Demand Driven Deployment Capabilities in Cyclus

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Outline

Cyclus

Cyclus is an agent-based nuclear fuel cycle simulator with a modular architecture. It has three types of agents: Facility, Institution, and Region.

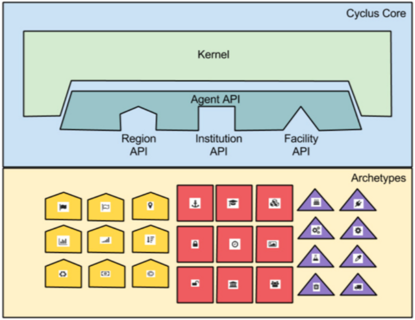


Figure 1: Once Through Nuclear Fuel Cycle [1]

Motivation

Gap in capability: User must define when support facilities are deployed.

Figure 2: User defined Deployment Scheme

Bridging the gap: Developed `d3ploy`, a demand-driven deployment capability in Cyclus.

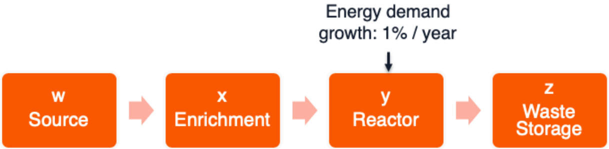


Figure 3: Demand Driven Deployment Scheme

Goals

Goals of this work

- Develop demand driven deployment capabilities in CYCLUS (`d3ploy`)
- Demonstrate the use of `d3ploy` to set up transition scenarios from the current once through Light Water Reactor (LWR) fuel cycle to four other more promising fuel cycles.

Table 1: Descriptions of the current and other high performing nuclear fuel cycle evaluation groups described in the evaluation and screening study [2].

Fuel Cycle	Open or Closed	Fuel Type	Reactor Type
EG01 (current)	Open	Enriched-U	Thermal critical reactors
EG23	Closed	Recycle of U/Pu with natural-U fuel	Fast critical reactors
EG24	Closed	Recycle of U/TRU with natural-U fuel	Fast critical reactors
EG29	Closed	Recycle of U/Pu with natural-U fuel	Fast critical reactors and thermal critical reactors
EG30	Closed	Recycle of U/TRU with natural-U fuel	Fast critical reactors and thermal critical reactors

Outline

d3ploy Objectives

d3ploy's **Main Objective**

Minimize the number of time steps of undersupply of power.

d3ploy's **Sub-Objective**

Minimize excessive oversupply of all commodities.

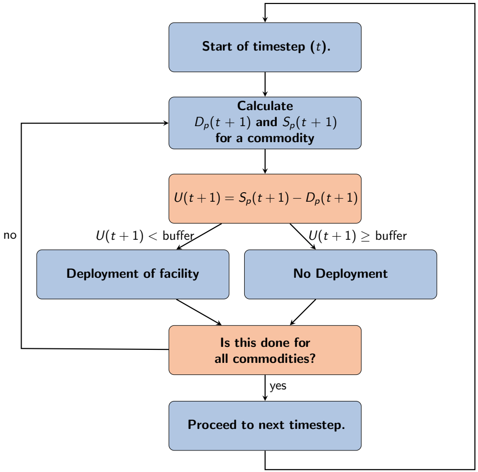
$$obj = min \sum_{i}^{N} |D_i - S_i|$$

d3ploy Input Parameters

Table 2: d3ploy's required and optional input parameters with examples.

