Can complex models help with operation and online control?

Examples of good, bad and the ugly

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Interreg Baltic Sea Region

EUROPEAN REGIONAL DEVELOPMENT FUND

EUROPEAN UNION

sumo dynamita PROCESS MODELING

Definitions

- Model
- Control
- Online

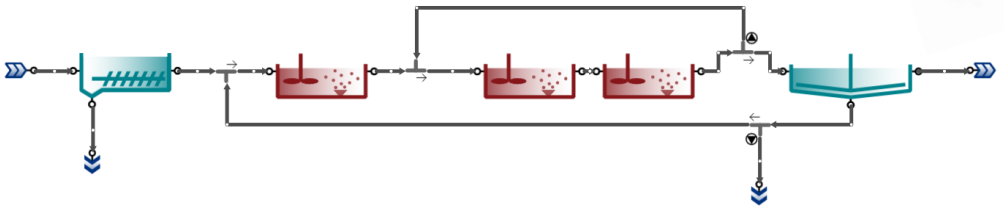
What does “Online” mean?

1. Automated data transfer from plant to model
2. Automated operational optimization (offline advice)
3. Automated controller tuning
4. Automated model calibration
5. Model-in-loop – true online model based control
6. Artificial Intelligence (AI)

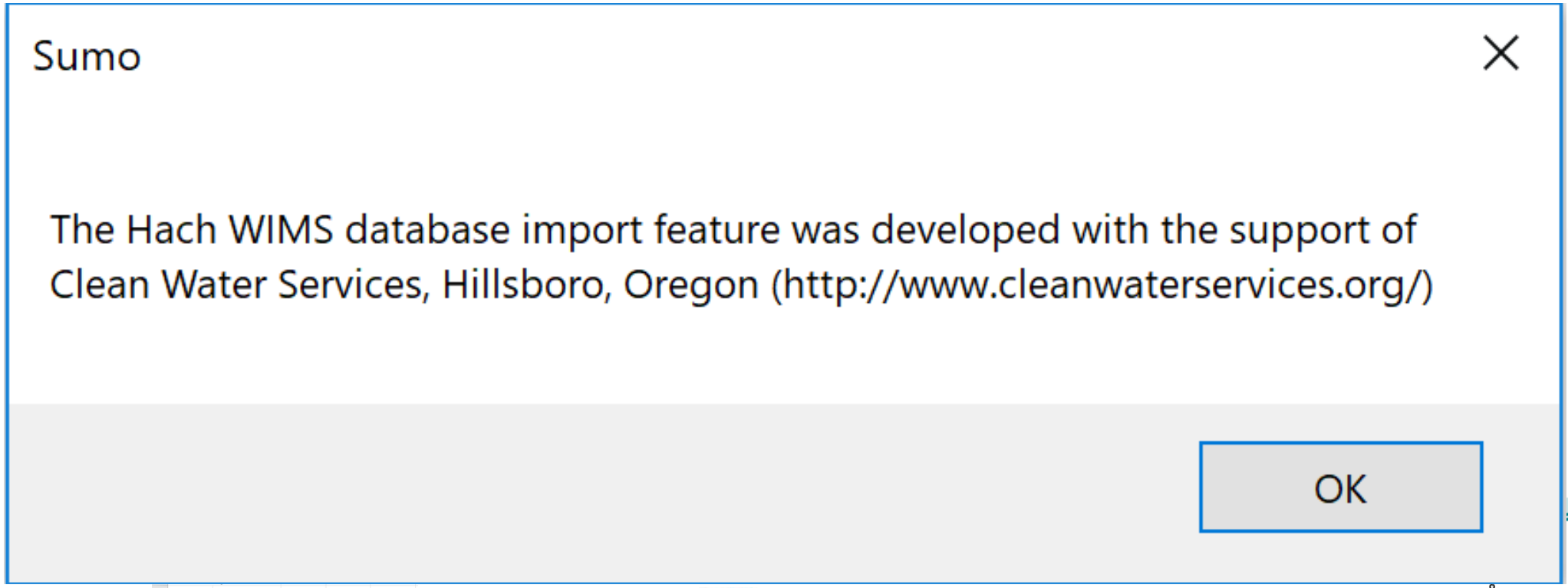
1. Automated data transfer from plant to model

- Possible offline (manually)? Yes.
  - Copying data from Excel sheets to simulation software
- Online, automated:
  - Needs software link (driver)
  - Increased risk of bad data input

	A	B	C	D	E
1	**Chemical dosing**		Alum	Ferric	
2		E PI	0.0071	0.0124	MGD
3		W PI	0.0071	0.0124	MGD
4		ES_WPL	0.0024	0.004	MGD
5		WS_WPL	0.0024	0.004	MGD
6		Nit Odd	0.009	0.015	MGD
7		Total	0.028	0.0478	MGD
8			105.9915	180.9427	m3/d
9			15898729	18094268	g/d
10					
11	**Sludge production**				
12		Dewatered sludge	269863	195196	lbs/d
13					
14		**Precipitates**			
15	Dewatered sludge	XCaCO3	14.97914	61.43125	mg TSS/L
16		XACP	52.30247	54.92137	mg TSS/L
17		XSTR	349.2055	264.3659	mg TSS/L
18		XVivi	6.86E-11	43254.33	mg TSS/L
19		XHFO_H	2.36E-17	1.83E-05	mg Fe/L
20		XHFO_L	1.19E-09	54.2516	mg Fe/L
21		XHFO_old	1.32E-08	12.18489	mg Fe/L
22		XHFO_H_P	8.44E-17	1.91E-05	mg Fe/L
23		XHFO_L_P	1.01E-11	0.446063	mg Fe/L
24		XHFO_H_P_old	2.35E-09	6.679851	mg Fe/L
25		XHFO_L_P_old	1.28E-12	0.486532	mg Fe/L
26		XAlOH	17373.86	1.07E-08	mg Al/L
27		XAlP	2868.927	1.04E-09	mg Al/L



1. Automated data transfer from plant to model



15	Dewatered sludge	XCaCO3	14.97914	61.43125	mg TSS/L
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27		XAlP	2868.927	1.04E-09	mg Al/L

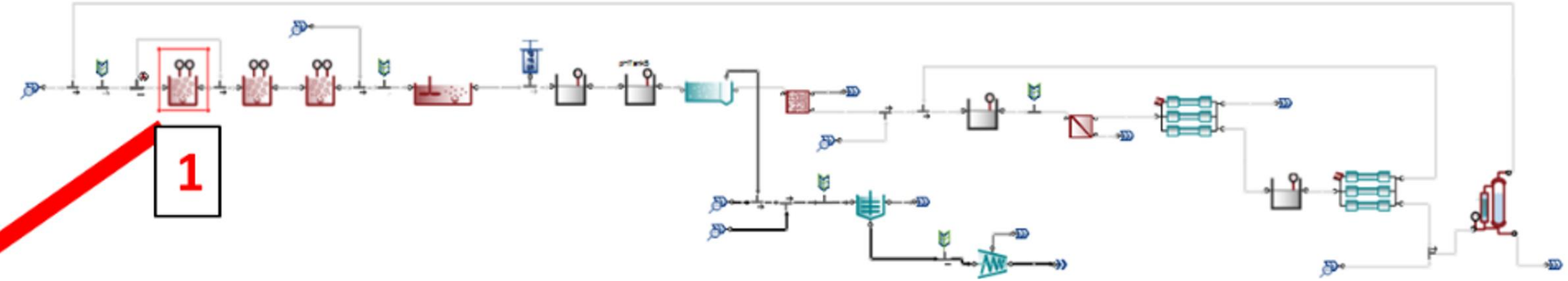
2. Automated operational optimization

- Possible offline (manually)? Yes.

