Log File-Based Automated Parsing and Statistical Process Control of Adaptive MR-Guided Radiotherapy Workflows

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ABSTRACT

Purpose:
MR-guided radiotherapy, especially adaptive therapy, involves complex, multi-stage clinical workflows that are challenging to quantify using conventional manual metrics. In-depth, quantitative, understanding of the clinical workflow can provide crucial insights to identify bottlenecks and improve operational efficiency. This work developed a machine log file-based automated tool to automatically derive clinically meaningful workflow timelines during the entire treatment process and to assess workflow quantitatively using statistical process control (SPC) methods.

Methods:
Machine log files from a clinical 0.35 T MR-linac (March to October 2025) were extracted and parsed to identify time-stamped events corresponding to imaging, patient positioning, adaptive planning, and treatment delivery. These events were mapped to discrete workflow intervals, including MRI simulation duration, positioning and setup time, adaptive planning duration, geometry approval time, plan review time, beam-on time, and treatment interruptions. Time intervals were aggregated across treatment sessions and analyzed using control charts and descriptive statistics to quantify variability and identify outliers. Data acquired from machine commissioning and QA were excluded to reflect routine clinical operation.

Results:
Automated parsing and log-derived workflow intervals enabled objective quantification of multiple components of the adaptive radiotherapy process without manual data collection. Adaptive planning-related intervals exhibited the greatest variability relative to imaging and delivery components. Control charts revealed stable operating ranges for several workflow stages while highlighting sessions exceeding expected duration thresholds. Across all analyzed MR simulations (N = 470), mean simulation duration was 19.31 minutes, with 8 (1.70%) cases exceeding 30 minutes. Across all analyzed adaptive sessions (N = 378), mean adaptive planning duration was 33.42 minutes, with 16 (4.23%) cases exceeding 1 hour.

Conclusion:
Automated log file analysis enables scalable, objective characterization of MRgRT workflows. Together with SPC, the tool enables medical physicists to monitor workflow stability, identify deviations, and support data-driven quality assurance and continuous process improvement in MR-guided radiotherapy.

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Innovation/Impact

Adaptive MR-guided radiotherapy workflows involve numerous interdependent steps spanning imaging, positioning, adaptive planning, and treatment delivery. Quantitative assessment of these workflows has traditionally relied on self-reported timestamps or limited cohort analyses, restricting scalability and reproducibility. This work introduces an automated framework that leverages routinely collected MR-linac machine log files to derive clinically meaningful workflow time intervals and apply statistical process control (SPC) methods to adaptive radiotherapy operations. By mapping specific machine log events to discrete workflow milestones, treatment sessions can be decomposed into standardized temporal components, including MRI simulation, positioning and setup, adaptive planning, geometry approval, plan review, beam delivery, and interruption-related delays. This enables objective and reproducible measurement of workflow performance across large numbers of treatment sessions without additional clinical burden. The application of control charts to these log-derived intervals provides a physics-led approach to evaluating workflow stability and variability. Rather than focusing on individual treatment sessions in isolation, this methodology characterizes expected operating ranges for each workflow component and highlights deviations that may warrant further investigation. These tools extend quality assurance concepts familiar to medical physicists beyond dosimetric and geometric metrics to encompass operational workflow performance.

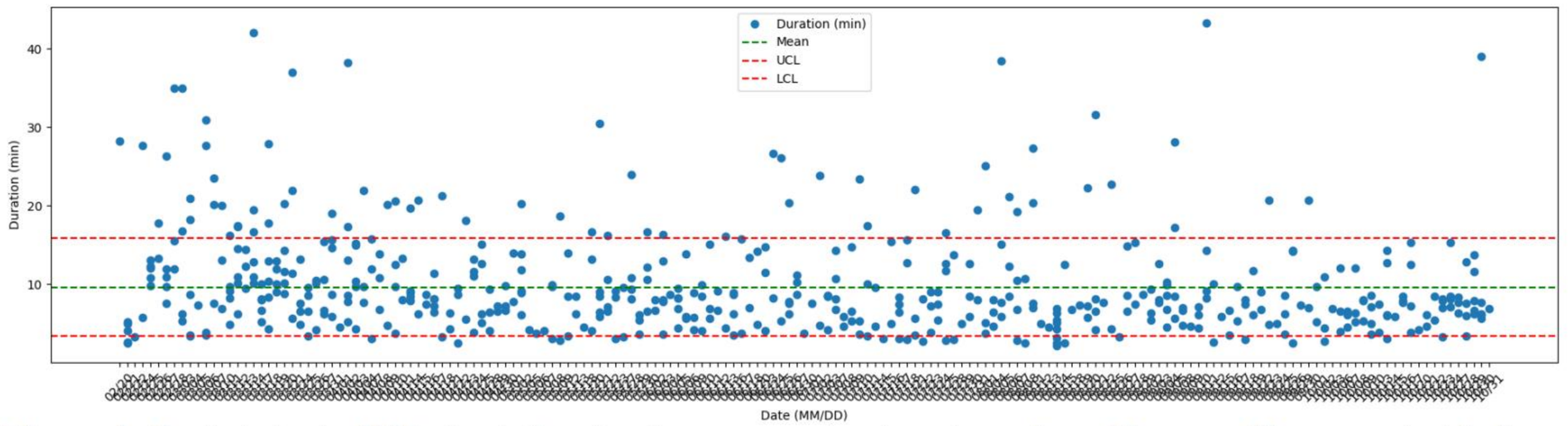

Figure 1: Control chart of MR simulation durations across treatment sessions. Upper and lower control limits are one standard deviation from the mean.

