Application of computer simulation analysis to assess the effects of relocating a hospital phlebotomy department

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Abstract

Background This study describes a systematic approach to assess the effects of relocating a hospital department.

Methods Using the phlebotomy service as an example, computer simulation was applied to predict changes in performance indicators, such as patient turn-around time (TAT), when planning a procedural and/or architectural redesign.

Results Average patient TAT fell from 12 to 8 min, enabling the department to cope with any increase in numbers of patients.

Conclusion This type of study can provide useful information in assessing the consequences of future changes in the location of a hospital department.

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Introduction

Moving a hospital department to a new location almost always results in changes in operational procedures, as well as in the physical layout. There may therefore be a need for a business process redesign to obtain an optimally running department. Business process redesign has been advocated as one of the research priorities in health informatics.[1]

Because most health care organizations are complex, it is difficult to assess the effects of a departmental relocation and/or redesign. In this article we present a systematic approach that can be used for this purpose. We use a computerized simulation technique to calculate performance measures under different circumstances and have investigated the usefulness of this approach.

In the provision of a phlebotomy service, managers aim to employ the minimum number of staff that can process patients in a timely cost-effective manner. In practice, a compromise is reached between the time a patient has to wait and the number of staff required. Additional constraints may include the quality of medical care delivered and work satisfaction. In The Netherlands and in many other countries, the phlebotomy service may be the first service used by patients when they visit hospital. Therefore their impression of the hospital as a whole may be influenced by their initial experience with the phlebotomy service.

To assess the performance of the phlebotomy service an indicator is needed that can be used to compare different situations. Commonly used standards are the average turn-around time (TAT), costs per blood draw, patient satisfaction, average quality of the blood samples and the error rate. In this study, the average TAT is the main performance indicator used. This was also used by Klafehn and Connolly,[2] who used a simulation model to assess the number of staff needed for a new phlebotomy service to obtain reasonable TATs. They distinguished between clerical and technical staff and studied the impact of employing cross-trained clerical staff, who, they believed, would make the laboratory more efficient. The results of the study were used to convince the management of the presence of bottlenecks that had already been observed by the technical staff. They did not study layout or procedural changes.

In the manufacturing industry simulation is used to analyse the flow in a designed layout of a plant.[3] Slack *et al.*[4] argue that simulation is one of the most powerful tools for designing a process.

The phlebotomy service in the present study is located in a general hospital. Users of this service include medical specialists from the local hospital and regional general practitioners. Because of a planned renovation of the hospital, the phlebotomy service will be moved to a new location. This necessitates the development of a floor plan of the phlebotomy service at the new location. The management of the hospital had determined to which location the service had to move, therefore several design parameters such as dimensions and the location of the entrance were already defined. The relocation provided an opportunity to introduce new technologies. It is expected that the number of patients that visit the phlebotomy service will rise in the near future, as more patients visit hospital. Before constructing the new facility it is important to know whether the proposed layout will be an improvement over the current situation, given the expected trends.

Methods

Delineation of problem

This study deals with the effects of both the redesign of the architectural layout and changes in organizational procedures on selected performance indicators of the phlebotomy service.

Figure 1 illustrates the process of analysing the effects of relocating a department within a hospital setting. First, the different processes carried out in the current situation are described and the observed TAT of the patients is measured. On the basis of these data, a simulation model of the current situation is developed. In the next step, an inventory of existing bottlenecks is made. The processes are now redesigned in such a way that bottlenecks are removed or reduced and a floor layout of the future location is made. After finishing these activities, a simulation model of the future phlebotomy service is developed. Using the simulation models, performance measures may be calculated for both the current and proposed layout. These performance measures can be compared and a decision made either to implement the proposed processes and architectural layout or create another model. This procedure is repeated until acceptable results are obtained.

General approach to modelling

The technique used to compare the current and proposed layout is simulation. Simulation is defined as 'the imitation of the operation of a real-world process or system over time'. While running a simulation model, an artificial history of the system is created. A simulation model can be used as a tool for predicting the impact of a change in an existing system and can provide an answer to 'what if' questions concerning the behaviour of the system under study. It is one of the most widely used and accepted tools in operational research and systems analysis. Some of the advantages of simulation are (see Banks *et al.*[5] for an extensive list):

- The effects of new organizational or operational procedures can be assessed without changing the operations of the real system.
- Bottlenecks can be identified (with simulation) and a solution tested without changing the real system.
- 'What if?' analyses can be performed and the results analysed.

Besides these advantages there are also some disadvantages (see Banks *et al.*[5] for an extensive list):

- Model building is half an art, half a science.[6] Model building can be time-consuming. The modeller has to be familiar with the topic under study and spend time talking with those more familiar with the issues.
- People with (some) simulation background are needed to perform the simulation study. However, simulation software is user-friendly; the skills needed today are less than those needed 10 years ago.
- A simulation experiment is an experiment in which a model (always a simplification) of an organization is used. It is not a real-life experiment.

A simulation study consists of several steps.[7,8] Two important steps are verification and validation. In verification, the operation of the model is investigated. Does the proposed model run properly? In the validation step, the results of the simulation model are compared with actual observations of the modelled system.

When using the validated model for investigating new situations in which a modified simulation model is used, one may expect that the outcome of a simulation is also valid for the new situation. Every simulation model has a certain 'bandwidth' within which modifications do not influence the validity of the model. However, there may be changes in the model that may invalidate it and this is not always predictable. It is therefore always useful to report not only how the model was validated but also whether the predictions for the new situation were correct.

