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Implementation of simulation software packages for healthcare scheduling

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ABSTRACT

Simulation methodology is considered an effective decision making tool in the process of patient scheduling in healthcare centers. In spite of the large number of simulation software packages that are commercially available, operation researches still are facing difficulties to implement simulation models in healthcare centers. In many cases, healthcare schedulers must spend extra efforts trying to mold scheduling requirements to conform to the features of the package. In this paper, we offer a systematic approach that can be used by practitioners to successfully adopt the available software simulation packages, develop simulation models, and transform their findings into practical scheduling rules. A radiology center in a Midwestern Hospital is used to illustrate the proposed methodology.

INTRODUCTION

When compared to other alternatives, simulation methodology offers several advantages to the decision-making process in the area of scheduling. Simulation is easily understood by decision-makers and aids discussion of different options that may be used to improve the system. These properties are very important in healthcare, since decision-making in this environment is often a matter of negotiations between medical, administrative and nursing disciplines. Simulation allows the medical staff to ask "what-if" questions and review the implications and consequences of alternatives without altering the present situation.

Recently, computer simulation packages have become more sophisticated and visual. Most simulation-based applications focused on patient scheduling use the minimization of the waiting time as the objective function (Advice, 1991; Mahachek, 1992; Benneyan et al., 1994; and Benneyan, 1997). Other applications include nurse scheduling (Arthur and Ravindran, 1981), staffing and operations improvement (Allen et al., 1997), and critical care operations management (Lowery and Martin, 1992). Scheduling of the radiology center is found to be rare (Coffin

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et al., 1993) as compared to other facilities such as emergency centers (Badri and Hollingsworth, 1993) and operating rooms (Charnetski, 1984).

In spite of the previous research in healthcare simulation, as well as the large number of simulation packages that are now commercially available for sale or lease, operation healthcare schedulers are facing difficulties to implement these application packages in healthcare centers. Early predictions, suggesting that operations research techniques will have problems in being accepted by healthcare planners (Shuman et al. 1974), are proven to be true even with simulation models. The acceptance problem is related to the analysts' inability to connect the theoretical model with an appropriate approach for implementation. Healthcare centers have unique requirements that the simulation packages may not address. In such cases, the initial purchase price of the simulation package can be deceptive because of the hidden implementation costs.

The purpose of this paper is to provide a systematic approach, which can be used by healthcare operation practitioners in the process of implementing application software simulation packages for patient scheduling. The proposed methodology may serve as a modeling framework for implementing simulation models in a wider range of applications and with cost effective solutions.

The paper is structured in the following sections. In the next section, we introduce our proposed REPLICATE methodology. Then we illustrate our ideas by implementing this methodology into real hospital settings. A regional healthcare center (RHC) is used as a source of data and as an implementation site. Each step of the implementation process of the proposed approach is described in a separate section. Our major findings and conclusions are provided in the last section of this study.

THE REPLICATE METHODOLOGY

In order to implement an application software package for the simulation of healthcare centers, the designer must consider several factors: complexity and uncertainty of the system, dynamic nature of the decision making process, and how much a given software can fulfill the specific model constraints. Based on the above factors as well as on our thorough investigation of the scheduling environment in hospital settings, we propose the "REPLICATE" methodology. This name implies the replication of the scheduling environment into the simulation model. During this replication process, the decision maker is able to capture the complexity and uncertainty of healthcare patient scheduling system into simulation models and successfully select and implement commercial simulation packages for patient scheduling. The methodology includes the following nine steps, each starting with the one respective letter from the word R-E-P-L-I-C-A-T-E.

Review Available Simulation Packages

During this preliminary stage, the operations managers must investigate all possible existing application software packages that deal with simulation models in healthcare systems. Pos-

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sible sources of this information include literature review, simulation software companies, and the Internet. The outcome of this step is a short list of potential simulation packages, which are commercially available and can potentially be used in the healthcare center.

Environment Analysis of Scheduling Problem

In order to finalize the process of selecting a single application package, the decision maker must investigate all possible constraints of scheduling problem. Such constraints include scheduling objects, resources, and scope. Several entities can serve as potential scheduling object: patients, equipments, rooms, and medical staff. Scheduling must also consider both monetary and labor resources.

