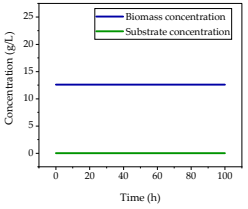
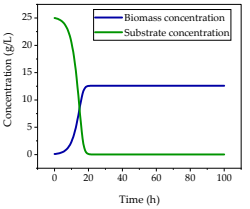
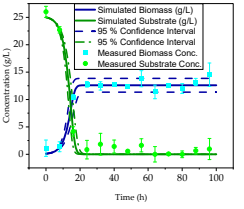
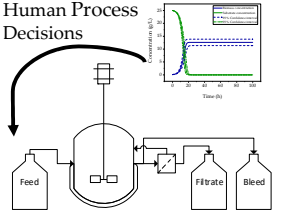
Digital Models → Digital Twins

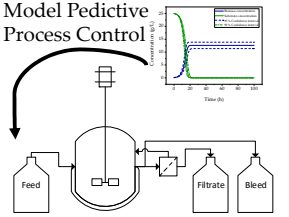
Steady-State Model	Dynamic Model	Validated Model	Digital Shadow	Model-Based Control
$\frac{dm}{dt} = 0$	$\frac{dm}{dt} \neq 0$	$\frac{dm}{dt} \neq 0$	$\frac{dm}{dt} \neq 0$	$\frac{dm}{dt} \neq 0$
Parameter estimates	Parameter estimates	Process data for validation	Real-time data	Real-time data & control











- Steady-state mass and energy balances
- First pass optimization and calculation procedures at initial design stage

- System behavior over time
- Identify optimal operational conditions
- Scaling up of design and process control

- Inclusion of more complex phenomena, e.g. feed-back inhibition
- Validation against process data

- Execution in real-time based on automated input through data link with process

- Closed-loop process control and on-line optimization