Demand Driven Deployment Capabilities in Cyclus

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ILLINOIS

Outline

1. Background and Motivation
   - Cyclus
   - Goal
2. Method
   - d3ploy
3. Results
   - Comparison of Prediction Methods
   - Sensitivity Analysis of Power Buffer Size
   - Best Performing Transition Scenarios
4. Conclusion
   - Conclusion
   - Future Work

Cyclus

`Cyclus` is an agent-based nuclear fuel cycle simulator with a modular architecture.

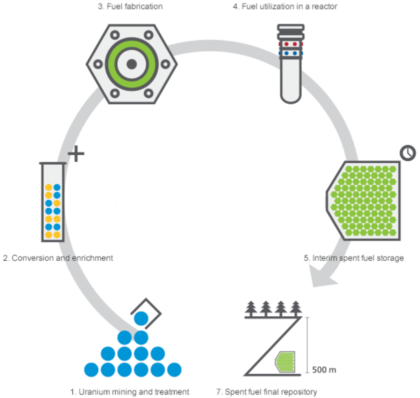

Figure 1: Once Through Nuclear Fuel Cycle [?]

Motivation

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

Figure 2: User defined Deployment Scheme

Bridging the gap: Developed demand-driven deployment capability in Cyclus. This capability is named `d3ploy`.

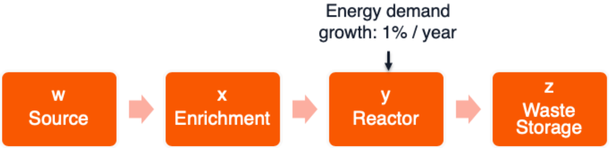

Figure 3: Demand Driven Deployment Scheme

Goals

Goals of this work

- Develop demand driven deployment capabilities in CYCLUS (`d3ploy`)
- Demonstrate the use of `d3ploy` to set up EG01-23, EG01-24, EG01-29 EG01-30 transition scenarios with constant and linearly increasing power demand curves.

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d3ploy Objectives

d3ploy's Main Objective

Minimize the number of time steps of undersupply or under capacity of power.

d3ploy's Sub-Objectives

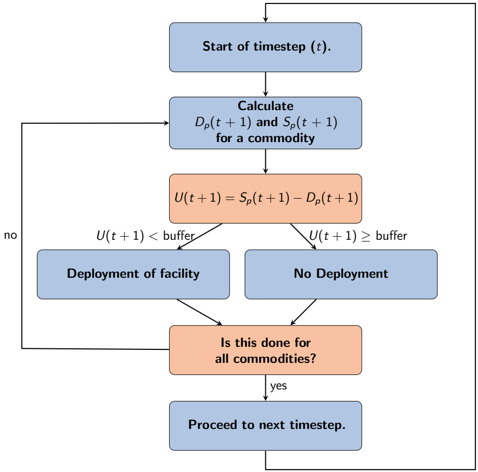
- Minimize the number of time steps of undersupply or under capacity of any commodity.
- Minimize excessive oversupply of all commodities

d3ploy Input Parameters

Table 1: d3ploy's required and optional input parameters with examples.

	Input Parameter	Examples
Required	Demand driving commodity	Power, Fuel, Plutonium, etc.
	Demand equation	P(t) = 10000, sin(t), 10000*t
	Facilities it controls	Fuel Fab, LWR reactor, SFR reactor, Waste repository, etc.
	Capacities of the facilities	3000 kg, 1000 MW, 50000 kg
	Prediction method	Power: fast fourier transform Fuel: moving average Spent fuel: moving average
	Deployment driven by	Installed Capacity/Supply
Optional	Supply/Capacity Buffer type	Absolute
	Supply/Capacity Buffer size	Power: 3000 MW Fuel: 0 kg Spent fuel: 0 kg
	Facility preferences	LWR reactor = 100-t SFR reactor = t-100
	Facility constraint	SFR reactor constraint = 5000kg of Pu

d3ploy logic flow



D_p : *PredictedDemand*
S_p : *PredictedSupply*
$U = S_p - D_p$

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
- Triple Exponential Smoothing (`holt-winters`)

Stochastic-Optimizing Methods

- Auto-Regressive Integrated Moving Averages (`ARIMA`)

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Breakdown of Results

The goal is to set up 4 transition scenarios in which undersupply and under capacity of all commodities is minimized.

