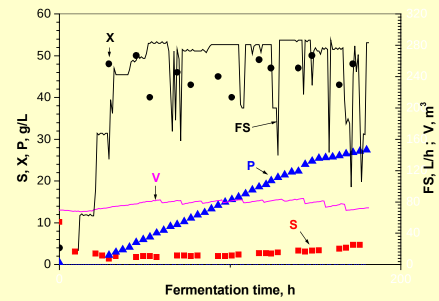
# State prediction and optimal scheduling for fed-batch fermentation

J. Q. Yuan[1], J. Liu[1] and P. Vanrolleghem[2]

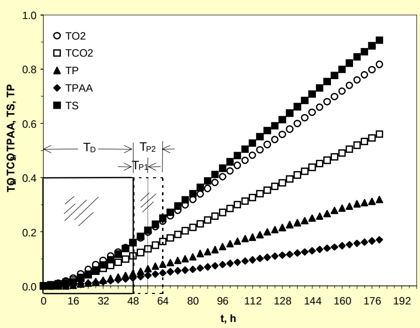
*School of Electronics and Informatics, Shanghai Jiaotong University, PR China*
*BIOMATH, Ghent University, Coupure Links 653, B-9000 Gent, Belgium*

- **Development of software prediction technology**
- **Testing results**
- **Prediction of the profit function**
- **Online classification and optimal scheduling**
- **Demonstration of the software**

## Typical time course of penicillin fed-batch fermentation




## Integrated substrate consumption & product formation




**Input**: discretized process variables within $T_D$

**Output**: variables to be predicted up to 5-steps-ahead
step length: 8h for antibiotic fermentation

**Generation of input-output data-pairs**: MDW-technique

**Training database**: $\theta = \{\theta_{1\sim n}\ \theta_{n+1}\}$

**Most important factors (Yuan and Vanrolleghem, JB, 1999)**:

- selection of historical batches
- time span covered by historical batches
- off-line and online updating of the database
- detection and remediation of bad local minima

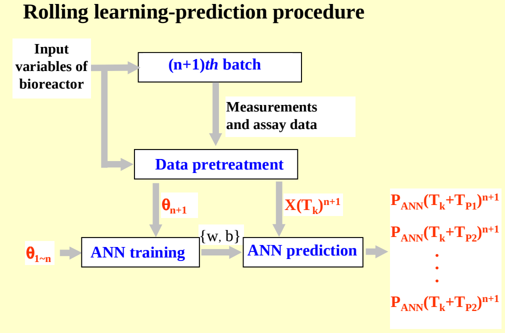
**The k*th* data-pair** $[X(T_k), Y(T_k)]$ is presented by

$$X(T_k) = \begin{bmatrix} T_k \\ x(T_k) \\ x(T_k - 1\tau) \\ x(T_k - 2\tau) \\ \vdots \\ x(T_k - m\tau) \end{bmatrix}$$

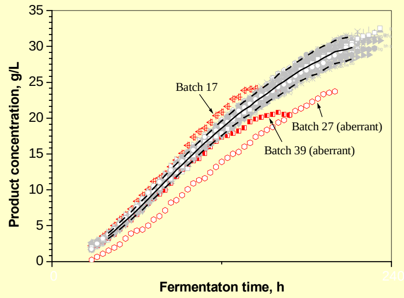
$$x(T_k)=[TO_2(T_k)\ TCO_2(T_k)\ TP(T_k)\ TPAA(T_k)\ TS(T_k)\ ..\ ..]^T$$

$$Y(T_k)=[P(T_k+T_{P1})\ P(T_k+T_{P2}),\ ....\ P(T_k+T_{P5})]^T$$

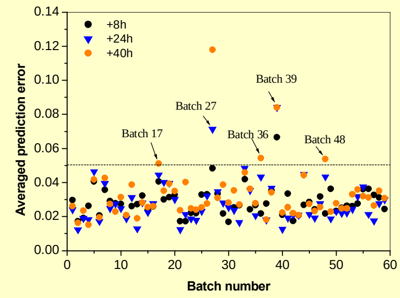
## Rolling learning-prediction procedure