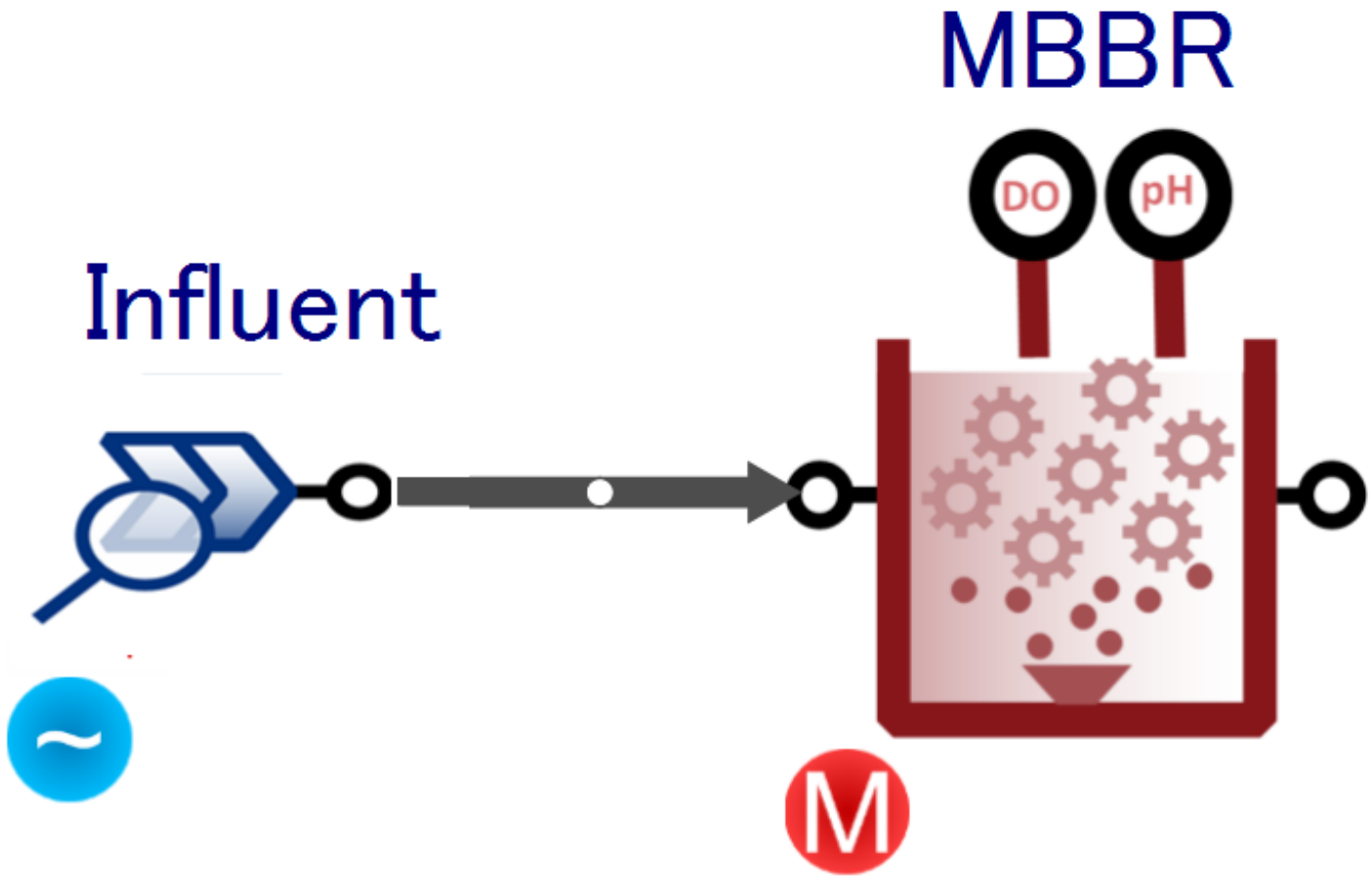
- Prepared scenarios or operational tables
- Choosing the best options for the objective (lowest cost)