1. EG01-23 Constant Power Demand
2. EG01-24 Linearly Increasing Power Demand
3. EG01-29 Constant Power Demand
4. EG01-30 Linearly Increasing Power Demand

This is achieved by:

1. Comparison of prediction methods for each of 4 scenarios is conducted to determine the best method.
2. Sensitivity analysis of power supply buffer is conducted to determine best buffer size.
3. Using best prediction method and buffer size, demonstrate `d3ploy` deploying reactor and supporting facilities to meet power demand for 4 scenarios.

Comparison of Prediction Methods

EG01-23 Constant Power Demand Transition Scenario

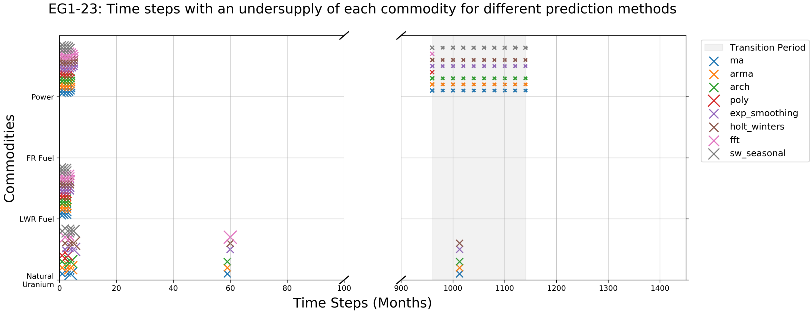

Figure 5: Time dependent undersupply of commodities for different prediction methods for the EG01-23 Transition Scenario with Constant Power Demand. The size of each cross is based on the size of the undersupply. Fewer crosses on plot indicates the method is more successful at preventing undersupply of each commodity

Comparison of Prediction Methods

EG01-23 Constant Power Demand Transition Scenario

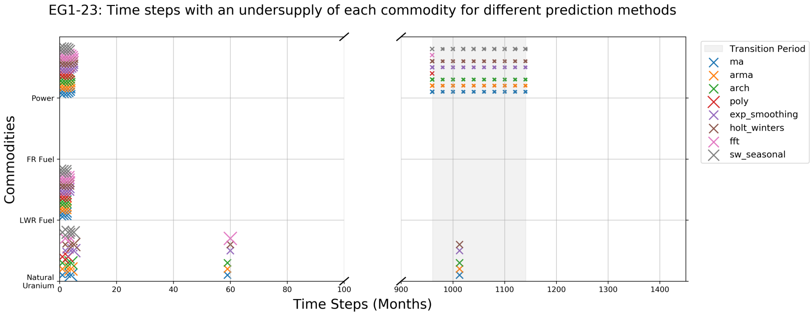

Figure 6: Time dependent undersupply of commodities for different prediction methods for the EG01-23 Transition Scenario with Constant Power Demand. The size of each cross is based on the size of the undersupply. Fewer crosses on plot indicates the method is more successful at preventing under capacity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

Comparison of Prediction Methods

EG01-24 Constant Power Demand Transition Scenario

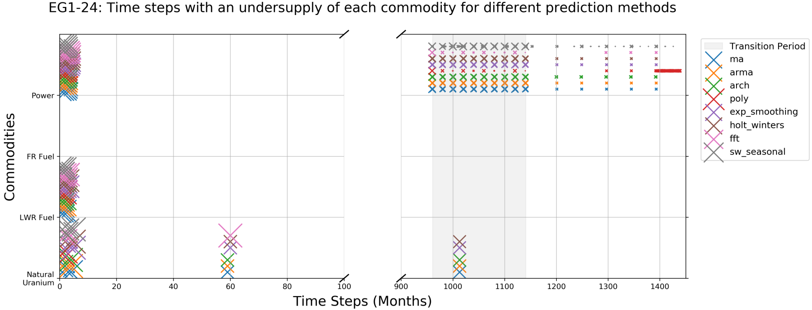

Figure 7: Time dependent undersupply of commodities for different prediction methods for the EG01-24 Transition Scenario with Linearly Increasing Power Demand.The size of each cross is based on the size of the undersupply. Fewer crosses on plot indicates the method is more successful at preventing undersupply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

