SELECTING A NEW ROBOT FOR THE CLINICAL LABORATORY BY USING A SIMULATION MODEL

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Abstract

When Health Clinics, Hospitals and Emergency Departments are optimizing their operations in order to reduce costs, clinical laboratories must also improve their operations. The most common solution is to hire more staff or reconsider the everyday activities. However, all problems can not be solved by using these methods. The actual analysis phases in a laboratory are performed by certain machines, and the capacity of those machines usually defines how efficient the process is (how many samples it is possible to analyze within a certain period of time). If the situation changes, and some other units start to deliver their samples to the laboratory in question as well, the only way to keep the operation as efficient as it was before is to purchase new equipment with enough capacity to handle it all within certain timelines. However, the selection of new equipment is very difficult if there are several choices with almost equal capacities. This is where a simulation model like the model described in this study can become very useful. This paper presents a simulation model which describes the operations of the clinical laboratory at the Central Hospital in Jyväskylä, Finland. We use the developed model in selecting a new robot by using the amount of handwork as the main target variable. By defining different machine candidates in the model as a resource and studying the operations (activities) around them, it is possible to arrange the different machines in order of superiority. The results showed that different robots require various amounts of handwork around them although they were efficient enough to handle all the specimens.

Keywords: Health care, clinical laboratory, robot, simulation

Presenting Author's biography

Toni Ruohonen is a senior researcher at the University of Jyväskylä. Mr. Ruohonen holds a bachelor's degree in Information Technology (telecommunication) from Satakunta University of Applied Sciences, Finland. He has successfully defended his doctoral thesis on simulation in health care as well and currently holds a PhD degree (University of Jyväskylä).

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1 Introduction

Nowadays, when Health Clinics, Hospitals and Emergency Departments are optimizing their operations in order to reduce costs, Clinical Laboratories must do this as well. Changes in operations or centralizing different operations in other health care units may lead to increased amounts of specimens in the laboratory. This might form a problem for the laboratory's efficiency and the laboratory managers have to find solutions on how to meet these challenges. The traditional way to solve these problems is to hire more staff or to reconsider the everyday activities. However, sometimes these methods are not sufficient enough. There might be a possibility that the old equipment is not capable of handling more specimens. It means that new equipment purchases have to be made.

Normally the selection of new equipment is done without using any tools. The decisions are based only on managers' and staff's own experience, as well as the technical information of the equipment. It can be very risky and costly. This is why it is useful to use methods which can give important information on the effects of different solutions.

A computer simulation is this kind of a method. It can be used as a decision support tool, which gives important information on the present operation and the effects of proposed alterations. Its suitability for improving the operations in a clinical laboratory has been studied in a few contributions (1)(2). Staff assignments, queue length evaluation, priority handling, turnaround times of different sample types and turnaround times of analyzers have also been under examination (3)(4)(5)(6)(7)(8)(9).

However, simulation has rarely been used directly in new equipment selection. And if it has been used, the concentration has normally been on the efficiency of the equipment and the main target variable has been the average throughput time. The labor costs are usually ignored, although it is a very important variable when trying to improve operation. Some robots may process the specimens more effectively than others but they may also require more handwork around it. This is causing labor costs and increasing the utilization of the staff.

In our study a simulation model of the Clinical Laboratory at the Central Hospital of Jyväskylä, Finland is developed. The model is used in selecting a new preprocessor robot. The main target variable in our study is the amount of handwork required. It will reveal which robot needs the least work around it, and thus enables laboratory technicians to perform other activities in the process. First the development of the simulation model is described. Then the validity of the model is proven. After the validation phase has been described, all the robot scenarios are developed, simulations are performed and the results are presented.

2 The development of the simulation model

In this study, which is a part of approved doctoral thesis (10), a simulation model is used in selecting a new preprocessor robot for the laboratory. The main interest is not in the throughput time of the samples but in the amount of work done by hand around the robot. Although different robot candidates may be efficient enough to handle all samples in the required time, there may still be big differences in manual operations which need to be done around the robot in order to successfully operate the samples. This is why the main target variable in the simulation of a clinical laboratory is the amount of handwork.