2. Automated operational optimization

- Industrial plant



2. Focus on one unit

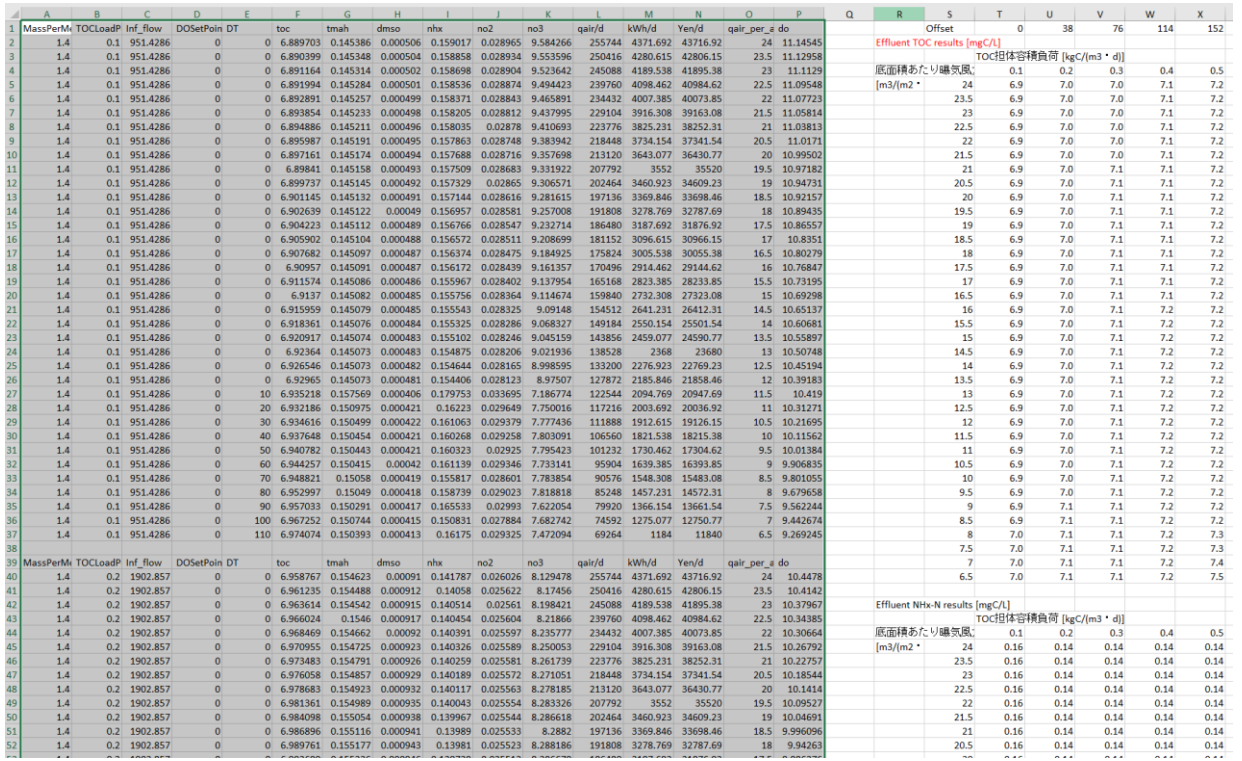


2. Generate “surface” based on calibrated model

A. Influent composition changes:
   Recalibrate model

B. Generate operating surface
   Airflow, TOC load

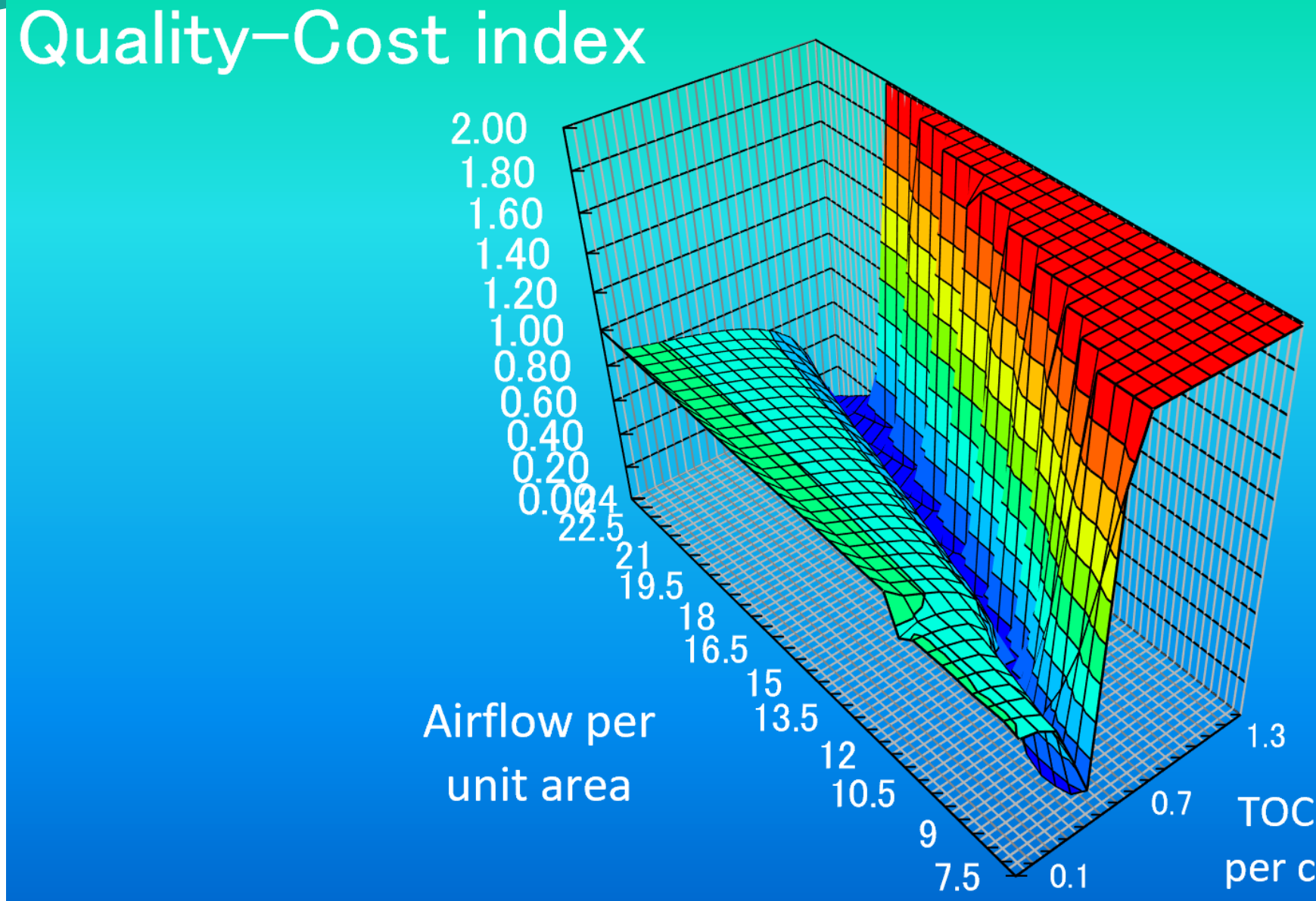
C. Choose optimum settings daily



MassPerM	TOCLoadP	Inf_flow	DOSetPoin	DT	toc	tmah	dmso	nhx	no2	no3	qair/d	kWh/d	Yen/d	qair_per_a	do
1.4	0.1	951.4286	0	0	6.889703	0.145386	0.000506	0.159017	0.028965	9.584266	255744	4371.692	43716.92	24	11.14545
1.4	0.1	951.4286	0	0	6.890399	0.145348	0.000504	0.158858	0.028934	9.553596	250416	4280.615	42806.15	23.5	11.12958
1.4	0.1	951.4286	0	0	6.891164	0.145314	0.000502	0.158698	0.028904	9.523642	245088	4189.538	41895.38	23	11.1129
1.4	0.1	951.4286	0	0	6.891994	0.145284	0.000501	0.158536	0.028874	9.494423	239760	4098.462	40984.62	22.5	11.09548
1.4	0.1	951.4286	0	0	6.892891	0.145257	0.000499	0.158371	0.028843	9.465891	234432	4007.385	40073.85	22	11.07723
1.4	0.1	951.4286	0	0	6.893854	0.145233	0.000498	0.158205	0.028812	9.437995	229104	3916.308	39163.08	21.5	11.05814
1.4	0.1	951.4286	0	0	6.894886	0.145211	0.000496	0.158035	0.02878	9.410693	223776	3825.231	38252.31	21	11.03813
1.4	0.1	951.4286	0	0	6.895987	0.145191	0.000495	0.157863	0.028748	9.383942	218448	3734.154	37341.54	20.5	11.0171
1.4	0.1	951.4286	0	0	6.897161	0.145174	0.000494	0.157688	0.028716	9.357698	213120	3643.077	36430.77	20	10.99502
1.4	0.1	951.4286	0	0	6.89841	0.145158	0.000493	0.157509	0.028683	9.331922	207792	3552	35520	19.5	10.97182
1.4	0.1	951.4286	0	0	6.899737	0.145145	0.000492	0.157329	0.02865	9.306571	202464	3460.923	34609.23	19	10.94731
1.4	0.1	951.4286	0	0	6.901145	0.145132	0.000491	0.157144	0.028616	9.281615	197136	3369.846	33698.46	18.5	10.92157
1.4	0.1	951.4286	0	0	6.902639	0.145122	0.00049	0.156957	0.028581	9.257008	191808	3278.769	32787.69	18	10.89435
1.4	0.1	951.4286	0	0	6.904223	0.145112	0.000489	0.156766	0.028547	9.232714	186480	3187.692	31876.92	17.5	10.86557
1.4	0.1	951.4286	0	0	6.905902	0.145104	0.000488	0.156572	0.028511	9.208699	181152	3096.615	30966.15	17	10.8351
1.4	0.1	951.4286	0	0	6.907682	0.145097	0.000487	0.156374	0.028475	9.184925	175824	3005.538	30055.38	16.5	10.80279
1.4	0.1	951.4286	0	0	6.90957	0.145091	0.000487	0.156172	0.028439	9.161357	170496	2914.462	29144.62	16	10.76847
1.4	0.1	951.4286	0	0	6.911574	0.145086	0.000486	0.155967	0.028402	9.137954	165168	2823.385	28233.85	15.5	10.73195
1.4	0.1	951.4286	0	0	6.9137	0.145082	0.000485	0.155756	0.028364	9.114674	159840	2732.308	27323.08	15	10.69298
1.4	0.1	951.4286	0	0	6.915959	0.145079	0.000485	0.155543	0.028325	9.09148	154512	2641.231	26412.31	14.5	10.65137
1.4	0.1	951.4286	0	0	6.918361	0.145076	0.000484	0.155325	0.028286	9.068327	149184	2550.154	25501.54	14	10.60681
1.4	0.1	951.4286	0	0	6.920917	0.145074	0.000483	0.155102	0.028246	9.045159	143856	2459.077	24590.77	13.5	10.55897
1.4	0.1	951.4286	0	0	6.92364	0.145073	0.000483	0.154875	0.028206	9.021936	138528	2368	23680	13	10.50748