Comparison of Prediction Methods

EG01-24 Constant Power Demand Transition Scenario

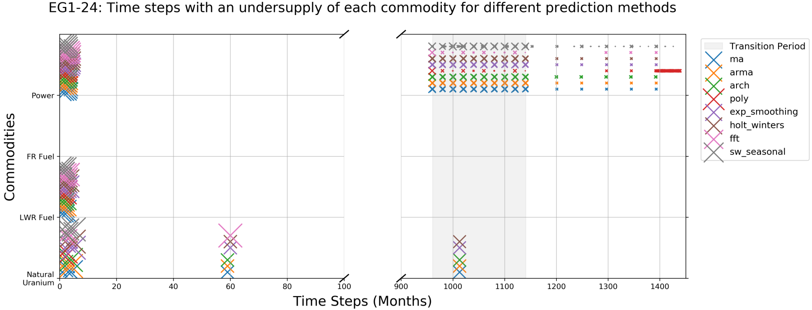

Figure 8: Time dependent undersupply of commodities for different prediction methods for the EG01-24 Transition Scenario with Linearly Increasing Power Demand. The size of each cross is based on the size of the under capacity. Fewer crosses on plot indicates the method is more successful at preventing under capacity 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: `poly`
2. EG01-24 Linearly Increasing Power Demand: `fft`
3. EG01-29 Constant Power Demand: `poly`
4. EG01-30 Linearly Increasing Power Demand: `fft`

Sensitivity Analysis of Power Buffer

EG01-24: Linearly Increasing Power Demand

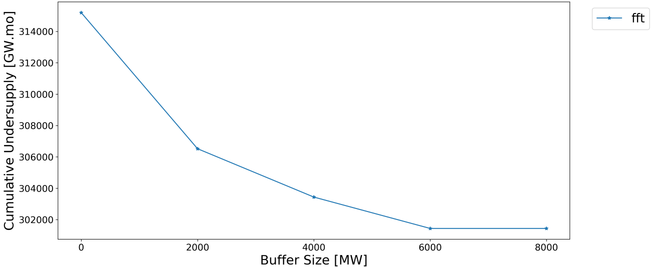

Figure 9: Sensitivity Analysis of Power buffer size on cumulative undersupply of Power for EG01-EG24 transition scenarios with linearly increasing power demand using the fft prediction method.

Sensitivity Analysis of Power Buffer

EG01-30: Linearly Increasing Power Demand

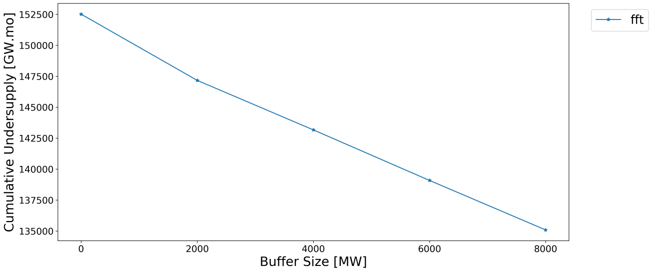

Figure 10: Sensitivity Analysis of Power buffer size on cumulative undersupply of Power for EG01-EG30 transition scenarios with linearly increasing power demand using the fft prediction method.

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 2: `d3ploy`'s input parameters for EG01-EG23, EG01-EG24, EG01-EG29, and EG01-EG30 transition scenarios that minimizes undersupply of power and minimizes the undersupply and under capacity of the other facilities.

Best Performing Transition Scenarios

EG01-23: Constant Power Demand

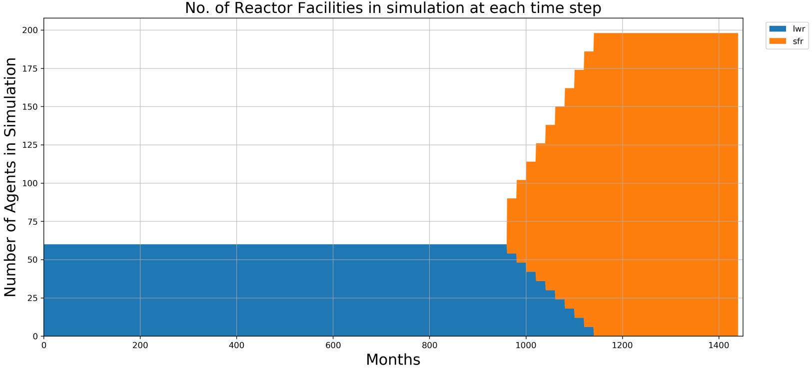

Figure 11: Time dependent deployment of reactor facilities in the EG01-23 constant power demand transition scenario. `d3ploy` automatically deploys reactor facilities to set up a supply chain to meet constant power demand of 60000 MW during a transition from LWRs to SFRs

