Standardized Modeling and Simulation of Hospital Processes – Optimization of Cancer Treatment Center

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Abstract

In 2004 reimbursement policies of hospitals based on Diagnosis Related Groups (DRGs) have been introduced in Germany. These force hospitals to minimize cost of treatment and improve quality of care, in order to attract more patients and become more competitive. To achieve these goals hospital processes have to be optimized and compared with processes in competing hospitals. For this analysis, comparison, and optimization of hospital processes it is necessary that standardized validated and executable models of hospital processes are developed.

This paper describes research on developing standardized building blocks for rapid modeling and simulation of hospital processes based on clinical pathways. For the example of a cancer treatment center it is shown how the developed library is used to rapidly model clinical processes, improve allocation of resources and significantly reduce cost.

1. INTRODUCTION

Health care costs in Germany have been rising exponentially within the last years. With 10.8% of GNP in 2003 it became one of the highest in Europe. In order to overcome this problem, in 2004 reimbursements of hospital services based on disease patterns were introduced by the German government. Under these new reimbursement rules hospitals are no longer reimbursed according to the number of days an inpatient is cared for, but on the basis of Diagnosis Related Groups (DRGs), independent of the actual inpatient treatment time.

Income and profit of hospitals may rise if treatment cost is reduced and the number of medical treatments is increased.

Treatment cost is strongly related to treatment time and number of hospital resources used during this time. The number of patients is a function of number of resources available at the hospital to treat these patients and number of referrals to fill the available capacity. The number of referrals increases with quality of care and attractiveness of hospital facilities.

E.D. Peterson et al. [1] show that institutional quality of care is strongly related to composite adherence to guideline-recommended treatments. Analysis, comparison and optimization of hospital processes should therefore include guideline-recommended treatments. Validated standardized hospital work flow building blocks have to be developed that follow guideline-recommended treatments.

This paper describes research on development of standardized building blocks for rapid modeling and simulation of hospital processes based on guideline-recommended treatments. Section 2 describes the selection of a validated simulation and optimization environment. Section 3 describes the development of a guideline-recommended treatment library for the selected simulation environment. Section 4 describes the optimization of a cancer treatment center of a German university hospital. Section 5 summarizes the results.

2. SELECTION OF SIMULATION ENVIRONMENT

The throughput of hospital processes is a function of the hospital architecture, the availability of quantity shared resources like beds, server shared resources like physicians and nurses and proper scheduling of treatment events. A simulation environment for evaluation of hospital processes must meet the following requirements,

1)Execute models for workflow simulation and permit optimization of architecture and function
2)Include quantity and server shared resources
3)Must be completely validated
4)Must have a hierarchical GUI based modeling environment for rapid model development
5)Must support distributed Monte Carlo simulation to be able to rapidly analyze the statistical nature of hospital process data

Simulating workflows requires discrete event simulators. Some simulators have specifically been developed to model hospital processes [2]. However, we found that discrete event simulators for development of e.g. simulating communication networks are much more mature than those developed for simulating business processes. Additionally, they are much faster, since they have to handle millions or billions of communication packages instead of hundreds or a few thousands of patients. They are therefore better suited for optimization of complex multi-department hospital processes. However, hospital workflow specific libraries have to be developed to permit hospital process optimization.

The simulation environment which meets all our requirements is MLDesigner [3]. MLDesigner is a multi-domain simulator, that includes schedulers for discrete event, synchronous and dynamic data flows, and analog schedulers and a UML 2.0 like finite state machine (FSM) – permitting model checking for formal validation of models. Technical applications range from design and optimization of architecture and function of .highly secure avionics systems for aircraft, global satellite communication systems, networked electronics in the automobile to integration of the design flow of software and hardware for embedded systems, all of which have very high quality requirements. However, MLDesigner also has been used for optimization of production processes [4] and development processes for automotive electronics.

In a feasibility study for modeling hospital processes [5], MLDesigner was used to model and evaluate the clinical pathways for acute coronary syndromes as an extension of the Siemens Process Framework for hospitals [6]. The feasibility study validated the use of MLDesigner for modeling hospital processes but showed the need for a library of functional and architectural hospital process components to facilitate rapid model development. This library must use notations and abstractions familiar to hospital personal, be able to describe optimized workflows like PAC (Production Authorization Card [4]), and permit optimization workflows, e.g., by genetic algorithms [7].

