Appendix 1: details on testing van validation procedures

Table 1A Validity Test Recap.

Test	Explanation Validity
Structure confirmation	The model was presented to the stakeholders in order to check the accuracy of the interpretation of the facilitator about the topic.
Sensitivity test	Sensitivity test was performed, and some variables are considered sensitive.
Extreme condition test	The test was performed on three main variables, workload, total patient, and nurse on shift at recovery.
Dimensional consistency	The dimensions of the model are consistent and there is one cheat variable that reflects no real-life values.
Boundary adequacy	The model contains all aspects that were discussed in the GMB sessions.
Structure assessment	The model has three different main views – human resource, workload, and recovery model - that consist of several co-flows to mimic the real system. Moreover, some assumptions were considered.
Integration error	A time interval- and integration test are performed, and time step chosen was insensitive because there was no difference.
Behaviour reproduction	Based on the data given by PACU Inc., statistical measures were performed to see the behaviour and compare with the behaviour that is depicted by the model. The model is able to mimic the behaviour of the provided data.

Boundary adequacy

The boundary adequacy test is intended to assess the appropriateness of the model boundary in regard to the topic (Sterman, 2000). Within this study, the three primary models are appropriate to satisfy the goal for which the model is intended. The model incorporates all of the critical operational aspects that may influence the workload of the nurses in the recovery area. The workload view includes a lot of exogenous variables that affect the total nurses available on duty, such as nurses that are not available due to circumstances (e.g., sick or burnout). Nonetheless, the model does not consider the movement of nurses to POK and KLOK, other specific variables that might cause nurses to be unavailable to work and different types of surgery disciplines.

Dimensional consistency

Every single thing in the model has a unit. A perception variable or soft variables are “dimensionless". Furthermore, no severe typographical errors, a changed proportion, or a missing time consistent were discovered while running the unit check. The researcher opted to ignore three-unit errors because they were done on purpose: inflow of CT patients, inflow of new normal, and inflow of POK patient. The researcher had purposefully set the units to patient/day whereas the system prefers dimensionless units as the function that is embedded in variable is Normal function – a well-used function to produce stochastic variables - to generate fluctuation of patients inflow mimicking the real-life scenario. The decision was made in order to ensure dimensional consistency within the main model. Moreover, within this model there is one “cheat” variable – Patients per Surgery -, in order to make the units consistent. Nonetheless, as Sterman (2000) emphasizes, a model that produces no blunder messages is not ensured to pass. Along these lines, the creators did coordinate reviews and it very well may be found in Appendix 15. Documentation, which involves every one of the parts of the models, their units, and significance for everything.

Structure assessment

The goal of the structural assessment test is to determine whether the model is consistent with the knowledge about the problem's reality (Sterman, 2000). The model contains three different main views, workload, recovery model and human resource. These models combined are adequate to represent the dynamic of the recovery room. Some assumptions within the model have been made. They are as follows:

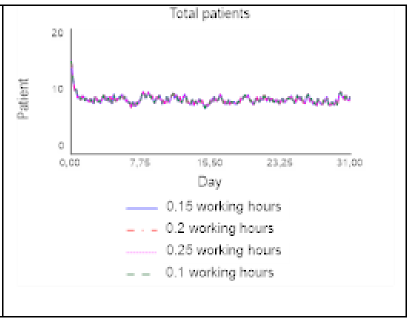
- The workload is the only trigger for nurses to become unavailable to work.
- Recovery room and POK patients are combined to be taken care of by the nurses, instead of a nurse having to leave for the POK. A fraction of POK patients come to the recovery room at between 16:00 until 18:00. Based on the surgeries, the inflow of patients in recovery is constructed.
- Nurses can be hired as a certified and uncertified (training). The nurses in training enter the certified nurses' stock at some point. Both types of nurses combined become the total FTE. In reality a nurse on training cannot treat the same amount of patients as a certified nurse. The model is not corrected for this.
- An average is taken over the ASA complexity present within the number of patients.
- The inflow of POK, CT and new patients happens randomly uniformly based on the minimum, maximum, standard deviation and mean. This creates uncertainty in inflows and peaks in behaviour.

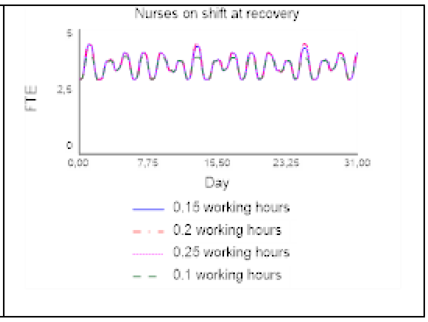
Sensitivity test

Sensitivity analysis

Average amount of Hours Worked a Week

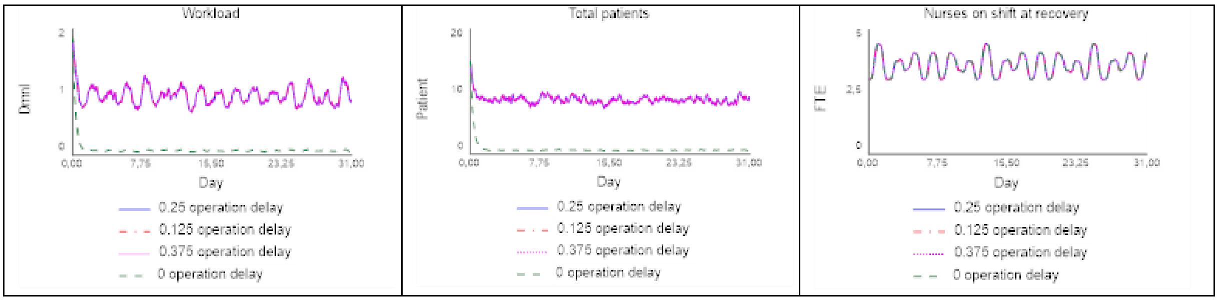
Table 2a Average amount of Hours Worked a Week Sensitivity Analysis.





