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# Application of Drum-Buffer-Rope Methodology in Scheduling of Healthcare System

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## Abstract

Theory of constraints (TOC) is a management philosophy that seeks to increase throughput (efficiency or performance) of the system by identifying those processes that are constraining the system bottlenecks. There have been very few profound studies of TOC in health care systems. In order to fill this gap, this study was conducted to determine how healthcare systems are utilizing components of TOC to schedule operations and what results are being obtained. This is done by using a patient flow model for a radiotherapy section of a hospital. The drum-buffer-rope (DBR) was used as the methodology for scheduling this flow. Successful outcomes obtained by proposed model improved the efficiency and quality of radiotherapy treatment.



**Key words:** Theory of Constraints, Drum-Buffer-Rope scheduling, healthcare system, radiotherapy planning

# 1. Introduction

Theory of constraints (TOC) emphasizes the importance of improving system performance by exploiting the bottleneck. The underlying concept of the TOC is that any system has at least one constraint which limits its performance. Since a system can best perform only as well as its constraints, TOC focuses on the system's constraints, their exploitation according to the goal of the organization, and implications of exploiting these constraints on the rest of the system. TOC increase that improving constraints performance, which directly results in total system performance (Schragenheim & Ronen, 1990) and (Stahl, 1999). The scheduling system TOC uses is often referred to as drum-buffer-rope (DBR). DBR methodology operates by developing a schedule for the system's primary constraint (Mahapatra & Sahu, 2006). It is now being implemented in a growing number of organizations enabling better scheduling and decision-making that helps the manager to concentrate on the most critical issues. According to Goldratt, a perfectly balanced operation with no excess capacity is undesirable, and some amount of both imbalance and excess capacity is necessary to ensure optimal performance. Based on this logic, DBR systems work by identifying the system's primary resource constraint and then develops a schedule for it that ensures a high utilization rate while simultaneously leaving some amount of excess capacity at all other resources (i.e. non constraints) (Atwater & Chakravorty, 1995) (Goldratt & Fox, 1986) (Chakravorty & Atwater, 2005).

Three TOC paradigms that have evolved over the last twenty five years are logistics, global performance measures, and thinking processes. Originally, the logistics paradigm had managers looking for, and elevating, system constraints in order to increase throughput. This included using drum-buffer-rope scheduling techniques and the five focusing steps of TOC. In the second paradigm, global performance measures were effectively utilized. These measures, based on throughput, operating expense, and inventory, allow managers to easily assess the impact of any given decision and help the manager to focus on the system goal (Moos, 2007).

Patient scheduling in health care systems has been researched extensively over the last 50 years. One special area of concern is medical treatments involving radiation applications to cancer patients, where improper scheduling procedures could have a severe impact on the success of treatments and, above all, could potentially affect the survival rate of the same patients. Indeed, many cancer patients receive combined radiation therapy in accordance with a schedule. Failure to arrange for an appointment for one of the procedures may compromise the treatment (Conforti, 2007).

Health care systems always have mixed-manufacturing characteristics within their operation in which the TOC logistics and or scheduling paradigms may be customized and utilized (Moos, 2007). Consequently, TOC seems to be a natural fit for healthcare systems; in fact, some of its means and concepts have been applied to this situation. However, there are still no reported applications of TOC's DBR tool and inadequate customizations regarding scheduling health care systems. Therefore a better understanding of them by using DBR method is needed. This study aims to investigate the efforts which have previously been done for applying TOC for scheduling and will result in possible models that can be a starting point for using DBR for scheduling health care systems. We begin with a description of TOC and DBR scheduling logic and a brief review of the literature that has led up to this study. We then proceed to define our model of radiotherapy patient scheduling of an oncology section of a hospital. Following the modeling section, we provide model analysis. In the final section, we discuss the conclusions drawn from this study and identify directions for future research. To the best of our knowledge, this is the first study which uses DBR optimizing the radiotherapy planning.