2.1 Background and location definitions

The model was created by using the Windows-based simulation tool MedModel. The actual layout was used as a background and the operational areas (locations) of the process were defined in the layout by using the elements in the graphical libraries of MedModel software. Using the actual layout of the clinical laboratory in the simulation made it possible to demonstrate the operation of the model more accurately to the staff. The future changes and their effect on the process were also much easier to present and explain when the real floor plan was used in the visualization.

The processes in the laboratory were complex and included both handwork and mechanized work, and therefore the operational areas for both work phases needed to be defined separately.

After the locations had been defined, they had to be connected to each other in order to make it possible for samples and staff to move from one part of the process to another and from one area to another. When that was done, the structure of the model was ready.

However, the structural definitions formed just a framework for the model. To make the model functional, more definitions had to be made. It required information on entities, information on resources, logic definitions (operational logic and route logic), and information on operation times.

2.2 Entities in the laboratory model

There were different types of specimens in the laboratory, with different priorities, so they had to be categorized into different groups.

The first division was done by priority. This partition formed two different groups: the ED specimens and the specimens from other health care units around the county. If the specimen was from the emergency department, the priority was higher than for the other specimens, and the specimen was going to be processed before the others. After that, the specimens from elsewhere were handled on an equal footing.

The second division was made for both priority classes by forming different specimen type groups.

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Different types of specimens were processed and analyzed partially by their own analyzers and own staff. That is why this kind of definition was important to make.

In our study, five different types of specimens for both priority classes (ED specimens and the others) were included in the model (altogether 10 groups). These five specimen groups were clinical chemistry, hematology, coagulation, blood type and acid-based equilibrium. Process logic, including operation logic and route definition, was defined for each specimen type individually. The entity definitions are shown in Figure 1.

Name	Speed	Stats
Clinical chemistry sample (ED)	50	Time series
Hematology sample (ED)	50	Time series
acid-based equilibrium (ED)	50	Time series
Blood type sample (ED)	50	Time series
Coagulation sample (ED)	50	Time series
Clinical chemistry sample (Other)	50	Time series
Hematology sample (Other)	50	Time series
acid-based equilibrium (Other)	50	Time series
Blood type sample (Other)	50	Time series
Coagulation sample (Other)	50	Time series

Figure 1: Entity definitions

2.3 Resource definitions in the laboratory model

A resource is anything that transports entities, performs maintenance on locations, assists in performing operations on entities at locations or performs maintenance on other resources. It can be a person, piece of equipment, or some other device. In this model only staff members are considered as resources. Equipment and devices are defined as location elements, because analyzers and centrifuges are machines with a high capacity and their operations are easier and simpler to define as location elements.

There are different kinds of actors at the different phases of the process, and their properties are defined individually. For example, at the beginning of the process there are various persons handling the specimens. For ED samples there is a laboratory technician who goes to the emergency department, takes the blood samples and delivers them to the laboratory. For the blood samples from elsewhere there are persons who sort the samples, put them into racks or feed the samples into centrifuges. After that all the samples are handled by the same resources (certain nurses), depending on the sample type. Altogether eight different resource groups were defined in the model.

2.4 Processing logic of the model

Processing defines the operations that take place at each location which are defined in the model, and it defines also the routing of entities through the system. The logic and routes are described for each sample type and both priority classes individually, because equipment and human resources for handling them may be partially different.

The samples arrive at the laboratory in two different ways. They are fetched from the emergency department by a laboratory technician or some other health care unit of Central Finland sends them to the laboratory by car. If the sample is from the ED, it possesses a higher priority than the samples from other health care units. This feature divides the samples in two different groups (priority groups) depending on from where they are delivered to the laboratory. Because there are different flows for each priority group, the arrival distributions are defined for each group individually. Also, the first few phases of the process differ between these two groups, so it is important to describe the operation logic and route definitions for each priority group separately.

Processing of the ED specimens

The process for the ED samples starts at the emergency department. There a laboratory technician takes a blood sample from the patient. The number of samples s/he takes depends on how many requests have arrived to the laboratory before s/he has started the round. After all the samples have been taken, they are delivered to the laboratory.

The first phase in the laboratory for the ED samples is receipt. All the samples have to be receipted before they can advance in the process. After the receival, the laboratory technician delivers the samples into the right processing area. Where the samples are delivered after that, depends on the sample type. There are different areas, procedures and staff for every type.

