How to deal with fluctuations in hospital processes to improve accessibility?
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A dynamic speed limit is used to reduce fluctuations in speed in order to prevent traffic jams.

“Simple is the hardest”
Johan Cruijff
CHAPTER 6

How to reduce waiting times at an MRI department of a university radiology department

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Submitted
Abstract

Objectives To identify the causes for long waiting times at the MRI unit and the best scenarios for reducing these waiting times.

Methods A process analysis was performed to gain insight into the processes of the MRI unit and into the reasons for long waiting times. A simulation model was developed to imitate the current situation and to quantify the effect of different scenarios on the waiting times. These results were then used as input for the 2k factorial design method.

Results There are two main causes for waiting times in the waiting room: actual durations of scans exceeding the scheduled durations, and last-minute daily adjustments that disrupt the schedule. Reducing supervision by radiologists, more accurate attunement of scheduled and actual durations, and eliminating patients with unexpected issues from the regular MRIs reduces waiting times the most, namely 25%, 8.5%, and 5% respectively (these three form the first group of causes).

Conclusions In order to reduce the waiting times at MRI facilities, reducing the supervision by radiologists is advised. Furthermore, the scheduled durations should be better attuned to actual durations, and patients with unexpected issues should be eliminated from the regular MRIs or placed at the end of the regular program.
6.1 Introduction

Reducing waiting times is a hot topic in health care management. There are two types of waiting times: the time between the referral for a consultation or diagnostic examination [1], and the time the patient actually spends waiting on the day of the appointment. Our study deals with the latter situation: the waiting time prior to an MR (magnetic resonance) examination on the day of the appointment.

Long waiting times are associated with low overall patient satisfaction (see [2-5]) particularly when perceived times exceed expectations, according to the disconfirmation paradigm [6, 7]. Furthermore, in a more competitive health market, increased waiting times decreases patients’ willingness to return [8]. Therefore, several hospitals have started programs to improve their service. Hosts and hostesses are hired to help patients find their way around the hospital, and reading tables and televisions are provided to make waiting more comfortable. Although this leads to higher patient satisfaction (being entertained during the wait is also a significant predictor of patient satisfaction [2]), this does not really tackle the cause of the problem, but just deals with its consequences.

Several studies have been published on waiting time management in outpatient departments [9] and emergency departments [10, 11]. Computer simulation has been used to optimize these processes [12]. However, very few studies have been performed on reducing waiting time in diagnostic departments. The studies that have been done in diagnostic departments are mainly concerned with X-rays and CT (computed tomography) scans and are based on a walk-in structure, in which patients have a different arrival pattern than in departments with appointment-based scheduling. Rosenquist [11] showed how queuing theory could be used for the X-ray department to balance cost of service against utilization of equipment, and to evaluate the waiting times involved. A related operations research method was shown by Jeans et al. [14], who generated a simulation model to predict the effects of changes in workload and resources on the waiting times for the X-rays. Reinus et al. [15] showed how an analytical model based on queuing theory can be used to evaluate expected steady-state wait periods for the CT scanner. By breaking as many activities as possible out of the scanner, waiting times for regular as well as urgent patients could be reduced considerably.

The main objective of our study was to test how an operations research method could be used to reduce waiting times for a more complex facility within a diagnostic department, namely the MRI (magnetic resonance imaging) unit. The MRI unit of the radiology department in the Academic Medical Center (AMC) in Amsterdam, the Netherlands was used as a case study, since the problem of long waiting times was felt to be an important logistical problem by the referring clinicians, the patients, and the department management.
Our two research questions were:
1. What are the main reasons for long waiting times for the MRI?
2. Which scenarios are best for reducing waiting times?

6.2 Material and Methods

A process analysis was performed to gain a better understanding of the MRI unit. This analysis was based on structured interviews with radiologists and radiological technicians (RTs), observations of the process for the MRI, and data. After this process analysis, a simulation model was developed to quantify the effect of different causes, following the $2^k$ factorial design method that was used to determine which causes contribute most to long waiting times.

6.2.1 Process analysis

The capacity of the radiology department’s MRI unit increased from one 1.5 Tesla MRI and one 3 Tesla MRI in 2006 to two 1.5 Tesla MRIs, one 3 Tesla MRI, and one open MRI in 2007. The production of 2007 was 12,000 MRI scans. Most patients come from the outpatient and clinical departments.