# 2. Review of Related Research

## 2.1 Theory of Constraints

Theory of Constraints (TOC) came into view as a tool for optimization of the manufacturing and service systems. Goldratt in his first book "the goal" gave the introduction of TOC and its application in factory scenario. The theory was developed as a management philosophy when the Optimized Production Technology (OPT) scheduling software was introduced in 1979 (Goldratt & Fox, 1986). Goldratt presented his ideas of production management in the form of a book and highlighted the difficulties faced by most of the production managers in their day-to-day work. He presented the drawbacks of conventional measurement systems and suggested three measurement yardsticks to gauge the performance of the system defined as below:

a. Throughput: Defined as the rate at which the system generates money by the sale of the goods and services which it produces.
b. Inventory: Money that a system is invested in purchasing the things that it intends to sell.
c. Operational expenses: Money which a system spends, to convert inventory into throughput.

Therefore all the parameters can be defined in terms of money. He highlighted the reasons for buildup of inventory in the manufacturing organizations. He defined a constraint resource, the role of constraints in determining the output of organization, and methods to identify and exploit constraints (Bhardwaj & Gupta, 2010).

While a lot of researchers have contributed to the development of TOC, in this paper Watson's (2007) approach in summarizing the development of the theory is followed. To clearly focus on the development of principles of TOC concepts, they segmented the evolution of TOC into five Eras as follow:

1. The Optimized Production Technology Era, the secret algorithm
2. The Goal Era- articulating Drum-Buffer-Rope scheduling
3. The Haystack Syndrome Era- articulating the TOC measures
4. It's not luck Era- thinking process applied to various topics
5. The critical chain Era- TOC project management

To constructively exploit this segmentation for this paper, the discussion of The Goal Era is cited in order to investigate the utilization of DBR methodology for the health care systems.

### 2.2 Era 2: The Goal

Goldratt and Cox in "The Goal", 1984, explained the situation of Alex Rogo, who saves his plant with the help of some pointed questions by his mentor, Jonah. The goal was written largely to educate workers at facilities employing OPT in an effort to have them follow OPT schedules. The Goal describes a number of heuristics and techniques that have become the foundation for TOC practice. The Goal outlines the Five Focusing Steps (5FS), the process by which TOC concepts are implemented. The 5FS have evolved into what is now called the process of ongoing Improvement, a combination of the Five Focusing Steps and the two prerequisites for implementation. The first prerequisite for implementation is to describe the system under investigation and identify its purpose. The second one is to define measurements that align the system to that purpose. (Watson, 2007) . The 5FS are as follow:

1. Identify the system constraint(s). A constraint is any element or factor that prevents a system from achieving a higher level of performance relative to its goal (Blackstone & Cox, 2004). Having defined the purpose of the system, Identification of the constraint follows from the principal opinion of TOC, "constraints determine the performance of a system." Since there are few constraints in any system, management of these few key points allows for effective control of the entire system.

2. Decide how to exploit the system constraints. This means making sure that the utmost is done to ensure that processes leading up to the constraint resource always run as smoothly as possible. In other words once the constraint has been identified, the next step is to determine the most effective means to exploit it. Exploitation of the constraint seeks to achieve the highest rate of throughput possible within the confines of the system's current resources. The output of the system is limited by the rate of throughput at the constraint.
3. The third step is to subordinate the system to the constraint. This eliminates waste and insures maximum responsiveness since the system only works on that which it can reasonably expect to turn into cash through sales in the near term.
4. Elevate (improve the performance of) the system constraint. It means elevating the throughput by adding capacity to the system at the constraint location. This may result in the acquisition of additional capacity, new machines or new technology to lift or break the constraint. Improving the performance of the constraint leads to improvement in the performance of the entire system (Moos, 2007).
5. If, in the previous steps, a constraint has been removed, go back to step one, but do not allow inertia to cause another constraint. The fifth step renews the improvement cycle (Hutchin & Jeary, 2006) and (Watson, 2007). It is very likely that once a constraint has been identified and addressed, another constraint will become evident. This should be addressed through the same 5-step process. A process of ongoing or continuous improvement has begun (Moos, 2007).

An organization needs to repeat these steps in order to achieve the continuous improvement. From the early works, practicing managers started thinking that application of TOC is confined only to production area. To break this misconception, "Goal II" was written, and it highlights the method to apply TOC in marketing (Bhardwaj & Gupta, 2010). Due to simple methodology the application of TOC techniques, have been discussed in the academic literature, retailing, supply chain, process improvement, and in a variety of production environments. TOC techniques will result in increased output while decreasing both inventory and cycle time. Other studies show that TOC techniques exceeds the performance of those using manufacturing resource Planning (MRP-II), lean manufacturing, agile manufacturing, and just-in-time (Cook, 1994); (Watson, 2007).

