



Predictive Smart-Spill Scheduling: Minimizing Dead Time In Synchrotron-Based Spot Scanning Via Look-Ahead Energy Management

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ABSTRACT

Synchrotron-based proton spot scanning includes non-productive dead time from layer switching and spill change / synchrotron reinjection¹. Spill changes are commonly triggered only after beam exhaustion, causing sequential overheads.

OBJECTIVES

We propose a predictive Smart-Spill strategy that initiates spill changes earlier so the spill change can be overlapped with unavoidable dead time, reducing total delivery duration without compromising plan integrity².

METHODS

DIGITAL TWIN SIMULATOR

A high-fidelity model of the TPS ↔ DCS timing handshake, explicitly modeling layer-switch latency, spill change and synchrotron reinjection, and PST off/on events at break spots.

COST-BASED LOOK-AHEAD

At each candidate layer transition, the optimizer evaluates whether initiating a spill change in advance allows layer-switch or break-spot dead time to be absorbed into the spill-change interval, converting sequential delays into parallel background operations.

SAFEGUARD HEURISTIC

Optimization is permitted only when the ratio of beam wasted to maximum available beam is smaller than the ratio of time saved to spill-change duration, preventing excessive beam loss that could otherwise force an additional spill cycle.

RESULTS

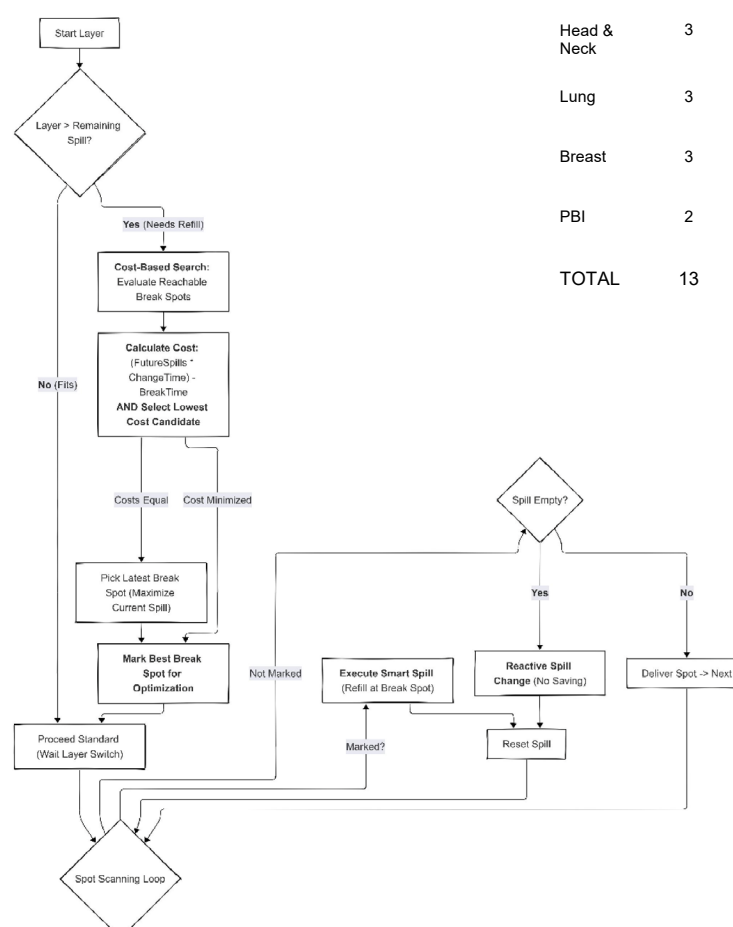
Five clinical proton cases (Prostate SBRT, Head & Neck, Lung, Breast, PBI). Total delivery time = beam + modeled dead time, summed across all fields.

Total dead time absorbed: 3.27s

Proactive triggers fired: 13

Cases with extra spill cycles: 0

ALGORITHM



Case	# Fields	Standard (s)	Smart-Spill (s)	Saved (s)	%
Prostate SBRT	2	79.74	78.49	1.26	1.57%
Head & Neck	3	123.92	123.42	0.50	0.41%
Lung	3	59.71	59.71	0.00	0.00%
Breast	3	250.88	249.62	1.26	0.50%
PBI	2	34.42	34.16	0.25	0.73%
TOTAL	13	548.67	545.40	3.27	0.60%

CONCLUSIONS

Predictive Smart-Spill scheduling provides a software-only, plan-dependent reduction in synchrotron spot-scanning dead time, with safeguards that prevent increases in delivery time.

REFERENCES

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2. Liang X, Liu C, Furutani KM, et al. Investigation of beam delivery time for synchrotron-based proton pencil beam scanning system with novel scanning mode. *Phys Med Biol*. 2022;67(17). doi:10.1088/1361-6560/ac8410