3. DEVELOPMENT OF LIBRARY OF STANDARDIZED BUILDING BLOCKS FOR CLINICAL PROCESS SIMULATION WITH MLDESIGNER

Before developing a library with building blocks for clinical process simulation, it is necessary to structure and standardize clinical processes by developing a process reference model. We started with the development of a master clinical process model and added details step by step for the reference model. Company specific models are then derived from the reference model.

Figure 1 shows the master model for clinical processes.

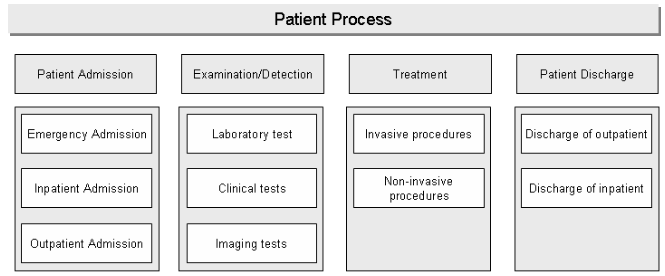

Figure 1: Master model for clinical processes

Taking the master model as the basis, we continued to detail every process category of the master model. In order to have comprehensive acceptance within the health care arena, we did the development of the master model by reconciling every process description with clinical staff. Figure 2 shows the process steps of a percutaneous transluminal coronary angioplasty (PTCA). This process belongs to the process category of the invasive procedures.

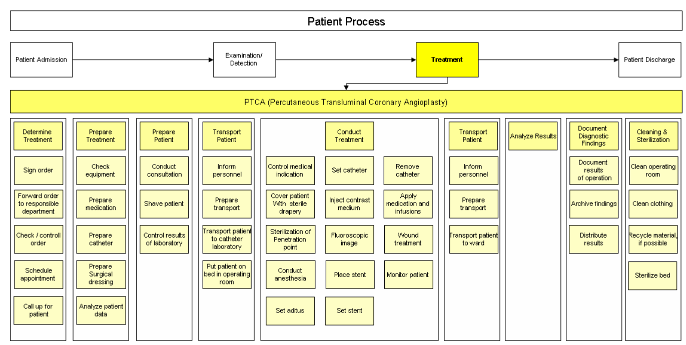

Figure 2: PTCA (coronary angioplasty)

After finishing the description of a standardized process reference model, we started developing the building blocks with MLDesigner. Figures 3 and 4 show examples of the developed building blocks for the process of outpatient admission.

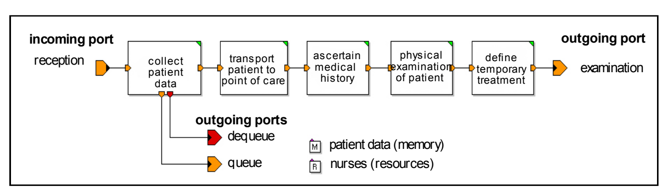

Figure 3: Building block for outpatient admission

The building block in Figure 3 comprises the process steps of an outpatient admission on process level 2. Patient data and resources, e.g., nurses are kept in global memories. Passing only pointers to these data from one module to the other significantly speeds up simulations.

Figure 4 shows the process steps for recording patient data (process level 3 of the reference model), which is a sub-process of the outpatient admission. This particular building block generates the duration of this process step based on a given probability distribution. It also allocates necessary resources (i.e. nurses) as well as deployment of resources and protocols the measured beginning and end of this process step in a data table.

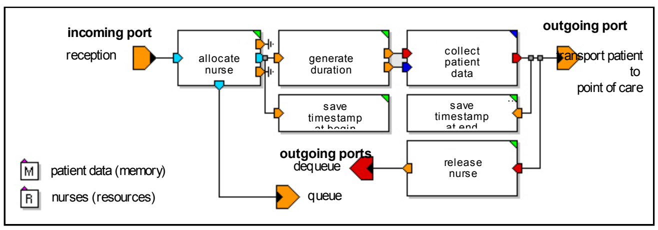

Figure 4: Building block for the process steps of recording patient data as part of the outpatient admission

Figures 5 and 6 show examples of the developed building

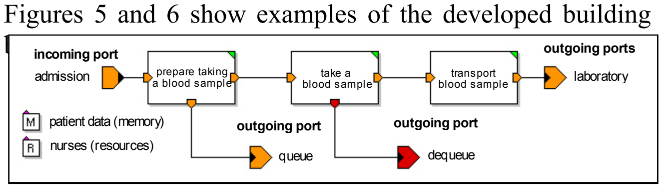

Figure 5: Building block for taking blood samples

Figure 6 shows the process steps for preparation of taking blood samples (=process level 3), which is a sub-process of taking blood samples. Similar to what has been described above, this building block generates the duration of preparation of taking blood samples based on a given probability distribution. It allocates necessary resources (i.e. nurses) as well as deployment of resources and protocols the measured beginning and end of this process step in a data table.