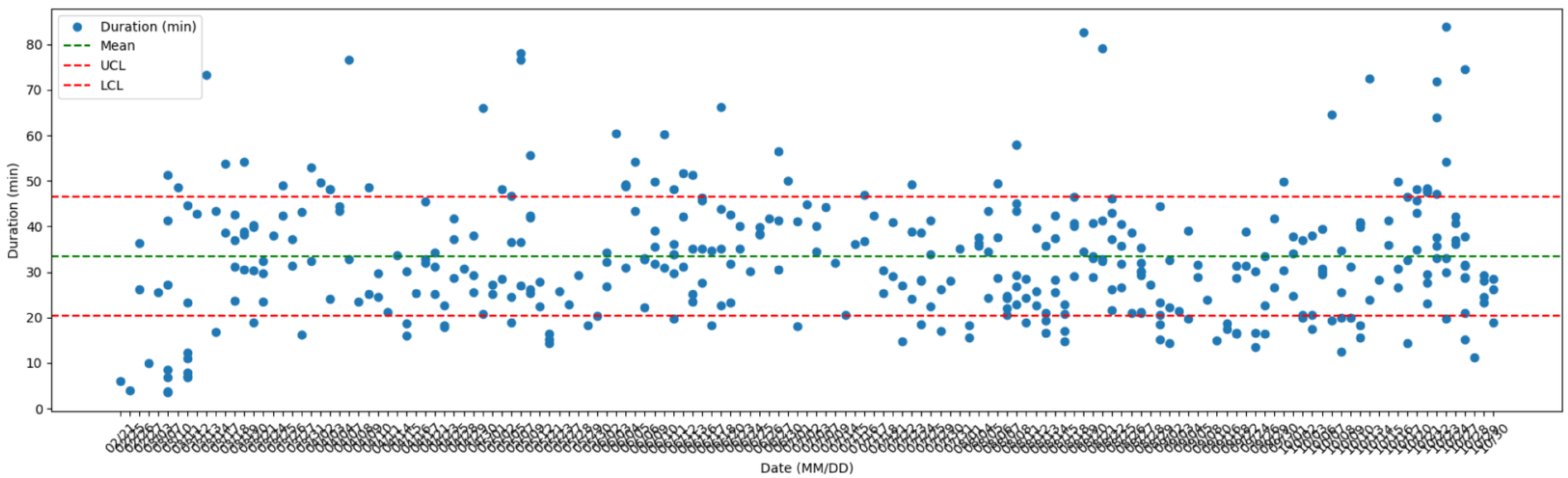

Figure 2: Control chart of adaptive planning durations across treatment sessions. Upper and lower control limits are one standard deviation from the mean.

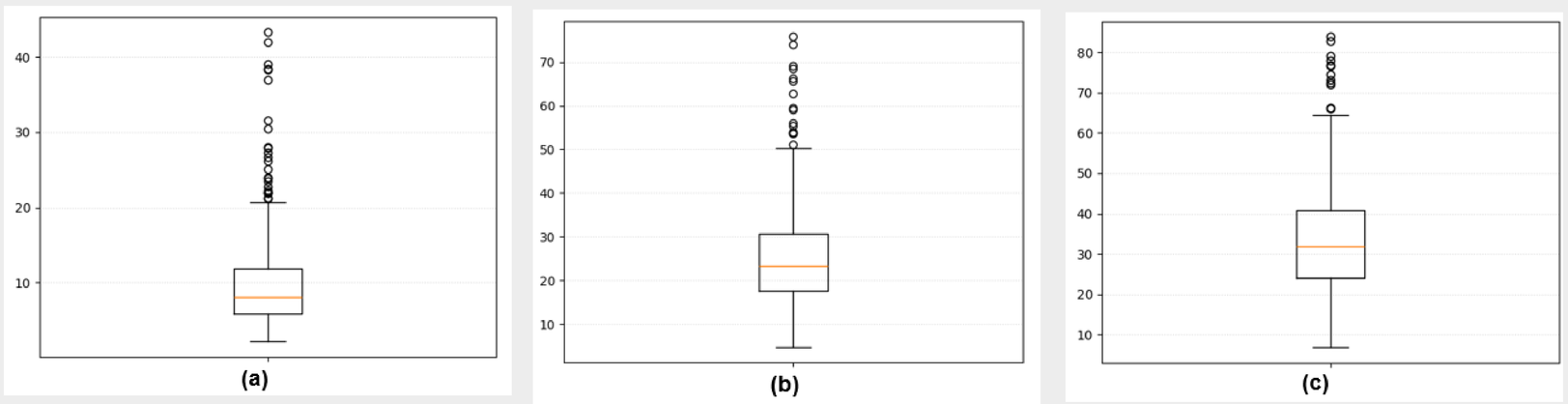

Figure 3. Box plots of example MR-guided radiotherapy (MRgRT) sub-process durations. **(a)** Simulation scans. **(b)** Online adaptive contouring. **(c)** Online adaptive planning and delivery.