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Managing hospital visitor admission during Covid-19: A discrete-event simulation by the data of a German University Hospital

Christina C. Bartenschlager
University of Augsburg
christina.bartenschlager@uni-a.de

Ramona Frey
University of Augsburg
ramona.frey@uni-a.de

Marie Freitag
University Hospital of Augsburg
marie.freitag@uk-augsburg.de

Johanna-Maria Classen
University Hospital of Augsburg
johanna-maria.classen@uk-augsburg.de

Helmut Messmann
University Hospital of Augsburg
helmut.messmann@uk-augsburg.de

Jens O. Brunner
University of Augburg
jens.brunner@uni-a.de

Selin Temizel
University Hospital of Augsburg
selin.temizel@uk-augsburg.de

Christoph Römmele
University Hospital of Augsburg
christoph.roemmele@uk-augsburg.de

Abstract

The Corona pandemic and the associated need for visitor restrictions have defined an entirely new management task in hospitals: The hospital visitor management. The admission process of hospital visitors and the implementation of associated infection-prevention strategies such as the delivery of face masks thereby pose major challenges. In this work, we evaluate both implemented and planned admission processes in a German University Hospital based on a discrete-event simulation model and provide distinct recommendations for hospital visitor management with special consideration of digitalization, antigen testing, waiting times, space and staff utilization. We find the extraordinary potential of digitalization with a reduction of visitor waiting and service times of up to 90 percent, the significant burden for personnel and room capacity, in terms of antigen testing, especially, and the need for visitor restrictions in terms of a maximum number of visitors per inpatient.

1. Introduction

The Covid-19 pandemic and the associated need for visitor restrictions have defined an entirely new management task in German hospitals and many other hospitals throughout the globe: The hospital visitor management. We define hospital visitor management to involve the entire admission process from visitor's arrival at the hospital to the place of visit, i.e. usually the patient room. This process contains infection-prevention strategies, such as delivery of face masks, antigen testing, the management of visitor flows, visitor restrictions and registration activities in terms of contact tracing.

Besides visiting times, there were usually few to no guidelines in German hospitals regarding visitation prior to the Covid-19 pandemic outbreak. Quite the opposite, many studies demonstrated the advantages of unlimited in-person visitation regarding patient outcome [e.g., 1]. In the United States, nonetheless, visitor scheduling and the people allowed to visit an inpatient are usually restricted [2]. However, the restrictions have the background of avoiding crime rather than preventing virus infections during pandemics. It is therefore hardly surprising that the regulations, especially at the beginning of the pandemic, sometimes differ significantly between hospitals, as a survey of Taiwanese facilities showed [3]. Besides, little research on managing hospital visitor admission during Covid-19 exists.

In this work, we evaluate both implemented and planned hospital visitor admission processes with regard to waiting and service times, space and staff utilization by a discrete-event simulation (DES) model and data of a German maximum care University Hospital, the University Hospital of Augsburg, with approx. 1000 inpatient beds in the main building and approx. 1700 beds altogether. A maximum care hospital offers a comprehensive range of health care services covering a majority of medical disciplines. The digital solution, which enables visitor pre-registration, and the hospital visitor management

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system of the University Hospital of Augsburg are an exception in the German hospital system, as only about 12 percent even have a digital hospital visitor management system [4]. At the same time, the digital solution is not used by all visitors, for example, due to their lack of computer skills. Therefore, we are able to compare analog and digital processes in visitor management and the impact on waiting times by focusing the data of the University Hospital of Augsburg. Besides, the entrance area at the University Hospital does not show any special features that could hinder a transferability of our results.

While we do not study the impact of vaccination or recovery of Covid-19, the contributions of our paper include: (1) We are the first to apply a DES to Covid-19 hospital visitor admission. (2) We model four admission processes differing in, among others, space and staff utilization, infection-prevention strategies and visitor restrictions based on several performance indicators such as waiting times in the sense of a hospital. (3) We provide hospital managers with distinct recommendations regarding visitor admission from a management perspective. (4) We examine and quantify the potential of digitalization in hospital visitor management based on our simulation model.