Best Performing Transition Scenarios

EG01-23: Constant Power Demand

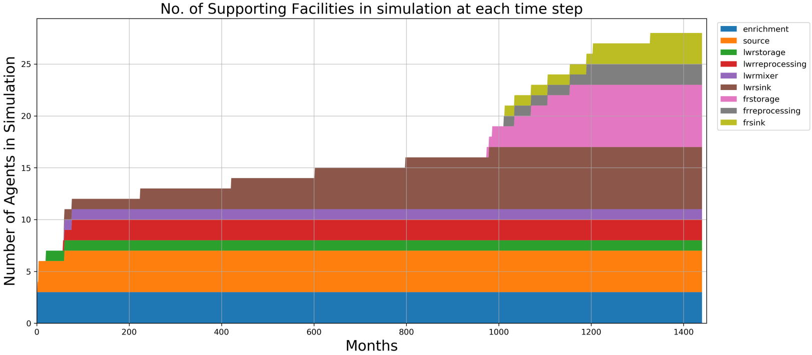

Figure 12: Time dependent deployment of supporting facilities in the EG01-23 constant power demand transition scenario. `d3ploy` automatically deploys reactor facilities to set up a supply chain to meet constant power demand of 60000 MW during a transition from LWRs to SFRs

Best Performing Transition Scenarios

EG01-30: Linearly Increasing Power Demand

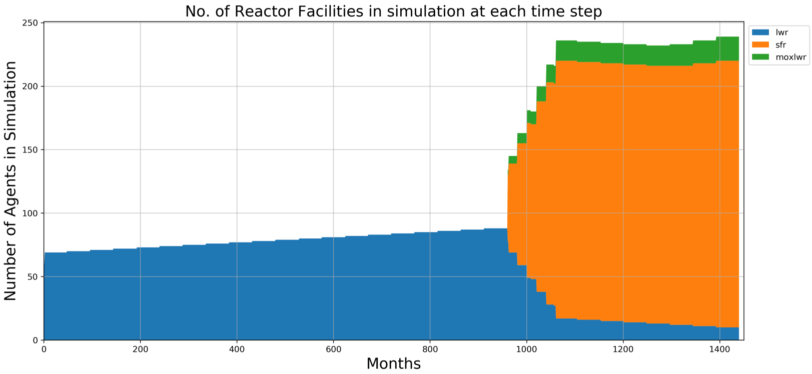

Figure 13: Time dependent deployment of reactor facilities in the EG01-30 linearly increasing power demand transition scenario. `d3ploy` automatically deploys reactor facilities to set up a supply chain to meet constant power demand of $60000 + 250t/12$ MW during a transition from LWRs to SFRs

Best Performing Transition Scenarios

EG01-30: Linearly Increasing Power Demand

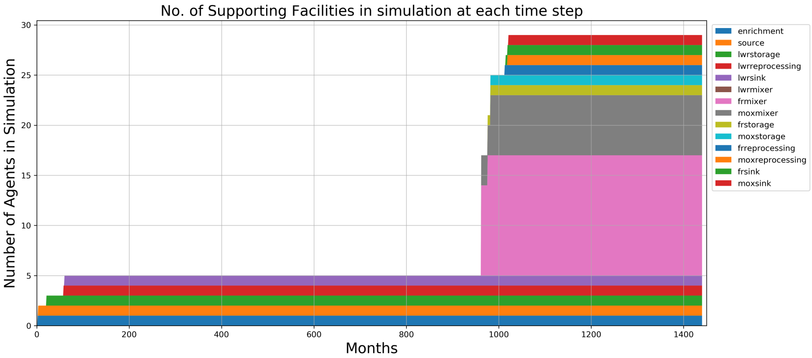

Figure 14: Time dependent deployment of supporting facilities in the EG01-30 linearly increasing power demand transition scenario. `d3ploy` automatically deploys reactor facilities to set up a supply chain to meet constant power demand of $60000 + 250t/12$ MW during a transition from LWRs to SFRs

Best Performing Transition Scenarios

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

Table 3: Undersupply/capacity of commodities for the best performing EG01-EG23,24,29,30 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

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Conclusion

These results demonstrate that by carefully selecting `d3ploy` parameters, we are able to **effectively automate deployment** of reactor and supporting facilities to set up 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.

Acknowledgement

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References I