There are two main patient flows at the MRI. The largest group is made up the regular patients, for whom an appointment-based, computer-based (X-care by McKesson) scheduling system is used. For the more urgent patients (i.e., when an MRI is needed from within 24 hrs to 2 weeks), manual planning is a regular procedure. This paper focuses on the first group of scheduled patients.

When patients arrive at the MRI, they check in at the reception desk, and then go to the waiting room (see Figure 6.1). A few minutes before the actual start of the MRI scan, an RT will call for the patient, bring him or her to an unoccupied dressing room, and prepare the patient for the MRI scan. This ensures optimal use of the MRI unit, and no valuable time is lost. Radiologists supervise the scans, since due to complex pathology, the majority of patients are referred from other hospitals.

Figure 6.1: Process for the MRI of a radiology department
In general, there are two reasons for increased waiting times: the actual duration of scans exceeding the scheduled duration, and last-minute daily adjustments that disrupt the schedule and therefore cause additional waits.

Scheduled versus actual duration

During October and November of 2006, measurements were taken in the MRI unit to obtain estimates of the actual durations of the scans compared to the planned ones. According to these measurements, the actual durations differ from the scheduled durations by an average of -1.22 minutes and a standard deviation of 17 minutes. The mean of the difference between the scheduled and the actual durations is negative, which indicates that the scheduled time is sufficient for average cases. However, the standard deviation from this average difference is 17 minutes, which means there are scans that exceed their scheduled time, resulting in waits. An analysis of the causes of this discrepancy showed that various factors contributed to this:

Supervision by radiologists: The first reason for this variation is that, prior to finalizing the procedure, supervision of the MR examination by a radiologist is thought to be essential in a significant number of investigations. For this purpose, 15 minutes of additional time is reserved and added to the original scheduled duration. However, the extra time that is actually needed varies, and may be longer than the extra reserved time. This would then exceed the total scheduled duration of the scan (with an average of 2.03 minutes and a standard deviation of 22.3 minutes) and would therefore cause waiting times.

Insufficient scheduled durations: According to the measurements, scans not supervised by a radiologist exceed the scheduled duration by an average of -2.2 minutes and a standard deviation of 15.37 minutes. Therefore, one may assume that the time reserved for the different examinations is not always sufficient.

Unexpected patient-related issues, not canceling the scan: A third reason for high variation in the difference between planned and actual durations are unexpected patient-related issues like claustrophobia. Because these patients are afraid of being inside the largely enclosed MRI, it may take longer to take good pictures, or it might be necessary to stop an MRI scan (see next section). Because no measurements were available of these MRI scans, the analysis was based on the experience of the RTs.

Interruptions to the regular schedule

Another reason for waiting times in the waiting room are interruptions to the daily schedule. There are several reasons for this:

Too late: Patients receive a letter from the MRI unit about their appointment date and time, and are asked to arrive 15 minutes early. Even so, some patients arrive too late. Patients’ arrival times were also noted during measurements of waiting times in the waiting room taken at the end of April and the beginning of May 2007; 107
patients participated in these measurements and their arrival time varied from 90 minutes early to 20 minutes late.

**No-shows:** Sometimes a patient does not show up at all. The RT decides if this gap is going to be filled. Although gaps can be filled by clinical patients, there is quite a difference between the moment the RT finds out there is a no-show and the moment the urgent patient actually arrives at the MRI unit. Therefore, the RT will check to see if the next scheduled patient is present. This patient can then be scanned first, followed by the urgent patient, who in this way has had enough time to be transported to the MRI. If the next scheduled patient is not present, the RT works with a certain margin of time when deciding if there is enough time left to examine an urgent patient. The margin used depends on the RT; sometimes this works out well, but other times it does not, causing waiting times.

**Unexpected patient-related issues, canceling the scan:** When a patient arrives at the MRI, the RT will check to see if the patient has a contraindication for an MRI, for example, a pacemaker or metal parts in the patient’s body. If this is the case, the patient cannot have an MRI scan. When this happens, the RT has to make the same decisions as with a no-show. Is the gap going to be filled by an urgent patient, with the consequence of overrunning the schedule? The same holds for situations where scans of patients with claustrophobia are canceled at the start of or halfway through the scan.