1.4	0.1	951.4286	0	0	6.926546	0.145073	0.000482	0.154644	0.028165	8.998595	133200	2276.923	22769.23	12.5	10.45194
1.4	0.1	951.4286	0	0	6.92965	0.145073	0.000481	0.154406	0.028123	8.97507	127872	2185.846	21858.46	12	10.39183
1.4	0.1	951.4286	0	10	6.935218	0.157569	0.000406	0.179753	0.033695	7.186774	122544	2094.769	20947.69	11.5	10.419
1.4	0.1	951.4286	0	20	6.932186	0.150975	0.000421	0.16223	0.029649	7.750016	117216	2003.692	20036.92	11	10.31271
1.4	0.1	951.4286	0	30	6.934616	0.150499	0.000422	0.161063	0.029379	7.777436	111888	1912.615	19126.15	10.5	10.21695
1.4	0.1	951.4286	0	40	6.937648	0.150454	0.000421	0.160268	0.029258	7.803091	106560	1821.538	18215.38	10	10.11562
1.4	0.1	951.4286	0	50	6.940782	0.150443	0.000421	0.160323	0.02925	7.795423	101232	1730.462	17304.62	9.5	10.01384
1.4	0.1	951.4286	0	60	6.944257	0.150415	0.00042	0.161139	0.029346	7.733141	95904	1639.385	16393.85	9	9.906835
1.4	0.1	951.4286	0	70	6.948821	0.15058	0.000419	0.155817	0.028601	7.783854	90576	1548.308	15483.08	8.5	9.801055
1.4	0.1	951.4286	0	80	6.952997	0.15049	0.000418	0.158739	0.029023	7.818818	85248	1457.231	14572.31	8	9.679658
1.4	0.1	951.4286	0	90	6.957033	0.150291	0.000417	0.165533	0.02993	7.622054	79920	1366.154	13661.54	7.5	9.562244
1.4	0.1	951.4286	0	100	6.967252	0.150744	0.000415	0.150831	0.027884	7.682742	74592	1275.077	12750.77	7	9.442674
1.4	0.1	951.4286	0	110	6.974074	0.150393	0.000413	0.16175	0.029325	7.472094	69264	1184	11840	6.5	9.269245
MassPerM	TOCLoadP	Inf_flow	DOSetPoin	DT	toc	tmah	dmso	nhx	no2	no3	qair/d	kWh/d	Yen/d	qair_per_a	do
1.4	0.2	1902.857	0	0	6.958767	0.154623	0.00091	0.141787	0.026026	8.129478	255744	4371.692	43716.92	24	10.4478
1.4	0.2	1902.857	0	0	6.961235	0.154488	0.000912	0.14058	0.025622	8.17456	250416	4280.615	42806.15	23.5	10.4142
1.4	0.2	1902.857	0	0	6.963614	0.154542	0.000915	0.140514	0.02561	8.198421	245088	4189.538	41895.38	23	10.37967
1.4	0.2	1902.857	0	0	6.966024	0.1546	0.000917	0.140454	0.025604	8.21866	239760	4098.462	40984.62	22.5	10.34385
1.4	0.2	1902.857	0	0	6.968469	0.154662	0.00092	0.140391	0.025597	8.235777	234432	4007.385	40073.85	22	10.30664
1.4	0.2	1902.857	0	0	6.970955	0.154725	0.000923	0.140326	0.025589	8.250053	229104	3916.308	39163.08	21.5	10.26792
1.4	0.2	1902.857	0	0	6.973483	0.154791	0.000926	0.140259	0.025581	8.261739	223776	3825.231	38252.31	21	10.22757
1.4	0.2	1902.857	0	0	6.976058	0.154857	0.000929	0.140189	0.025572	8.271051	218448	3734.154	37341.54	20.5	10.18544
1.4	0.2	1902.857	0	0	6.978683	0.154923	0.000932	0.140117	0.025563	8.278185	213120	3643.077	36430.77	20	10.1414
1.4	0.2	1902.857	0	0	6.981361	0.154989	0.000935	0.140043	0.025554	8.283326	207792	3552	35520	19.5	10.09527
1.4	0.2	1902.857	0	0	6.984098	0.155054	0.000938	0.139967	0.025544	8.286618	202464	3460.923	34609.23	19	10.04691
1.4	0.2	1902.857	0	0	6.986896	0.155116	0.000941	0.13989	0.025533	8.2882	197136	3369.846	33698.46	18.5	9.996096
1.4	0.2	1902.857	0	0	6.989761	0.155177	0.000943	0.13981	0.025523	8.288186	191808	3278.769	32787.69	18	9.94263