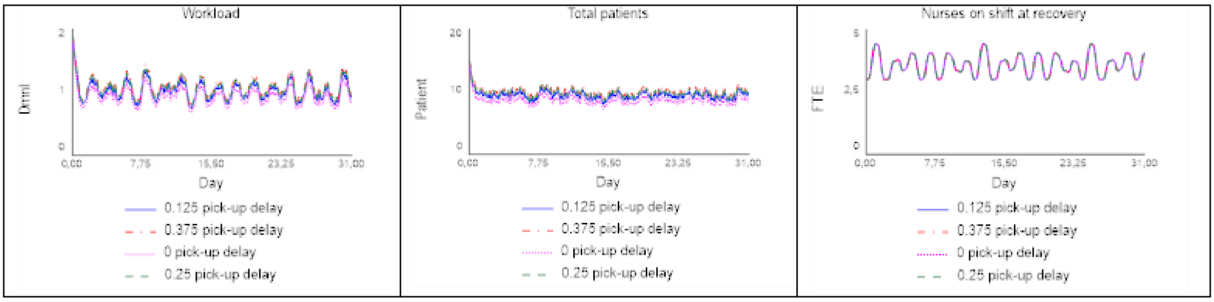
Average Delay of Planned Surgery

Table 3a Average Delay of Planned Surgery Sensitivity Analysis.



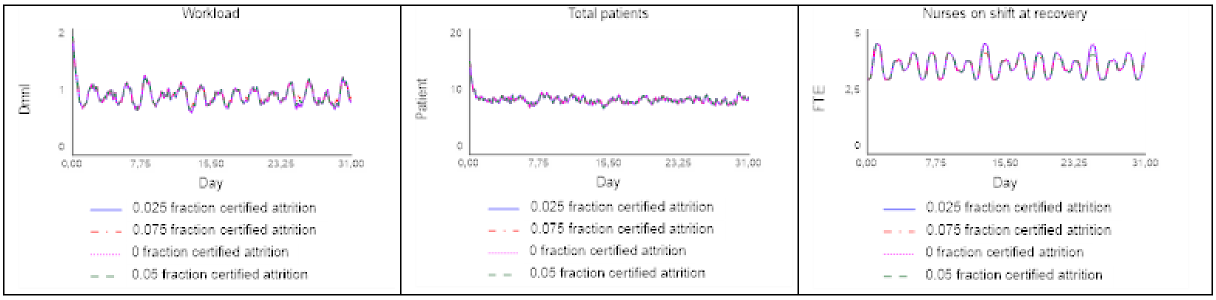
Average Delay Pick Up

Table 4a Average Delay Pick Up Sensitivity Analysis.



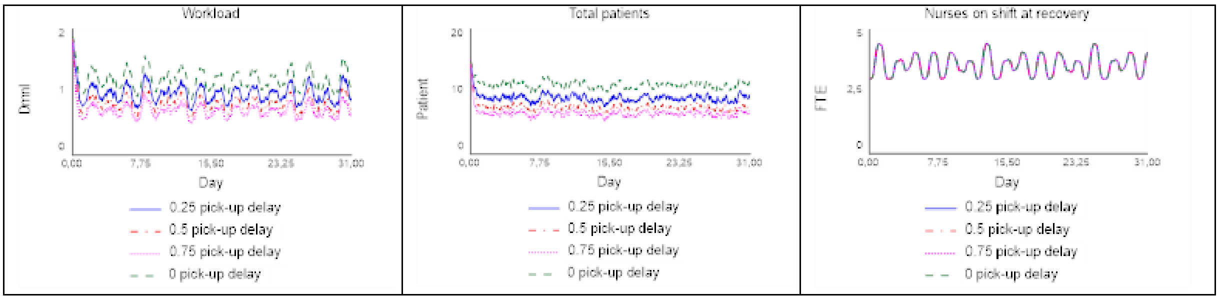
Certified Nurse Attrition Rate

Table 5a Certified Nurse Attrition Rate Sensitivity Analysis.



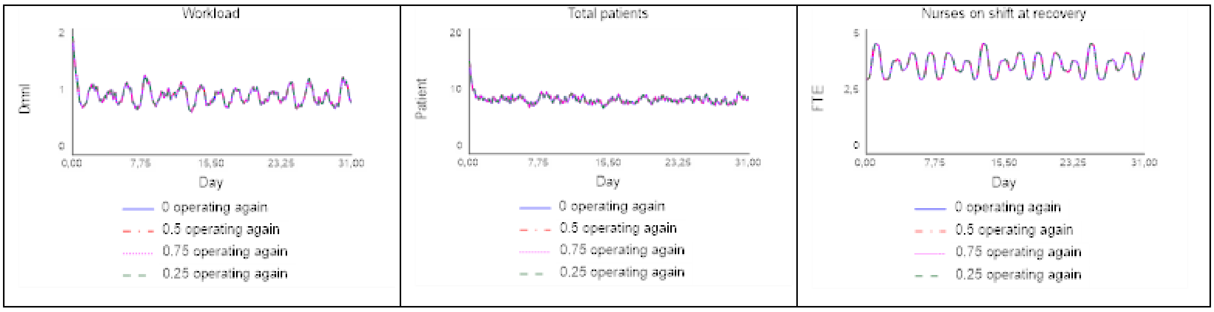
Fraction Delayed Pick-Up Patients

Table 6a Fraction Delayed Pick-Up Patients Sensitivity Analysis.