### 2.3 Drum-Buffer-Rope

Flowing directly from the 5FS, The Goal develops the scheduling methodology employed under TOC: drum-buffer-rope (DBR). The constraint, or drum, determines the pace of production. The rope is the material release mechanism, releasing material to the first operation at a pace determined by the constraint. Material release is offset from the constraint schedule by a fixed amount of time, the buffer. Buffers are strategically placed to protect shipping dates and to prevent constraint processes from starvation due to a lack of materials. Consistent with the step one of the 5FS, identification of the drum, or constraint, is required for implementation of a DBR system.

The second step of the 5FS, exploit the constraint, necessitates strategic buffering at the constraint and at other system control points to protect the ability of the system to produce the schedule. The term ‘‘buffer’’ is often synonymous with work-in-process or finished goods inventory. Finally, consistent with step three of the 5FS, the rope subordinates non-constraint machines to the constraint, releasing inventory to the system based on the rate of consumption at the constraint. The "length" of the rope, hence the amount of inventory in the system, is determined by the protection to the constraint provided by the buffer. Since work-in-process inventory downstream of the constraint is negligible, the rope acts to keep minimal and constant inventory levels in the system. Therefore, TOC systems exhibit reduced and consistent lead times when compared to traditional management techniques.

As previously stated, testing of DBR points out that TOC systems produce greater numbers of product while reducing inventory, manufacturing lead time, and the standard deviation of cycle time (Watson, 2007).

### 2.4 Scheduling in DBR

DBR are the three components of the OPT scheduling and control system. OPT makes a distinction between two types of constraints: bottlenecks and Capacity Constrained Resources (CCRs). A bottleneck is a resource whose capacity is less than or equal to the market demand. A CCR is a resource which, if not scheduled properly, can damage due date performance or throughput. Buffers are also allocated before assembly stations where products arriving from bottleneck resources are assembled. Their main purpose is to prevent the system from stopping because of statistical fluctuations. Another place where buffers are located is in front of the orders. This enables the user to control the due dates and supply. The rope is the third component in the OPT scheduling concept. Since scheduling is done according to the drum, the rope is the offset of time between the scheduling of the drum and the release of raw materials. The OPT concept suggests that the drum can be either at the end of the process or at any other place. The drum is identified according to the circumstances; it is the bottleneck of the system (Ronen & Starr, 1990).

It is wrong to believe that the application of theory of constraints is confide to production functions only. It can be applied to any type of organization with same degree of success (Bhardwaj & Gupta, 2010). During the past 15 years, there has been a move to expand TOC non-manufacturing applications. The drum-buffer-rope (DBR) scheduling technique can be used in services as well as in manufacturing. While manufacturing uses DBR to schedule machinery, services may use DBR to schedule people within the organization, to set appointments for customers, or to predict lead-times for customers (Moos, 2007).

## 3. Model of Healthcare System

From an operation management view, hospital care processes are considered to be rather complex as compared to processes in industry or most other types of service organizations. This may explain the difficulties that often are encountered during efforts to apply operations management (OM) principles and technologies in hospital care surroundings. However, complex operational processes also exist in industry, and operations management principles have been successfully applied to many of them. Because TOC is a management philosophy, it has broad applicability. Services can improve their processes and procedures just as can manufacturers (Moos, 2007).

### 3.1. Similarities and Differences between Industrial OM and Health OM

"In manufacturing industry, competition between companies was one of driving forces for an evolution in OM. Competition creates a high pressure on performance in terms of quality, efficiency, and flexibility. Production control or logistics can be defined as the coordination of supply, production and distribution processes in manufacturing systems to achieve specific delivery flexibility and delivery reliability at minimum costs. Related objectives are to decrease the lead-times delivery times and costs and to increase throughput, revenues and profit of the organization. Logistics-oriented manufacturing has contributed in many circumstances to improvements in customer performance (delivery times, delivery reliability) as well as efficiency by the better balancing of delivery performances and efficiency. Health care is confronted with similar challenges: Increased complexity of processes by shorter lengths of stay patients, a shift from inpatient treatment towards ambulatory treatment and day care, use of new technology and increased specialization; Need for efficient utilization of resources and reduction of costs; Increased pressure to improve the quality of services by, among other things, decreasing waiting listed and in-process waiting times; Need to control the workload of nursing staff and other personnel in order to avoid adverse impacts on their working conditions. Similarities and Differences between Manufacturing Systems and Healthcare Systems are shown in table 4-1.