Another important constraint, one must consider in this step, is the scope of the model. The scope is related to both organizational scope and time frame for which simulation model will run. The outcome of this step consists of a list of scheduling constraints which provides answers to such questions as, what is the object of scheduling, what are specific resource constraints, what is organizational unit where the application must be implemented, and what is the time line for the selected scheduling problem.

Package Selection

The purpose of this step is to select an appropriate application package based on the set of constraints identified in the previous step. Among the list of potential simulation packages, one must select software that can best accommodate the problem constraints. The successful use of the package in similar situations in other healthcare centers and familiarity with the software are two additional factors one must consider in this step.

Logical Design Specifications

Decision maker designs a simulation model that represents the existing scheduling environment constraints and the actual scheduling heuristics. Abstraction is used to suppress the unnecessary details and consider only the significant constraints when designing the simulation model. At this stage, the decision maker will look for possible areas of improvements, such as potential bottlenecks, underutilization of resources, or significant waste of processing time. The existing simulation model will serve as the basis for initial statistical testing, which is carried out in the following step.

Initial Statistical Testing

During this stage, preliminary statistical testing and analysis are carried out with the purpose of simulation model refinement. Such tests include defining the necessary stochastic distributions and their parameters. Instances of such distributions include patient arrivals and processing time distributions. At this stage, the decision maker also tests the validity and the reliabil-

ity of the existing simulation model. The output of this stage consists of several distribution functions and other important simulation parameters, such as, the number of cases to be simulated and other reliability measures.

Complete Statistical Testing

A more detailed statistical analysis is performed in this step. Main hypothesis are formulated and tested. Statistical findings are used as the basis for reliable proposals for process improvements. These statistical findings are used in the next stage to propose new scheduling heuristics.

Analyze Results and Propose Heuristics

Statistical findings are converted into practical scheduling rules. Sometimes, a compromise must be set between statistical analysis findings and the newly proposed scheduling heuristic. Very often, theoretically based conclusions may not be practically feasible to be implemented in real settings. For example, analysis of the simulation model parameters may suggest that the best heuristic to sequence patients in the emergency room is shortest processing time (SPT), since it can significantly reduce the average patient waiting time. However, this approach is not practical. Every healthcare operation scheduler knows that emergency patients must be sequenced based on the severity of their case, not on the basis of which patient requires less time to be treated.

Test Newly Proposed Heuristics

This step is carried out only in the cases when new heuristics are proposed. The proposed heuristic is simulated and additional statistical results are generated. The purpose of this stage is to provide not only good solutions from the operations management point of view, but also to provide feasible and practical solutions. Most of the times, healthcare centers will compromise the operations performance measures, in order to achieve higher patient satisfaction and better conformance with medical procedures.

Evaluate Practical Implementations

This is the final step, where in cooperation with the medical staff the above scheduling heuristics are transformed into user-friendly practical recommendations. Implementation of the newly developed heuristics will be successful when the suggested new rules are incorporated with existing set of medical procedures. Follow-up tests and training sessions can also be carried out during this stage.

The following section describes the application of REPLICATE methodology during the process of selecting and implementing a simulation software package for patient scheduling in a Midwestern hospital setting.

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IMPLEMENTATION OF REPLICATE METHODOLOGY

In order to illustrate the proposed methodology, we implemented the above steps in a real setting of a healthcare center. The healthcare center has served the regional community for nearly 110 years and today strives to be the area's finest hospital. It offers a full range of healthcare services for the community and has earned the distinction as one of the country's top 100 hospitals by HCIA and Mercer Management Consulting, Inc. Over the years, the operational performance has been improved with the purpose of achieving patient satisfaction. The radiology department was considered as a simulation site and patient sequencing was used as a scheduling problem. Personal observations and about three hundred actual cases were carefully analyzed

Step 1: Review Available Simulation Packages

While reviewing commercially available simulation packages we found several sources of interest. The Internet site www.rapidmodeling.com/O/businesslsimulationlsoftwarei.htm provides a detailed list of simulation literature. A list of available healthcare simulation packages include such products as MedModel provided by Promodel Corporation, Medical Software provided by The Health Care Net, and Rapid Engineering Methodology (REM) provided by Rapid Modeling Corporations. Applications of these packages include but are not limited to, facilities design (labs, clinics, radiology, ER's etc.), emergency services planning and design, staff planning, analyzing patient capacity, equipment planning logistical analysis, and emergency preparedness.