If the sample belongs to clinical chemistry, it has to be stabilized for a while before it can advance in the process and that is why the laboratory technician delivers it to the area where this is done. After the stabilization, the sample is put into the centrifuge by a nurse at the clinical chemistry. The centrifuge processes the sample for a certain time, after which it is delivered to the analyzer. The ED samples are fed into the analyzer before other samples, and do not have to wait. The analyzer processes the samples and then gives out the results. If everything is all right and there is nothing wrong with the results, they are automatically sent to the ED. If there is something wrong with the sample, it has to be checked by the nurse or reprocessed by the analyzer.

If the sample is a hematology sample, it is delivered to the hematology area by a laboratory technician, who took the sample at the ED. The sample is left on the table, where a nurse, who is working in that area, takes it to the analyzer. The samples are fed into the analyzer in their own rack. After the analyzer has processed them, the results are sent to the computer. A nurse checks the results and then sends them to the ED.

If the sample is a coagulation sample, it is delivered to the coagulation area by the same laboratory technician who takes all the samples to the ED and collects them from there. The sample is handed over to a nurse, who is working in that area. After the sample has arrived at the coagulation area, it is put into the centrifuge. The

centrifuge processes the sample for a while and after that it is fed into the analyzer by a nurse. When the sample has been analyzed, the results are sent to the ED.

If the sample is a blood type sample, it is delivered to the corresponding area and fed into the blood type analyzer. The processing time is quite long and there was no accurate information available of the operation times either, so this part of the process is based on estimations.

If the sample is an acid-base equilibrium sample, it is delivered directly to its own analyzer. There is no staff dedicated handling just these samples; any readily available staff member can put them into the analyzer and collect the results. An acid-base equilibrium sample has to be processed right away, otherwise it will be spoiled.

The above mentioned sample types are ED entities in the simulation model. The number of the ED samples, which are transported at once, is usually 1-5. The whole process for the ED samples is shown in figure 2.

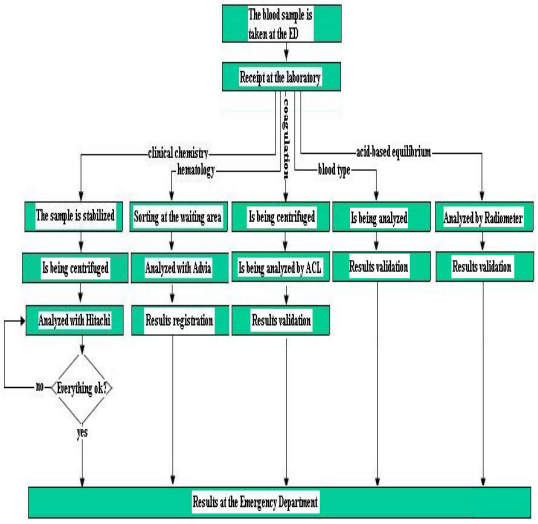

FIGURE 2: The emergency department sample flow in the laboratory

Processing of the other samples

The beginning of the process for the samples from other health care units is somewhat different from that for the ED samples. The ED samples are taken at the ED when needed, whenever there is a patient who needs to be tested, after which the sample is delivered to the laboratory right away. However, the samples from other units are delivered in larger batches and on a certain times of the day by car. However, the processes between these two sample groups differ only at the beginning and after they have been handled by the same staff and same equipment (except for little variations on the operation). That is why only the beginning of the processing logic is described for the other samples.

The process starts at the arrival. The samples are delivered to the laboratory in larger batches, and the first phase is to receive and sort them. After that the process advancement depends on the sample type. Is the sample belongs to clinical chemistry it has to be centrifuged. These samples are fed into the centrifuge. After the centrifuge has performed its action, they are put into the racks and delivered to the clinical chemistry area. They do not have to be stabilized like the ED samples. Nevertheless, corks are removed with a special machine. After that they follow the same processing logic as the ED samples do. Other samples can be delivered forward after the sorting right away. After that they proceed to their own processing areas and follow the same process phases as the ED samples do.

The samples from other units are transported in racks, in larger batches than the ED samples. Usually the batch size is between 50-200 samples. Also their priority is lower than that for the ED samples. This means that they are processed and analyzed after the ED samples. The process flow of the other samples is shown in Figure 3.