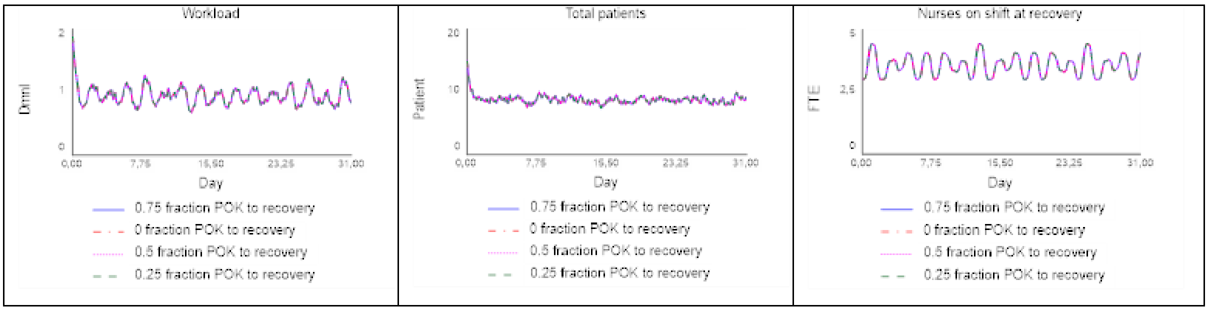
Fraction of Recovery Surgery Again

Table 7a Fraction of Recovery Surgery Again.



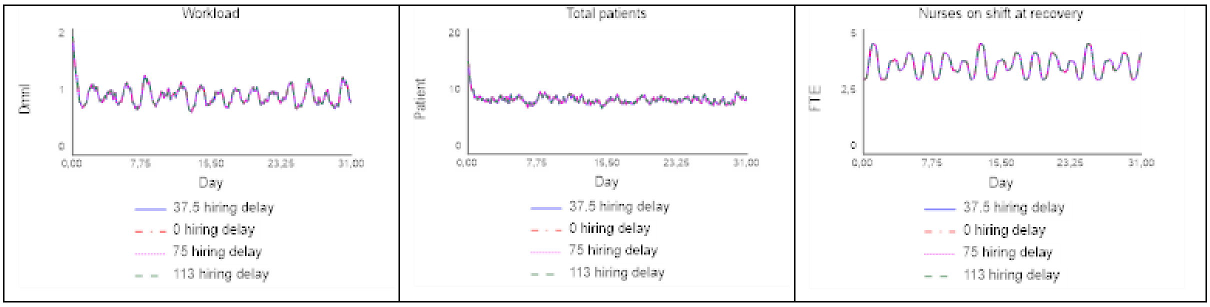
Fraction POK Patients Going to Recovery

Table 8a Fraction of POK Patients Going to Recovery Sensitivity Analysis.



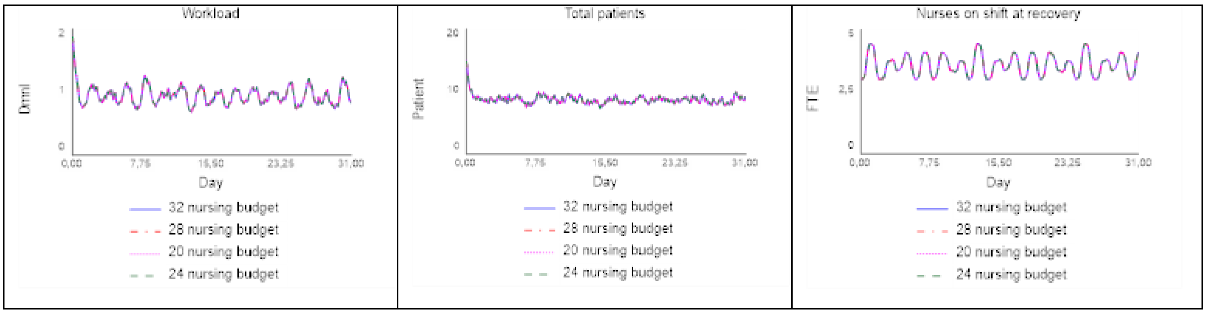
Hiring Delay

Table 9a Hiring Delay Sensitivity Analysis.



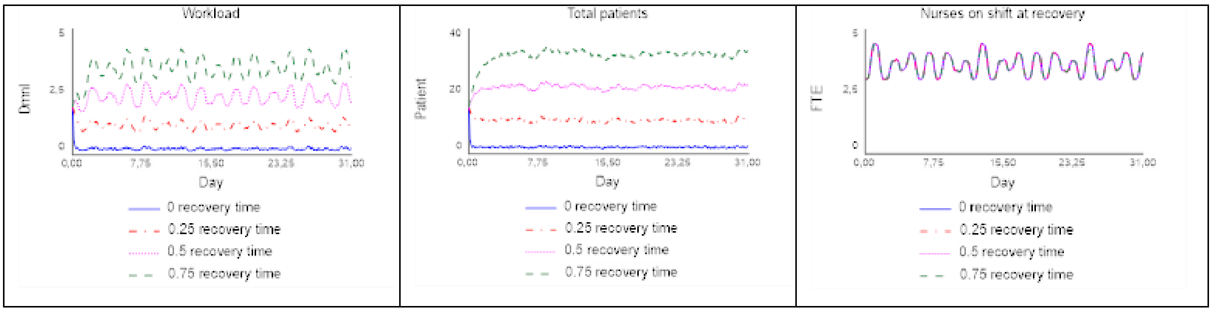
Nursing Budget

Table 10a Nursing Budget.