### 6.2.2 Simulation model

A discrete event simulation model was developed to quantify the effects of different last-minute daily adjustments on the waiting times in the waiting room. A simulation model was chosen rather than an analytical model because of the high variability in the arrival times of patients and the actual durations of the scans. Discrete event simulation is concerned with modeling a system as it evolves over time by a representation in which the state variables change instantaneously at separate points in time. These points in time are the ones at which an event occurs. In the case of our study, the events are a patient’s arrival at the reception desk in the MRI unit, the actual start of an MRI scan, the end of an MRI scan, and finally, the patient’s departure from the MRI suite.

**Input parameters:** The input parameters of our model were deterministic as well as stochastic. The deterministic input parameter is the MRI schedule, which contains the day and starting time of an MRI scan of a regular or semi-urgent patient, the scheduled duration of the scan, and the specific MRI used to make the scan. The stochastic input parameters are empiric distributions used to determine the number of urgent patients arriving on a given day, the urgency of these patients, the scheduled duration of the MRI scans, and the MRI used to make the scan. Distributions are also
used to determine the time it takes to help a scheduled patient at the reception desk and the actual duration of the MRI scan for scheduled as well as urgent patients.

During September, October, and November of 2006, measurements were taken to obtain estimates of the discrepancies between the actual durations of the scans and the scheduled time frame. These results were used as input parameters for the distribution of the actual duration of the scans. The distributions used to determine the number of urgent patients, the duration of their scans, and the specific MRI used to make the scan were based upon the experience of the RTs, because these data were not available from the data systems. The schedule for regular and semi-urgent patients used in the simulation model was obtained from the regular planning system (XCare by McKesson).

**Output parameters:** The output parameters of the simulation model are the mean waiting time in the waiting room. The simulation program used was MedModel Professional Version 7.

In simulation, two sorts of systems can be modeled: a terminating and a non-terminating system. In a terminating system, some natural event terminates the operation of the system. In a non-terminating system there is no such event, and the system is a continuous stream of activity [18]. The MRI unit could be seen as a terminating system, because work begins at 8:30 a.m. and ends at 5:00 p.m. But at the same time it is also a continuous system, because work will continue the next day. In our study we have chosen for a non-terminating system because our working days are not completely independent of each other - some urgent patients are moved to the next day. Because a non-terminating system has strong initial bias, the first day of each simulation run was deleted from our estimation of the waiting times. The Welch method was used to determine the length of this warm-up period [18].

Because the schedule used as an input parameter contained 167 days, this was also the length of the simulation run. The number of replications was determined using this fixed length and the replication/deletion method [18]. The number of replications was set at 25, because we stated that the 95% confidence interval could have a relative half-width (error) of a maximum of 5%.

The simulation model was validated successfully and was used for the 2k factorial design method.

### 6.2.3 2k factorial design

Just as the simulation model was developed to imitate the current situation and to quantify the effect of different scenarios on waiting times, the 2k factorial design method [17] was used to calculate the individual and the interaction effect of these scenarios. The method deletes the correlation between the different scenarios and identifies the important experimental factors whose changes are most likely to yield to the desired result [19], in our case, the reduction of waiting times. In the 2k
factorial design, “k” is the number of experimental factors. When there are three factors, the experimental design looks like the one in Table 6.1. An experimental factor can have two levels, denoted by a - and + sign; changing a sign from its - to its + level means changing the factor from its current situation (causing waiting times) to a new situation. In the experimental design in Table 6.1, there are $2^3 = 8$ scenarios. Two effects can be measured using the $2^k$ factorial design: the main effect per factor, and the interaction effects. The main effect is the mean average effect on the response of changing a factor from its - to its + level. The interaction effect results from the change of more than one factor at a time. This effect can be very useful, for instance, when the effect of changing two factors is the same as changing only one of these factors. This prevents two interventions being implemented when one would have been sufficient.

Three factors were chosen for the $2^k$ factorial design: 1) supervision by radiologists, 2) accuracy of the scheduled durations, and 3) unexpected patient-related issues (not canceling the scan). Other factors like no-shows and arrival times of the patients were not included because, in practice, these factors are difficult to influence and therefore improve.

The - level of all three factors is the current situation. The + level of the first factor is stated as the situation in which radiologists no longer check the scans made by the RTs. As mentioned earlier, measurements were carried out in the fall of 2006. During these measurements it was also noted when a radiologist wanted to check the scans. Using these results, a distribution could be determined for the actual duration of scans for the - level as well as the + level.

