GENIUSv2 Discrete Facilities/Materials Modeling of International Fuel Cycle Robustness

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I. INTRODUCTION

The GENIUS project (Global Evaluation of Nuclear Infrastructure Utilization Scenarios) was conceived as the top-level nuclear enterprise simulation tool in the Simulation Institute for Nuclear Enterprise Modeling and Analysis (SINEMA) framework[1]. The current version, GENIUSv2, is an object-oriented C++ application with Python-based pre- and post-processing.

The GENIUSv2 fuel cycle tool proposes to inform nuclear fuel cycle technology and policy by providing a richly detailed, modular platform capable of dynamically modeling inter-regional and inter-institutional relationships and incorporating user-defined, facility specific technologies.

Here we present results from the GENIUSv2 testing suite demonstrating the detailed, robust and modular nature of its modeling capability and computational methodology.

II. MODELING & METHODOLOGY

II.A. Regions, Institutions, and Facilities (R-I-F)

GENIUSv2 employs the hierarchical inheritance paradigm of C++ to model the real-world hierarchy of regions (e.g. nations), institutions (e.g. utilities), and individual facilities (mines, reactors, etc.). GENIUS also employs a ‘discrete-facility, discrete-materials’ (DF/DM) approach that models individual nuclear energy systems at the facility level and records material flows at isotopic resolution, facilitating detailed comparison of different fuel cycle technologies and combinations thereof. This discrete approach is more informative than fleet-based approaches which fail to incorporate technological heterogeneity of real-world facility deployment and dynamic inter-/intra-regional dependencies.

II.B. Materials Routing Problem (MRP)

The R-I-F framework also provides the mechanism for matching transactions of discrete quanta of nuclear material between individual supplier and customer facilities. Transactions are handled by a materials routing formulation in which facilities send material orders to one another by writing an offer of, or request for, material. This message is passed up the hierarchy to the simulation manager, which performs a matching algorithm on the set of messages based on some set of rules (II.C.) Once matched, the manager then passes instructions back down the hierarchy to the appropriate facilities.

II.C. Customer-Supplier Matching

The GENIUSv2 Network Flow algorithm treats facilities of the fuel cycle as nodes—sources (supplier nodes) and sinks (customer nodes) for the flow of commodities (yellowcake, unenriched UF_6, fuel, etc.) along arcs connecting compatible source and sink facilities.

Currently, arc costs reflect user-defined *affinities* for trade between elements in the R-I-F hierarchy. Default behavior assumes facilities owned by the same institution have a higher affinity for trading with one another than facilities owned by two different institutions, and facilities in the same region have a higher affinity than facilities in two different regions. Affinities at the very high and low ends of the scale can be used to model long-term contracts and embargos, respectively.

III. THREE REGION SCENARIO

From the GENIUSv2 test and demonstration suite we present two once-through problems that demonstrate GENIUSv2’s ability to handle large scenarios and highlight the richness and flexibility of the R-I-F model and our MRP solution.

Two regions with different electricity demands contain three institutions: two fuel fabricators (one small and one large) and a reactor operator which builds PWRs to match each region’s linear demand curve. The third region contains only a large fabricator.

In the first problem, the MRP is solved according to the default affinities described in *II.C.* In the second problem two rules alter the default behavior: Institutions 1 and 4 (the reactor operators) are preferentially matched with Institution 7 (the extra-regional fuel fabricator) as if they were all the same Institution. This affinity assignment could represent a long-term contract, an institution merger, or perhaps some price advantage benefiting Institution 7. Figure 1 shows the cumulative travel of fabricated fuel from the various suppliers to the reactor fleet in the two different problems. At top, we see the default behavior; the extra-regional fabricator is the supplier of last resort and is only purchased from when the fabricators in the reactor regions are already selling at capacity. Conversely, the bottom plot shows that the foreign fabricator is preferred in the second problem.

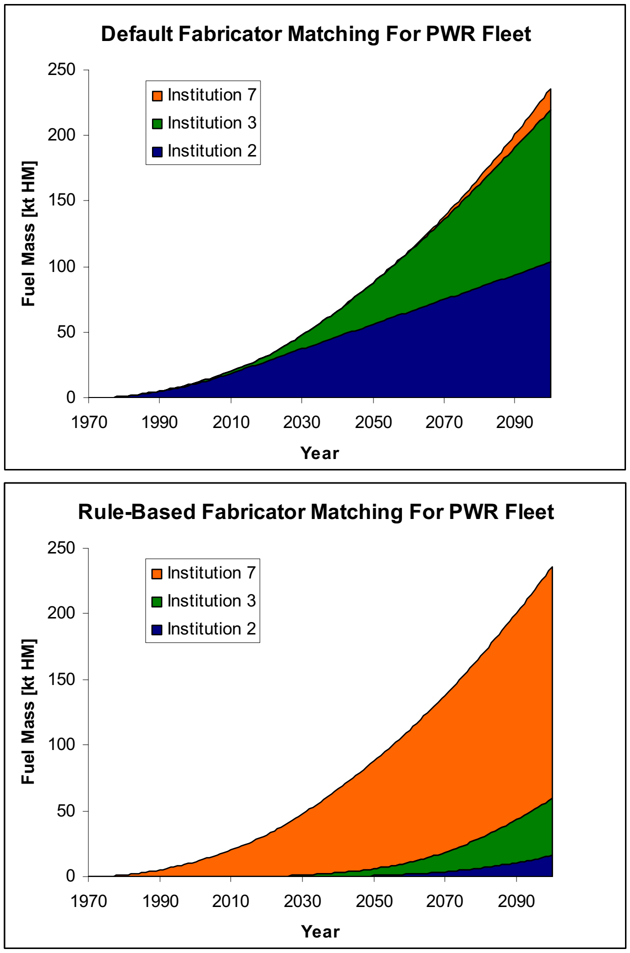

Fig. 1. Change in matching of PWR fuel fabricators to reactors placing orders. When the reactor operator's affinity for trade with Institution 7 is increased sufficiently, it becomes the favored supplier even though it's located in another region.

IV. CONCLUSIONS

We conclude from this work that GENIUSv2 is sufficiently detailed to investigate standard nuclear fuel cycle scenarios, sufficiently robust to store and process the large amount of data that accumulate when discretely modeling those scenarios, and sufficiently flexible to model technical and socio-economic relationships between the various entities in a region-institution-facility hierarchy. The test suite also demonstrates how the R-I-F hierarchical matching framework, under carefully chosen arc costs, has the potential to help policy makers understand the effects of tools like trade agreements, tax incentives, long-term contracts, and other mechanisms.

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