As simulation models mimic a real-world process, they are frequently applied to Covid-19 challenges as in Covid-19 triage [5], bed occupancy [6] or cost-effectiveness analyses [7], for instance. In health care, Monte Carlo simulation, system dynamics, agent-based simulation and DES are frequently used simulation techniques [8]. The latter, in particular, is suitable for queuing [9], health service, health economics [8] and health systems [10], whereby states change stochastically dynamically based on a discrete time-space [11]. Therefore, we apply a DES to our hospital visitor admission problem. Related applications of DES in hospitals include patient flow, i.e. admission or scheduling, and resource allocation, i.e. scheduling, sizing, assignment or allocation, with a strong focus on the emergency department. Regarding patient flows, Cocchi et al. [12], for example, compare real-life patient waiting times in the front office with simulated outcomes. [13] study alternative strategies in the medical record department and Easter et al. [14] examine the physical design of an emergency department. [15], [16], [17], [18] and [19] also research the emergency department. Regarding resource allocation, Qureshi et al. [20] study the ratio of staff to patients. [21] support the design of an extension to the emergency department. Resource allocation in the emergency department is also studied by [22]. DeRienzo et al. [23] and Williams et al. [24] examine resource allocation in the Intensive Care Unit. [25] evaluate operating room management policies.

The work is structured as follows: Section 2 presents the input data for our simulation model and defines the four different processes studied on. The results in terms of performance indicators of the four processes are given in section 3. In section 4, we comparatively discuss these results and limitations of our study, as well. Section 5 concludes.

2. Methods

We apply a discrete-event simulation model to measure the performance in terms of mean waiting, service and utilization time, i.e. outputs, of both implemented and planned hospital visitor admission processes. The model has been implemented in AnyLogic being a standard simulation tool for researchers and practitioners. One hundred simulation runs per setting are performed with pseudo-random starting values and a reference period of one week. A DES is characterized by the sequence of discrete events in time. Before these events and the processes are explained, at first, we introduce the different groups of people and their arrival rates, i.e. inputs, in the main entrance area of the University Hospital of Augsburg.

2.1. Arrival rates at the hospital

Since hospital visitor management naturally focuses on the entrance area of a hospital, visitor flows are influenced by other groups of people entering the hospital, too: Staff, in- and outpatients, their companions and other visitors such as technicians, students or lecturers. We determine average arrival rates of employees via the time recording system of the hospital, of inpatients via the hospital information system, of outpatients via controlling data and of companions and visitors via the hospital visitor management system. We only consider people who actually enter the building via the main entrance and not, for example, outpatients whose ambulance is not regularly accessed via the main entrance.

During the Corona pandemic in Germany, the authorities defined different visitor restrictions per day and inpatient, e.g., zero, one or three different visitors. Zero visitors or a visitor stop, respectively, means visitors are only permitted in justified exceptional cases, such as for palliative care patients. This results in approx. 60 visitors per day. Since an export of the data from the hospital visitor management system was only possible from the second pandemic wave in Germany onwards, in which a visitor stop was imposed, assumptions are made for the overall number of visitors in case of other restrictions.

Table 1. Average bed occupancy (main building)

Mon	Tue	Wed	Thu	Fri	Sat	Sun
1008	1036	1047	1030	957	906	933

The assumptions are based on several interviews with staff experienced in inpatient care on different wards and the average bed occupancy per day (see Table 1). For the "one visitor per day" restriction, we assume that 60 % of inpatients receive one visitor daily during the week. On Fridays and weekends, 65 % and 70 %, respectively, receive a daily visit from one person. This results in approximately 600 visitors per day if the "one visitor per day" restriction is considered.

Table 2. Number of employees, patients, companions and visitors arriving at the hospital per day

	Staff	Patients and com-panions	Visitors for 0, 1 or 3 visitors per inpatient	Other visitors
Mon	782.50	880.09	63.25, 601,79, 801.72	39.00
Tue	971.60	862.46	71.60, 618.70, 824.60	32.00
Wed	1298.00	812.12	87.80, 624.67, 833.55	28.20
Thu	1453.50	786.56	82.00, 614.72, 819.63	29.00
Fri	1043.50	652.86	69.60, 618.70, 827.59	20.50
Sat	270.75	51.21	54.00, 630.64, 837.53	10.00
Sun	257.50	56.83	32.00, 649.53, 862.40	8.00

If visiting regulations get loosened again in the future, a limit of three visitors per patient per day is assumed, and approximately 800 visitors per day enter the hospital. This results from the assumptions that 25 % of the inpatients receive one visitor per day on weekdays and 28 % on weekends, 20 % and 22 % receive visits from two persons and 5 % and 7 % receive visits from three persons per day. Table 2 presents the average number of people in the predefined groups entering the University Hospital throughout the week. Figure 1 gives an overview of thereupon average arrival rates throughout the day.