There are several methods that may be used to validate a simulation model; animation and historical data validation are two examples.[9,10] In general, a

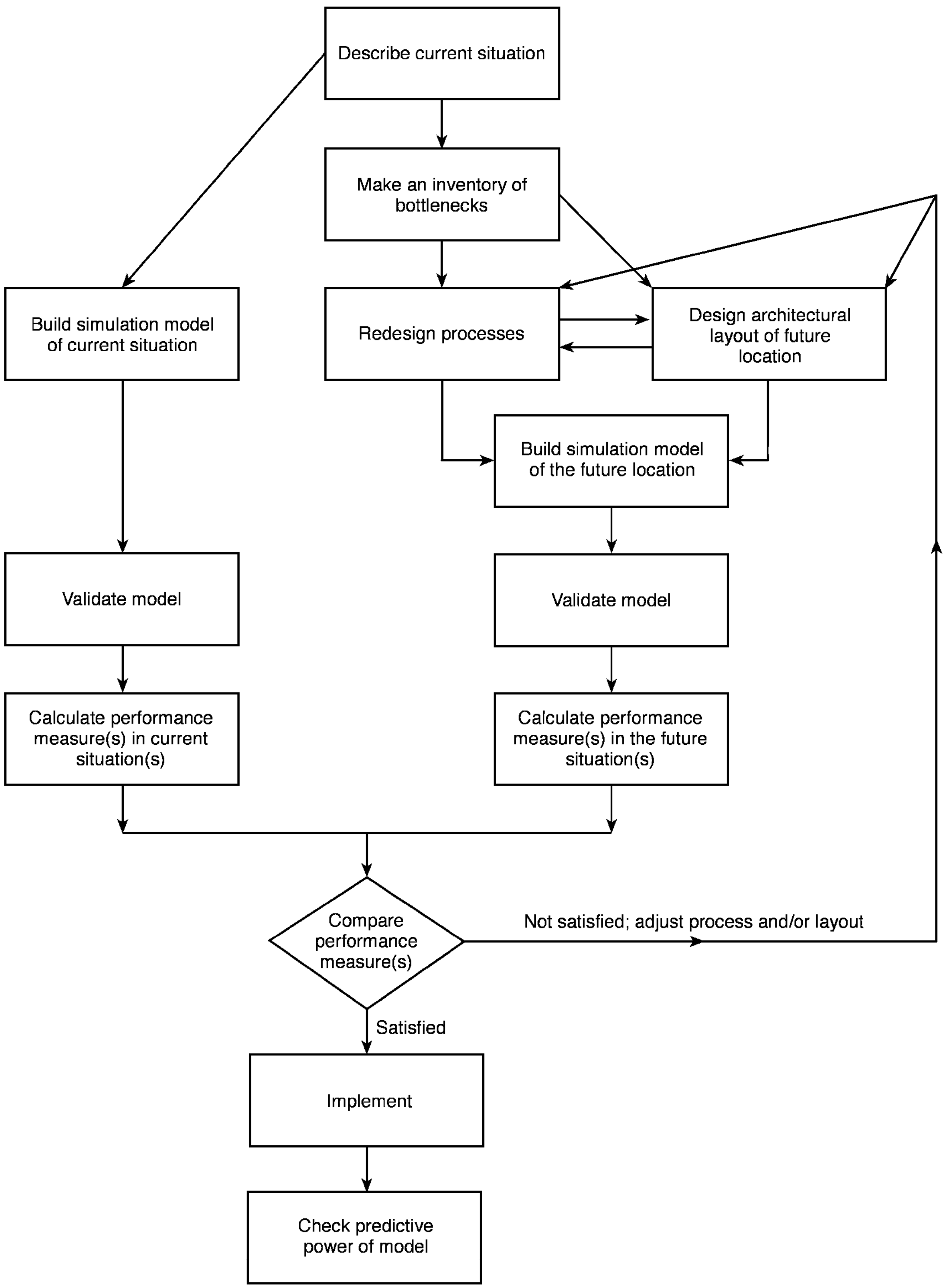


Figure 1. *The process of assessing the effects of relocating a department of a health care organization.*

validated simulation model can be used to analyse different scenarios and therefore it can be used as a decision support tool.

A simulation model of patient flow in a health care organization can be characterized as a queuing model.[11] Using discrete event simulation, utilization of resources and average service times can be calculated. Different queuing principles such as 'first in first out' or 'last in first out' can be tried out.

In this study, MedModel[12] was used to implement the simulation model. MedModel is a discrete event simulation package with a graphical user interface. It