The + level of the second factor was accomplished by halving the variance in the difference between the scheduled durations and the actual durations of the scans, thereby leaving the mean of this difference undisturbed. Reducing the variance by half was chosen because reducing the variance to zero is very difficult to do in practice.

### Table 6.1: $2^k$ factorial design with three experimental factors

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>- (current)</td>
<td>- (current)</td>
<td>- (current)</td>
<td>R1</td>
</tr>
<tr>
<td>2</td>
<td>+ (new)</td>
<td>-</td>
<td>-</td>
<td>R2</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>+ (new)</td>
<td>-</td>
<td>R3</td>
</tr>
<tr>
<td>4</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>R4</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
<td>+ (new)</td>
<td>R5</td>
</tr>
<tr>
<td>6</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>R6</td>
</tr>
<tr>
<td>7</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>R7</td>
</tr>
<tr>
<td>8</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>R8</td>
</tr>
</tbody>
</table>
The distributions used for the difference between the scheduled and the actual durations are beta and gamma. For example, the mean of the beta distribution is given by

\[ E(X) = \frac{\alpha}{\alpha + \beta} \]

where \( \alpha \) and \( \beta \) are shape parameters, determined using the results of the measurements. The formula for the variance is

\[ \text{Var}(X) = \frac{\alpha \beta}{(\alpha + \beta)^2 (\alpha + \beta + 1)} \]

\( E(X) \) and \( \text{Var}(X) \) were calculated for the current situation. Because the mean is kept unchanged, the \( E(X) \) formula can be rewritten as

\[ \beta = \frac{1 - E(X)}{E(X)} \alpha \]

and can be substituted in the formula for the halved variance:

\[ \frac{1}{2} \text{Var}(X) = \frac{1 - E(X)}{E(X)} \frac{\alpha^2}{(\alpha + \frac{1 - E(X)}{E(X)} \alpha)^2 (\alpha + \frac{1 - E(X)}{E(X)} \alpha + 1)} \]

Because \( E(X) \) and \( \frac{1}{2} \text{Var}(X) \) are both scalars (the current mean and the halved variance respectively), the only unknown variable \( \alpha \) can be determined and subsequently \( \beta \). These \( \alpha \) and \( \beta \) are used in the distributions of the \( + \) level of factor 2.

The \( + \) level of factor 3 is the situation in which there are no unexpected patient-related issues during a given day, which could be accomplished by pre-screening.

### 6.3 Results

The eight different scenarios were simulated and the results are shown in Table 6.2. Using the results from this table, the main effects of the different factors can be calculated:

Main effect (1) = \( \frac{(R8 - R7) + (R6 - R5) + (R4 - R3) + (R2 - R1)}{4} = -0.79 \)

Main effect (2) = \( \frac{(R8 - R6) + (R7 - R5) + (R4 - R2) + (R3 - R1)}{4} = -1.67 \)

Main effect (3) = \( \frac{(R8 - R4) + (R7 - R3) + (R6 - R2) + (R5 - R1)}{4} = 0.99 \)
When a factor has a negative main effect, the mean average effect on the response of changing the factor from its - to its + level is a decrease in waiting time. Factor 1 provides a reduction of 24%, factor 2 a reduction of 8.5%, and factor 3 a reduction of 5%.

The interaction effects are as follows:

Interaction effect \((1,2) = \frac{(R_1 - R_2 - R_3 + R_4 + R_5 - R_6 - R_7 + R_8)}{4} = 0.11\)

Interaction effect \((1,3) = \frac{(R_1 - R_2 + R_3 - R_4 - R_5 + R_6 - R_7 + R_8)}{4} = -0.29\)

Interaction effect \((2,3) = \frac{(R_1 + R_2 - R_3 - R_4 - R_5 - R_6 + R_7 + R_8)}{4} = -0.11\)

The interaction effects are calculated by adding up the scenarios in which the two factors have the same level, and subtracting all the scenarios in which the two levels are different. When an interaction effect is positive, it means that the waiting time is higher when the two factors have the same level; therefore, the levels should be opposite. Inversely, when the effect is negative, the two levels should be kept equal to each other.