	Input Parameter	**Examples**
	Demand driving commodity	Power, Fuel, Plutonium, etc.
Required	Demand equation	P(t) = 10000, sin(t), 10000t
	Available facilities	Fuel Fab, LWR reactor, Waste repository, etc.
	Facility capacities	3000 kg, 1000 MW, 50000 kg
	Prediction method	Fast Fourier Transform
	Deployment driving method	Installed Capacity or Supply
Optional	Buffer type	Absolute or relative
	Buffer size	Power: 3000 MW Fuel: 0 kg Spent fuel: 0 kg
	Facility preferences (transition time)	LWR preferred $\leq$ 100 time steps SFR preferred $>$ 100 time steps
	Facility constraint	SFR constraint = 5000kg of Pu

d3ploy logic flow



$$D_p = \text{Predicted Demand}$$
$$S_p = \text{Predicted Supply}$$
$$U = S_p - D_p$$

Figure 4: d3ploy logic flow at every timestep in CYCLUS.

d3ploy Prediction Methods

Non-Optimizing Methods

- Moving Average (ma)
- Autoregressive Moving Average (arma)
- Autoregressive Heteroskedasticity (arch)

Deterministic-Optimizing Methods

- Fast Fourier Transform (fft)
- Polynomial Fit (poly)
- Exponential Smoothing (exp-smoothing)
- Triple Exponential Smoothing (holt-winters)

Stochastic-Optimizing Methods

- Auto-Regressive Integrated Moving Averages (ARIMA)

Outline

Breakdown of Results

The goal is to simulate 4 transition scenarios with fuel cycle facility deployment driven by demand.

1. EG01-23 $D(t) = D_0$
2. EG01-24 $D(t) = D_0 + rt$
3. EG01-29 $D(t) = D_0$
4. EG01-30 $D(t) = D_0 + rt$

We achieved this by:

1. Applying and comparing all prediction methods for each scenario.
2. Exploring performance sensitivity to buffer size.
3. Using the best prediction method and buffer size, demonstrate `d3ploy` deploying reactor and supporting facilities to meet power demand for 4 scenarios.

Setting up the Problem

Mass Flow and Facilities in Transition Scenarios: EG01-23 and EG01-29.

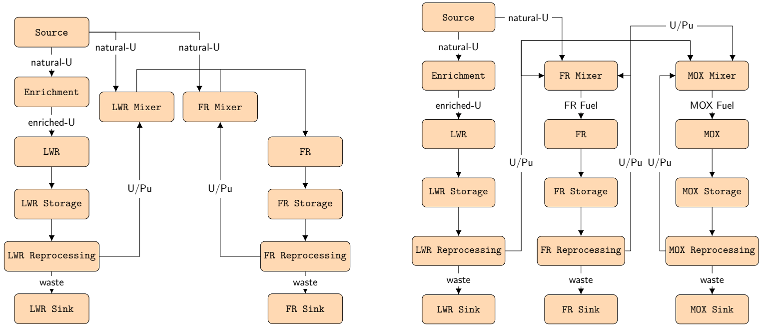


Figure 5: Diagrams with facilities and mass flow of the scenarios EG01-EG23 and EG01-EG29.

Comparison of Prediction Methods

EG01-23 Constant Power Demand Transition Scenario

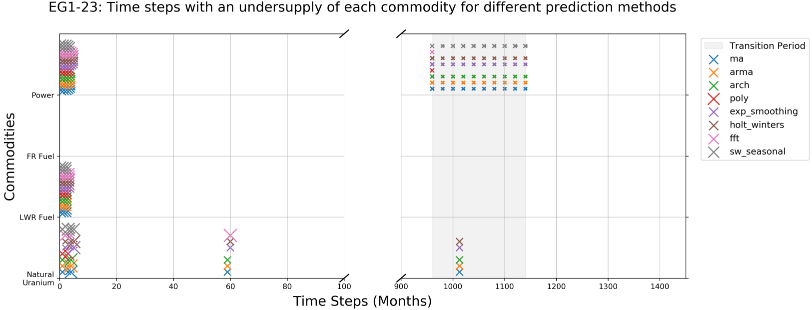


Figure 6: Time dependent undersupply of commodities for different prediction methods for the EG01-23 Transition Scenario with Constant Power Demand. The size of each cross is based on the size of the undersupply. Fewer crosses on plot indicates the method is more successful at preventing undersupply of each commodity