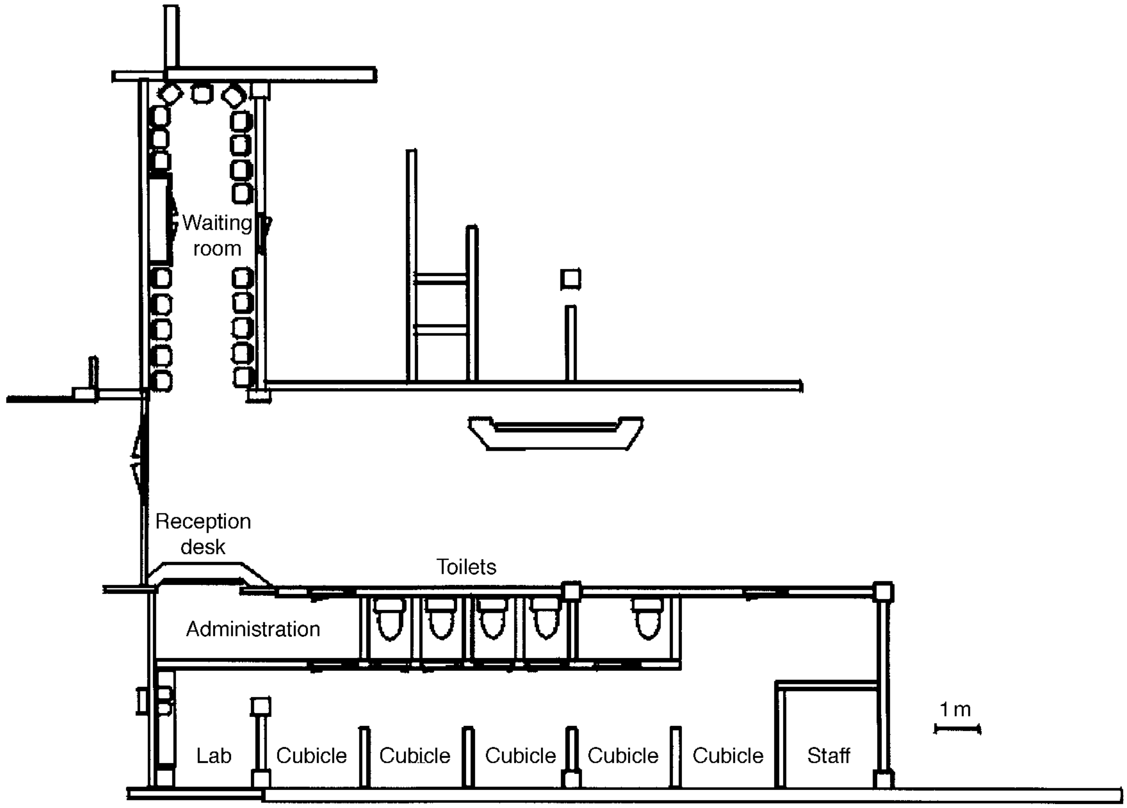


Figure 2. *Floor plan of the current phlebotomy service location.*

is based on the description of processes in a health care facility. The different locations are depicted with icons. The patients take part in various processes and activities and the use of specific resources (e.g. the drawing of blood by a nurse in the cabin) form part of the process description. The duration of these activities is described by statistical distribution functions. The patients move between the various locations on so-called 'path networks', which are an implementation of queuing networks. During simulation, animation visualizes the movement of the patients through the organization.

Development of the phlebotomy service model

The floor plan of the current phlebotomy service is shown in Fig. 2. The department consists of nine employees [5·8 full-time equivalents (FTE)], including nurses who also take blood from the patients at the wards. At any one time a maximum of five nurses (4·5 FTE) provide the service, one of them continuously manning the reception desk. The other nurses work in the cubicles, in which the blood is taken. Departmental opening hours are from 0800 until 1700 h and an average of 271 patients visit the department daily. Patients are referred to the department from outpatient clinics or by a general practitioner. At time $T1$, the patient arrives in the department. At time $T2$, they report to the reception desk where they identify themselves and hand over the request form. On average this takes 48 s. Only one patient at a time can be served at the reception desk. After a nurse has checked the forms, the patient is sent to the waiting room, which has a capacity of 18 chairs. In instances where blood is not required, patients hand over urine or faecal samples and then leave.

When a nurse is available, the patient is guided from the waiting room to one of the five cubicles or to one of the five toilets at time $T3$. Depending on the request, the patient has to give blood and/or urine. The patient leaves the service at time $T4$. If the request is a STAT, a nurse brings the sample directly to the clinical laboratory, located at a distance of 279 m. On average, the total distance a nurse walks per patient is 37·5 m (STAT samples not included). There is no difference in the procedure between patients referred from outside the hospital and patients referred from the outpatient clinic.

A brief international survey showed that the process described above is very similar in five European countries. In some countries the process of drawing blood is not centralized; it is performed in various departments within the hospital.

A work-flow analysis was carried out. During one working day all patients who visited the phlebotomy service had their times of arrival at the different locations recorded. For all the patients, the test request forms were examined and the different request types were scored.

The following bottlenecks in the system were identified by means of the work-flow analysis:[13]

- STAT samples are time-consuming for the nurses because they have to be taken directly to the laboratory.
- The process of calling a patient and guiding him/her from the waiting room to the cubicles by a nurse is time-consuming.
- Too little capacity is available at the reception desk (only one nurse).
- There is little privacy at the reception desk.

Based on these observations a number of changes were suggested for the new phlebotomy service. The introduction of a pneumatic tube to transport samples to the laboratory would reduce the time wasted by nurses in transporting STAT samples to the laboratory. At the counter a second workplace would be created, which unlike the first counter, would not be constantly attended; but, if there were patients waiting in the queue, the first nurse that was available would attend the second counter instead of going to patients in the waiting room.

A callboard would direct patients to a specific cubicle or toilet, obviating the need for the nurse to guide the patient. However, it is assumed that currently, on average, 50% of the patients have to be accompanied by a nurse from the waiting room to the cubicle or toilet because of their mental or physical condition.

Implementation of the simulation models

While building the model several decisions were made:

- Patient arrivals were modelled using an arrival cycle. The arrival cycle, a MedModel phrase, indicates the measured percentage of patients arriving in 30-min time windows (*see* Fig. 4). Within these time-frames the arrivals are assumed to be uniformly distributed.
- No distinction was made between individual nurses. All nurses performed all tasks within a task-specific time-frame.
- There were eight different procedures in the cubicle and one (urine collection) in the toilets.
- TATs were calculated only for patients who visited a cubicle and/or a toilet.
- Coffee breaks and lunch breaks were included in the model. These occur at fixed times, although all on-going procedures are completed before breaks are taken.
- The time taken for each patient consultation at the reception desk depends on the number of patients in the queue. For example, individuals in a queue of ten patients are more likely to ask fewer questions than those in a queue of two because they would delay more people by holding up a longer queue. If there are no patients in the queue, then individuals may ask more elaborate questions. Nurses behaved similarly when answering patients' questions. They took longer to answer questions from patients who were in short queues than from patients in long queues.

  The time taken to process 53 patients at the reception desk was measured, together with the number of patients in the queue when the first patient was processed. Three situations were identified depending on whether there were (1) zero, (2) one or two, or (3) more than two additional patients in the queue. A statistical tool included in MedModel was used to fit these data with suitable probability distribution functions. Based on the goodness-of-fit, asymmetric distributions such as Weibull, Pearson V and Pearson VI (see Law and Kelton[7] for more details on distribution functions and about fitting of distributions) were chosen and their parameters obtained.
- Figure 2 shows the floor plan for the simulation. The dimensions of the cubicles are known, and the pathways were scaled to real-life.
- In the future situation the medical laboratory will use new equipment, resulting in a reduction in the number of blood tubes that need to be collected from each patient and the number of forms that need to be completed. This will reduce the time spent in each cubicle.