Taking these similarities into account, we can define production control in health care organizations, analogous to the definition of production control in industrial setting- as:

The design, planning, implementation and control of coordination mechanisms between patient flows and diagnostic and therapeutic activities in health service organizations to maximize output/throughput with available resources, taking into account different requirements for delivery flexibility (elective/appointment, semi-urgent) and acceptable standards for delivery reliability (waiting list, waiting times) and acceptable medical outcomes" (Vissers & Beech, 1994).

Table 4-1: Similarities and Differences between Manufacturing Systems and Healthcare Systems

| Characteristics | Manufacturing | Health care |
|---|---|---|
| Object | Material flow | Patient flow |
| Specification of end product requirement | Up-front specified | Subjective and fuzzy |
| Means of production | Equipment and staff | Equipment and staff |
| Buffers | Stock or lead-times | Waiting times and lead-times |
| Financial goal | Profit | Cost control |
| Market environment | Market competition | Limited market competition |

### 3.2 Applicability of OM Principals to Healthcare, Considerations for Defining a Healthcare Model

The essential assumption underlying OPT mechanism is that there exists a stable bottleneck resource in the production system. By definition, this is also the case for production processes in hospitals. Applying this principle is very useful in tracing the bottleneck. Given the great variation in patient flows, there is often more than one potential bottleneck for the hospital as a whole. An analysis of patient flow gives insight into the bottleneck for each of these flows. The relevance of tracing the bottleneck is obvious: to optimize the use of this resource, to enlarge this resource, to reduce the throughput time.

At the conceptual level, much can be learned from industrial production control. However, methods and techniques are mostly not directly applicable due to the very specific characteristics of certain hospital health care processes. These include the high variability and high uncertainty in the processing steps required the use of a specialist resource in many processing steps, and the different levels of urgency providing health care (Vissers & Beech, 1994). The scheduling researches related to health care management and logistics were done in the following areas:

- Patient scheduling: patient-staff scheduling, patient flow, appointment scheduling
- Resource scheduling: nurse scheduling, Operating room and physician scheduling,
- Logistics

### 3.3 Radiotherapy Patient Scheduling Model

In this part we are going to discuss the radiotherapy patient scheduling problem. The model is defined and developed within the oncology section of a hospital which is customized to deal with the theory of constraints features. The process by which patients are scheduled for treatment is crucial for the efficiency of the patient flow and, thus, it strongly influences the overall performance of health care systems (Conforti, 2007). By developing a patient process flow map, the aim is to identify where the flow is slowed within the overall process of care. In the whole patient journey until discharge after treatment, it is very likely that there will be at least one constraint. A constraint in this model can be any part of the system where patient flow is obstructed causing waits and delays. It interrupts natural flow and hinders movement along the care pathway, determining the pace at which the whole process works.  For improving the process the constraint should be tackled. Any service improvement is unlikely to succeed because the patient will be accelerated into the queue, only to be halted further along the pathway by the constraint (NHS, 2008).

There are different approaches to mapping patient journey, procedures, and administrative processes in healthcare services. Mapping patient journeys is an essential tool to reduce delays and highlight improvements for patients and staff. It is worthwhile to observe that radiotherapy patient scheduling differs from the classical scheduling problem because the radiation schedule is tailored to particular circumstances based on the size, number, and location of tumors, overall healthy conditions and body size (Conforti, 2007). In what follows, we describe the proposed model. The objective of the optimization model is to maximize the number of patients to be scheduled. For developing and mapping the radiotherapy patient model, we need to make the following assumptions.

- We start the description of the proposed basic model by observing that, in practice, the first treatment requires more time than the subsequent ones. This is mainly due to the fact that the operator has to introduce the treatment parameters into the linear accelerator (i.e., electron or X-ray mode, intensity, duration), has to memorize the coordinates of the center of the tumor, etc. In addition, part of the first visit to the radiation oncology will be spent determining precise details of how best to treat the patient: it is necessary to determine the correct position of the patient on the treatment bed, to mark his skin with small dots, using temporary or permanent ink, and to create shields for sensitive organs; all these actions are called "simulation" (Turner & Qian, 2002). Before beginning the treatment plan it is necessary to validate first time the radiotherapy parameters and also the constructed shields; this action takes an estimated time of 15min.
- The treatment of each patient takes 15 minutes for each session.
- Only one linear accelerator is available.