2.2. The base visitor admission process at the University Hospital of Augsburg

To study the visitor admission processes, waiting and service times are determined based on several internships in the entrance area of the University Hospital of Augsburg and structured interviews with responsible managers. In this section, we describe a base visitor admission process of which the implemented and planned processes are deduced. Figure 2 shows the blueprint of the entrance area at the University Hospital of Augsburg with the former library, the main entrance, its revolving door and the foyer. Figure 3 provides a thereupon visualization of the base process in AnyLogic.

All groups of people enter the main building of the hospital through the main entrance. There are two queues here: one for people who registered online in advance and thus received a Quick Response (QR) code, and one queue for the rest of the people. Employees do not have to queue and directly proceed to the admission control (AC), where they disinfect their hands and receive a face mask. For patients, the staff member at the admission control takes the body temperature (TC) - in addition to the hand disinfection notice - and hands out the patient questionnaire, which is filled out by the patient in the outpatient clinic or ward and checked by the staff for risk constellations.

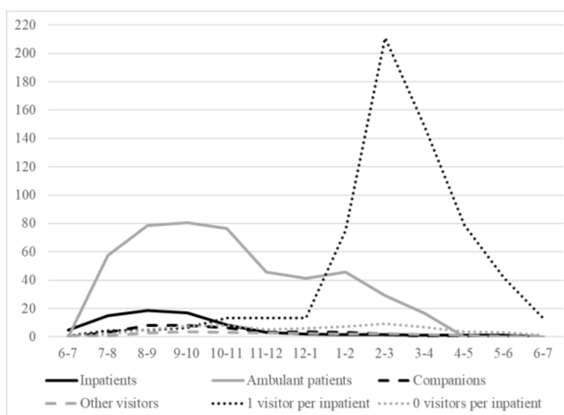

Figure 1. Average number of arrivals of visitors, companions and patients throughout the day

Visitors and accompanying persons are passed on directly after hand disinfection to TC. All persons then pass into the foyer. Staff can proceed directly to their workplace. Patients, accompanying persons and visitors must line up at the scheduler (S). If visitors are undergoing an antigen test, testing (T) and waiting (W) for the result take place before arriving at S. Due to face masks and distances explicitly implemented in our model, we assume that visitors tested positive for Covid-19 do not infect other persons in the waiting area.

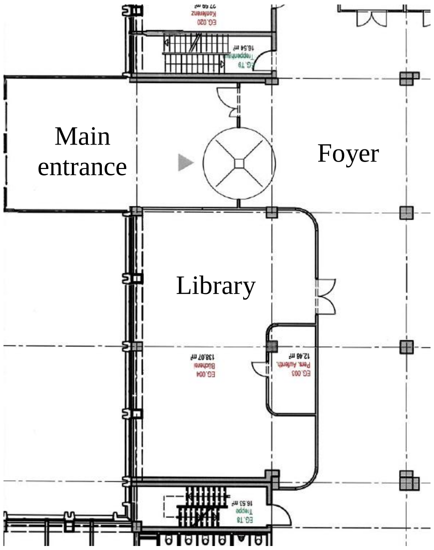

Figure 2. Blueprint of the entrance area at the University Hospital of Augsburg

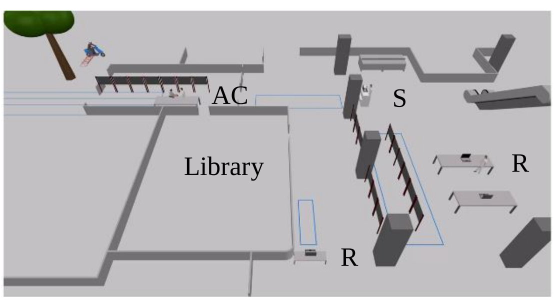

Figure 3. Visualization base process

The queue at S is limited to approximately six people due to space limitations. At S, people are either registered or visitors of patients are directed to registration (R). People who have already registered online and bring a QR code can go to a separate fast track registration desk. If the registration is busy and a long queue has formed as a result, visitors without a QR code will also be processed at the QR registration if the load is lower here. The queue of regular registration or QR registration is limited to approximately sixteen or five people. After registration in the hospital visitor management system, the visitor is allowed to enter the hospital (see Figure 4).