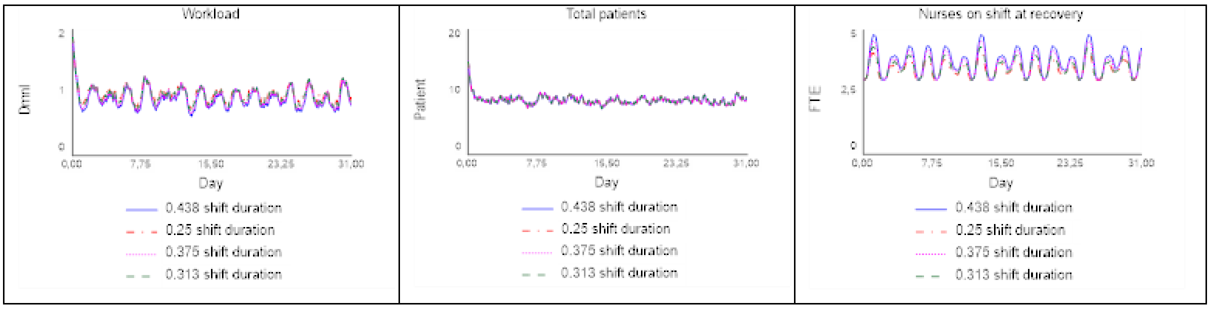
Recovery Time

Table 11a Recovery Time.



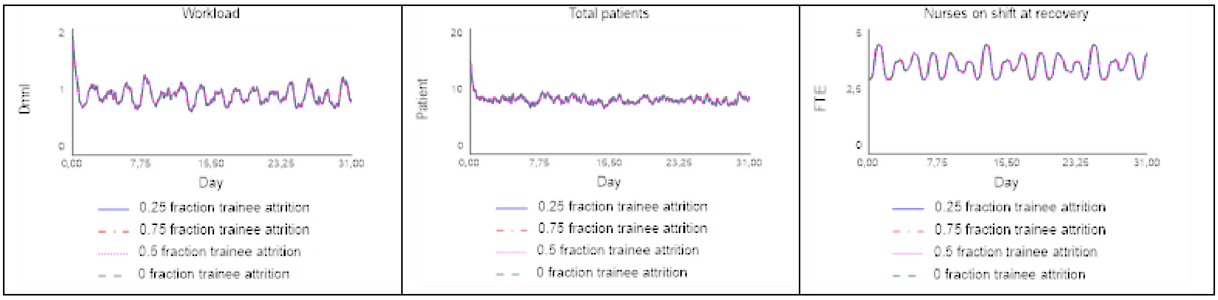
Shift Duration

Table 12a Shift Duration Sensitivity Analysis.



Trainee Attrition Fraction

Table 13a Trainee Attrition Fraction.



Training Duration

Table 14a Training Duration.

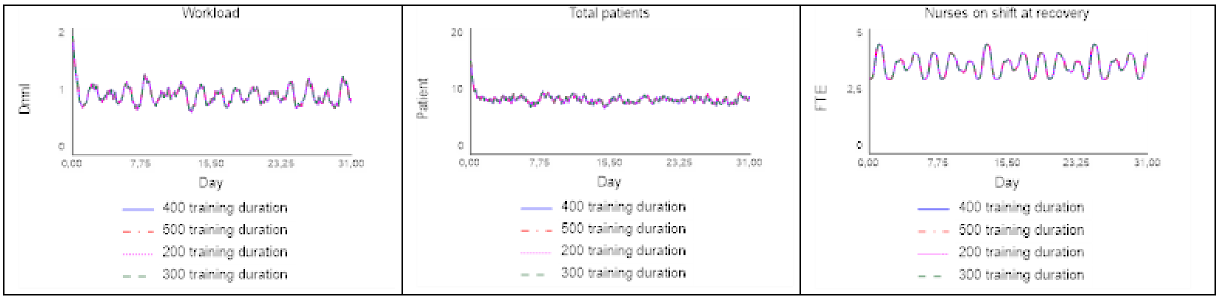


Table 15a Sensitivity Analysis Overview.

Variable	Sensitivity
Average Amount of Hours Worked a Week	Fairly Sensitive
Average Delay of Planned Surgery	Moderately Sensitive
Average Delay Pick Up	Fairly Sensitive
Certified Nurse Attrition Rate	Fairly Sensitive
Fraction Delayed Pick-Up Patients	Moderately Sensitive
Fraction of Recovery Surgery Again	Not Sensitive
Fraction POK Patients Going to Recovery	Not Sensitive
Hiring Delay	Not Sensitive
Nursing Budget	Not Sensitive
Recovery Time	Highly Sensitive
Shift Duration	Fairly Sensitive
Trainee Attrition Fraction	Not Sensitive
Training Duration	Not Sensitive

Extreme condition test

The aim of this test is to evaluate if the model shows a reasonable and plausible behaviour when some of the variables are pushed to extreme conditions (Barlas, 1996). A critical test in the model is to observe what happens to the nurses on shift and the workload if no patients are present at the recovery rooms. The expected system's behaviour would be that the number of nurses on shift is not affected by the number of patients present at the recovery rooms. Indeed, they are hired by the hospital and not working "on call". This expected result is confirmed in Figure 14, which compares the base scenario (Scenario 1, dotted blue line) and the scenario under extreme conditions (Scenario 2, dashed red line). Differently, as expected, Figure 15 shows nurses' workload when no patients are present at the recovery rooms, which is equal to zero.