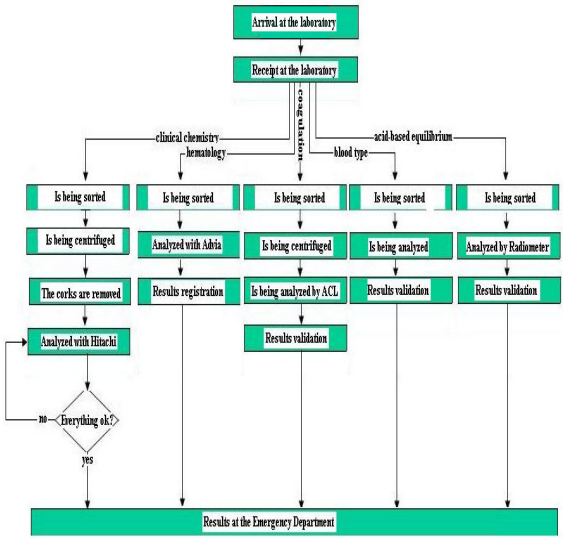

FIGURE 3: Process flow for the samples from other health care units

The samples arrive at the laboratory in two different ways. They are fetched from the emergency department by a laboratory technician; alternatively some other Central Finland health care unit can send them to the laboratory by car. If the sample is from the ED, it possesses a higher priority rating than the samples from other health care units. This feature divides the samples into two different groups (priority groups) depending on the location from where they were delivered to the laboratory. Because there are different

flows for each priority group, the arrival distributions are defined for both groups individually. Also the first few phases of the process differ between these two groups, so the operation logic and route definitions are described for both priority groups separately.

2.5 Data collection and statistical analysis

Data was collected by tracking the tubes through the process. It was carried out by an external consultation company. They labeled the tubes, and the lab personnel at different workplaces wrote down the sample number and the time when they saw a tube with a certain label. The gathered data were then used in the model. Operation times for each phase of the process were defined using the Stat:Fit statistical software. The collected data in an existing text file were loaded into a data table, and the distributions were fitted to the input data by using the Auto:Fit property. The distributions were ranked according to their relative goodness of fit. An indication of the distribution being accepted as a good representation of the input data was also given. The highest ranked distributions were selected for the model. The process times for each phase are summarized in Figure 65.

Clinical chemistry (ED)	**Time(min)**	**Clinical chemistry (other samples)**	**Time(min)**
Walking time + blood test	T(4,8.15,26.5)	Receipt	5 sec/tube
Receipt	10 sec/tube	Centrifuge	U(10,1)
Stabilization	15 min	Sorting	E(6.4)
Centrifuge	U(10,2)	Corks off and shifting	U(3,1)
Hitachi analyzer	P5(2.58,18.5)	Waiting time before Hitachi	U(5.5,0.5)
		Hitachi analyzer	P5(2.58,18.5)
Hematology (ED)	**Time(min)**	**Hematology (other samples)**	**Time(min)**
Walking time + blood test	T(4,8.15,26.5)	Receipt	5 sec/tube
Receipt	10 sec/tube	Sorting	U(3,1)
Advia analyzer	ER(2,5.99)	Waiting time before Advia	U(4,1)
Results checking	U(3,1)	Advia	0.25 min/tube
		Results checking	U(3,1)
Coagulation (ED)	**Time(min)**	**Coagulation (other samples)**	**Time(min)**
Walking time + blood test	T(4,8.15,26.5)	Receipt	5 sec/tube
Receipt	10 sec/tube	Sorting	U(3,1)
Centrifuge	U(11,1)	Centrifuge	U(10,1)
ACL analyzer	P5(1.26,7.18)	ACL analyzer	P5(1.26,7.18)
Acid-base equilibrium (ED)	**Time(min)**	**Acid-base equilibrium (othet samles)**	**Time(min)**
Walking time + blood test	T(4,8.15,26.5)	Receipt	5 sec/tube
Receipt	10 sec/tube	Radiometer analyzer	U(4,2)
Radiometer analyzer	U(4,2)		
Blood type (ED)	**Time(min)**	**Blood type (other samples)**	**Time(min)**
Walking time + blood test	T(4,8.15,26.5)	Receipt	5 sec/tube
Receipt	10 sec/tube	Sorting	U(3,1)
Analyzer	U(660,60)	Analyzer	U(660,60)