Offset	0	38	76	114	152
Effluent TOC results [mgC/L]					
TOC担体容積負荷 [kgC/(m3・d)]					
底面積あたり曝気風	0.1	0.2	0.3	0.4	0.5
[m3/(m2・	24	6.9	7.0	7.0	7.1	7.2
	23.5	6.9	7.0	7.0	7.1	7.2
	23	6.9	7.0	7.0	7.1	7.2
	22.5	6.9	7.0	7.0	7.1	7.2
	22	6.9	7.0	7.0	7.1	7.2
	21.5	6.9	7.0	7.0	7.1	7.2
	21	6.9	7.0	7.1	7.1	7.2
	20.5	6.9	7.0	7.1	7.1	7.2
	20	6.9	7.0	7.1	7.1	7.2
	19.5	6.9	7.0	7.1	7.1	7.2
	19	6.9	7.0	7.1	7.1	7.2
	18.5	6.9	7.0	7.1	7.1	7.2
	18	6.9	7.0	7.1	7.1	7.2
	17.5	6.9	7.0	7.1	7.1	7.2
	17	6.9	7.0	7.1	7.1	7.2
	16.5	6.9	7.0	7.1	7.1	7.2
	16	6.9	7.0	7.1	7.2	7.2
	15.5	6.9	7.0	7.1	7.2	7.2
	15	6.9	7.0	7.1	7.2	7.2
	14.5	6.9	7.0	7.1	7.2	7.2
	14	6.9	7.0	7.1	7.2	7.2
	13.5	6.9	7.0	7.1	7.2	7.2
	13	6.9	7.0	7.1	7.2	7.2
	12.5	6.9	7.0	7.1	7.2	7.2
	12	6.9	7.0	7.1	7.2	7.2
	11.5	6.9	7.0	7.1	7.2	7.2
	11	6.9	7.0	7.1	7.2	7.2
	10.5	6.9	7.0	7.1	7.2	7.2
	10	6.9	7.0	7.1	7.2	7.2
	9.5	6.9	7.0	7.1	7.2	7.2
	9	6.9	7.1	7.1	7.2	7.2
	8.5	6.9	7.1	7.1	7.2	7.2
	8	7.0	7.1	7.1	7.2	7.3
	7.5	7.0	7.1	7.1	7.2	7.3
	7	7.0	7.1	7.1	7.2	7.4
	6.5	7.0	7.1	7.1	7.2	7.5
Effluent NHx-N results [mgC/L]					
TOC担体容積負荷 [kgC/(m3・d)]					
底面積あたり曝気風	0.1	0.2	0.3	0.4	0.5
[m3/(m2・	24	0.16	0.14	0.14	0.14	0.14
	23.5	0.16	0.14	0.14	0.14	0.14
	23	0.16	0.14	0.14	0.14	0.14
	22.5	0.16	0.14	0.14	0.14	0.14
	22	0.16	0.14	0.14	0.14	0.14
	21.5	0.16	0.14	0.14	0.14	0.14
	21	0.16	0.14	0.14	0.14	0.14
	20.5	0.16	0.14	0.14	0.14	0.14

2. Surface model example

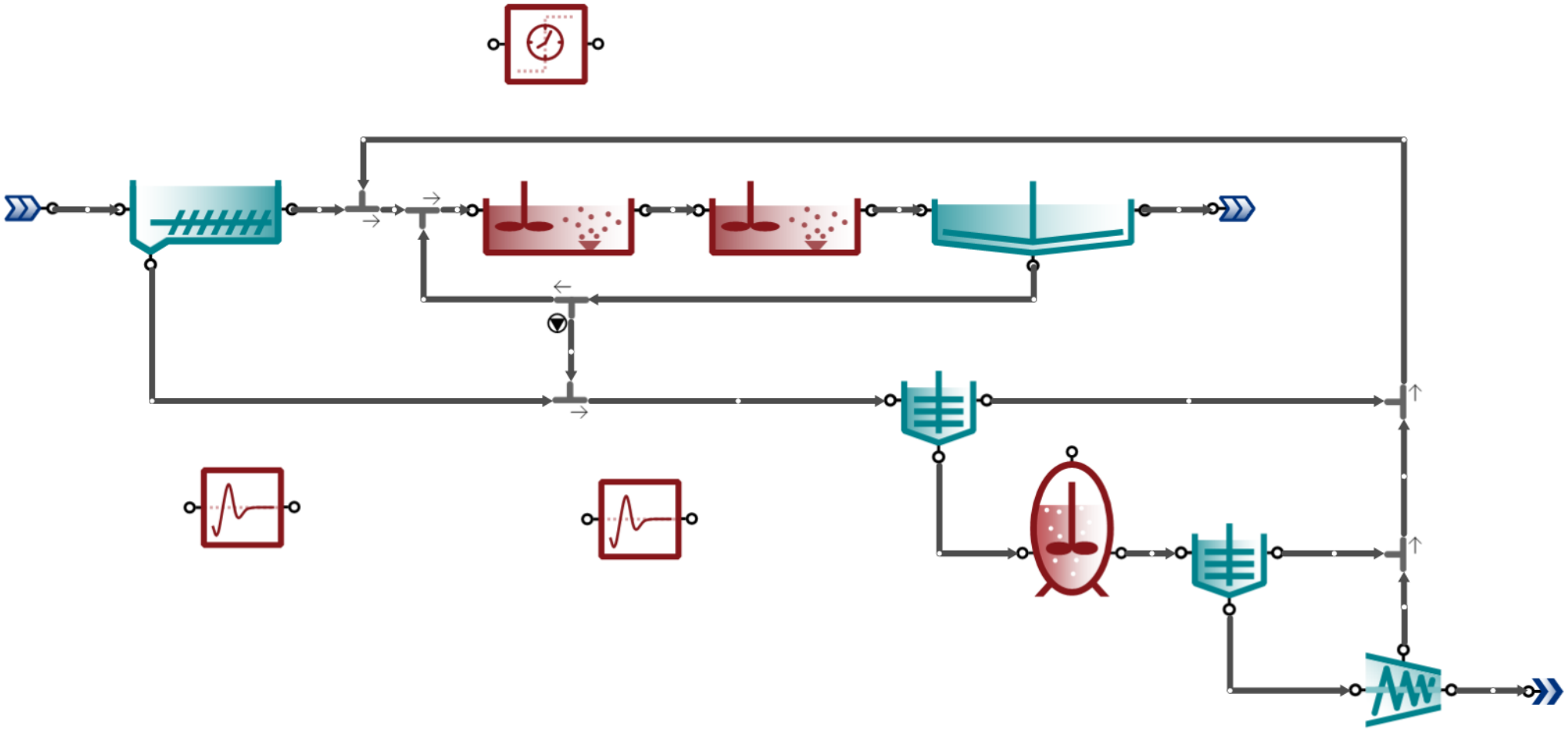


3. Automated controller tuning

- Possible offline (manually)? Yes.