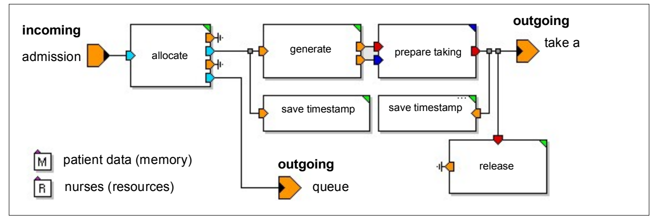

Figure 6: Building block for the process step "preparation of taking blood samples" as part of the process of "taking blood samples"

For analyzing the deployment of resources, we used standard quantity shared and server shared resources of MLDesigner. A sample of resource deployment for the occupational category of physicians is shown in Figure 7:

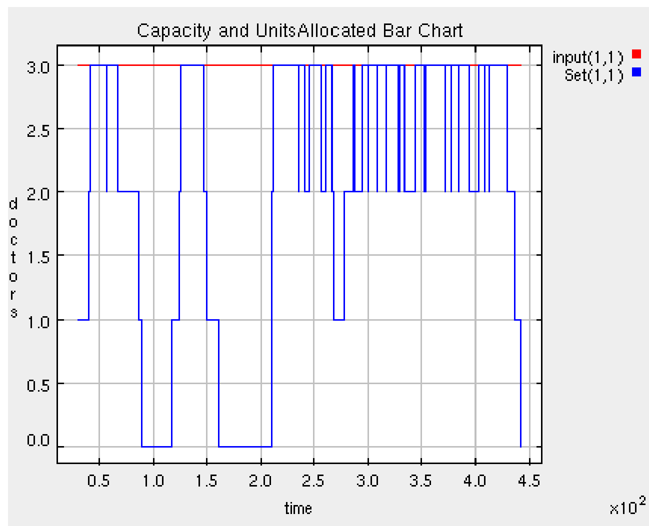

Figure 7: Sample of resource deployment: Deployment of physicians

The required libraries of building blocks were developed [8] to validate this approach for the case of a cancer treatment center of a German university hospital.

4. OPTIMIZATION OF A CANCER TREATMENT CENTER

For analysis, modeling and optimization of the cancer treatment center of a German university hospital, the follow steps were taken:

1) Analysis of the organization and existing processes
2) Collection of relevant data for modeling and simulation and for later comparison with achieved process improvements
3) Development and validation of a model of the existing process
4) Optimization of the process model
5) Implementation of the refined process
6)

The analysis of the available data at the cancer treatment center showed that most of the required data were not available and had to be collected first. A structured template was developed and used for data collection. Before starting data collection, staff was trained on how to correctly use the template form. Data were collected over a period of 55 working days. Afterwards, plausibility and completeness were checked. Among others, the following data have been collected for each patient:

1) Arrival time of patient
2) Start and end time of patient admission
3) Start and end time of taking blood samples
4) Start and end time of examination by doctors
5) Time of placing order for chemotherapies in the hospital-internal pharmacy
6) Start and end time of chemotherapy
7) Time of patient discharge

Furthermore, utilization of patients' beds as well as utilization of staff was captured

.

Based on those data, waiting times between all process steps were computed. Under consideration of the results of this analysis, concrete and measurable project goals were finalized together with management and staff of the cancer center. The main goal was to shorten the hours of operation by one hour from 5 p.m. to 4 p.m. by reducing average waiting time of patients as well as by optimizing utilization of patients' beds. These goals had to be accomplished under ceteris paribus conditions, i.e. same number of staff, same average number of patients per day, same equipment.