Model validation

To validate the model, the output of the simulation model is compared with the data of the actual system.[7] Validation of the model is an important step in any simulation study and several methods have been described to validate a simulation model.[5,9,10] In one of these,[9] the author stresses that actual results (including determined variances) should be published to convince users of the correctness of the model and its results. In addition, as explained earlier, it would be good to show that the suggestions of a validated simulation model for a new situation are correct. The outcomes of decisions based on simulations are usually not reported in the literature, although the outcome can shed additional light on the adequacy of a model. It demonstrates the power of simulation as a tool for redesign.

Experiments

To assess the predictive power of our simulation model a new situation was created by the introduction of a second workplace at the reception desk and this was then modelled. The effects on the TATs were simulated and compared with observed values (experiment 0). In situation A, the number of workspaces is one and in situation B the number of workspaces is two; in both situations the layout of the current department is used. Situation B is the experimental situation specially created for this study. When the observations regarding situation B were made, new equipment was in use in the laboratory. As this required fewer tubes and request forms, the process times in the cubicles were sometimes reduced.

In experiment 1 the effect of the new layout on the TAT was investigated. The need for one or two workspaces at the reception desk in the new layout was also ascertained. In situation C the future layout was used with one workspace at the desk; in situation D another workspace was added. The number of patients was kept fixed at the current level. In this way both the effect of the new layout and the presence of one or two workspaces could be studied. The main characteristics of situations A–D are summarized in Table 1.

In experiment 2 the number of patients was varied to study the effects on the TAT when varying numbers of patients visit the phlebotomy department. The number of staff was fixed at the current value.

The duration of patients' contact at the reception desk influences the number of patients in the queue at the counter. If for some reason the counter is staffed with non-specialized personnel, the duration of the contacts at the counter will likely increase. On the other hand, if the request forms are printed out and the nurses do not have to identify what is written on the request form, a decrease of the duration of the contact with the patient at the counter can be expected. To investigate these effects, in experiment 3 the minimum amount of time spent at the counter (one of the parameters of the distribution) was varied for both the current and the future layout (one and two workspaces at the counter). It is assumed that the shape of the probability distribution describing the contact time remains the same.

Taking into account the frequencies of the different types of phlebotomy requests for different laboratory disciplines and the average time needed for carrying out each of these request types, the average TAT at the cubicle and/or lavatories was found to be 4 min 19 s. The average time a patient spent at the counter was 46 s. Therefore, a patient will on average spend 5 min 5 s in the phlebotomy department (walking and waiting not included). If one accepts the criterion that, on average, a patient should not wait longer than the time needed to be served (5 min 5 s), the average TAT at the phlebotomy service should be equal to, or less than, 10 min 10 s.

Results

Validation of the model

Two methods were used to validate the model of situation A, one based on animation and validated by nursing staff and the other using actual historical data. The observed data were obtained during one day. In total, 20 simulation runs were carried out (the statistics are presented in Table 2). In each simulation run, one day is simulated in which 271 patients arrive at the phlebotomy area according to the arrival pattern shown in Fig. 4. Average values of $T4 - T1$ over all runs are calculated by taking into account only those patients who actually visited a cubicle and/or a lavatory (so excluding patients that only handed over urine or faecal samples).

A histogram of the observed and simulated TATs is presented in Fig. 5. The distributions of $T4 - T1$ do not differ significantly ($\chi^2 = 12{\cdot}36$, df = 6, $P = 0{\cdot}95$), nor do differences (Δ) between the mean observed and simulated values of $T4 - T1$ ($\Delta = 12$ s, $t = 0{\cdot}52$, df = 5620, $P = 0{\cdot}80$; two-sample t-test). Based on these results it is concluded that the model of situation A is valid.

The models of the future layout (situations C and D) were validated using animation.

Simulation experiments

For each experiment, 20 simulation runs were carried out. During each day 271 patients visited the phlebotomy area.

Table 1. *Summary of the main differences between situations A, B, C and D*

Situation	Layout	Number of workspaces at the reception desk	STAT samples to the laboratory	Process time in cabin
A	Fig. 2	1	Walking	Normal
B	Fig. 2	2	Walking	Reduced
C	Fig. 3	1	Pneumatic tube	Reduced
D	Fig. 3	2	Pneumatic tube	Reduced

Table 2. *Observed and simulated turn-around times for current and future layouts*

	Situation A				Situation D	
	Observed		Simulated		Simulated	
	Mean	SD	Mean	SD	Mean	SD
$T2-T1$	2 min 19 s	2 min 12 s	1 min 15 s	1 min 44 s	0 min 26 s	0 min 30 s
$T3-T2$	5 min 40 s	4 min 39 s	6 min 29 s	5 min 35 s	3 min 41 s	3 min 58 s
$T4-T3$	4 min 12 s	2 min 24 s	4 min 20 s	1 min 5 s	3 min 49 s	1 min 4 s
$T4-T1$	11 min 52 s	5 min 59 s	12 min 4 s	6 min 19 s	7 min 57 s	4 min 18 s

$T2-T1$ is calculated for all patients; $T3-T2$, $T4-T3$ and $T4-T1$ are calculated only for patients who visited a cubicle or a lavatory.
SD = standard deviation.