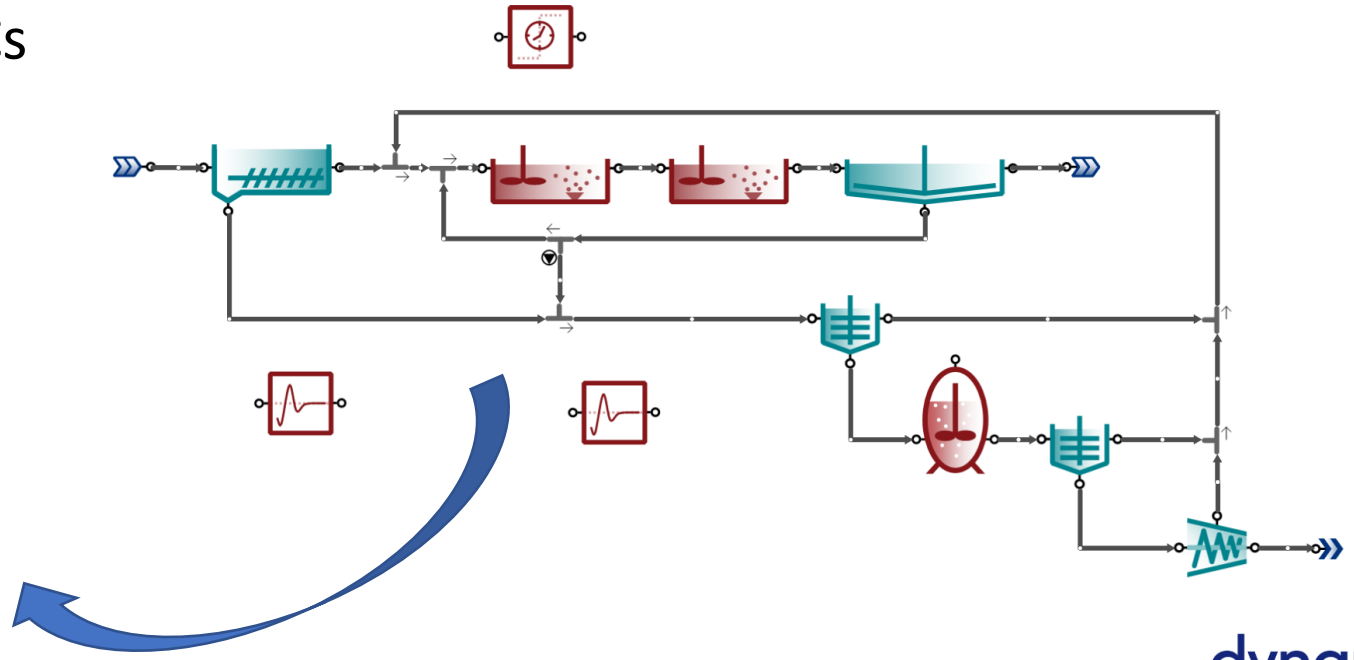
- Calibrated model and same controller code as in PLCs
- Tuning controller gain etc. for different periods, operational conditions

3. Automated controller tuning



3. Automated controller tuning

- Online, it needs:
  - Automated data transfer (1)
  - Calibrated model (manual or item 4)
  - Autotuning algorithms (since 1940s e.g. Ziegler-Nichols)
  - Transfer of gains etc. to PLCs