Step 2: Environment Analysis of Scheduling Problem

The administration at the hospital believes that the best ways to keep costs down is by providing higher patient satisfaction. Based on data from a preliminary study, we found a strong correlation between patient waiting time and their overall satisfaction ($r = .76$). Minimization of patient waiting time is an important goal in the RHC. Other measures of performance include increasing the number of patients that will be served, increasing available resource utilization, and minimizing total processing time, or makespan. The scope of our study consists of simulating a 24-hour typical working day in the radiology department of the RHC. To better define the scheduling objects, we identified three types of radiology patients:

- Inpatients. About one third of all patients are those who are already staying in the hospital as inpatients. At times, inpatients may require certain radiology procedures. Inpatients stay in their rooms and are moved to the radiology center any time that a regular radiology resource (room) becomes available.
- Outpatients. If an X-ray is needed for an inpatient early in the morning, this patient may have to wait until late afternoon, because the center gives priority to outpatients. The outpatients tend to come on ambulatory basis during the morning hours.
- Emergency Patients. There are always patients who need a priority treatment because of their critical condition. This priority was carefully kept even when alternate heuristics were proposed.

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Step 3: Package Selection

For this study, we used MedModel, a simulation package provided by Promodel Corporation. Promodel is a world-leader in providing simulation-based solutions to hospitals and other healthcare institutions. Their customer list includes HCA, Stanford University Medical Center, TriCare and military hospitals around the world. Some recent applications of special interest to our study include the application of MedModel for patient scheduling in the radiology department in St. John's hospital, St. Luke's hospital, and Durham healthcare facilities. More details about these success stories are provided in the following website: http://www.promodel.com/solutions/healthcare/

Step 4: Logical Design Specifications

The scheduling process in the radiology department of RHC is repetitive. That means that the system is flushed during the night hours and it will start over at seven o'clock in the morning. Emergency cases are an exception to this rule and their arrival distribution is simulated on a continuous basis. Other major characteristics of the existing system, which are also used for actual simulation model, are the priorities in which different types of patients are treated. The radiology department operates under the following existing three priorities:

- Emergency patients first. According to this rule, any time an emergency patient needs radiological procedure, preemption occurs. This rule is followed under the reasonable assumption that emergency cases that are "life threatening situations" should be treated first although "fair treatment" or waiting time can be compromised.
- Outpatients first. If there is no emergency, outpatients are given priority over inpatients. This rule seems to be "easier" to apply, since outpatients usually just show up and sometimes with no appointments arranged in advance. Although an inpatient may have an earlier need for a test than an outpatient, he/she is usually not called in because the patient "can wait" in the hospital room and not in the waiting room of the radiology department.
- First come-first served (FCFS). Within the same group, patients are treated based on the FCFS dispatching rule. This rule minimizes the variance of the patient waiting times. Although this rule is considered to provide a "fair" treatment for all patients, it equalizes rather than minimizes patients' waits.

Figure 1 illustrates the actual dispatching heuristic. Upon arrival, patients are classified based on their type. Emergency patients are sent directly to the radiology room. Between inpatients and outpatients, the latter have priority.