FIGURE 65: Processing times for each specimen group (T=Triangular, E=Exponential, U=Uniform, P5=Pearson 5)

2.6 Model validation

In both the model verification and validation, numerical and visual information was used. In the case of the ED samples numerical information (time stamps) was available, and it was used to verify and validate the ED sample flow. The main target variable was the average throughput time of different sample types. The validation was done by carrying out the confidence interval examination. First the real average throughput times were defined statistically from the real collected data. These times were:

Coagulation: 98 minutes

Hematology: 66 minutes

Clinical chemistry: 94 minutes

The defined values were then compared with the values of the model shown in Figure 4.

REPLICATION ANALYSIS (Sample size 35)

Statistic	Avg	Median	Min	Max	Std Dev	Std Err
Coagulation sample - Average Value	97.18	93.65	86.80	113.86	10.18	4.55
Hematology sample - Average Value	64.23	64.53	53.39	72.10	4.14	0.82
Clinical chemistry sample - Average Value	96.02	95.52	85.39	103.79	4.24	0.84

FIGURE 4: The results of simulation in a numerical form

The results of the comparison are shown graphically in Figure 5.

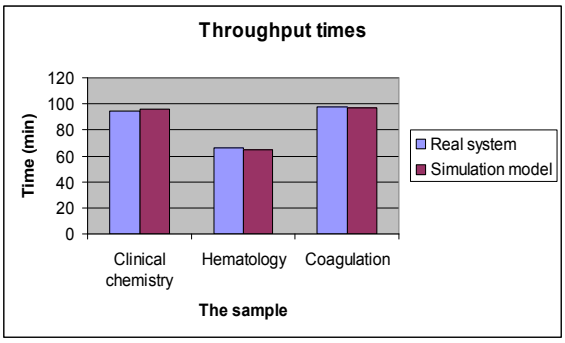

FIGURE 5: A comparison of the throughput time between the real system and the simulation model

The results showed that the error of the model was 2.1% in the case of clinical chemistry, 2.7 % in the case of hematology and 0.01% in the case of coagulation.

However, in order to take the random features into account as well, the confidence interval examination had to be made (just like we did it in ED simulation). We wanted to be 95 % confident about where the true mean falls so we defined the lower and upper limits by using the same equation that we used in model validation. This equation was:

95 % CI = p ± 1,96 * S, where p = the average value of the patient's length of stay, S = standard error of the mean and the value 1,96 was obtained from normal distribution.

95 % CI (coagulation) = 97,18 ± 1,96 * 4,55 = 97,18 ± 8,9 = 88,28 – 106,08

95 % CI (hematology) = 64,23 ± 1,96 * 0,82 = 64,23 ± 1,6 = 62,63 – 65,83

95 % CI (clinical chemistry) = 96,02 ± 1,96 * 0,84 = 96,02 ± 1,65 = 94,37 – 97,67

As can be seen by examining the margin of error and performing the confidence interval examination, there are no significant difference between the model and real data. The model is therefore valid and can be used as decision support tool.

The verification and validation of samples from other units was a little more difficult, because accurate time information was not available. In this case the model was verified by using its visual information. The model was examined thoroughly by the staff. The structure of the model was presented phase by phase and compared to the real world. After the staff had approved the operation of the model, it was ready to use.

3 Selecting a new preprocessor robot with the help of the simulation model

New equipment purchase and selection is a very challenging job, especially in a dynamic and complex environment, such as a laboratory. Usually the processes are studied manually and the main focus is on the qualities of the equipment (capacity, working methods, processing times, throughput times, etc.) and the selection is made based on that information. Of course it is important to know how efficient the robots are and how they will handle the samples. However, it is also important to find out how much handwork they will require around them. This aspect is quite often ignored, although it is a very important factor when improving the operation is attempted. Robots may still need various amount of handwork, and the impact on the staffing levels might not be felt as planned. It is important to find equipment which will automate the process the most and release the staff to perform some other activities in the process.

In the case of robot testing, the process was studied from the start only up to the tasks right after the robot phase, and the amount of handwork was selected as the main target variable. The handwork phases were defined in the model around the robot as follows: the tasks before the robot phase, the daughter tube making phase (done after the robot phase), and the other tasks after the robot phase.

