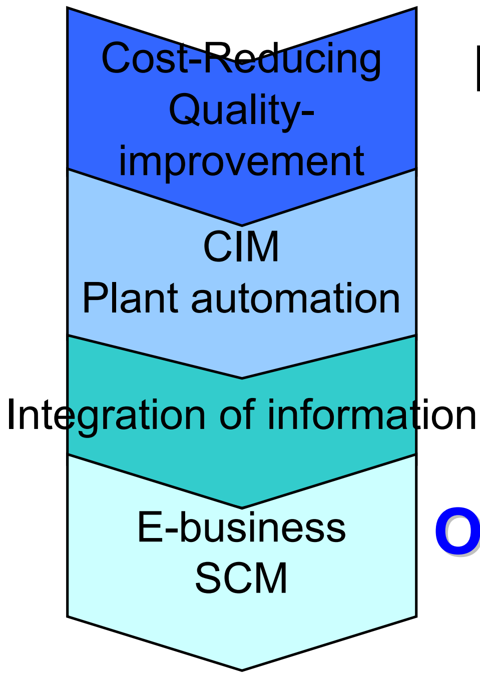


Supply Chain Management

- Integration and interconnection of values corresponding to all the finished goods and services
- Management paradigm which understands and analyzes as entire system



Supply-Chain Management



Efficiency and rationality of processes

Optimization of all related supply chain

Purchase, production, distribution of material

Motivation of SCM

- 60~70% of added value is made out side of manufacturing
- Supplier's uncertainty
  - Excess inventory for protection of fluctuation of lead time, quality
- Customer's uncertainty
  - information distortion
- Globalization
  - Local situation, difference
- "Inventory Push" -> "Customer Pull"
- Informationization of Process, Development of EDI

Importance of Supply Chain

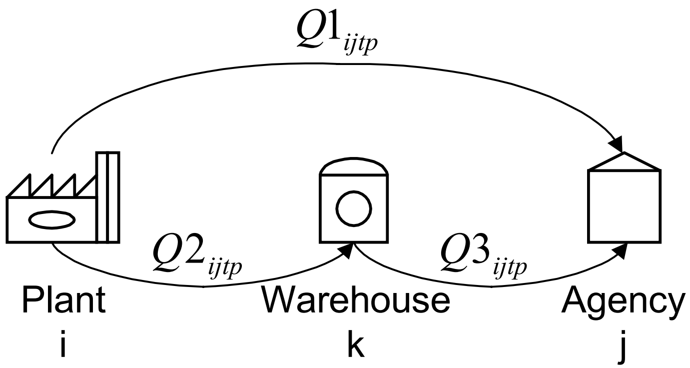
- SCM is related with raw material/intermediates from enterprise planning, manufacturing, to delivery as a whole process
- Industries of manufacturing, distribution, logistics have similar Supply Chain
- Therefore, management of appropriate Supply Chain is an important factor of business