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Figure 1. Algorithm for the Actual Rule
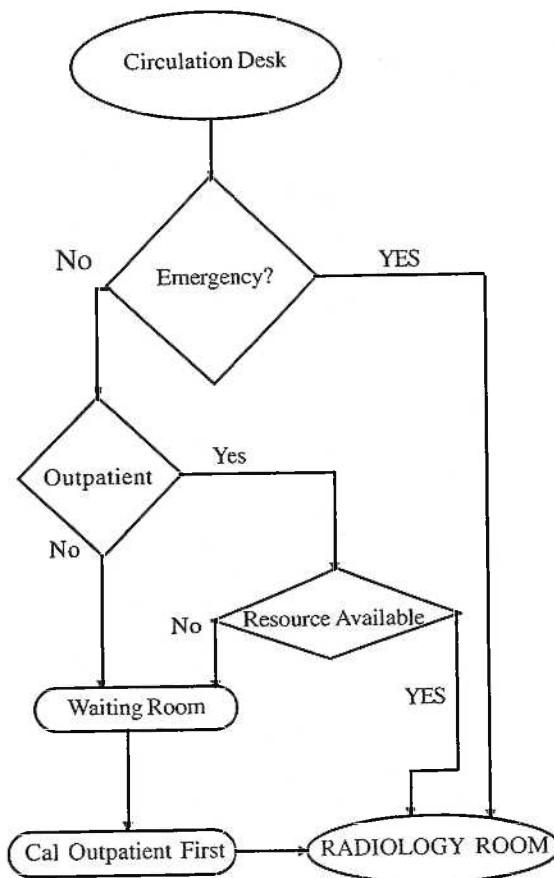
These priorities are combined using the MedModel simulation package. While patients enter the system, the model assigns preemptive priority to emergency patients, non-preemptive priority to outpatients, and no priority to inpatients. Within these groups, MedModel automatically select on the FCFS basis.

In order to generate alternative scheduling models, we used findings of previous research in such scheduling environment. Among others, Pinedo (1995, p. 352) provides several recommendations. Based on his findings, we proposed the following dispatching rules as the basis for alternative simulation models in the radiology department:

- Longest expected processing time (LEPT). This rule is optimal when the objective is minimization of the makespan. By minimizing the completion

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time for the last patient in the system, one can reduce the overall patient waiting time and increase the number of patients that are served. According to this rule, patients are served according to the priorities shown in Figure 2. From the pool of available patients, first priority is given to the patients who need a nuclear medicine treatment. Then those that need an ultrasound followed by those patients needing a CT-Scan are served. Patients that need X-ray are treated last.

- Shortest expected processing time (SEPT). This rule is optimal when the objective is minimization of the total completion times for all patients. For a given arrival and processing time, minimizing of the sum of completion times for all patients leads to minimization of the total waiting time. According to this rule, patients are treated according to the following priorities (also see Figure 2): From the pool of available patients, first priority is given to the patients who need a simple X-ray test, then those that need a CT scan, followed by those needing an ultrasound. Patients that need nuclear medicine are treated last.

Considering the emergency cases as priority over patient satisfaction through reducing patient waits, the emergency patient first rule is still kept intact when proposing the above scheduling alternatives

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Figure 2. Algorithm for LEPT (SEPT)

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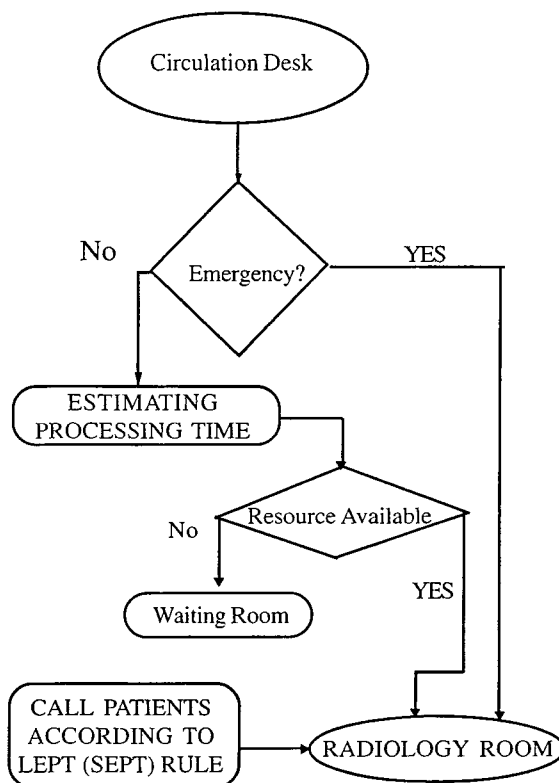
Step 5: Initial Statistical Testing

In order to define arrival distributions, the arrival times for inpatients, outpatients, and emergency patients are observed. For inpatients, the arrival time is recorded when the doctor notes in the patient requisition form a need for a radiology test. For outpatients and emergency patients, it is the time when they show up at the reception area. Using STATFIT, which is part of the MedModel simulation package, the arrival distributions are estimated as shown in Table 1.