In order to receive appropriate results, resources for every handwork phase were also defined. There was one laboratory technician for the preprocessing phase, one for the daughter tube process and one for the other after-treatment tasks. Using these same resources for each robot scenario and defining all the necessary tasks for every phase, it was possible to find out the amount of handwork. The results are presented using the utilization rate. The utilization rates of every resource in each scenario were compared to each other.

Because accurate information was not available, the data for every handwork phase and for every task around the robot were estimated by the staff. The simulation time was also selected to cover only the most crowded period which was 7 am -6 pm. Under the examination were only the samples from other health care units (not the ED samples). This was done because the ED samples were not going to use the robot during that period.

Altogether five different robot scenarios were defined and tested. Each scenario was created by replacing the centrifuges (three of them) in the original model with different robots. The robots were defined by using the information which the suppliers offered. There was information on the operation time, the capacity of the robot, and the capacity of the centrifuge. The qualities of the robots are presented in Figure 6.

Equipment	Capacity of centrifuge	Whole capacity (tubes/h)	Throughput time of centrifuged tube
Robot 1	72	500 tubes/h	15 min
Robot 2	96	400 tubes/h	21-37 min
Robot 3	96	400 tubes/h	21-37 min
Robot 4	40	160 tubes/h	15 min
Robot 5	40	160 tubes/h	15 min

FIGURE 6: The qualities of different robot candidates

3.1 Description of robot scenario 1

The specimens, in the case of robot 1, are delivered to the laboratory on their own rack. This means that the specimens are ready to be sent forward, without any operations, right after they have arrived at the laboratory. Because no preprocessing operations are needed, a laboratory technician delivers the sample rack to the robot. Before the samples are fed to the robot, they have to be separated. The robot does that. The specimens of clinical chemistry, special chemistry and coagulation go first through the receipt phase and immediately after that they are fed into the centrifuge and centrifuged for 10 min. Other specimens go through the receipt phase only. After the receival the specimens either go to the daughter tube processing phase or exit the robot. In the case of the daughter tube, a duplicate is made and, after that, the original and duplicate alike exit the robot. When the specimens exit the robot, all the others except coagulation specimens are sorted and placed into their own racks by the robot. The coagulation specimens have to be sorted manually. Also the specimens (daughter tubes) which are leaving the laboratory need to be corked. These two activities were the only handwork parts around the robot. The processing times were defined for both activities by the staff as follows: sorting of the coagulation specimen 5 sec/tube and corking 10 sec/tube. When all of these operations have been done, the samples advance in the process and the simulation ends.

3.2 Description of robot scenario 2

In robot scenario 2 the specimens are delivered to the laboratory on their own racks. It means that no preprocessing is required and the specimens can be delivered to the robot immediately. Before the specimens are fed to the robot, they have to be separated in order to get the different specimens into their correct places inside the robot. The robot does that. The specimens of clinical chemistry, special chemistry and coagulation first go through the receipt phase, and right after that they are fed into the centrifuge and centrifuged for 10 min. Other specimens go through the receipt phase only. The robot phase and all the phases after that follow the robot 1 process. The only difference between these two robots is in operation time and the capacity of centrifuge (see Table 1). The operation time and the capacity do not make any difference to the amount of the handwork, because all the samples are handled during the simulation run and all the handwork parts are exactly the same. Therefore the results are congruent with the results of robot 1.

3.3 Description of robot scenario 3

The samples arrive at the laboratory on their own racks, so no preprocessing is required in this case either. The racks are delivered right away to the robot. First, all the samples go through the receipt phase and after that they are sorted by the robot in order to process them properly. The samples of clinical chemistry, special chemistry and coagulation are fed into the centrifuge and centrifuged for 10 min. Other samples go through the receipt phase only. This robot doesn't make the duplicates (daughter tubes); they are made manually after the robot phase. When the specimens exit the robot, they are either sorted and put on the racks, or delivered to the duplicating phase. In the duplicating phase a laboratory technician makes a daughter tube manually and after that delivers the original tube and the duplicate on their racks. The duration of the duplication phase was estimated and tested by the staff, and their estimation was 30-60 sec/tube. Because any amount of time between 30 and 60 seconds was possible, uniform distribution was used to present the operation time. The operation time was therefore U(45,15). When the tubes are put on the racks, the racks are then sent forward and the simulation run ends.