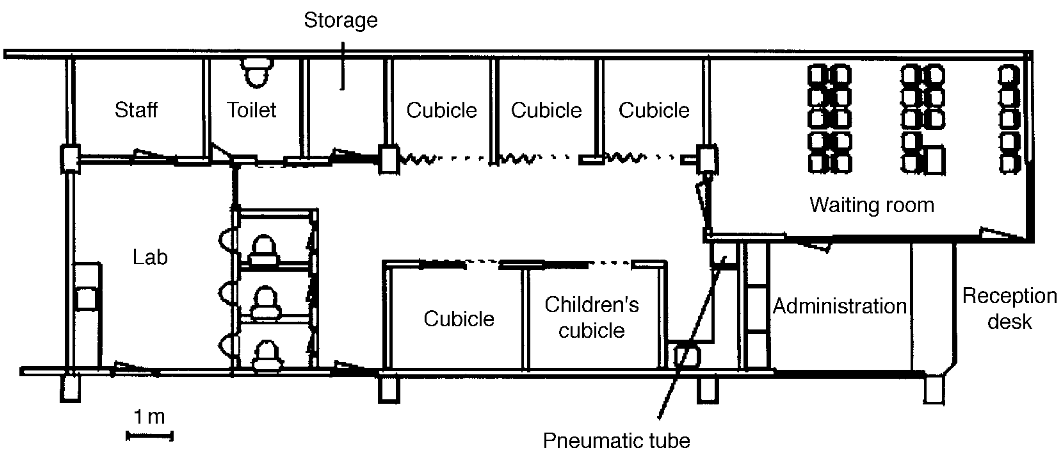


Figure 3. *Floor plan of the new phlebotomy area.*

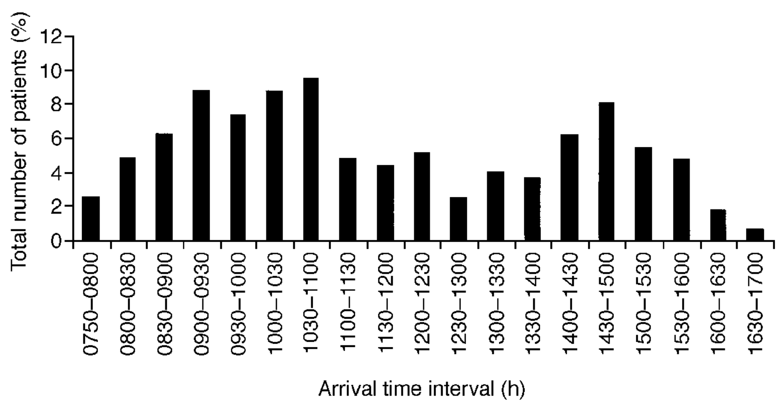


Figure 4. *Arrival cycle of patients at the phlebotomy area. The percentage of the total number of patients arriving at the area is indicated for each time-frame.*

Experiment 0

In experiment 0 the simulated value of $T4-T1$ in situation B was compared with the observed values of $T4-T1$ in the new situation. The observations in situation B were made during morning hours on four different days. The means of the simulated and observed values of $T4-T1$ are shown in Table 3; they do not differ significantly ($\Delta = 49$ s, $t = 1{\cdot}24$, df $= 5398$, $P = 0{\cdot}80$; two-sample t-test). A histogram of the observed and simulated values of $T4-T1$ in situation B is shown in Fig. 6.

The distributions of the observed and simulated values of $T4-T1$ do not differ significantly ($\chi^2 = 13{\cdot}96$, df $= 6$, $P = 0{\cdot}98$).

By comparing situation A and situation B using simulation, the combined effect on the TATs of a second reception desk and the requirements for fewer tubes to be taken and less paperwork to be completed is shown. The TAT in situation B is significantly lower than in situation A ($\Delta = 2$ min 27 s, $t = 21{\cdot}95$, df $= 10\,697$, $P < 0{\cdot}001$; two-sample t-test).

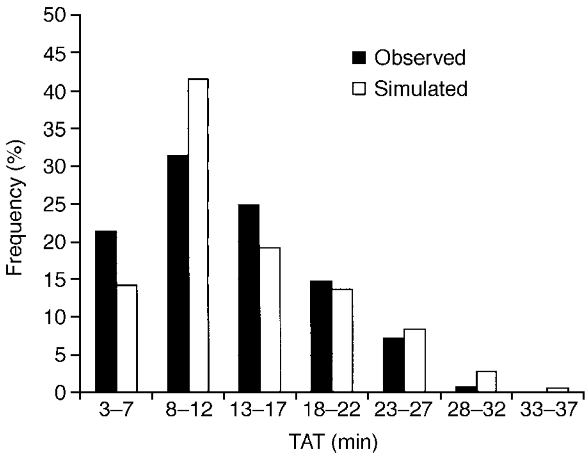


Figure 5. *Frequency distribution of the observed and simulated values of turn-around time (TAT) (T4 − T1) in situation A. Observed data are obtained from observations of 261 patients. Simulated data are obtained from 20 simulation runs (days). On each simulated day 270 patients arrive at the phlebotomy service.*

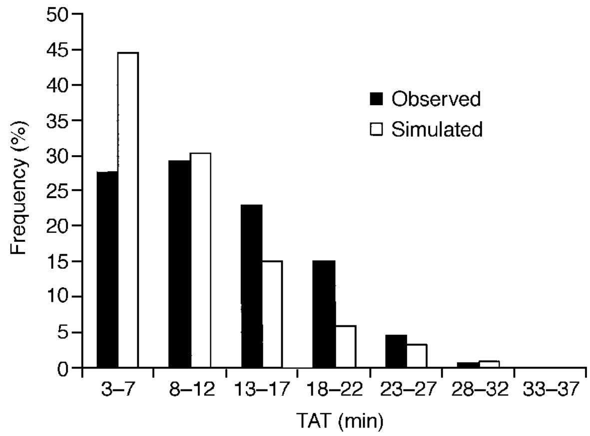


Figure 6. *Frequency distribution of the observed and simulated values of turn-around time (TAT) (T4 − T1) in situation B (current layout with two workspaces at the desk). Observed data are obtained from 62 observations. Simulated data are derived from 20 simulation runs (days). On each simulated day 270 patients arrive at the phlebotomy service.*

