Current Status of Predictive Transition Capability in Fuel Cycle Simulation

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Objectives

Identify flexible, general, and performant algorithms available for application to simulating demand-driven deployment of nuclear fuel cycle facility capacity in a fuel cycle simulator.

- Review nuclear fuel cycle simulator state-of-the-art.
- Investigate promising prediction algorithms.
- Identify algorithms successful in other domains.

Introduction

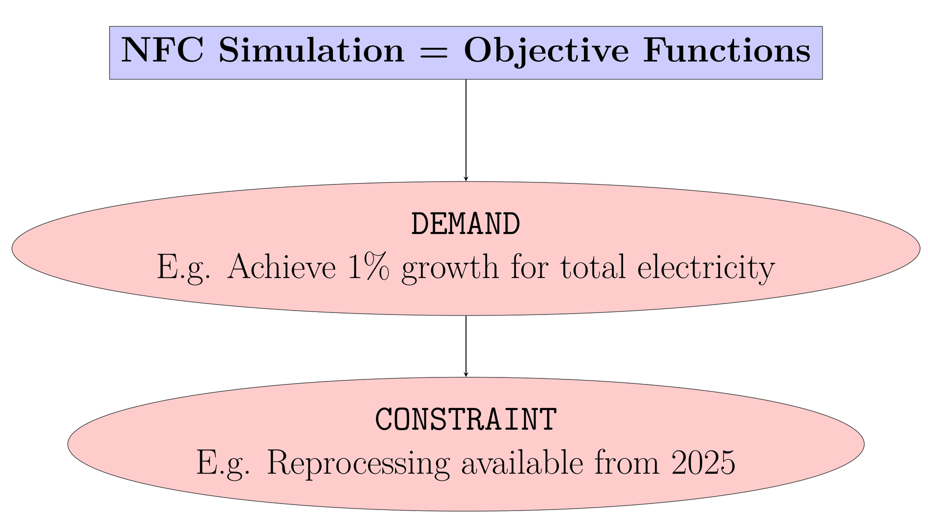

Figure: Nuclear fuel cycle scenarios are constrained objective functions.