Comparison of Prediction Methods

EG01-24 Linearly Increasing Power Demand Transition Scenario

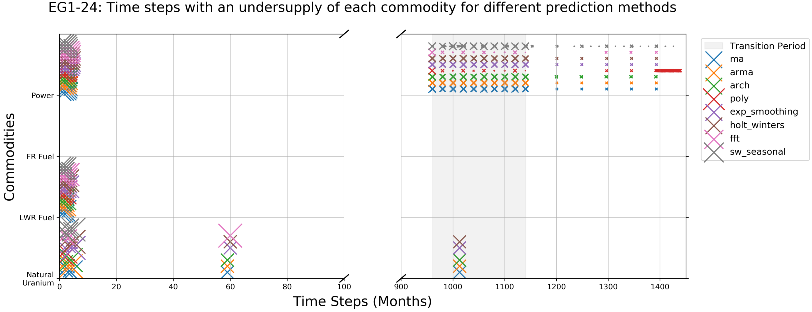


Figure 7: Time dependent undersupply of commodities for different prediction methods for the EG01-24 Transition Scenario with Linearly Increasing Power Demand.The size of each cross is based on the size of the undersupply. Fewer crosses on plot indicates the method is more successful at preventing undersupply of each commodity

Comparison of Prediction Methods

Main Takeaway

The best performing prediction method for each transition scenario is:

1. EG01-23 Constant Power Demand: Polynomial Fit
2. EG01-24 Linearly Increasing Power Demand: Fast Fourier Transform
3. EG01-29 Constant Power Demand: Polynomial Fit
4. EG01-30 Linearly Increasing Power Demand: Fast Fourier Transform

Sensitivity Analysis of Power Buffer

EG01-24: Linearly Increasing Power Demand

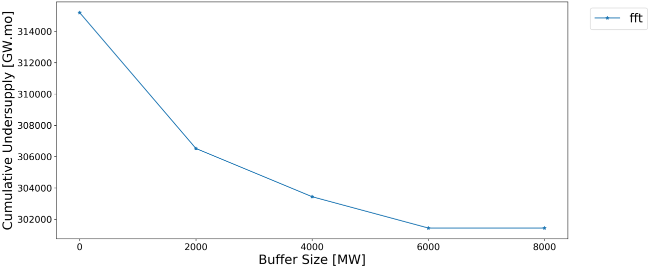


Figure 8: Sensitivity Analysis of Power buffer size on cumulative undersupply of Power for EG01-EG24 transition scenarios with linearly increasing power demand using the fft prediction method.

Sensitivity Analysis of Power Buffer

EG01-30: Linearly Increasing Power Demand

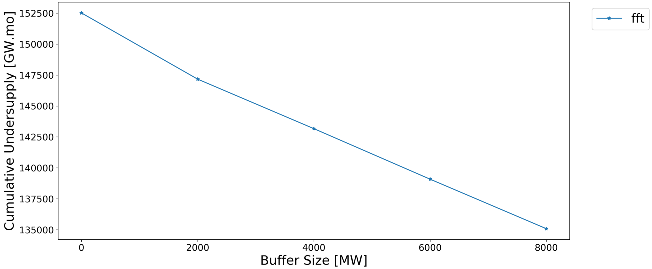


Figure 9: Sensitivity Analysis of Power buffer size on cumulative undersupply of Power for EG01-EG30 transition scenarios with linearly increasing power demand using the fft prediction method.