- The patients are served based on the FIFO rule (First In First Out).

The Arena Software is used for describing the model, afterward the 5FS are discussed for applying the DBR methodology based on the mentioned model. As figure 4-1 shows the patients first enter the radiotherapy section and check in at the reception. Based on the above assumption in the next step, the set-up, and simulation actions are taken and radiotherapy is completed using linear accelerator that is the equipment of the treatment. If the patient needs more radiation from different angles the process of adjusting the angle based on the tumor location takes time. After treatment the patient then finish up the process and check out. Figure 4-2 shows a sample run of the model when the patients are waiting to be treated.

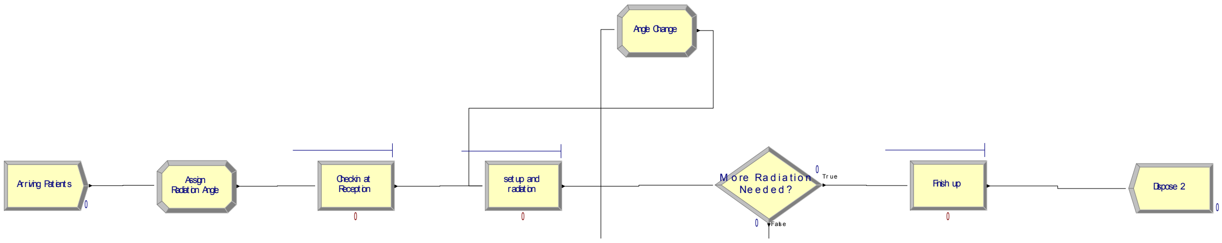


Figure 4-1: The radiotherapy patient flow scheduling model

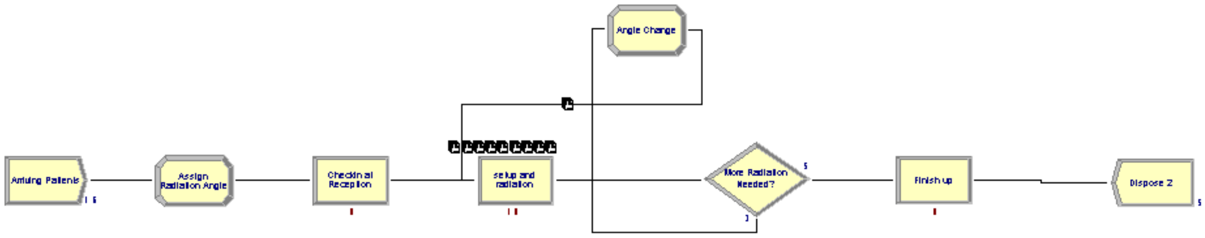


Figure 4-2: A sample run of the model

## 3.4 Five Focusing Steps for Scheduling Radiotherapy Patient Flow Model:

**3.4.1 Identifying the Constraint.** The model identified stages in the patient journey where patients have to queue or are put on a waiting list then mapped to the level of what one person does, in one place, with one piece of equipment, at one time. Look carefully for the true constraint. This is often a lack of availability of a specific skill or piece of equipment. The constraint must always be managed, as it determines the rate at which patients go through the system. It is therefore important to ensure that there is no idle or wasted time at this point in the process (NHS, 2008). By looking at the following flow (figure 4-2) it is known that the constraint of the model is the linear accelerator which is the equipment of the treatment. It makes a bottleneck in the treatment process which must be exploited. Detailed process templates will help to identify opportunities and help the operational management of constraints. This information will help to develop careful schedules around the constraint. This is important, as every minute that is not used at the constraint is a minute lost to the whole process.

**3.4.2 Define How to Exploit the Constraint, Discovering the Real Reason for the Delay.** In order to do this the following should be checked:

- Ensure that the bottleneck has no idle time, for example, have a list of stand by patients who can be called at short notice in the event of idle capacity
- Put inspection or checking tasks in front of the bottleneck
- Distribute the work amongst the clinical team so that everyone works to their highest level of skill and expertise.
- Separate responsibilities for clinical care and paper flow
- To increase the capacity of the bottleneck, give some of the work to non bottleneck areas, even if it is less efficient for these areas

**3.4.3 Improving the Whole Process.** Modeling the process in this way will results in identifying unnecessary delays, steps, handovers, duplication of effort and waste, things that don't make sense and not logical, likely hotspots, and bottlenecks or constraints. It is here that the organization needs to ensure that its own policies, resources, behaviors, measurements etc support the constraint to ensure that it is always working. Theory of Constraints recommends putting a 'buffer' (a small queue) in front of the constraint to ensure it is always fed and there is no 'down time'. At the same time, see if processes can be improved. Having improved the situation at one bottleneck, others may emerge as rate limiting steps in the patient journey. Bottleneck management is, therefore, a process of continual improvement.