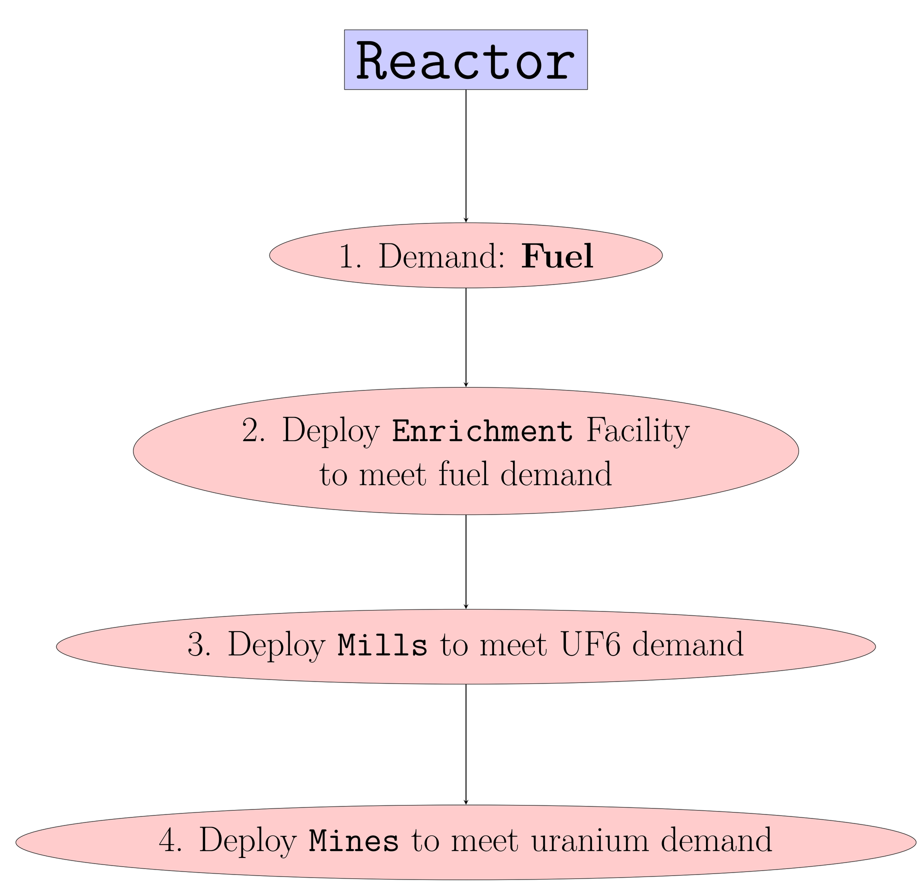

Figure: Dynamic deployment seeks to meet fuel demand.

Methods

A review of nuclear fuel cycle simulators (Table 1) and previous Nuclear Fuel Cycle gap analyses [3, 4, 18, 5, 13] distinguished existing simulators with regard to facility deployment and transition scenario capabilities. Capabilities were categorized as:

- **manual (MAN):** The user 'guesses' future deployment of reactor and facility.
- **proportional (PROP):** Deployment of fuel cycle facilities is in direct proportion with reactor deployments .
- **constrained reactor deployment (CONST):** Deployment of reactors is constrained by the existing and projected feedstock amounts.
- **predictive (PRED):** The simulator projects feedstock needs of current and future deployed reactors based on other heuristics and look-ahead predictions.
- **Demand-Driven (D-D):** The simulator deploys facilities according to demand

Simulator	Institution	Reactor	Facility
CAFCA [12]	MIT	MAN	MAN
CLASS [19]	CNRS/IRSN	MAN	MAN
COSI [6, 3]	CEA	D-D	PRED
Cyclus [14]	UW	D-D	MAN
DESAE [3]	Rosatom	MAN	MAN
DANESS [23]	ANL	D-D	PROP
DYMOND [20]	ANL	D-D	PRED
Evolcode[3]	CIEMAT	D-D	MAN
FAMILY [3]	IAEA	D-D	PRED
MARKAL [8]	BNL	D-D	MAN
NFCSim [21]	LANL	D-D	PRED
NGSAM [2]	ORNL	NONE	MAN
NUWASTE [10]	NWTRB	MAN	MAN
ORION [8]	NNL	CONST	PROP
VISION [8, 3]	INL	D-D	PROP
VISTA [15]	IAEA	D-D	PROP

Table: Simulators, categorized by their reactor and fuel cycle facility deployment strategies.

Promising Algorithms

Non-Optimizing (NO)

- Predict based on historical supply-demand data
- Does not attempt to meet demand optimally
- Fast execution time with limited precision
- E.g. Autoregressive Moving Average (ARMA), Autoregressive Conditional Heteroskedastic (ARCH)

Deterministic Optimizing (DO)

- Optimizes an objective function with set of constraints
- Replicable
- E.g. Global Change Assessment Model (GCAM), MARKet and ALlocation (MARKAL)

Stochastic Optimizing (SO)

- Probabilistic search into the objective function or constraint models
- Uncertainty in addition to mean
- Uses random samples from probability distributions
- E.g. Markov Switching-Model, Gaussian Process Regression

Successful Applications

These algorithms have succeeded for similar classes of problems in other domains, such as:

- lumber mill operations [25]
- weather-responsive building efficiency [11, 16]
- airline routing logistics [22]

Accordingly, their potential in nuclear fuel cycle analysis is promising.

Conclusion

The review concludes that fuel cycle simulation tools approach scenario objective functions by

- wrapping in an external optimizer
- or predicting deployment strategy with look-ahead methods.

Deployment models differ in terms of compute speed, flexibility (in terms of the range of scenarios capably simulated), **and robustness** (in terms of consistent fidelity of the modeling results). Finally, current NFC simulators may more flexibly support demand-driven deployment through incorporation of non-optimizing algorithms such as ARMA [24] and ARCH [17], deterministically optimizing methods such as those collected in GCAM [7] and MARKAL [9], or stochastic optimization techniques such as Markov Switching Models [1]. Such algorithms succeed in other fields.

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