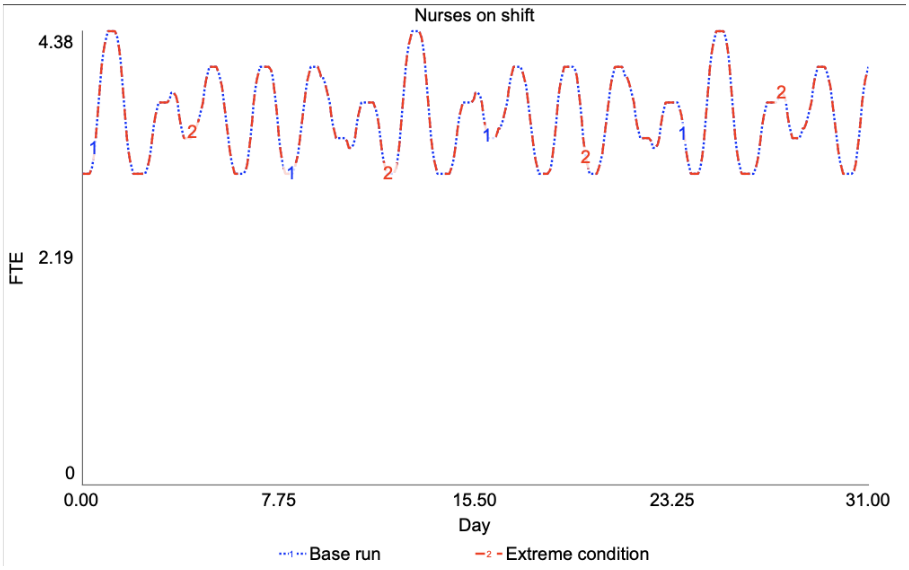


Figure 1a Simulation results for nurses on shift when no patients are present at the recovery room (Scenario 2, red line) compared to initial conditions (Scenario 1, blue line).

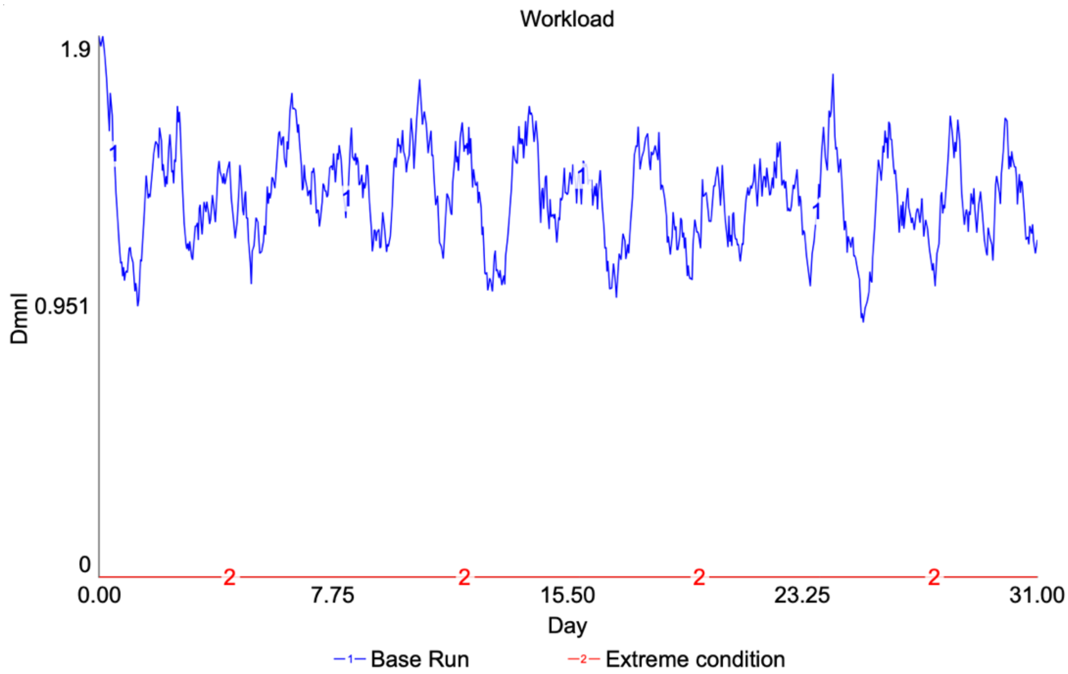


Figure 2a Simulation results for workload when no patients are present at the recovery rooms (Scenario 2, red line) compared to initial conditions (Scenario 1, blue line).

Similarly, if the inflow of new accessing patients at POK and recovery rooms is put equal to zero (Scenario 2, solid red line), as expected, the simulation results depicted in Figure 23a show that the number of total patients rapidly drops towards the zero value. It must be noted that the decrease is not immediate since in Figure 23a it is assumed that only the number of new accessing patients is put equal to zero, while the initial number of patients present at the recovery rooms depletes the stock as they recover and leave the recovery unit. In this case, the workload assumes a similar trend (see Figure 24a).