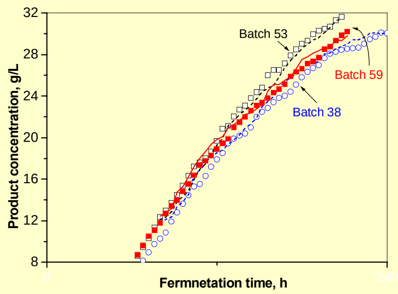
## Industrial fed-batch fermentations for testing of ANN-predictor




## Prediction accuracy (prediction of product concentration as an example)




## 40h-ahead prediction of product concentration

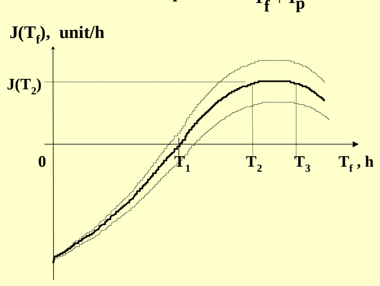



## Applications of the predicted state variables

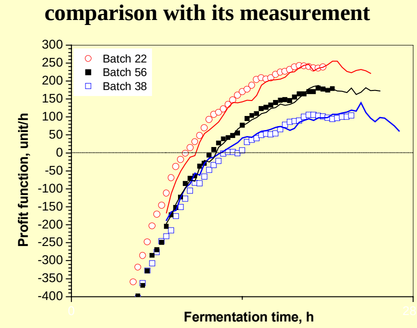
- Improvement of daily process supervision
- Early diagnosis of abnormal batches (indicated by unusual high prediction errors)
- Sub-optimal predictive control of feeding rates based on the predicted precursor/substrate uptake rates
- Estimation of economic potential for individual batches which may lead to optimal scheduling

## Profit function and optimal scheduling

**Profit function:** $J(T_f) = \frac{\text{Revenue} - \text{Total costs}}{T_f + T_p}$

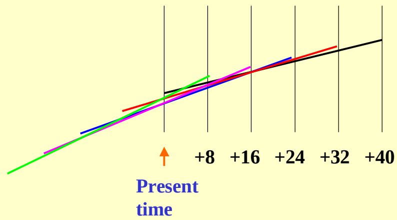



## 40h-ahead predicted profit function in comparison with its measurement

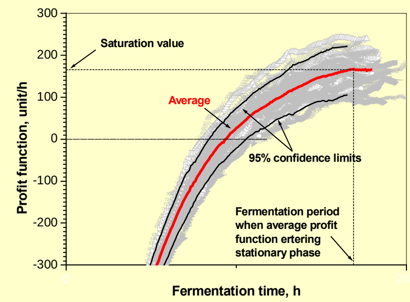


## Scheduling is done during last quarter of $T_f$

Using average predicted value $J(t,t+40)_{AP}$ to indicate the future tendency:




## Using average measured value $J(t,t+40)_{AM}$ of the profit function as basis




## Classification of batches according to economic potential

If $\|J(t,t+40)_{AP} - J(t,t+40)_{AM}\| > J(t,t+40)_{AM} \times (1+\beta)$
Then the *Good* category

If $\|J(t,t+40)_{AP} - J(t,t+40)_{AM}\| < J(t,t+40)_{AM} \times (1-\beta)$
Then the *Bad* category

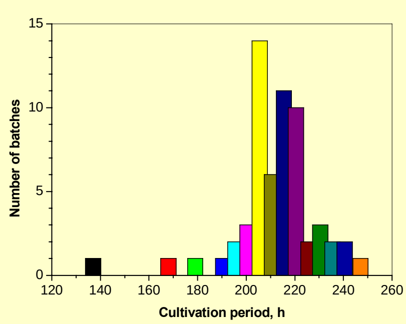
Otherwise, the *Normal* category

β - significance factor, confidence limit- related
β= 0.35~0.40 for the testing data set

## Scheduling rules for fed-batch cultivation

| Category | Scheduling strategy |
|---|---|
| *Good* | Maintain operation as long as possible |
| *Normal* | Terminating as planned |
| *Bad* | Break off at an earlier time point |

## Feasibility of online optimal scheduling under "golden recipe"




## Software demonstration given by Mr. Liu Jun