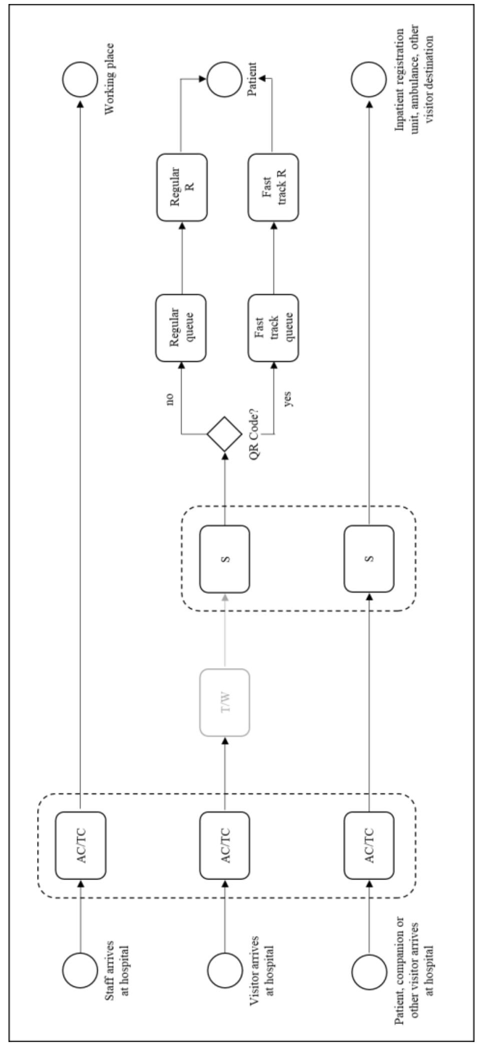

Figure 4. Flowchart base process with admission control (AC), temperature control (TC), testing (T), waiting (W), scheduling (S) and registration (R).

Table 3. Assumptions on triangular distributions in minutes

Step	Min	Mode	Max
AC/TC staff	0.03	0.08	0.13
AC/TC patients	0.167	0.33	0.75
AC/TC other	0.167	0.25	0.33
T	0.35	0.5	1
W	16.5	17	18.5
S	0.08	0.25	0.33
Regular R	1	2	3.5
Fast track R	0.5	1	2

The distribution of service times in minutes for the different activities have been discussed with staff at the admission control and are assumed to be a triangular distribution defined by the most frequent value (mode) and the interval limits (minimum and maximum), all shown in Table 3.

In general, a walking speed of 1.1 m/s is assumed for patients. For visitors this is 1.3 m/s and for employees 1.6 m/s. These assumptions are based on the study by Himann et al. [26].

2.3. The four visitor admission processes studied on

Based on the process described in Figure 3, the four processes studied on are deduced. Process 1 focuses the admission routine implemented in summer 2020 for a maximum of 1 visitor per inpatient and day. This results in approx. 600 visitors per day. The process does not involve testing and waiting for the test result. So, after the admission control (AC) visitors directly proceed to the scheduler and the registration desk. For patients, the admission control also involves the temperature control (i.e., AC/TC). Within process 1, the library is not used for visitor management (see Table 4 and Figure 5).

Table 4. Description of process 1

Process	1
Status	Implemented in summer 2020
Steps involved	AC/TC, S, R
QR registration	possible
Library utilization	no
Restriction	1 visitor per day
Visitors per day	Approx. 600

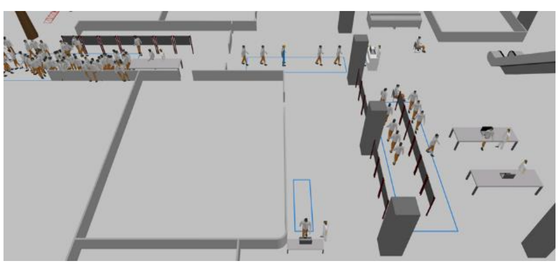

Figure 5. Visualization process 1

To avoid outdoor queues - especially in winter - the admission process was changed by utilizing part of the library to enhance the length of the waiting queue (process 2). This is also expected to improve the measurement of body temperature, because patients will have more time to acclimatize. Minor construction work was needed to realize these adjustments. For staff, the process at the entrance does not change. Patients are simply reminded at the entrance control (AC) to disinfect their hands and are handed a face mask. They then go through the side door into the library, where they line up to have their temperature control (TC). There, they also receive the patient questionnaire. After leaving the library, they can go directly to the outpatient clinic or admission ward. Other than for process 1, AC and TC are spatially separated in process 2 (i.e., AC, TC).