The MLDesigner model of the cancer treatment center was modeled after the layout, depicted in Figure 8

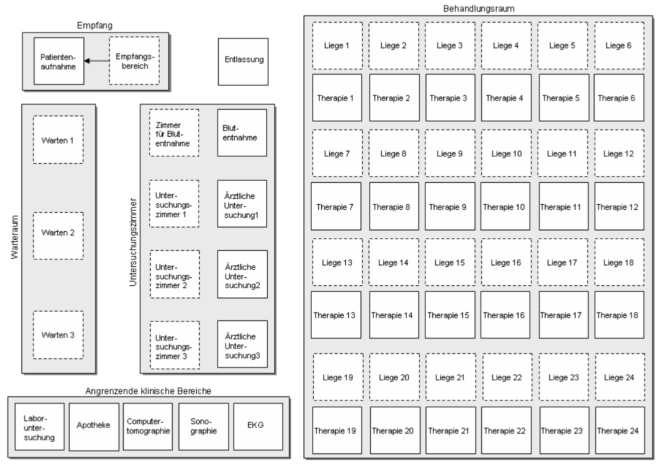

Figure 8 Layout of Cancer Treatment Center

Figure 9 depicts a block diagram of the model at hierarchy level 2. The next step was to verify the correct functionality of the modeled processes. Therefore, 15 working days were used out of the captured data set. For validation purposes, the remaining 40 days of captured data set were used.

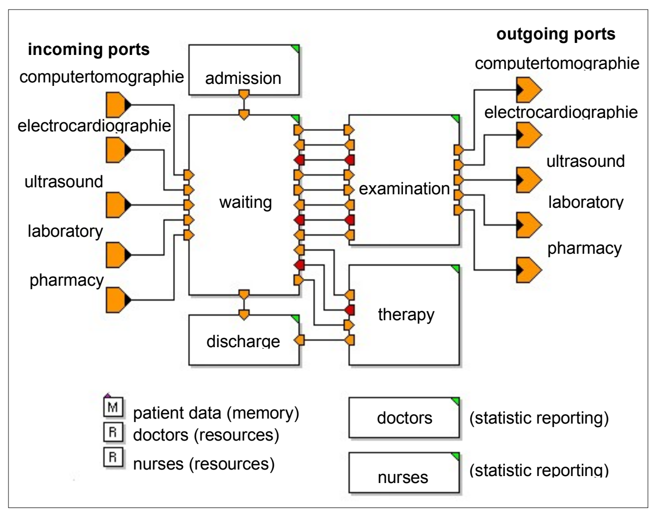

Figure 9: Level 2 Model of Cancer Center [9]

The model was calibrated until the deviation of model results and real data were less than 5% in average.
Figure 7 compares availability and use of physicians. Figure 10 compares availability and und use of nurses.

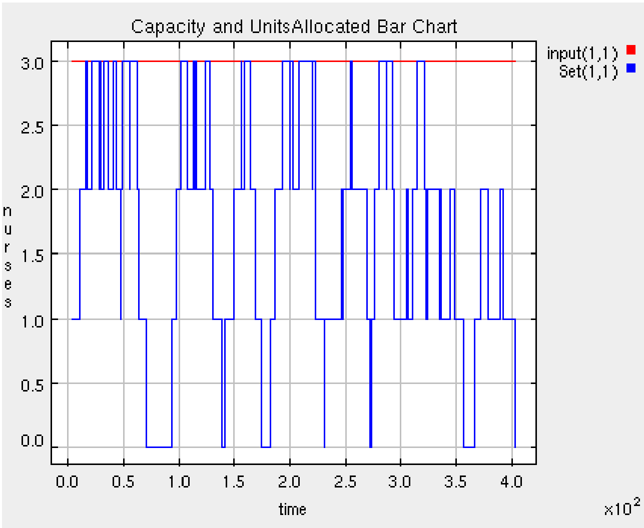

Figure 10: Availability and deployment of nurses

Figure 11 depicts availability and use of patient treatment places at the cancer treatment center.