Patient Type	Arrivals	Parameters
Emergency Patients	Weibull Distribution	Scale Value = .779 Mean = 64.8
Outpatients	Exponential	Mean = 9.64
Inpatients	Weibull Distribution	Scale Value = .858 Mean = 26.4

Table 1: Arrival Distributions for Different Types of Patients

Another set of random independent variables considered in the model is the processing times of different radiological procedures. Among a wide range of tests, we simplified the model by focusing on only four types of radiological tests. These four procedures were selected based on their frequency during our observation. Our analysis shows that simple X-rays (usually occurring in 40% of the patients), ultrasounds (about 25%), nuclear medicine (about 20%), and cat scans (about 20%). Other radiological procedures, such as mammograms, are excluded from the model since they are handled in separate rooms and by a special staff. Table 2 represents processing times for these radiological procedures as suggested by STATFIT simulation software.

Procedure Type	Processing Time Distribution	Parameters
X-ray	Normal	Mean = 8 Standard Deviation = 5
Ultrasound	Normal	Mean = 36.28 Standard Deviation = 12
Nuclear Medicine	Uniform	Mean = 127 Standard Deviation = 14.43
CT Scan	Normal	Mean = 32.5 Standard Deviation = 8

Table 2: Processing Time for Each Procedure

In order to estimate the number of replications needed to establish a confidence level, common statistical procedures are followed. Harrell et al., (1995, p. 67) provide an approach to computing the number of replications required to ascertain a selected degree of accuracy. Based

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on this approach and considering several preliminary observations, the needed number of replications is represented in Table 3. For example, the model based on the actual dispatching rules must run at least 25 times, in order to ensure a 95% confidence level that there is no significant difference between the sample and the population mean with respect to number of patients served.

Under the same conditions, the models based on the shortest expected processing time or the longest expected processing time dispatching rules must run respectively 18 or 48 times. The maximum value 47.67 shows that with respect to the number of patients served and in order to generate samples of the same size for statistical analysis, each model must run at least 48 times. Replicating the model 100 times will be sufficient enough to generate statistical significance for all cases under consideration.

Dependent Variable	Actual	SEPT	LEPT	MAXIMUM
Patients	24.49	17.93	47.67	47.67
Makespan	14.12	73.12	57.17	73.12
Resource Utilization	49.03	44.39	38.95	49.03
Waiting Time	25.41	44.52	25.04	44.52
Maximum	49.03	73.12	57.17	73.12

Table 3: Needed Number of Replications

Step 6: Complete Statistical Testing

Based on the suggestions from the literature, the following basic hypotheses are formulated:
- Hypothesis A: Replacing the current dispatching rule with LEPT dispatching rule will improve the following set of dependent variables:
  - HA1: Makespan: It is the completion time for the last patient in the system.
  - HA2: Number of Patients Served: It is the number of patients that leave the system after being treated.
  - HA3: Average Waiting Time: It is the average of the differences between completion (C) and arrival time (r) for each patient.
  - HA4: Resource Utilization: Another very important aspect of the hospital efficiency is the level of utilization of the lab technicians, nurses and physicians. This model is concentrated on the two groups of nurses who were usually available during the first shift.
- Hypothesis B: Replacing the current dispatching rule with SEPT dispatching rule will improve the following set of dependent variables:

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- HB1: Makespan: Same as HA1.
- HB2: Number of Patients Served: Same as HA2.
- HB3: Average Waiting Time: Same as HA3.
- HB4: Resource Utilization: Same as HA4.

In order to verify the above hypothesis, the simulation package generates data from three models: existing model, which represents the present dispatching rules, and alternative models, which respectively represent the longest and the shortest expected processing time dispatching rules.