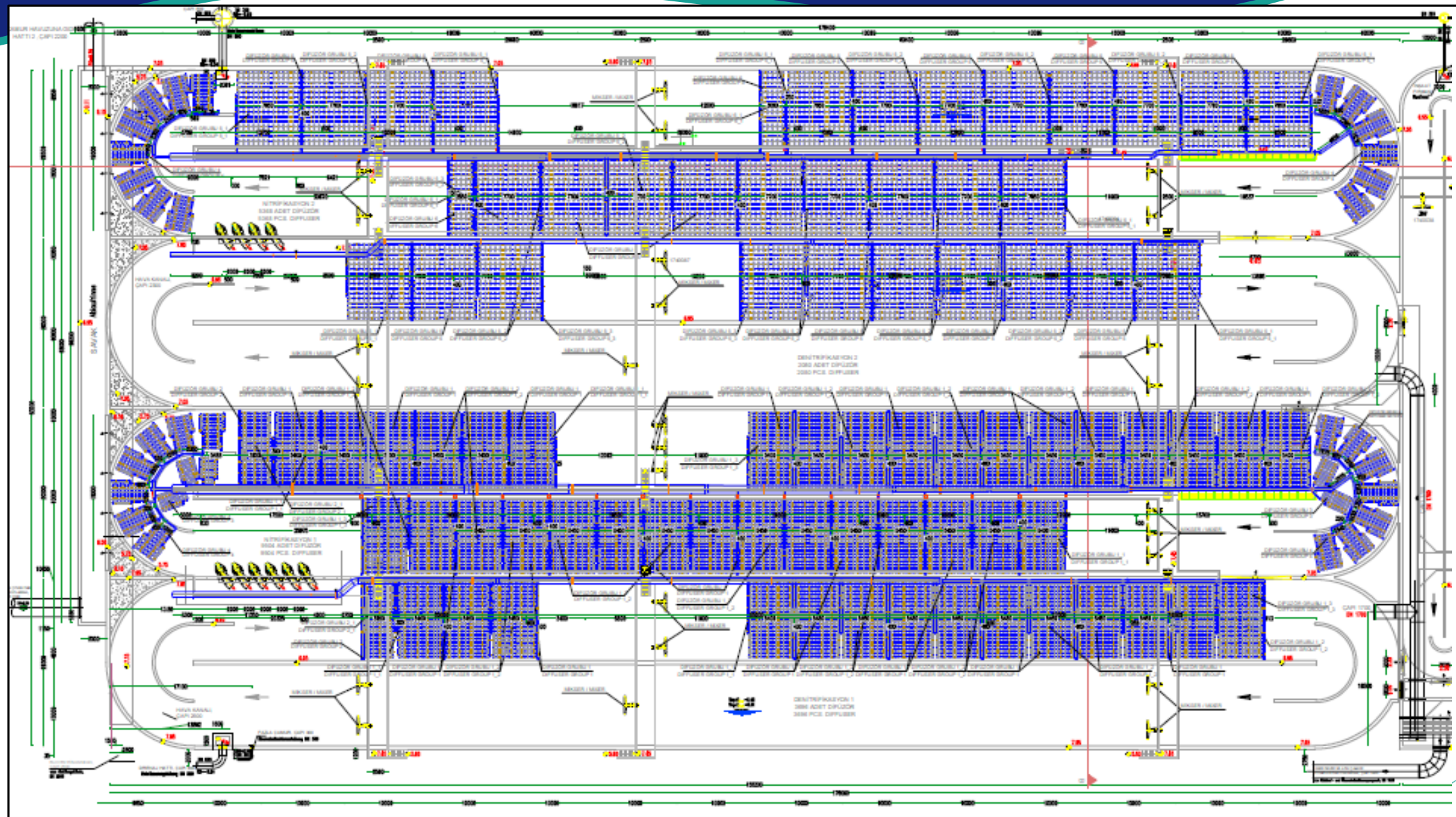


4. Automated model calibration

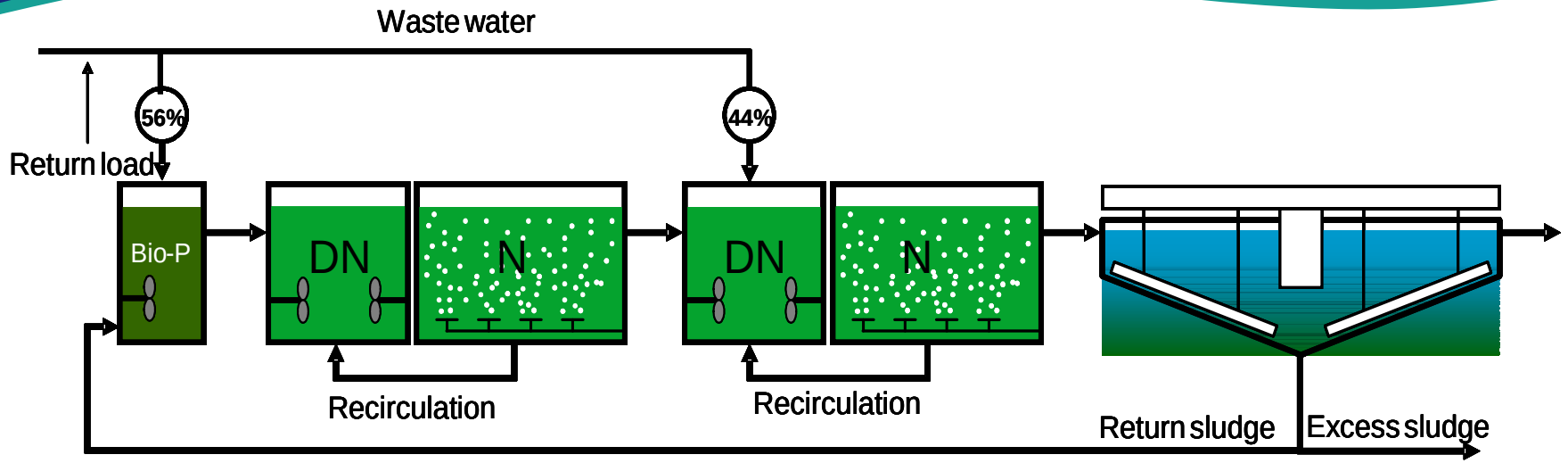
- Possible offline (manually)? Yes.

- Automatic data transfer
  - Continuous, daily, weekly, etc..
- Selected sets of model parameters changed to minimize predefined objective function, i.e.
  - change (uncertain) waste rate and (unmeasured) influent RBCOD
  - match MLSS and effluent TN
  - real cases are much more complex

4. Automated model calibration – complex plant



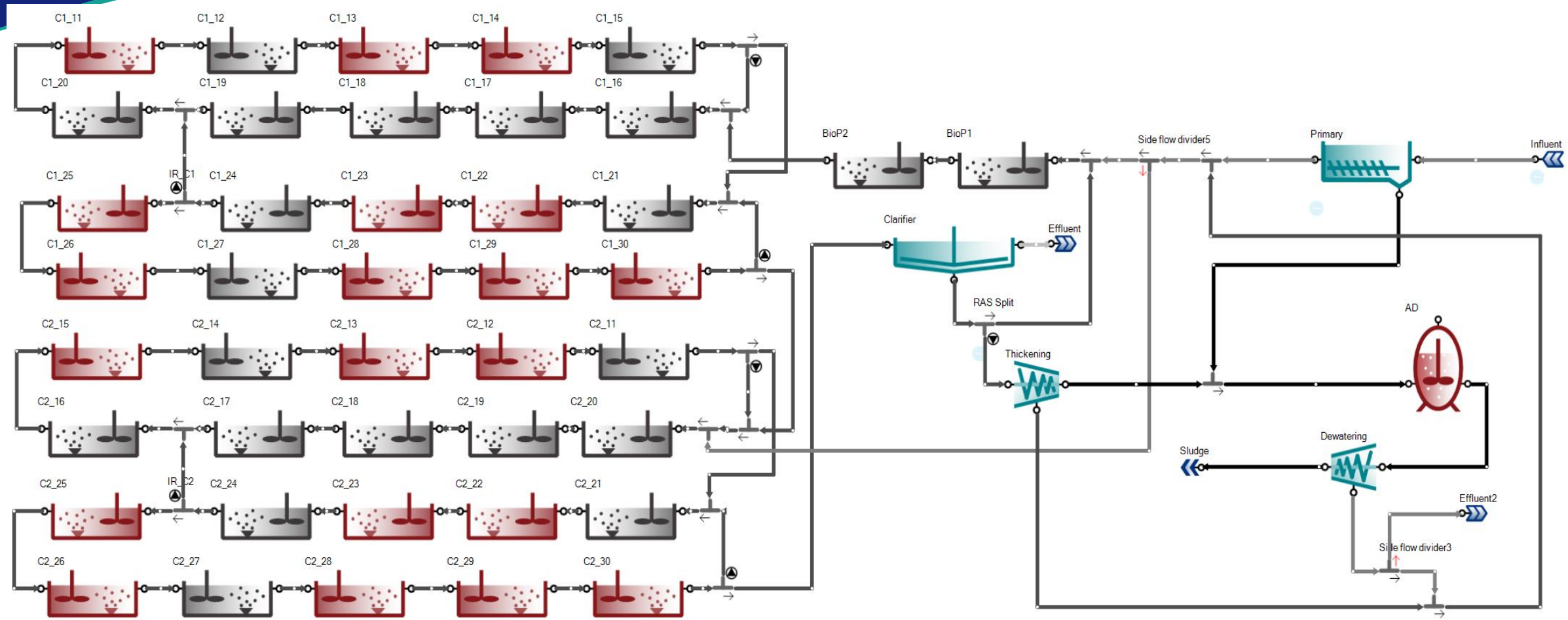
4. Automated model calibration – complex plant



Mixture of Processes at the same time:

- Step Feed
- A^2O
- Simultaneous Nite/Denite

4. Model implementation



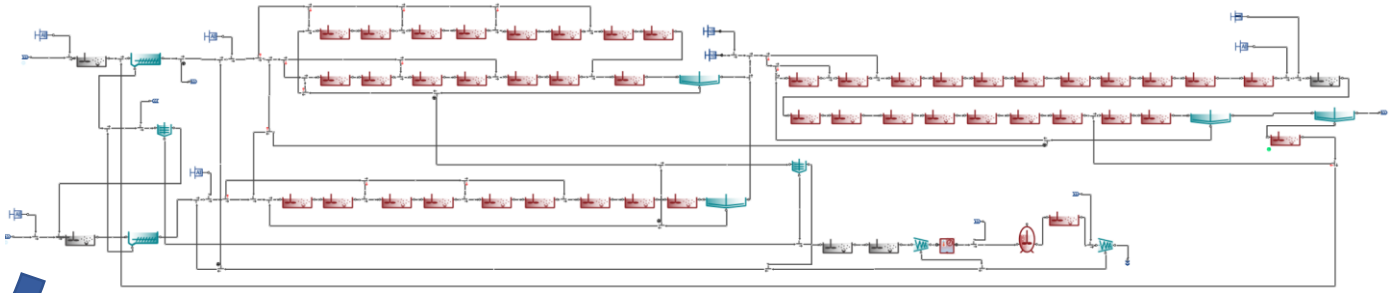
4. Automated model calibration – complex plant

- Calibration - control objectives
  1. Dissolved oxygen control
  2. Nitrate recycle control
  3. Cascade ammonia - DO control
- Impact of dynamic influent
- Location of probes

