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Short communication

Workflow optimization for robotic stereotactic radiotherapy treatments: Application of Constant Work In Progress workflow☆

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ABSTRACT

We present an application of the industrial Constant-Work-In-Progress (ConWIP) principle to radiotherapy treatments: from Operations Research to application in practice.

Radiotherapy involves a chain of preparation steps before treatment. The time periods between patient referral, initial Computed Tomography (CT) scan, and the treatment should always be as short as possible. This is important in order to not allow further tumor growth and to capture the correct patient anatomy for the treatment. Therefore, the high-in-demand limited machine capacity and scheduling of intermediate steps have to be balanced. Conventionally, the treatment machine calendar is consulted for an open spot and the preparation steps are scheduled around that appointment.

Conventional radiotherapy treatment scheduling is efficient in a predictable and low variability environment. Yet it is very inefficient for stereotactic radiotherapy treatments, due to the presence of (a) large variability in preparation time, (b) variable In Room Time especially for liver and lung treatments, which becomes known only right before the treatment, and (c) a high rate of cancellations. The end result is a suboptimal capacity use and high stress load for all personnel.

We present a different organization method, a hybrid ConWIP system utilizing standardized work: managing work-in-progress instead of scheduling all steps. Discrete Event Simulations were performed before implementation in order to test the hypothesis and obtain the optimal parameters. Treatment type distribution was as follows: lung (29%), liver (21%), intracranial (13%), head and neck (11%), prostate (7%) and 20% other localizations. Implementation of this ConWIP workflow was supported by workflow software (RT-Flow) combining workflow, prioritization and load balancing. This resulted in a 32% (24%–40%) (95% CI) increase in number of treatments for the CyberKnife® installation with a negligible increase in time from CT to treatment and an improved stress load for personnel.

1. Introduction

In Radiation Oncology, the time between first symptom and the end of treatment is of great importance [1–4]. However, before the treatment can start, a lot of preparation steps have to be performed. Moreover, the treatment machine capacity is in high demand, limited, and very expensive. Therefore, the machine capacity utilization has to be optimized and balanced with the preparation time and quality of the treatment plan. As the demand is not constant and there is a lot of variability present, the capacity should surpass the demand [5].

In a conventional radiotherapy workflow (Fig. 1), the schedule of the treatment machine is consulted for availability when patients are referred to the radiotherapy department [6]. Using this appointment date, a Computed Tomography (CT) scan is scheduled: a representation of the patient anatomy to be treated. Often, in the case of fiducial implants, the CT should be scheduled 2 weeks after the interventional radiology procedure (fiducial settlement). This CT simulation scan should not be too soon before treatment in order for it to reflect the real anatomy. But also not too late, in order to have time to perform the intermediate steps. Often, additional exams are required too (MRI, PET/CT, etc.). After the CT, the patient file is passed along through the department: staff meeting, organs at risk contouring, prescription, treatment planning (dosimetry), and approvals. This involves a variety of personnel groups (schedulers, technologists, MDs, MD interns, dosimetrists, physicists, etc.). The treatment is delivered in 1, 3, 5,

☆ Abbreviations: IRT = In Room Time; CK = CyberKnife; CT = Computed Tomography; ConWIP = Constant Work In Progress.

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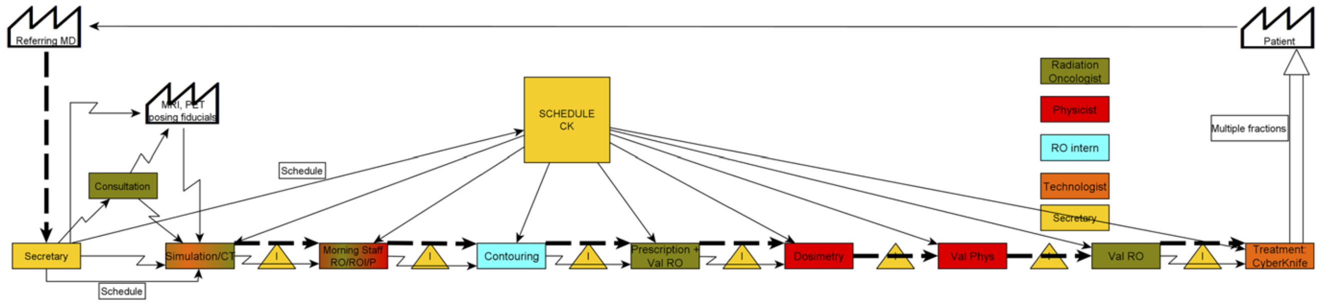

Fig. 1. Conventional workflow in radiotherapy: the machine schedule governs the timing of all other steps.