	Makespan		Patients		Waiting Time		Resource Utilization	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviaiton
Actual	691.07	9.06	69.77	10.02	119.85	31.60	73.01	5.98
LEPT	685.08	7.06	56.65	11.23	81.32	34.71	66.79	5.71
SEPT	694.33	6.53	74.12	10.04	115.41	31.03	74.71	6.41

Table 4: Mean and Standard Deviation for Each Dispatching Rule

Dispatching Rule	Makespan	Patients	Waiting Time	Resource Utilization
Actual	-	-	-	-
LEPT	-5.18	-8.67	-8.17	-7.49
SEPT	2.90	3.05	-1.00	1.93

Table 5: T-tests for Each Dependent Variable

Hypothesis	1 Makespan	2 Patients	3 Waiting Time	4 Resource Utilization
HA (LEPT)	Supported		Supported	
HB (SEPT)		Supported		Supported

Table 6: Verification of Hypotheses

As one can see from Tables 4, 5 and 6, SEPT rule performed significantly better than the others with respect to number of patients (alpha=0.05) and resource utilization (alpha=0.1). This

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rule gave no significant improvement with respect to makespan and patient waiting time. As a matter of fact, this rule has a significant but negative result with respect to makespan.

On the other hand, the LEPT dispatching rule has a significant (alpha = 0.05) positive impact with respect to makespan and waiting time. One should be careful when applying this rule because LEPT also has a negative impact with respect to the number of patients and resource utilization.

Step 7: Analyze Results and Propose Heuristics

When considering replacing the current heuristic with either SEPT or LEPT, one should evaluate whether or not such a decision might potentially threaten "fair" treatment of the patients. According to SEPT (LEPT), a patient who has arrived later than others and has a short (long) radiology test should normally be served before a patient who needs a longer (shorter) test. This problem does not exist for inpatients. Inpatients are waiting in their hospital rooms and cannot see who came first.

For outpatients, an appointment system is suggested. Also outpatients can still be called on the FCFS basis, while preliminary preparation can start in other rooms and the actual test is done on the appropriate dispatching rule. This practice is similar to that of ambulatory healthcare units. The nurse calls patients on a FCFS basis and the physician will see the patients on some other scheduling rule basis.

Step 8: Test Newly Proposed Heuristics

The proposed heuristics were consulted with the medical personnel in the RHC. Based on these discussions, we made sure that the proposed heuristics do not contradict any of the required medical procedures. The new heuristics assume that the emergency patient will always be treated first and an appearance of a FCFS rule will be observed whenever is possible.

Step 9: Evaluate Practical Implementations

Practical recommendations which can be suggested for scheduling personnel consist of two cases. If the objective is to increase the number of patients that can be served and increase the resource utilization, then the following patient dispatching procedure for the radiology department is suggested:

1. Keep track and register the arrival and expected processing times for each patient.
2. Process the emergency case first. If there is more than one emergency case, then process them on a FCFS basis.
3. Process any outpatient first. If there is more than one outpatient, then process them on a SEPT basis.
4. Process any inpatient. If there is more than one inpatient, then process them on a SEPT basis.

If the objective is to reduce patient waiting time and makespan, then patient dispatching proce-dure for the radiology department is almost the same. The only difference consists on replacing the SEPT with LEPT for steps 3 and 4.

CONCLUSIONS

This paper proposes a practical step-by-step methodology for selecting and implementing simulation software packages for scheduling in healthcare centers. Many simulation software products are now commercially available. However, their use in healthcare systems has been limited. This limitation is due to the high level of complexity and uncertainty in hospital settings. These two factors challenge healthcare schedulers with the daunting task of representing the existing system constraints into appropriate theoretical models. Simultaneously, the findings from simulation models need to be converted into meaningful and practical heuristics, which some time may contradict the existing medical procedures.

The proposed REPLICATE methodology can assist the medical practitioners to deal with the above difficulties in the process of implementing different simulation software packages. We have successfully implemented the methodology in a real hospital setting. The radiology department in a RHC was used as a source of illustration. Our experience shows that following the proposed steps of REPLICATE and a good cooperation with the medical personnel is the basis for a successful implementation of simulation methodology in healthcare scheduling.

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