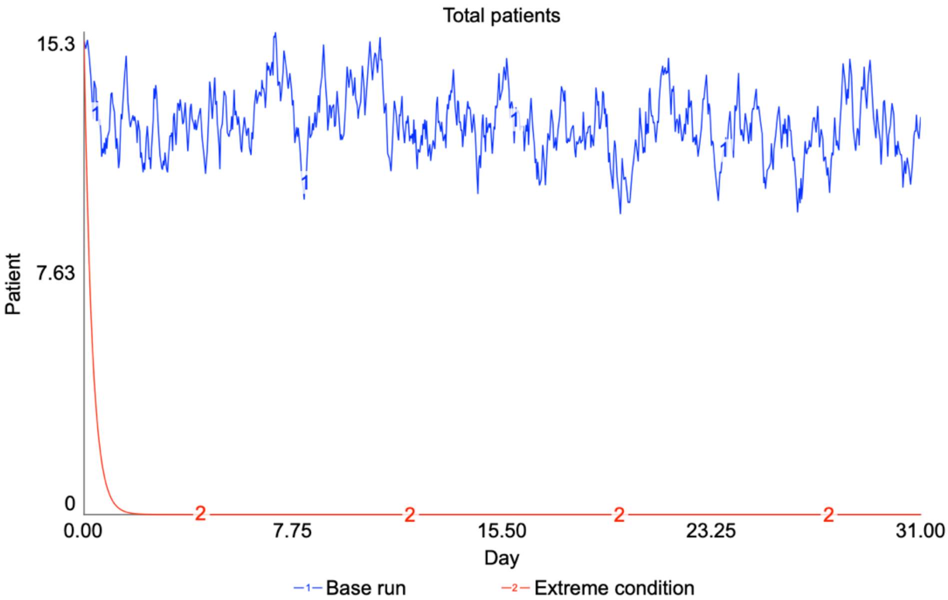


Figure 3a Simulation results for total patients assuming the inflow of patients is null (Scenario 2, red line) compared to initial conditions (Scenario 1, blue line).

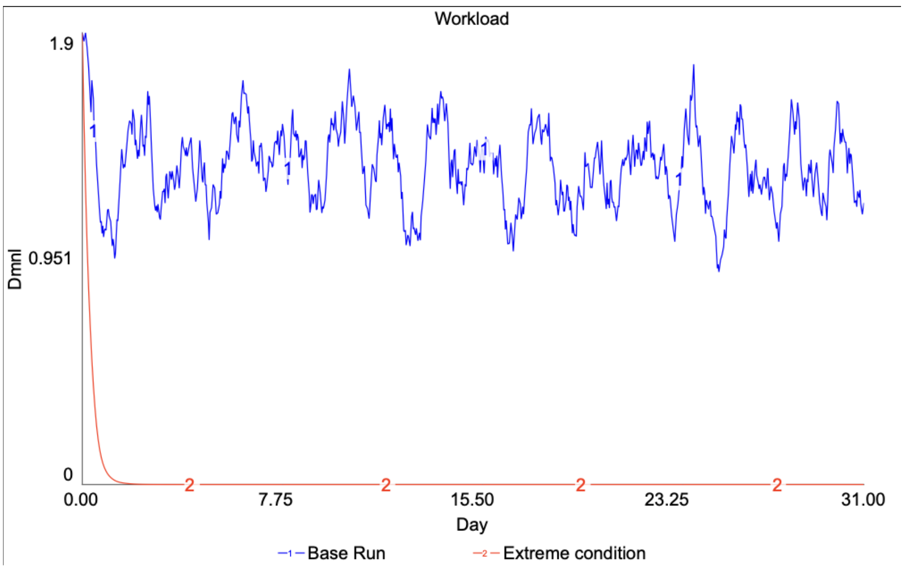
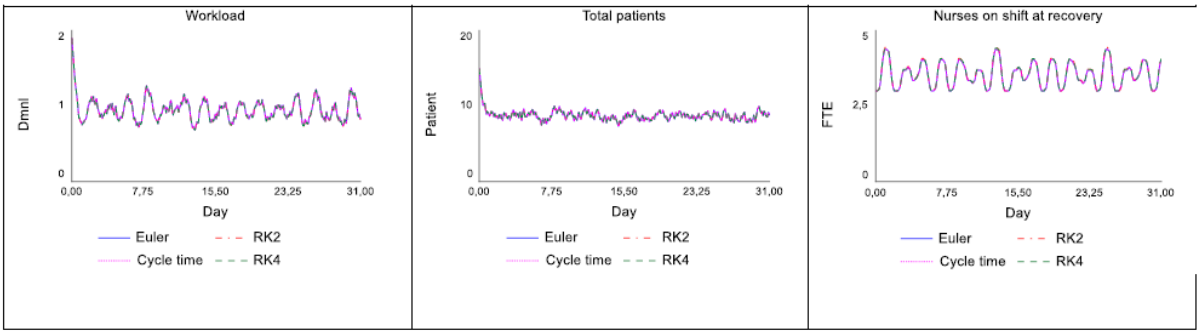


Figure 4a Simulation results for nurses' workload assuming the inflow of patients is null (Scenario 2, red line) compared to initial conditions (Scenario 1, blue line).

Integration error

Table 16a Integration Error.



Behaviour reproduction

The system exhibits oscillating behaviour, which indicates that the number of patients entering the system varies over time. This behaviour is consistent with the previous data sets provided, which were inflow of polyclinic patients, inflow of surgery patients, and inflow of new patients. The historical data also showed oscillation. Indeed, the model is capable of capturing the system's realistically and its uncertainty component.

