The Decay Vendor: A Stochastic Model for Medical Radioisotope Supply Chains

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Introduction

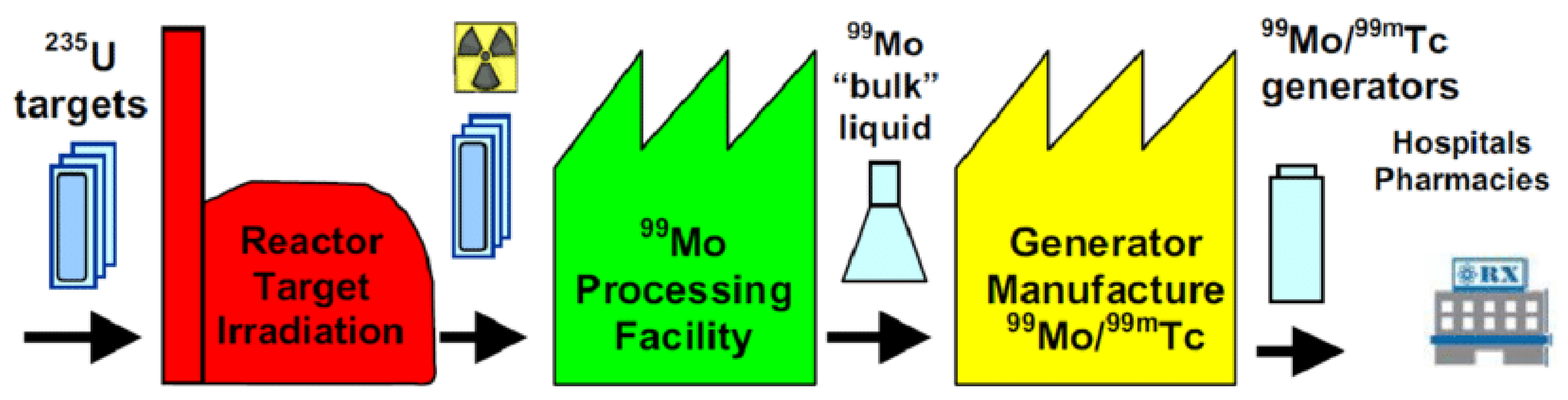
The Mo-99 and Tc-99m supply chain has been disrupted and challenged throughout the past decade. Supply chain variability and uncertainty is typically resolved with buffers in capacity, inventory, and time[1]. Given the decay and criticality of the product; inventory and time buffers are costly. Capacity buffers are being created with the development of new reactor- and non-reactor based projects worldwide[2].

Another way to increase effective capacity is by reducing the throughput time of the product. A simulation model of the entire supply chain can help increase transparency, supply chain performance, and coordination with downstream participants.

The "decay vendor" is based on the classical newsvendor model used in operations management to determine the optimal inventory level of a perishable product. The newsvendor model is used as a basis for more complex models in various fields and applications. Our model will serve as a building block for modelling the Mo-99 and Tc-99m supply chain.