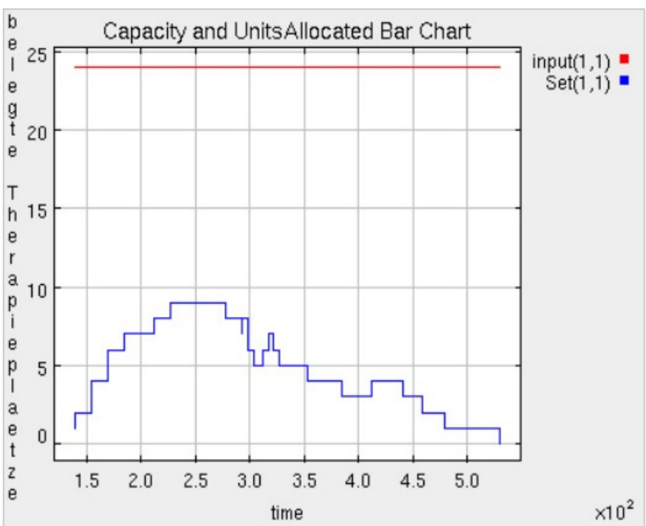

Figure 11: Availability and use of treatment places before optimization [9]

Simulation of the existing process clearly shows underutilization of all resources. Analyzing potential improvements showed the greatest potential in scheduling patients based on expected treatment time. A second area for major improvements turned out to be the integration of processes between all involved departments, e.g. ultrasound, computer tomography, electrocardiography, pharmacy and laboratories. A third major area for improvement turned out to be separating schedules for patients which needed blood sampling before treatment and those that did not.

Figure 12 shows availability and use of patient treatment places for the optimized model averaging 55 days of patient data (compare with Figure 11, obtained for the same data without optimization). As result all key figures of the optimized model had shown improvements in average. Beginning and end of examination as well as beginning and end of therapies were significant earlier as in the compared model. In figures the total waiting time of patient decreased 69 minutes in average. This equals an improvement of 44%. Adjusted at deviation of 5% the total waiting time improves 42% in result. Furthermore the last patient discharged more than one hour earlier. As shown the focused aims were met in the optimized model. Basically high cumulative waiting time was caused by random patient timing.

The found improvements were implemented in the real system. All improvements predicted by the simulation could be realized. The resources could be used more efficiently. The goal of reducing hours of operation of the cancer treatment center and closing at 4 pm was met.

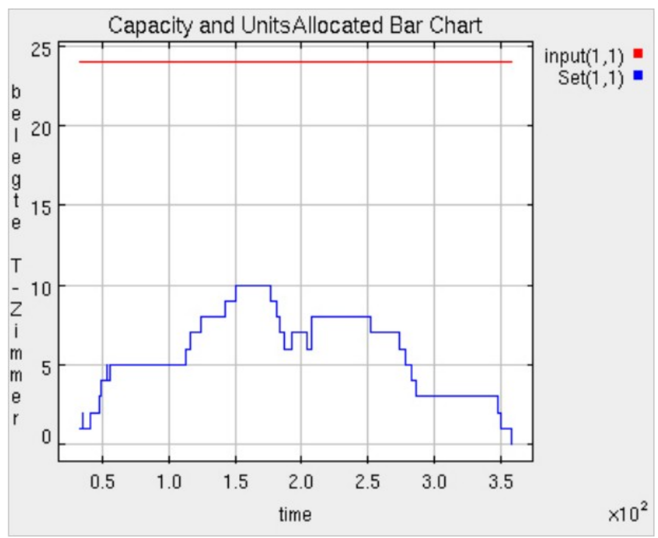

Figure 12: Availability and use of treatment places after optimization [9]

5. SUMMARY AND OUTLOOK

A library of standardized building blocks was developed for modeling, simulation, and optimization of hospital processes was developed. The processes of a cancer treatment center could be modeled, analyzed and optimized within a period of 6 weeks. Large reductions in cumulative patient treatment times could be realized.

Applying simulations, possible process improvements could be tested on the model before being implemented at the cancer center. This was mandatory in order to avoid any endangerment of patients' health as well as to avoid unintended interruption of the operation of the cancer center. The achieved improvements led to significant reduction of patients' waiting times, a significantly better deployment of existing resources as well as to measurable cost savings for the cancer center.

The standardized description of clinical processes in the reference model enables benchmarking projects with other hospitals. Since the reference model is based on a modular concept, it can be enhanced at any time – if necessary.

Due to the complexity of clinical processes, simulation studies will become more and more crucial to performance improvement projects as well as to organizational restructuring projects in hospitals. The developed standardized building blocks enable hospitals to significantly reduce development times for simulation models and employ MLDesigner optimization algorithms on the model if required.

Biography

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