Table 3. *Observed and simulated data for situation A (current layout with one workspace) and situation B (current layout with two workspaces at the desk)*

	Situation A				Situation B			
	Observed		Simulated		Observed		Simulated	
Δt	Mean	SD	Mean	SD	Mean	SD	Mean	SD
$T2 - T1$	2 min 19 s	2 min 12 s	1 min 15 s	1 min 44 s	0 min 57 s	1 min 11 s	0 min 32 s	0 min 36 s
$T3 - T2$	5 min 40 s	4 min 39 s	6 min 29 s	5 min 35 s	6 min 19 s	6 min 42 s	5 min 22 s	4 min 49 s
$T4 - T3$	4 min 12 s	2 min 24 s	4 min 20 s	1 min 5 s	3 min 11 s	1 min 22 s	3 min 51 s	1 min 5 s
$T4 - T1$	11 min 52 s	5 min 59 s	12 min 4 s	6 min 19 s	10 min 26 s	7 min 9 s	9 min 37 s	5 min 10 s

Simulated data are based on 20 runs. The observed values in situation A are based on 256 observations made on a single day. The observed values in situation B are based on 62 observations made during 3 days.
SD = standard deviation.

Table 4. *Simulated turn-around times in situations A (current layout), C and D (future layout with one workspace at the counter and with two workspaces at the counter, respectively)*

	Situation A		Situation C		Situation D	
Δt	Mean	SD	Mean	SD	Mean	SD
$T2 - T1$	1 min 15 s	1 min 44 s	1 min 6 s	1 min 10 s	0 min 26 s	0 min 30 s
$T3 - T2$	6 min 29 s	5 min 35 s	3 min 20 s	3 min 34 s	3 min 41 s	3 min 58 s
$T4 - T3$	4 min 20 s	1 min 5 s	3 min 49 s	1 min 5 s	3 min 49 s	1 min 4 s
$T4 - T1$	12 min 4 s	6 min 19 s	8 min 15 s	4 min 10 s	7 min 57 s	4 min 18 s

$T2 - T1$ is calculated for all patients; $T3 - T2$, $T4 - T3$ and $T4 - T1$ are calculated only for patients who visited a cubicle or a lavatory.
SD = standard deviation.

Experiment 1

Experiment 1 dealt with the question of whether the new layout would increase efficiency. Therefore the results of situation A and situation C were compared (*see* Table 4). The average TAT per patient was 3 min 49 s shorter in situation C. The mean TATs ($T4 - T1$) of situation A and situation C differ significantly ($\Delta = 3$ min 49 s, $t = 36{\cdot}93$, df = 10 692, $P < 0{\cdot}001$; two-sample t-test).

The mean simulated TATs for situations B (*see* Table 3) and D (*see* Table 4) also differ significantly ($\Delta = 1$ min 40 s, $t = 15{\cdot}09$, df = 10 679, $P < 0{\cdot}001$; two-

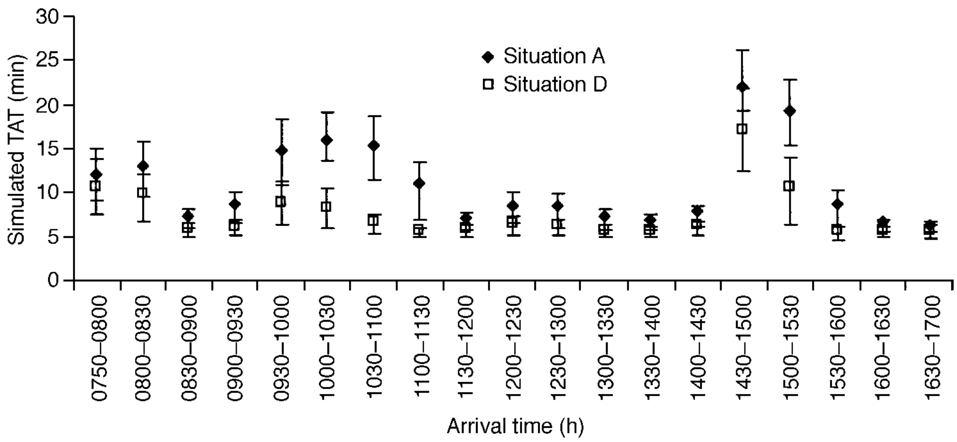


Figure 7. *Simulated turn-around time (TAT) as a function of the arrival time for situation A and situation D. The lower end of the vertical lines indicates the value of the 25th centile; the top end indicates the value of the 75th centile. Simulated data are obtained from 20 runs.*

Table 5. *Utilization of nurses and percentage of time walking in situations A-D*

	Situation A		Situation B		Situation C		Situation D	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Utilization of nurses (%)	75·22	1·45	69·29	1·16	62·49	0·81	63·11	0·93
Time of walking (%)	9·06	0·66	9·85	0·52	6·77	0·18	6·77	0·15

Data are based on 20 simulated days.
SD = standard deviation.

sample t-test). The TAT was also studied as a function of the arrival time of the patient. The relationship between the TAT and the arrival time at the department are presented for situations A and D in Fig. 7.

It can be deduced from Fig. 7 that the spread in TATs in the future layout as a function of the time of the day is less than the spread in TATs in the current layout.

Another performance measure is the utilization of nursing time. Utilization is defined as the percentage of the scheduled time a nurse is 'working'. A high utilization means that the nurses do not often have to wait for new patients. The mean utilization of the nurses is presented in Table 5. The differences (Δ) in terms of percentage utilization between the current and new layout are statistically significant (A–C: $\Delta = 12{\cdot}73\%$, $t = 34{\cdot}27$, df = 38, $P < 0{\cdot}001$; A–D: $\Delta = 12{\cdot}11\%$, $t = 31{\cdot}44$, df = 38, $P < 0{\cdot}001$; B–C: $\Delta = 6{\cdot}80\%$, $t = 21{\cdot}49$, df = 38, $P < 0{\cdot}001$; B–D: $\Delta = 6{\cdot}18\%$, $t = 18{\cdot}59$, df = 22, $P < 0{\cdot}001$; two-sample t-test).