Table 6.2: 2k factorial design applied to the MRI study

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Factor 1: Supervision by radiologists</th>
<th>Factor 2: Planned durations</th>
<th>Factor 3: Unexpected patient-related issues</th>
<th>Response: Mean waiting time (in minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>- (current)</td>
<td>- (current)</td>
<td>- (current)</td>
<td>19.62</td>
</tr>
<tr>
<td>2</td>
<td>+ (eliminated)</td>
<td>-</td>
<td>-</td>
<td>14.85</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>+ (better fit with actual durations)</td>
<td>-</td>
<td>18.47</td>
</tr>
<tr>
<td>4</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>14.24</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
<td>+ (no unexpected patient-related issues)</td>
<td>18.18</td>
</tr>
<tr>
<td>6</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>13.16</td>
</tr>
<tr>
<td>7</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>17.14</td>
</tr>
<tr>
<td>8</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>12.02</td>
</tr>
</tbody>
</table>
6.4 Discussion

According to our analysis, there are several causes for long waiting times in the waiting room, namely the supervision by radiologists, the difference between scheduled durations and actual durations, unexpected patient-related issues, patients arriving too late, patients not arriving at all, and patients with a contraindication. Computer simulation was used to determine which causes are worth tackling. The results of the simulation model show that several parts of the process can be adjusted to reduce waiting times in the waiting room. According to the $2^k$ factorial design, the greatest reduction would be accomplished by reducing the supervision by radiologists. If radiologists no longer check to see if the scans are satisfactory, the waiting time would be reduced by 25%. This could be accomplished by standardizing the MRI-protocols better so the quality of the scans will be satisfactory for all radiologists. In the current situation, only one radiologist decides upon the standard protocol and the other radiologists often want to check the scan and ask for additional series.

Besides a reduction in the variance of the duration of the scans and therefore in the waiting times, abolishing the supervision would also lead to the elimination of the extra 15 minutes reserved in the schedule. This means that more patients could be scheduled within the same amount of time.

Another reduction in waiting times could be achieved if the scheduled durations are more accurately attuned to the actual durations. This could lead to a reduction of 8.5%.

According to the $2^k$ factorial design eliminating patients with unexpected issues from the regular MRI would only result in a 5% reduction in waiting times. Therefore, the mean effect of eliminating these patients is not a substantial reduction in waiting times. However, shortly after this study was finished, an open MRI was installed especially for children. This open MRI could also be used for a patient with a contraindication or a patient who is afraid of being in a common MRI.

The $2^k$ factorial design was also used to calculate the interaction effect. Because in our case the outcomes were close to zero, the interaction effects are negligible.

In our study, we used a simulation model - which is very labor-intensive - rather than an analytical model. An analytical model is very helpful in the cases where patients walk in and the capacity has to be adapted, as shown by Reinus et al. [15]. But we did not find an applicable analytical model that determines waiting times in the waiting room for an appointment-based system. In addition, the process for an MRI is more complicated than the process for a CT scan. For comparison, Reinus et al. [15] mentioned that the scheduled durations of all scans is half an hour, whereas the MRI at the AMC has 80 different scans with 6 different durations. Furthermore, we were interested in specific steps in the process and found that the animation of
the simulation model would be helpful for the communication with the radiology department.

As mentioned in the introduction section, many studies have been performed on outpatient departments and emergency departments. However, we did not found a study which simultaneously incorporated supervision, more accurate planning of scheduled durations and preemptive consultations due to unexpected patient-related issues to reduce the waiting times in the waiting room.

Our research enables us to provide clear advice to the management of radiology departments that need to reduce waiting times:

- Reduce the supervision by radiologists as much as possible
- Measure the actual durations of the scans and examine which scheduled durations need to be updated.
- Use pre-screening to prevent unexpected patient-related issues. Eliminate these patients from the regular MRIs, or place them in a separate time frame where this cannot disrupt the regular program (for example, at the end of the daily program). The effect on the waiting time in the waiting room is not very substantial, but it also has a positive effect on the access time.
- Even though the process on the MRI unit is complex, computer simulation is an appropriate method to evaluate different scenarios in order to reduce the waiting time. With our paper we showed that this method is not only suitable for reducing access time, but also for reducing waiting time in the waiting room at the MRI unit.
- In our study we combined computer simulation with the 2k factorial design method, which we have not seen in other studies before. Although the interaction effect of the 2k factorial design was not significant in our case study, it can still be a powerful tool in other cases to evaluate the effect of multiple scenarios simultaneously.
References