Other alternative that may help to ensure maximum utilization are multi-skilling staff, as well as assisting with set up and paperwork activities to enable trained staff to concentrate on the use of the machinery itself. Where the constraint is equipment, it is important to ensure that it is always in use. Routine servicing of radiotherapy machines during the working week, will impact on throughput. Once the most out of a constraint is gotten, the bottleneck may move to another step in the process (NHS, 2008).

**3.4.4 Elevate the System's Constraint.** The basic approach of DBR is of exploiting the system constraints and subordinating the rest of the system to the exploitation of the constraints. If the constraint still exists after exploiting and subordinating everything else to it, then during this step the constraint is elevated and 'broken' by investing resources in it. This step is only necessary if the constraint is a true bottleneck. If the bottleneck breaks, the constraint will move. Knowing the constraint may be sufficient to help improve the process and to help its operational management (Schragenheim & Ronen, 1990).

**3.4.5 How good is the DBR Solution?** Based on the above steps we now define the DBR component for the radiotherapy planning model. The "Drum" is the linear accelerator which creates a bottleneck in the system based on the shown simulation of the system. In order to subordinate the system to constraint we put a buffer in front of the constraint. While a patient is in the set-up process, the constraint is idle. If we improve the constraint by reducing the idle time, the whole process will be improved because the throughput of the system (the number of patient who served / time) will be increased. The "Buffer" here means a room where the set-up and simulation can be done by the radiotherapy staff so the idle time of the linear accelerator will be reduced. The "Rope" is the pace that patients are entered into the system (the treatment room), and it is controlled by the performance of constraint (linear accelerator).

The modified and optimized model of the radiotherapy is shown in figure 4-3. Figure 4-4 shows a sample run of the modified model. The patients are in another queue before they get to the constraint of the system. This queue is the projected buffer which improves the constraint of the system. In other words the set-up process is done in another area before the bottleneck of the system, as a result the constraints will be exploited in a more efficient and quality mode. When the model was run, it is determined that the patients spend less time in the system because in the optimized model the constraint of the system is performing better.