Accompanying persons walk through the library with the patients and are registered with a scheduler after leaving. For other visitors and visitors with a QR code, registration takes place all day at the scheduler, so that a shorter waiting time can still be ensured. Visitors without QR codes will be directed to registration through the library. The scheduler can also assist with visitor registration. Therefore, we specify to register 10% of visitors passing through the library at S (see Table 5 and Figure 6).

The testing of visitors for Covid-19 upon admission to hospitals will be considered in process 3 involving a visitor stop. For this purpose, the admission process in the library will be modified in the simulation so that testing of visitors can be implemented. To compensate the space for process 3, the other part of the library can be used as additional room. The process for staff, other visitors, patients and accompanying persons does not change.

Table 5. Description of process 2

Process	2
Status	Implemented in winter 2020
Steps involved	AC, TC, S, R
QR registration	possible
Library utilization	yes, partially
Restriction	1 visitor per day
Visitors per day	Approx. 600

Figure 6. Visualization process 2

In the afternoon, visitors go through the library to the back of the library for testing. There, they first line up in the testing queue where the Covid-19 test is handed out. They then look for an empty seat in the waiting area. To be able to guarantee distances, there are only eight places available here. Each visitor performs the test and then waits 15 minutes for the result. Once the negative test result is available, the visitor proceeds to registration (see Table 6 and Figure 7).

Table 6. Description of process 3

Process	3
Status	Planned
Steps involved	AC, TC, T/W, S, R
QR registration	possible
Library utilization	yes
Restriction	0 visitors per day
Visitors per day	Approx. 60

In order to admit more visitors each day even with Covid-19 testing of visitors, the process is changed. For this purpose, patients and accompanying persons will no longer be directed through the library, but will enter the foyer through the revolving door and to the former registration after the admission control (process 4). Here, the temperature control as well as the registration of accompanying persons will take place.

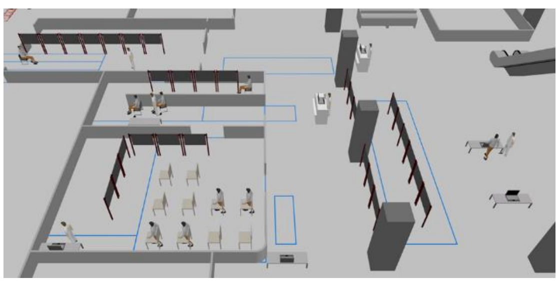
Figure 7. Visualization process 3

Table 7. Description of process 4

Process	4
Status	Planned
Steps involved	AC/TC, T/W, S, R
QR registration	possible
Library utilization	yes
Restriction	1 visitor per day
Visitors per day	Approx. 600

The patient library is used as an entire room - without the separation by the drywall - for testing visitors. Therefore, visitors go to the library all day after the admission control. They first queue at the testing desk and, after the test is handed out, find a free space in the waiting area to take the test. Due to the size of the library, it is possible for 33 people to test at the same time. Once the test turned out negative, visitors leave the library and line up for registration, which is now located at the former QR registration (see Table 7 and Figure 8).

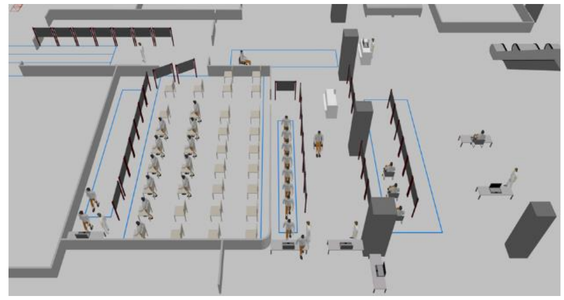
Figure 8. Visualization process 4

2.4. Staff for hospital visitor management

In order to handle all the steps of the process and to cope with the number of people, each hospital visitor management step requires a minimum number of staff hours throughout the day (see Table 8). The actual number of employees needed is defined by the distinct process implemented. Admission opens at 5:30 am, as employees arrive now and first patients arrive from 6:30 am. On weekdays in the morning, one staff member is responsible for providing face masks to the employees, as they have to start their shift promptly. Regular visiting hours are from 2 pm to 7 pm and at 8 pm the main entrance at the University Hospital is closed.