Sensitivity Analysis of Power Buffer

Main Takeaway

The best power supply buffer for each transition scenario is:

1. EG01-23 Constant Power Demand: 0 MW
2. EG01-24 Linearly Increasing Power Demand: 6000 MW
3. EG01-29 Constant Power Demand: 0 MW
4. EG01-30 Linearly Increasing Power Demand: 8000 MW

Best Performing Transition Scenarios

Input Parameters of best performing transition scenarios

	Input Parameter	Simulation Description			
		EG01-23	**EG01-24**	**EG01-29**	**EG01-30**
Required	Demand driving commodity	Power			
	Demand equation [MW]	60000	$60000 + 250t/12$	60000	$60000 + 250t/12$
	Prediction method	`poly`	`fft`	`poly`	`fft`
	Deployment Driving Method	Installed Capacity			
Optional	Buffer type	Absolute			
	Power Buffer size [MW]	0	6000	0	8000

Table 3: `d3ploy`'s input parameters for all 4 transition scenarios that minimizes undersupply of power and minimizes the undersupply and under capacity of the other facilities.

Best Performing Transition Scenarios

Undersupply and under capacity of commodities for the best performing transition scenarios

Table 4: Undersupply/capacity of commodities for the best performing transition scenarios.

	Undersupplied Time Steps			
Transition Scenario	EG01-EG23	EG01-EG24	EG01-EG29	EG01-EG30
Power Demand	Constant	Linearly Increasing	Constant	Linearly Increasing
Prediction Method	`poly`	`fft`	`poly`	`fft`
Power Supply Buffer [MW]	0	6000	0	8000
Commodities				
Natural Uranium	2	3	1	1
LWR Fuel	4	6	1	2
SFR Fuel	0	0	2	2
MOX LWR Fuel	-	-	2	2
Power	6	7	4	5
LWR Spent Fuel	1	1	1	1
SFR Spent Fuel	1	1	1	1
MOX LWR Spent Fuel	-	-	1	1

Best Performing Transition Scenarios

EG01-23: Constant Power Demand

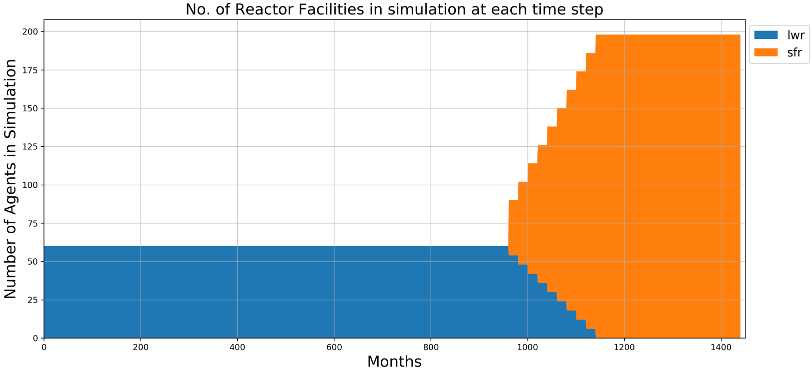


Figure 10: Time dependent deployment of reactor facilities in the EG01-23 constant power demand transition scenario. `d3ploy` automatically deploys reactor facilities to set up a supply chain to meet constant power demand of 60000 MW during a transition from LWRs to SFRs. Note: SFRs in this simulation have $\frac{1}{3}$ power capacity of PWRs.

Best Performing Transition Scenarios

EG01-23: Constant Power Demand

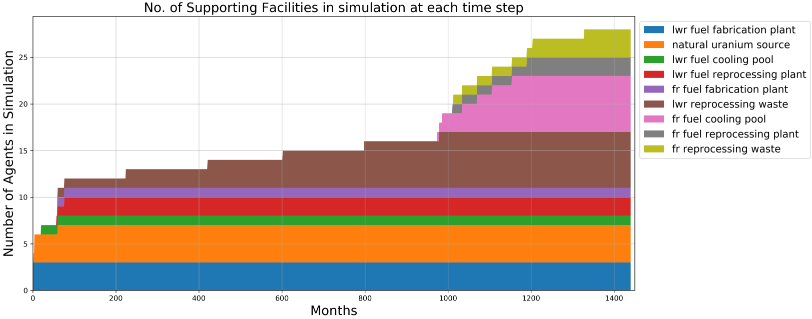


Figure 11: Time dependent deployment of supporting facilities in the EG01-23 constant power demand transition scenario. d3ploy automatically deploys reactor facilities to set up a supply chain to meet constant power demand of 60000 MW during a transition from LWRs to SFRs.