A different layout will also affect the percentage of the scheduled time that nurses are walking. In situations C and D they do not have to take STAT requests to the laboratory and they do not have to guide all patients from the waiting room to the cubicles or restrooms. The values of this performance measure are shown in Table 5. The percentage of time the nurses are walking as part of their work is almost the same in situation C as in situation D. Situation A differs significantly from situation C ($\Delta = 2{\cdot}29\%$, $t = 14{\cdot}97$, df = 38, $P < 0{\cdot}001$; two-sample t-test); situation B also differs significantly from situation C ($\Delta = 3{\cdot}08\%$, $t = 25{\cdot}03$, df = 38, $P < 0{\cdot}001$; two-sample t-test).

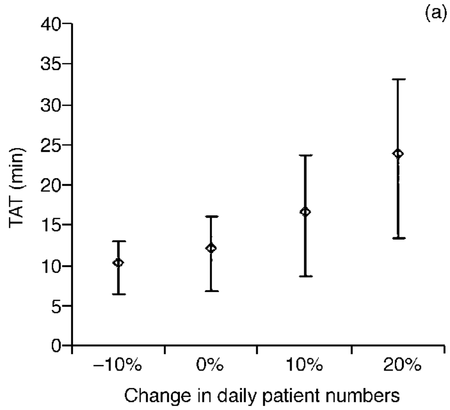
Experiment 2

In experiment 2, the effects on the TAT of an increase or decrease in the number of patients per day were investigated. The number of patients was decreased and increased in 10% increments. The results are shown in Fig. 8. For practical reasons the 25th and 75th centile values are presented.

Experiment 3

In experiment 3 the effect of changes in the minimum value of the contact time at the reception desk upon TAT were studied. The results are shown in Table 6.

Compared to the current minimum value of the contact time, a 30-s increase will cause a 40% increase (from 12 min 4 s to 16 min 53 s) in the average TAT. In the future layout, a 30-s increase in the minimum time will cause an increase in the average



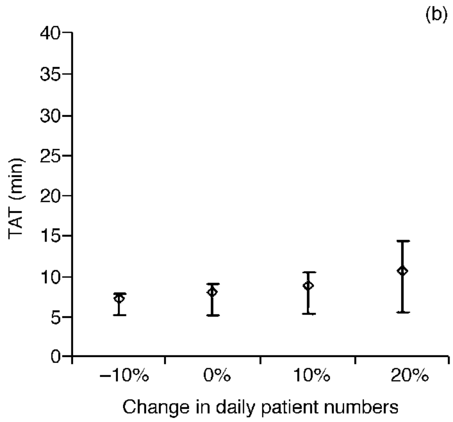


Figure 8. *Average turn-around time (TAT) at the phlebotomy department (T4 − T1) as a function of the number of patients for (a) situation A and (b) situation D. The lower point of the vertical lines represents the 25th centile, the upper point represents the 75th centile.*

TAT of 34% (from 8 min 15 s to 11 min 3 s) in situation C and of 22% (from 7 min 57 s to 9 min 49 s) in situation D.

Discussion and conclusions

To assess the effects of the relocation of a department, the steps described in Fig. 1 were carried out using the phlebotomy service as an example. The TAT of patients at the department was chosen as the main performance indicator. The data relating to the status quo were collected during one working day. During this day no irregularities occurred and it was classified by the nursing staff as a normal day. Both data analysis and model building took about 2 weeks. The implementation of a queuing model in MedModel proved to be successful.

Validation of the simulation model

The results of the historical data validation showed that the values of the TAT obtained by simulating the model were in agreement with the data observed. The differences between the observed values of $T2 - T1$ and $T3 - T2$ and the simulated values (*see* Table 2) can be explained by the fact that patients have to cross the queue to go to another department (*see* Fig. 2), which leads to delays. Often, another person accompanied a patient so there were more people present in the small area in front of the reception desk, disturbing the flow of patients. These circumstances are not included in the simulation model.

Klafehn and Connolly[2] only used animation to validate their model of an outpatient haematology laboratory. We believe that this should not be the only validation method used. A more quantitative validation method should also be carried out. We agree with the opinion of Bailey and D'Angelo[14] that good visualization of a simulation model is important, but animation should not be the only validation method used.

Table 6. *Turn-around times of patients and utilization of nurses as a function of the change in the minimum value of the contact time at the counter in situations A, C and D*

	Change in minimum contact time (min:s)											
	Situation A				Situation C				Situation D			
	−6	6	18	30	−6	6	18	30	−6	6	18	30
*T*2 − *T*1	0:59	1:22	1:55	3:8	0:56	1:16	1:50	2:52	0:25	0:30	0:32	0:37
	(1:11)	(1:48)	(2:1)	(3:4)	(1:4)	(1:25)	(1:53)	(2:50)	(0:28)	(0:37)	(0:38)	(0:44)
*T*3 − *T*2	6:59	6:17	8:35	9:23	3:4	3:43	3:56	4:23	3:32	4:7	4:37	5:22
	(6:8)	(6:4)	(6:56)	(7:13)	(3:20)	(3:52)	(4:7)	(4:29)	(4:8)	(4:19)	(4:29)	(4:54)
*T*4 − *T*1	12:20	13:2	14:52	16:53	7:49	8:49	9:34	11:3	7:44	8:25	8:57	9:49
	(6:40)	(6:50)	(7:49)	(8:32)	(3:54)	(4:37)	(4:52)	(5:38)	(4:28)	(4:41)	(4:52)	(5:20)
Utilization	74·71	76·33	79·14	81·79	60·99	63·70	66·31	68·21	61·30	64·28	67·13	69·70
of nurses (%)	(1·73)	(1·07)	(1·05)	(1·97)	(1·16)	(0·90)	(0·64)	(0·77)	(0·89)	(0·90)	(0·81)	(0·97)

Standard deviations are shown in parentheses.