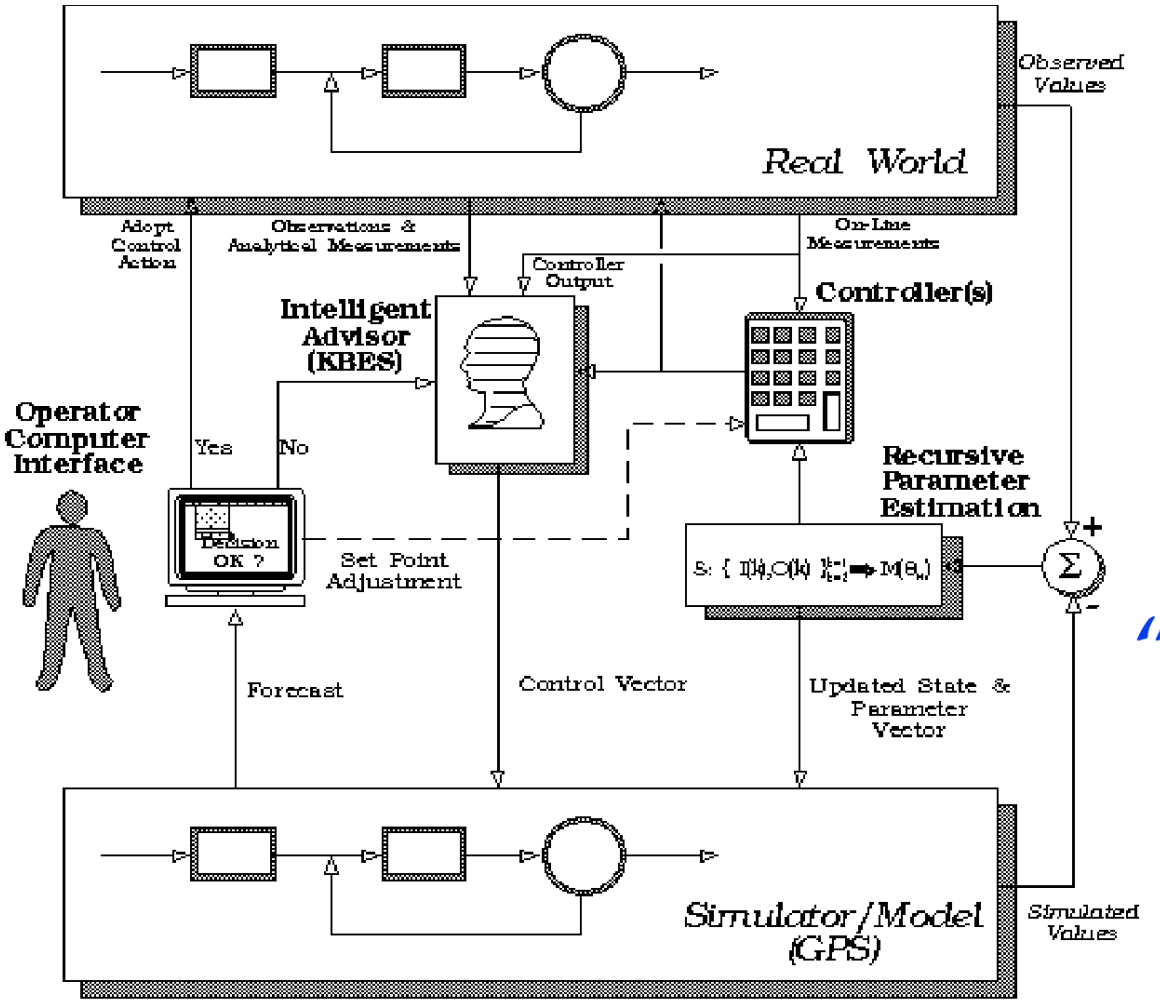
- Not trivial due to interactions and the need for clean data

5. Model-in-loop – true online model based control

- Possible offline (manually)? N/A.



5. Model-in-loop – true online model based control



Patry-Olsson 1985:

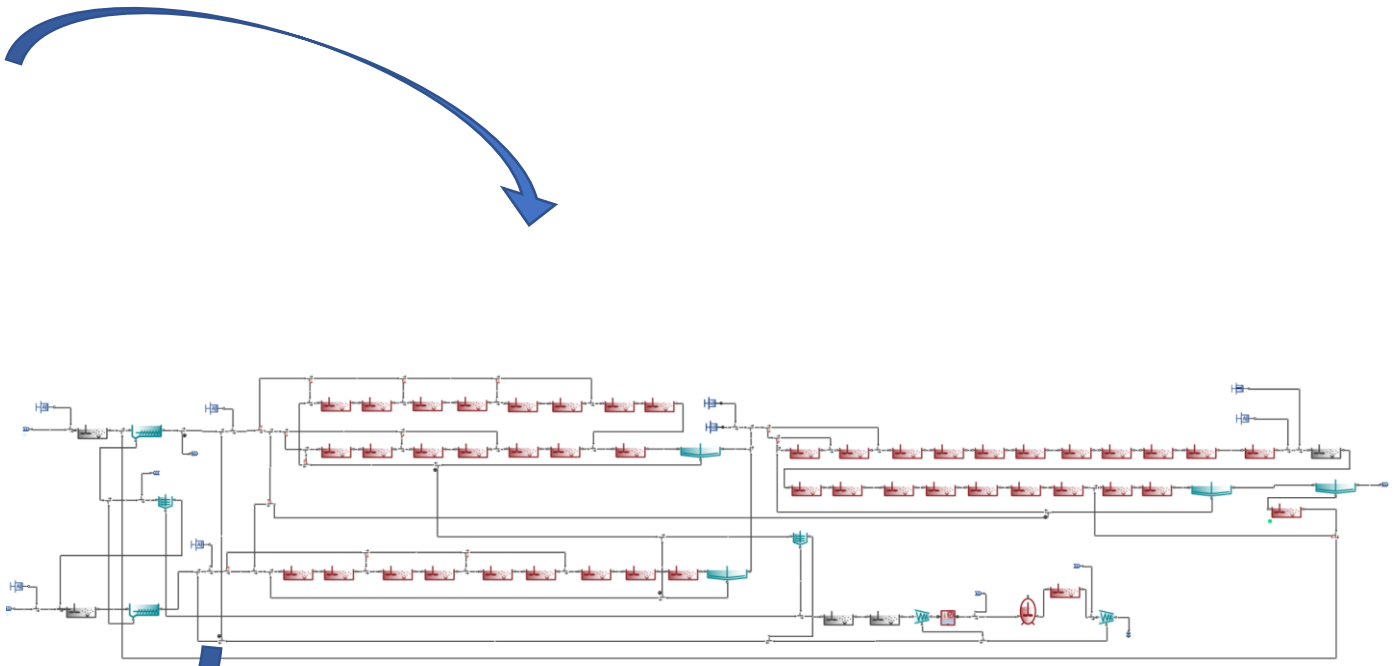
"Famous" Diagram

5. Model-in-loop – true online model based control

- Possible? Not yet today
- Not all inputs can be measured online
- Data reconciliation (fully automated) needed
- Risk of failure
- Large effort

- Engineer/operator brain is still needed
- Keep it as simple as possible (but not simpler)

5. Model-in-loop – true online model based control



Summary

1. **Automated data transfer from plant to model**
2. **Automated operational optimization (offline advice)**
3. **Automated controller tuning**
4. **Automated model calibration**
5. **Model-in-loop – true online model based control**
6. Artificial Intelligence (AI)

Thank you!

Questions?