Best Performing Transition Scenarios

EG01-30: Linearly Increasing Power Demand

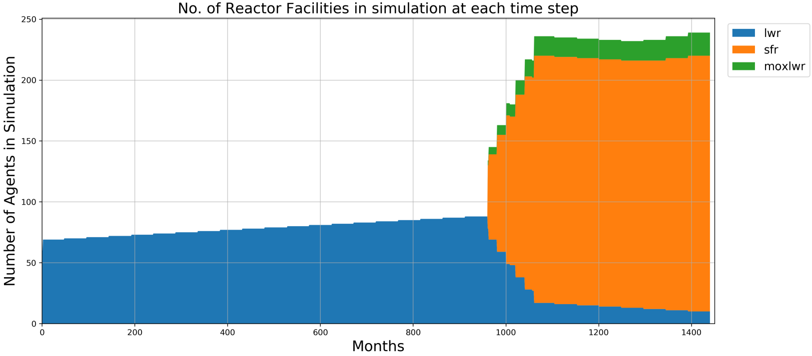


Figure 12: Time dependent deployment of reactor facilities in the EG01-30 linearly increasing power demand transition scenario. `d3ploy` automatically deploys reactor facilities to set up a supply chain to meet constant power demand of $60000 + 250t/12$ MW during a transition from LWRs to SFRs.

Best Performing Transition Scenarios

EG01-30: Linearly Increasing Power Demand

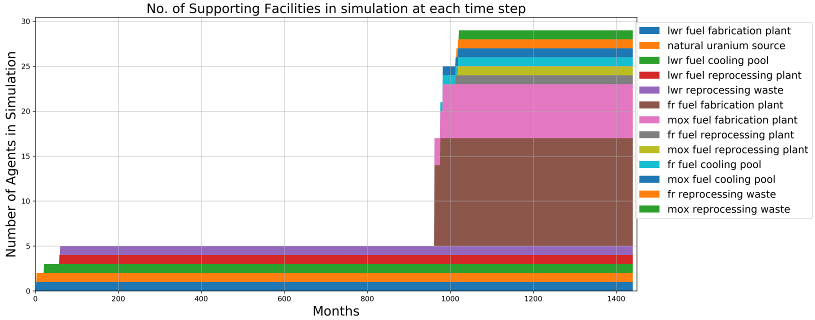


Figure 13: Time dependent deployment of supporting facilities in the EG01-30 linearly increasing power demand transition scenario. `d3ploy` automatically deploys reactor facilities to set up a supply chain to meet constant power demand of $60000 + 250t/12$ MW during a transition from LWRs to SFRs. Note: SFRs in this simulation have $\frac{1}{3}$ power capacity of PWRs.

Outline

Conclusion

These results demonstrate that by carefully selecting `d3ploy` parameters, we are able to **effectively automate deployment** of reactors and supporting facilities to simulate constant and linearly increasing power demand transition scenarios for EG01-23, EG01-24, EG01-29, and EG01-30 with minimal power undersupply.

Not completely eliminating undersupply and under capacity of commodities in the simulation is expected since without time series data at the beginning of the simulation, `d3ploy` takes a few time steps to collect time series data about power demand to predict and start deploying reactor and supporting fuel cycle facilities.

Future Work

`d3ploy` can be used to conduct nuclear fuel cycle **sensitivity studies**. One of the key issues facing nuclear fuel cycle transition scenario simulations is the presence of idle reactor capacity due to the lack of Pu to fabricate advanced fuels in the simulation. Previously, to conduct sensitivity analysis, the user would have to manually calculate the deployment scheme for every change in input parameter to avoid idle capacity.

Acknowledgement

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