Table 8. Minimum staff hours needed for hospital visitor management per admission step

Step	Time slot	Min (in h)
AC	6:30 am – 8 pm	13.5
AC staff	5:30 am – 8 am	2.5
TC	6:30 am – 7 pm	12.5
T/W	7 am – 8 pm	13.0
S	6:30 am – 8 pm	13.5
Regular R	7 am – 8 pm	13.0
Fast track R	2 pm – 6 pm	4.0

3. Results

In the following, we present performance indicators for the four processes. In particular, we provide the total time for patients and visitors with and without pre-registration, the maximum length of the queue, utilization during the process, a maximum visitor restriction and staff hours needed to run the admission of hospital visitors. Due to predefined shifts, we examine staff utilization until 12 pm and until 8 pm.

3.1. Process 1

The median time taken by visitors from arrival at the hospital to completed registration is 70.16 minutes. For visitors who registered online in advance, the total time is 9.59 minutes and patients take 1.28 minutes. The maximum average queue at the entrance is 173.09 people. The scheduler's utilization rate averages 18.48 % until 12 pm and 48.81 % until 8 pm. The employees at the registration are utilized to 89.49 %. On weekdays, about 53.5 staff hours are needed to run the process. The results are based on a "one visitor per bed" restriction. Nonetheless, a maximum of 3 visitors per day (approx. 800 visitors) might also work to service visitors in a reasonable period of time.

3.2. Process 2

This process results in an average for the total time for visitors of 30.01 minutes. Visitors with QR code need 3.03 minutes and patients need 2.80 minutes. There is a maximum of 84.10 people in the queue at the entrance on average. The scheduler's occupancy rate until 12 pm is 28.66 % and until 8 pm is 37.19 %. TC staff utilization at the library is 50.03 % until 12 pm and 61.8 3% until 7 pm. Scheduler's utilization is 22.75 % and registration utilization is 90.8 7%. On weekdays, about 64.5 staff hours are needed to run the process. The results are based on a "one visitor per bed" restriction whilst 3 visitors per day might overcrowd the queue. Note, we define a queue to be overcrowded, if waiting times exceed a reasonable period of time, for example, waiting times of more than 1 day.

3.3. Process 3

This admission process with testing of visitors results in an average median total time of 59.86 minutes for visitors and 54.52 minutes for visitors with QR codes. For patients, the total time is 2.61 minutes. The maximum average queue at the entrance is 66.64 people. The scheduler's utilization rate until noon is 6.74 % and until evening it is 4.96 %. The TC staff in library has a utilization rate of 49.91 % until 12 pm and 57.46 % until 8 pm. The utilization rate at T is 45.29% and at the registration desk it is 43.33 %. On weekdays, about 82.5 staff hours are needed to run the process. The results are based on a "zero visitors per bed" restriction whilst 1 visitor per day might overcrowd the queue.

3.4. Process 4

This process results in a median total visitor time of 99.22 minutes and 26.52 minutes for visitors with QR codes. Patients require a total time of 2.12 minutes. On average, there is a maximum of 191.90 people waiting at the entrance. The scheduler's utilization rate averages 6.84 % until 12 pm and 5.01 % until 8 pm. The TC employee has a utilization rate of 35.00 % until 12 pm and 28.36 % until 8 pm. The utilization rate at testing is 51.29 % and at registration it is 87.92 %. On weekdays, about 78.5 staff hours are needed to run the process. The results are based on a "one visitor per bed" restriction. Nonetheless, a maximum of 3 visitors per day (approx. 800 visitors) might also work to service visitors in a reasonable period of time.

4. Discussion

The processes differ in several performance indicators. This is why, we discuss the results in detail in this section. In addition, we summarize limitations of our simulation study.

4.1. Comparison of the four processes

Table 9 summarizes performance indicators for the four processes.

Process 2 guarantees minimal service and waiting times for visitors, while the maximum number of visitors for the process is limited to 600 persons. Processes 1 and 4 are applicable up to a visitor restriction of 3 visitors per day and inpatient. This finding implies that unlimited admission of visitors with pandemic visitor management is neither feasible from a management perspective nor from an infection-prevention perspective.