3.4 Description of robot scenario 4

Unlike in the earlier robot scenarios, in this scenario the specimens are not delivered on their own racks to the laboratory. It means that they have to be shifted onto their own racks manually after their arrival. In order to get appropriate results, the time for that process was estimated by the staff. The estimation was 10 sec/tube. When the specimens have been put on their own racks, they are ready to be sent forward to the robot. Before they can be fed to the robot, however, some preparations need to be made. Every sample requires 1-2 buckets and one jet of pipette. These things have to be inserted before the specimen can be handled by the robot. To find out the amount of handwork, time estimation is needed here again. The staff measured and estimated the operation. Their estimation was 6 sec/tube for both operations.

Inside the robot the first phase for all the samples is the receipt phase. After that they are sorted by the robot in order to process them properly. The samples of clinical chemistry, special chemistry and coagulation are fed into the centrifuge and centrifuged for 10 min. Other samples go through the receipt phase only. This robot doesn't make any duplicates (daughter tubes) either. The duplicates are made manually after the robot phase. When the specimens have exited the robot, they are either sorted and put into the racks or delivered to the duplicating phase. In the duplicating phase a laboratory technician makes a daughter tube manually, and after that delivers the original tube and the duplicate into their racks. The processing time definition for the duplicating process was the same as in the robot scenario 3. After the tubes have been put on the racks, they are then sent forward and the simulation run ends.

3.5 Description of robot scenario 5

The process flow of robot 5 differs from the process flow of robot 4 only in the end part. The preprocessing tasks are the same and the robot phase also follows the same routines. The only difference is right after the robot phase, when the specimens exit the robot. In the case of robot 4, the specimens of clinical chemistry were automatically transferred forward to the analyzer and the other samples needed to be shifted and sorted into their own racks. But in this case also the specimens of hematology are partially processed by the robot. They are sorted automatically by the robot, and only the shifting part has to be done manually. Because the process flow is mainly the same as with robot 4, there is no need to describe the process flow on a more detailed level here. The simulation run settings were also the same as in the other robot scenarios so they do not need to be described either.

3.6 Results

After all the robot scenarios were tested, the results of each scenario were compared with each other. The utilization rates of all the defined handwork phases were examined. The results show that there were two robots, which required notably less handwork than the others. These were robot 1 and robot 2. Other robots occupied the staff significantly more. The results are shown in figure 7.

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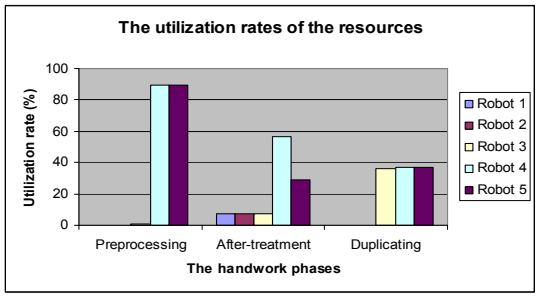

FIGURE 7: A comparison of the utilization rates between the different robot candidates

4 Conclusions

New equipment selections are normally made without using any tools. The decisions are usually based only on health care managers' and staff's own experience as well as on the technical information for the equipment. The throughput time is also usually used as the main target variable.

This kind of examination will not necessarily tell the whole truth about the suitability of the equipment for the laboratory. Because the effects on the whole operation are not known beforehand, this may lead to wrong decisions. The results in this study show that simulation is a very useful tool for new equipment selection. By using a simulation model the effects on the operation can be seen, and the robot candidates can be easily arranged in order of superiority.

The amount of handwork is also a very important variable to take into account when purchasing new equipment. If the main objective is to improve the whole operation, adequacy of the equipment efficiency is not going to assure that. As it was shown in this study, there is a lot of variation on the amount of the handwork around the different equipment candidates. The worst candidate may reserve more staff to handle the operation around it than the others, and this may lead to inefficiency in the operation of the clinical laboratory. All the problems mentioned can be avoided by using simulation and the right target variables.

5 Acknowledgements

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6 References

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