Effect of SCM

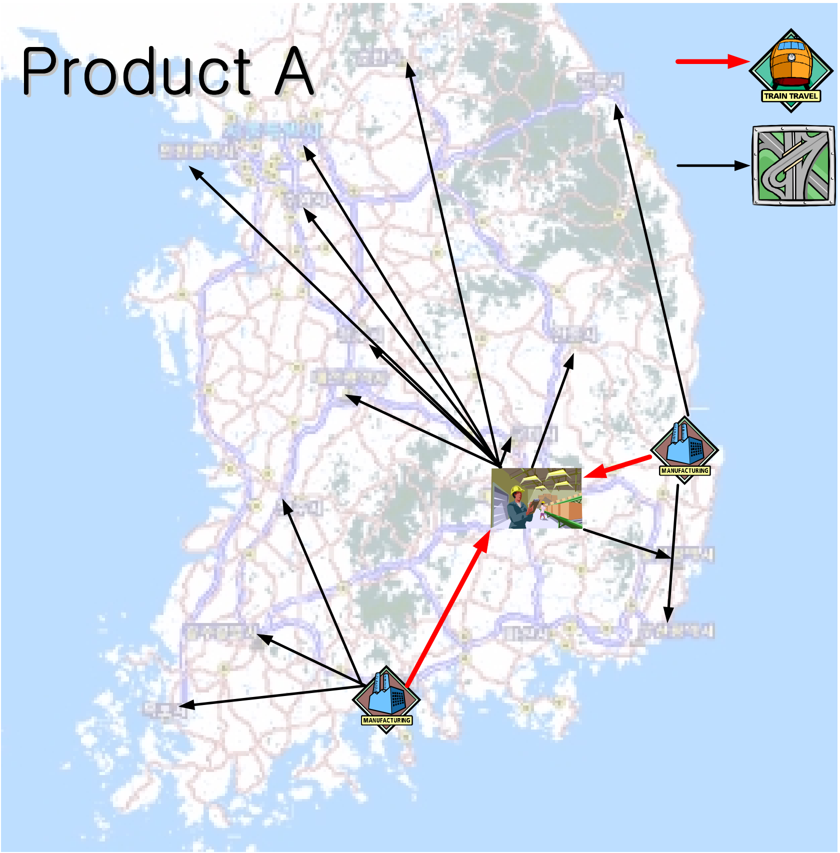
- Operating of integrated information systems
- Reducing logistics costs
  - Cost of inventory, transportation and handling
  - Accommodation of customer satisfaction, market place, shortage, delivery, lead Time
- Reducing purchasing costs
- Enhancement of efficiency of manufacturing
  - Reasonability of production plan by cleansing of uncertainty of order and delivery, reducing inventory, satisfaction of due dates
- Competitive advantage
  - Improvement of customer value, enhancement of stock price

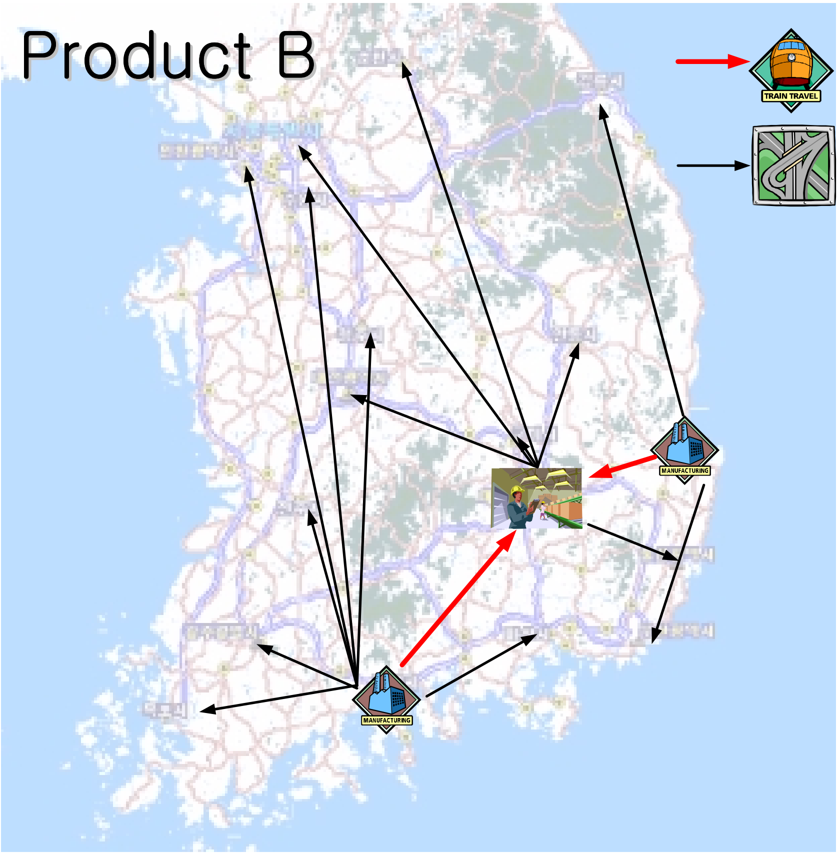
SCM Examples

- # of Plants = 2
- # of Products = 2
- # of Agencies = 16
- Safety-Stock
  - 10% of estimated demands
- Warehouse constraints
- Transportation restrictions



Results


Product A
TRAIN TRAVEL
MANUFACTURING


Product B
TRAIN TRAVEL
MANUFACTURING

Summary

- Process Identification for PID automatic tuning
- Advanced Control and Estimation System of Biological Wastewater Treatment Process
- Multivariate Statistical Process Monitoring
- Planning/Scheduling and Supply Chain Management