Process 1 is advantageous in terms of staff hours per weekdays. A slight increase in staff hours is induced by process 2 due to separate admission and temperature control. Nonetheless, in winter or in midsummer, a change in space utilization is necessary for reliable temperature control. Antigen testing (processes 3 and 4) causes a significant increase in staff hours per weekday whilst rather low utilization of scheduling and moderate utilization of testing. In addition, visitor waiting times might rise up to approx. 100 minutes.

Thus, without substantial reconstruction measures in the library, testing is only feasible during a visitor stop. From a management perspective, consideration needs to be given to providing appropriate incentives to ensure that a large proportion of visitors bring an antigen test from test centers, when other visitor restrictions are in place. The increasing number of fully vaccinated people will probably alleviate this problem in future.

Table 9. Performance of the four processes

Process	1	2	3	4
Total time visitors [min]	70.16	30.01	59.86	99.22
Total time visitors QR [min]	9.59	3.03	54.52	26.52
Reduction of total time visitors by QR [percent]	86.00	90.00	9.00	73.00
Total time patients [min]	1.28	2.80	2.61	2.12
Max. length of queue [persons]	173.09	84.10	66.64	191.90
Utilization TC [percent]	-	50.03	49.91	35.00
Utilization TC till evening [percent]	-	61.83	57.46	28.36
Utilization T [percent]	-	-	45.29	51.29
Utilization S till 12 am [percent]	18.48	28.66	6.74	6.84
Utilization S till evening [percent]	48.81	37.19	4.96	5.01
Utilization R [percent]	89.49	90.87	43.33	87.92
Staff hours per weekday	53.5	64.5	82.5	78.5
Max. visitor restriction per day	3.00	1.00	0.00	3.00

A major finding is the potential of digitalization in hospital visitor management: The fast track admission causes a reduction of the total time of visitors of up to 90 percent for process 2. The reduction is calculated based on the total time visitors and the total time visitors QR. In contrast, the use of corresponding software is comparatively low in Germany [4]. The introduction of hospital visitor management software could therefore be an important component of a pandemic preparedness model, saving hospital resources and leading to acceptance of and satisfaction with infection-prevention measures by the general public. The latter hypothesis, though, definitely needs further research focusing both a psychological visitor and patient perspective in hospital visitor management by detailed interviews and surveys.

4.2. Limitations

Our simulation model is substantially based on the spatial conditions given in the main entrance area at the University Hospital of Augsburg. In other hospitals, these conditions may differ. Nevertheless, the results are transferable to a certain extent, since no entrance areas at hospitals were designed to accommodate to testing capacity on a large scale. The same is true for the data used to model simulation processes.

In addition, only few hospitals use QR registration and a digital hospital visitor management system. This enables us to evaluate the potential of digitalization, but only allows a limited comparison with admission processes, which are paper-based in total.

In this study, we consider both implemented and planned admission processes. So, we validate existing models and at the same time evaluate processes that have not yet been implemented on this basis. For these, a personnel estimate had to be made accordingly, which may have to be adjusted again in the event of actual use. This is also suggested by the utilization of scheduling and registration shown in Table 9. Nonetheless spatial conditions are again a limiting factor, if, for example, admission and temperature control take place in different rooms.

5. Conclusion

In this work, we apply a discrete-event simulation model to the data of a German University Hospital in order to evaluate both, implemented and planned hospital visitor admission processes during Covid-19.

We find the extraordinary potential of digitalization within hospital visitor management causing a total waiting and service time reduction of up to 90 percent. Hospital visitor admission as a new management task in hospitals during Covid-19 is a significant additional burden for limited staff capacity. If antigen test offers are to be added to visitor management, this can only be achieved with considerable restructuring measures in terms of space utilization and even more personnel. Unlimited admission of visitors during pandemics is basically not feasible from a management perspective and not only from an infection-prevention perspective.

In the University Hospital of Augsburg, as the incidence was below 100, the visitor stop was lifted in early summer 2021 and one visitor per patient per day is allowed. Due to our simulation results, visitors are approved to visit a patient if they can prove to be either vaccinated or recovered from Covid-19 or have a current negative test result. The test needs to be made externally, e.g., in a test center or a pharmacy, in order to save hospital resources and handle hospital visitors in a reasonable period of time. This application of our results emphasizes how helpful simulation can be in supporting decision making.

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