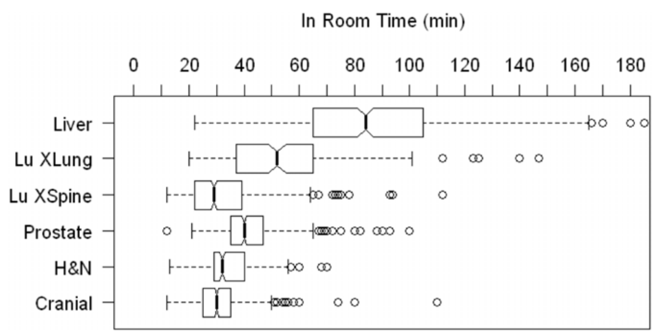

Fig. 2. Boxplot of the in-room time variations among indications (all fractions confounded, for more detailed information, please see Ref. [11]). Abbreviations: Lu XLung: lung treatments using XSight Lung tracking; Lu XSpine: Lung treatments using Xsight Spine setup; H&N: Head and Neck.

6, or more fractions, depending on the indication, every other day. The different fractions have to be performed consecutively due to radiobiological reasons [7].

At our department, a wide variety of disease sites are treated with stereotactic body radiotherapy (SBRT) with CyberKnife® (Accuray Incorporated, Sunnyvale, CA) [8–10]: lung (29%), liver (21%), intracranial (13%), head and neck (11%), and prostate (7%). The analysis of the In-Room Times (IRT) and technical interventions were the subject of a previous study [11]. It showed large differences in IRT among indications, but also large variability of IRT within each indication, as represented in Fig. 2. There were also variations between first and other fractions (not shown here).

The goal of the current study was to obtain a more efficient workflow by applying Industrial engineering techniques [12–14]. A commonly investigated solution is the application of optimization algorithms for scheduling. The drawback of these is that they are hard to implement in reality, both due to reluctance of people but also small unexpected issues not taken into account beforehand.

2. Material and methods

2.1. Conventional workflow and pull workflows: Kanban, ConWIP

Conventional radiotherapy workflow is based on the schedule of the final step: the machine schedule. Most other steps are retro programmed from this schedule. This conventional organization is depicted in Fig. 1.

A Kanban system (also known as Just In Time system), as used commonly in industrial production [12], is a pull system ideal in a repetitive, constant work pace environment. Need for work is signaled downstream through cards. Each workflow step indicates to the preceding step if that step may work: the work is limited between each process step by a number of cards. This system strives toward a zero inventory environment and regulates the work between several production steps. However, this is not ideal in an environment with job orders with non-constant work pace [12].

In a ConWIP system (Constant work in progress) [15], new work can only be released into a chain when other work in progress has finished the whole line. A comparison can be made with tunnel management: in order to prevent traffic jams inside the tunnel when a certain limit of cars are inside the tunnel, only when a car has left the tunnel, a new one may enter, taking into account that a truck is not the same as a motorcycle or car. A ConWIP system can be seen as a generalized form of Kanban system: the last step in the chain indicates when new work may be released at the start of the chain. Naturally, a ConWIP system will follow the "bottleneck" rule [16]: there will be just enough WIP to keep the bottleneck system occupied, meaning idle time for other (faster) steps. As such, a ConWIP system shares the advantages of a Kanban system with more leniencies for a non-constant work pace environment.

2.2. Discrete Event Simulations

Discrete Event Simulation software [17,18] (DES) was written in Python, using the SimPy package. All delay distributions and (if possible) distribution fits per indication and workflow step were measured and modeled into a database. Analytical fitting results (gamma distributions) for IRTs were taken from [11]. Simulation results were evaluated in steady state, simulating several years.

Simulations were performed to assess (a) conventional scheduling: raising the occupancy by overbooking and thus creating waiting times for patients in the waiting room just before treatment, (b) ConWIP workflow: WIP level, occupancy, and the time between CT and treatment.

2.3. Workflow software: RT-Flow

As the ConWIP process is not common in healthcare, the RT-Flow workflow software was created in collaboration with Surgiqual Institute (Grenoble, France). RT-Flow supports both conventional and the ConWIP process and combines this with prioritization and load balancing (multiple machines). The goal of the software was the implementation of rules, semi-automated optimization of machine load/delays and visualization for personnel.

3. Challenges faced

3.1. Conventional workflow

The first step was the analysis of the old organization, giving way to the construction of the original workflow map, depicted in Fig. 1.

This conventional organization is especially susceptible to variations in: patient arrivals, process times, cancellations, unforeseen delays and unknown real In Room Time. Due to these variations, the real schedule will never correspond to the initial schedule. Queuing theory clearly shows that each source of variability will