Appendix 2: parameter details

Table 17a Documentation

		Equation	Properties	Units	Documentation	Annotation
	ASA_Classification:					
	ASA_Growth(t)	ASA_Growth(t - dt) + (ASA_Increase) * dt	INIT ASA_Growth = 1	Patient/FTE	The growth of ASA overtime.	
	ASA_Growth_Rate	0,00015		1/Day	Constant growth amount of ASA per day.	
	ASA_Increase	-(ASA_Growth*((IF COVID19_PULSE = 0,5 THEN 0,001 ELSE ASA_Growth_Rate)))		Patient/(FTE*Day)	The rate of ASA increase per day. The increment is the result of ASA Growth times 0.001 if COVID Pulse is 0.5 otherwise, times ASA Growth Rate.	
	Average_complexity_of_recovery_patients	(IF SW_ASA_Growth = 0 THEN Complexity_ASA_1*Fraction_ASA_1+Complexity_ASA_2*Fraction_ASA_2+Complexity_ASA_3*Fraction_ASA_3+Complexity_ASA_4*Fraction_ASA_4+Complexity_ASA_5*Fraction_ASA_5 ELSE (Complexity_ASA_1*Fraction_ASA_1+Complexity_ASA_2*Fraction_ASA_2+Complexity_ASA_3*Fraction_ASA_3+Complexity_ASA_4*Fraction_ASA_4+Complexity_ASA_5*Fraction_ASA_5)*ASA_Growth)		Patient/FTE	The average amount of patients a nurse can take care of.	
	Complexity_ASA_1	4		Patient/FTE	The amount of ASA 1 patients that one nurse can take care of.	
	Complexity_ASA_2	3		Patient/FTE	The amount of ASA 2 patients that one nurse can take care of.	
	Complexity_ASA_3	1		Patient/FTE	The amount of ASA 3 patients that one nurse can take care of.	
	Complexity_ASA_4	1		Patient/FTE	The amount of ASA 4 patients that one nurse can take care of.	
	Complexity_ASA_5	0,2		Patient/FTE	The amount of ASA 5 patients that one nurse can take care of.	
	COVID19_PULSE	1-(IF TIME >= (14) AND TIME <= (STOPTIME) AND (TIME - (14)) MOD (90) < (21) THEN 1 ELSE 0)*0,5*SW_COVID				

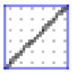
	Fraction_ASA_1	5945/32194		Dmnl	The amount of ASA 1 patients per the total amount of patients.	
	Fraction_ASA_2	17320/32194		Dmnl	The amount of ASA 2 patients per the total amount of patients.	
	Fraction_ASA_3	7861/32194		Dmnl	The amount of ASA 3 patients per the total amount of patients.	
	Fraction_ASA_4	1066/32194		Dmnl	The amount of ASA 4 patients per the total amount of patients.	
	Fraction_ASA_5	2/32194		Dmnl	The amount of ASA 5 patients per the total amount of patients.	
	SW_ASA_Growth	1		Dmnl	Switch to activate the ASA Growth. When the value is 1, the switch will be activated	
	SW_COVID	1		Dmnl	Switch to activate the COVID pulse. When the value is 1, the switch will be activated	
	Dashboard:					
	HR:					
	Certification_rate	Nurses_in_training/Training_duration		FTE/Day	The amount of nurses being certified per day.	
	Certified_nurse_hiring_rate	(Gap_between_total_nursing_FTE_and_budget*Hiring_fraction_certified_nurses)/Hiring_delay		FTE/Day	The amount of nurses being hired per day.	
	Certified_nurses(t)	Certified_nurses(t - dt) + (Certification_rate + Certified_nurse_hiring_rate - Certified_nurses_attrition_rate) * dt	INIT Certified_nurses = Certified_nurses_initial_value	FTE	The total amount of certified nurses.	
	Certified_nurses_attrition_fraction	3/365		1/Day	The ratio of certified nurses that are leaving the hospital per day.	
	Certified_nurses_attrition_rate	Certified_nurses*Certified_nurses_attrition_fraction/COVID19_PULSE		FTE/Day	The pace of certified nurses that are leaving the hospital.	
	Certified_nurses_initial_value	INIT(21,8)		FTE	The base amount of the certified nurses.	

	Gap_between_total_nursing_FTE_and_budget	Nursing_budget-Total_FTE		FTE	The difference of the budgeted FTE and current FTE.	
	Hiring_delay	75		Day	The time needed to hire new nurses.	
	Hiring_fraction_certified_nurses	34/37		Dmnl	The ratio of certified nurses that is hired.	
	Hiring_rate_nurses_in_training	(Gap_between_total_nursing_FTE_and_budget*(1-Hiring_fraction_certified_nurses))/Hiring_delay		FTE/Day	The pace of hiring un-certified nurses.	
	Nurses_in_training(t)	Nurses_in_training(t - dt) + (Hiring_rate_nurses_in_training - Certification_rate - Nurses_in_training_attrition_rate) * dt	INIT Nurses_in_training = Nurses_in_training_initial_value	FTE	The total amount of un-certified nurses.	
	Nurses_in_training_attrition_rate	Nurses_in_training*Trainee_attrition_fraction/COVID19_PULSE		FTE/Day	The pace of un-certified nurses leaving the company.	
	Nurses_in_training_initial_value	INIT(4,4)		FTE	The base amount of un-certified nurses.	
	Nursing_budget	28		FTE	The previously agreed number of FTE by the board.	
	Total_FTE	Certified_nurses+Nurses_in_training		FTE	The current total amount of FTE equivalent nurses.	
	Trainee_attrition_fraction	0,5/365		1/Day	The ratio of un-certified nurses that are leaving the hospital.	
	Training_duration	450		Day	The time needed to train the uncertified nurses to be a certified nurse.	
	Patient_inflows:					
	Inflow_of_CT_patients	(NORMAL(MEAN_CT_patients; STDEV_CT_patients; MEAN_CT_patients; MIN_CT_patients; MAX_CT_patients))*COVID19_PULSE		Patient/Day	The amount of CT patients coming in per day.	