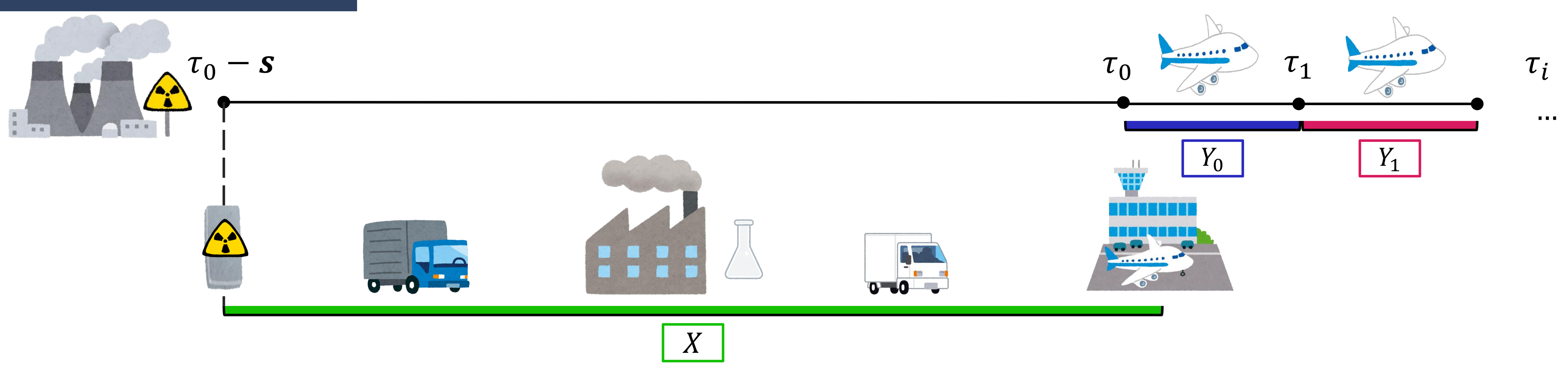
Objectives

- Calculate the expected inventory given a decaying product, a stochastic process, the process start-time, and a fixed critical event
- Create the foundation for modelling a supply chain of a radioactively decaying product
- Compare two policies for determining the process start time
- This model is an initial step in a PhD project to create a discrete-event simulation tool of the entire Mo-99/Tc-99m supply chain.



Visualization of the steps in an Mo-99/Tc-99m supply chain[3]

Model



Description

Suppose, a decay vendor needs to deliver a radioactively decaying product to a critical event (τ_0) that has an uncertain departure (Y_0). The entire process leadtime (X) of manufacturing, transportation, and delivery to the event is stochastic. There are back up events in case the delivery does not arrive on time. These events (τ_i) also have their own uncertain delays (Y_i). Once the process starts (s) relative to the critical event, the product begins decaying. If the process starts a lot earlier than the event, then it decays while waiting for departure. Inversely, starting the process too close to the event risks missing it and waiting for the next one.

When should production of a decaying product start in order to maximize the amount of viable inventory at a critical event?

Policies

Naive Heuristic: start time is calculated based on the distribution of x and y

$$s = \mathbb{E}[X] - \mathbb{E}[Y_0] + 2\sqrt{(\sigma_x^2 + \sigma_{y_0}^2)}$$

Maximize Inventory: start time is found by optimizing for the maximum expected inventory

$$I(s) = \mathbb{E}\left[I_0 e^{-\lambda A}\right]$$

$$s_I^* = \operatorname{argmax} I(s)$$

Equations for age (A) and inventory (I):

$$I = I_0 e^{-\lambda A}$$

$$A(s) = \begin{cases} s + Y_0 + \tau_0, & X \le s + Y_0 + \tau_0 \\ s + Y_i + \tau_i, & s + Y_{i-1} + \tau_{i-1} < X \le s + Y_i + \tau_i \end{cases}$$

Initial Results

The numerical experiment consisted of 3,721 combinations of flight schedules and distributions of X and Y.

Parameters	
X μ	24, 36, 48
X cv	.25, .5, .75
Y μ	1/60, .5, 1
Y cv	5/60, 15/60, 30/60
flights a day	1, 2
next flight	2, 8, 12, 16, 22, 24

On average, the naive heuristic policy delivers **60.03%** of the initial inventory and the maximize expected inventory policy delivers **64.90%** of the initial inventory.

The optimal policy (maximize inventory) performs **7.5%** better than the heuristic policy. The optimal policy performs better than the naive heuristic the coefficient of variation of X is. In some cases, the optimal policy can even deliver 17.6% more inventory.

Future Work

- Increase model complexity (e.g., multi-echelon, multi-stage)
- Simulate various steps and entirety of Mo-99 supply chain
- Create disruption and cost scenarios of varying levels of severity and impact to explore with the model
- The PhD and future model(s) aim to identify innovative solutions for improving the coordination, security, available inventory, and resilience of the supply chain.

References

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[3]Corbière, F., Deltour, F., Geffroy, B., Bretesché, S. & Lairet, G. (2013). *Managing risks across organizational actors boundaries: the case of the medical nuclear supply chain.* 29th European Group for Organizational Studies Colloquium.

Molybdenum-99 International Symposium – 05/10/2022 – This project is funded by the EU-QUALIFY project