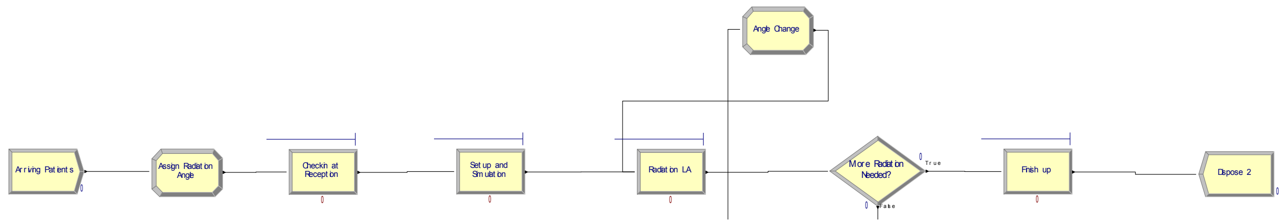


Figure 4-3: The optimized radiotherapy patient flow scheduling model

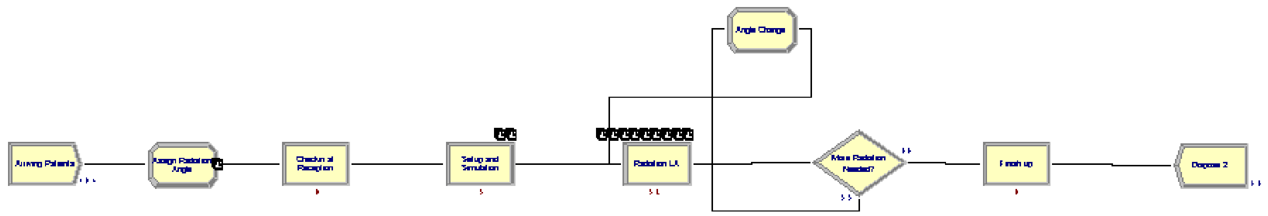

Figure 4-4: A sample run of the model

## 4. Conclusion and Future Work

As a management philosophy, TOC has wide-ranging applicability, and this study has investigated its application to health care systems. This is done by exploring the TOC principles into health care and confirming an instrument for that exploration. The instrument is the Drum-Buffer-Rope which is used for scheduling the radiotherapy within the oncology department of a hospital. The five focusing steps are explored for this case in order to apply the scheduling for the model. The successful outcomes obtained by the proposed model improve the efficiency and quality of radiotherapy treatment. This outcome leads to a reduction of waiting time and waiting lists for radiotherapy treatments and it improves the real schedule. In this way the excessive waiting time, often the major reason for patients' dissatisfaction, is minimized as much as possible in outpatient services.

Clearly there is more research to be done with respect to the use of TOC within health care systems. Future research should consider various sections of health care systems in order to identify the constraint of the systems and improve the whole system by exploiting the constraint. Future work may also concentrate on improving such sections by removing the constraint and exploring the next in order to put the model in the improvement cycle. By extending the model to a more tailored and detailed one, the problem would be more comparable to the real situations. Some examples include involving more equipment and personnel, considering different treatment plans, and diversifying programs for radiations which will lead to a more precise study about application of DBR for healthcare systems.

**References:**


Atwater, & Chakravorty. (1995). Using the Theory of Constraints to guide the impelementation of quality improvment Projects in manufacturing environments. International Journal of Production Research, Volume 25, Issue 2, March 2007, Pages 387–402 .

Bhardwaj, & Gupta. (2010). Drum-Buffer-Rope: The Technique to Plan and Control the Production Using Theory of Constraints. World Academy of Science, Engineering and Technology, Article 19, page 103.

Blackstone, & Cox. (2004). APICS Dictionary. VA: Alexandria, Volume 25, Issue 2, March 2007, Pages 387–402.

Chakravorty, & Atwater. (2005). The impact of free goods on the performance of the drum-buffer-rope scheduling systems. International Journal of Production Economics, volume 95, issue 3, , Pages 347–357.

Conforti. (2007). Optimization Models for radiotherapy patient scheduling. A Quarterly Journal Of Operations Research, Volume 6, Number 3, 263-278.

Cook. (1994). A simulation comparison of traditional, JIT, and TOC manufacturing systems in a flow shop with bottlenecks. Production and Inventory Management Journal , Vol. 18 Iss: 4, pp.336 - 355.

Goldratt, & Fox. (1986). The Race. The Race. [Croton-on-Hudson, NY]: North River Press. pp. 179. ISBN 978-0884270621.

Hutchin, & Jeary. What is Drum-Buffer-Rope (DBR)? TOC Lean Operations Management. Leicestershire: TOC-Lean Institute.

Mahapatra, & Sahu. (2006). APPLICATION OF THEORY OF CONSTRAINTS ON SCHEDULING OF DRUM-BUFFER-ROPE SYSTEM. International Conference on Global Manufacturing and Innovation.

Moos. (2007). Improving Service Quality with the Theory of Constraints. Journal of Academy of Business and Economics, 4(3) 1-15 .

NHS. (2008). Retrieved Dec 8, 2011, from http://www.institute.nhs.uk: http://www.institute.nhs.uk/quality_and_service_improvement_tools/quality_and_service_improvement_tools/bottlenecks.html

Ronen, & Starr. (1990). Synchronized manufacturing as in OPT:From practice to theory. Computer and Industrial Engineering, Vol. 18 No. 4, pp .

Schragenheim, & Ronen. (1990). Drum-Buffer-Rope shop floor control. Production and Inventory Management Journal , third quarter.

Stahl, M. J. (1999). Encyclopedia of health care management. 567.

Turner, & Qian. (2002). Protocol techniques for testing radiotherapy accelerators. Springer-Verlag, Berlin, November 2002

Vissers, J., & Beech., R. (1994). Health operations management: patient flow logistic in health care. 26-37.

Watson. (2007). The evolution of a managemnt philosophy: The Theory of Constraints. Journal of Operation Managemnt, 25 (2007) 387– 402 .