Experiments

It is assumed in all the experiments that the nursing staff will work in the new situation in the same way they do now. Furthermore, no distinction is made between types of patients (i.e. the elderly, children, disabled, etc.). The contact time at the reception desk and the time in the cabin may differ for these groups. Incorporating these distinctions will probably lead to a more accurate model but will require a large amount of data to determine the corresponding distributions and its parameters. As we stated before, because of these simplifying assumptions it is good practice to test the predictive power of such models and to publish the results. Differences between prediction and actual results may be used to update the model.

Because during some periods of the day patients can be served immediately, and in other periods the patients have to wait, relatively high standard deviations of the TAT were found.

Experiment 0

In experiment 0 we wanted to demonstrate the predictive power of the model. We simulated the addition of a second workspace in the old situation and actually added a second workspace. The results of the simulation runs of this model are in good agreement with the observations. The relatively small number of observed low TATs can be explained by the higher number of patients at the time of the observations, although the total number of patients that were bled was normal. It shows that our simulation model has the predictive power to assess the TAT in a new situation.

Experiment 1

In experiment 1 we investigated whether the new layout would improve the efficiency. The results of the simulation show that the average TAT in situation C (*see* Table 1) is indeed significantly lower (3 min 49 s) than in situation A (*see* Table 4).

The addition of a second workspace (situation D) results in a significant decrease in the mean TAT compared with situation C ($\Delta = 18$ s, $t = 3{\cdot}66$, df = 10 685, $P < 0{\cdot}001$; two-sample t-test). The addition of a workspace at the counter reduces the average waiting time ($T2 - T1$) to 43 s in the old layout (originally 1 min 15 s) and to 40 s in the new layout (originally 1 min 6 s).

With one workspace at reception, the time between leaving reception and entering the cubicle or lavatory ($T3 - T2$) is less compared with the corresponding values obtained with two workspaces at the counter. This is because, having bled the patients, nursing staff return to reception to ascertain whether assistance is required. They stay there until no patients remain in the queue. This therefore results in fewer nursing staff being available for phlebotomy. However, this increase in waiting time after reception is more than compensated by the decrease in waiting time at reception. The utilization of nursing staff is less in situation B than in situation A due to the changes in the laboratory. They have to collect fewer blood tubes and have to complete less paper work.

Experiment 2

In experiment 2 the effect on the TAT of varying the number of patients per day was investigated. As shown in Fig. 8, an increase in the number of patients per day will lead to an increase in the average TAT since more patients have to be dealt with by the same number of staff. Also, an increase in the range between the 25th and 75th centile values can be observed. In the current layout, the increase is larger compared with the future layout. Experiment 1 showed that utilization of nursing staff in the future layout was less than that in the current layout. In the future layout the nurses on average have time left to serve more patients. So the TAT will increase less in situation D compared with that in the current layout.

It was assumed that the age of the patient population remains the same. However, if an increase in the number of patients is caused solely by an increase in the number of elderly people, then consultation times (e.g. in the cubicle) may increase. These changes will cause an increase in the TAT.

Experiment 3

In experiment 3 the effects of changes in the contact time at the counter were studied. It was assumed that the shape of the different distribution functions describing the contact times remain the same and that only the minimum value of the different distribution functions changes. Table 6 shows the effects of these changes on the TAT. The time spent at reception may be longer with new, inexperienced nurses. It is shown in Table 6 that an increase in the minimum value will result in an increase in the average value of the TAT ($T4 - T1$). Again, the increase is higher in the current layout than in the future layout. A patient waiting in the queue has to wait longer before being served at the desk. In situation D two nurses can work at the desk so the time a patient has to wait will be shorter compared with situations A and C (*see* Table 1). If the minimum value increases by 6 s, the chance that when a patient arrives another patient is present at the desk increases. This will cause the value of $T2 - T1$ to rise. In situation D a nurse attends the second workspace if there are patients waiting in front of the desk. At that moment he/she is not available to help patients in the cabin or instruct them in the lavatories. This will increase the value of $T3-T2$ as was shown in experiment 1. The rise in the value of $T3-T2$ is also caused by the increase in the contact time.

During the working day a maximum of five nurses simultaneously provide the phlebotomy service. The effect of assigning an extra nurse to the second workspace was also studied. When the minimum value of the contact time was increased, the value of $T4-T1$ slightly increased, the value of $T2-T1$ hardly changed and the value of $T3-T2$ increased as much as the minimum value since there were enough nurses to serve the patients in the waiting room. The utilization of the extra nurse was low. Thus the provision of an extra nurse solely to attend the workspace is an expensive solution to reduce the TAT when for some reason the contact time at the desk has increased.

Simulation experiments allowed us to assess the effects on the performance indicators without carrying out real-life experiments. We could verify some of the predictions of the simulations. In the case of the phlebotomy service under study, it was shown that the proposed changes could significantly decrease the average TAT of each patient by about 4 min. In the new layout the utilization of the nurses is less than in the current layout. Therefore, in the future layout, any increase in the number of patients or increase in the contact time at the desk will affect the TAT less.

The approach presented in Fig. 1 proved to be a useful way of assessing the effects of the relocation of a department, in this case a phlebotomy service, within a health care organization. We think that modelling and simulation can be used on a much larger scale in health care than is now the case. At this moment future managers are trained when to apply simulation, how to use simulation software and how to interpret the results.[15] This, combined with the increasing user-friendliness of the software, leads us to expect an increase in the application of simulation in health care.

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