	Inflow_of_new_patients	(NORMAL(MEAN_new_patients; STDEV_new_patients; MEAN_new_patients; MIN_new_patients; MAX_new_patients))*COVID19_PULSE		Patient/Day	The amount of new patients coming in per day.	
	Inflow_of_POK_patients	(NORMAL(MEAN_POK_patients; STDEV_POK_patients; MEAN_POK_patients; MIN_POK_patients; MAX_POK_patients))*COVID19_PULSE		Patient/Day	The amount of patients coming in per day for the policlinic.	
	MAX_CT_patients	4		Patient/Day	The maximum amount of CT patients per day.	
	MAX_new_patients	58		Patient/Day	The maximum amount of new patients per day.	
	MAX_POK_patients	5		Patient/Day	The maximum amount of patients for the policlinic per day.	
	MEAN_CT_patients	1,71		Patient/Day	The average amount of CT patients per day.	
	MEAN_new_patients	35,28		Patient/Day	The average amount of new patients per day.	
	MEAN_POK_patients	1,56		Patient/Day	The average amount of patients for the policlinic per day.	
	MIN_CT_patients	1		Patient/Day	The minimum amount of CT patients per day.	
	MIN_new_patients	2		Patient/Day	The minimum amount of new patients per day.	
	MIN_POK_patients	1		Patient/Day	The minimum amount of patients for the policlinic per day.	
	STDEV_CT_patients	0,83		Patient/Day	The amount of variation or dispersion of CT patients.	
	STDEV_new_patients	9,8		Patient/Day	The amount of variation or dispersion of new patients.	
	STDEV_POK_patients	0,78		Patient/Day	The amount of variation or dispersion of the patients going to the policlinic.	
	Recovery_model:					
	Average_delay_of_plan	0,1		Day	The average delay time before the surgery can be executed.	

	ned_surgery					
	"Average_delay_pick-up"	16,71/(24*60)		Day	The average delay time to get the patient picked up.	
	Fraction_delayed_picked_up_patients	0,29		Dmnl	The ratio of patients that got delayed getting picked up.	
	Fraction_of_recovery_surgery_again	0,2		1/Day	The ratio of patients that need to be surgery again after the main surgery.	
	Fraction_POK_patients_going_to_recovery	0,01		Dmnl	The ratio of policlinic patients going to the recovery room.	
	New_PACU_patients	(Surgery_executed*Patients_per_surgery)+Inflow_of_CT_patients		Patient/Day	The rate of patients going to the recovery room per day.	
	New_POK_patients	Inflow_of_POK_patients		Patient/Day	The rate of patients coming to policlinic per day.	
	New_surgery	(Inflow_of_new_patients/Patients_per_surgery)+(Patients_in_PACU*Fraction_of_recovery_surgery_again/Patients_per_surgery)		Operation/Day	The rate of new patients that will go through the surgery per day.	
	Patients_in_PACU(t)	Patients_in_PACU(t - dt) + (New_PACU_patients + POK_patients_going_to_recovery - Patients_recovered) * dt	INIT Patients_in_PACU = Patients_in_recovery_initial_value	Patient	The amount of patients in recovery room.	
	Patients_in_POK(t)	Patients_in_POK(t - dt) + (New_POK_patients - POK_patients_going_to_recovery - POK_patients_recovered) * dt	INIT Patients_in_POK = Patients_in_POK_initial_value	Patient	The amount of patients in policlinic.	
	Patients_in_POK_initial_value	INIT(0)		Patient	The base amount of policlinic patient.	
	Patients_in_recovery_initial_value	INIT(15)		Patient	The base amount of patients in recovery room.	

	Patients_per_surgery	1		Patient/Operation	The amount of patients in an surgery room.	
	Patients_recovered	((Patients_in_PACU/Recovery_time)+(Patients_in_PACU*Fraction_delayed_picked_up_patients/(Recovery_time+"Average_delay_pick-up")))/2		Patient/Day	The rate of patients recovered (being discharged) from the recovery room.	
	POK_patients_going_to_recovery	(Patients_in_POK*Fraction_POK_patients_going_to_recovery)/Transfer_time		Patient/Day	The rate of policlinic patients going to the recovery room.	
	POK_patients_recovered	Patients_in_POK/POK_recovery_time		Patient/Day	The rate of patients recovered (being discharged) from the policlinic.	
	POK_recovery_time	48,67/(24*60)		Day	The time needed for the policlinic patient being discharged.	
	Recovery_time	0,3		Day	The time needed for patient from recovery room being discharged.	
	Surgery_capacity	NORMAL(36,87; 15; 36,87; 8,29; 99,69)		Operation/Day	The amount of available surgery capacity per day.	
	Surgery_executed	MIN((Surgery_planned/Average_delay_of_planned_surgery); Surgery_capacity)		Operation/Day	The amount of surgery performed per day.	
	Surgery_planned(t)	Surgery_planned(t - dt) + (New_surgery - Surgery_executed) * dt	INIT Surgery_planned = Surgery_planned_initial_value	Operation	The amount of surgery planned.	
	Surgery_planned_initial_value	INIT(30,99)		Operation	The base amount of surgery planned.	
	Total_patients	Patients_in_POK+Patients_in_PACU		Patient	The total amount of patients from policlinic and recovery room.	
	Transfer_time	1		Day	The transfer time of patients needed from policlinic to the recovery room.	
	Workload1:					
	Average_amount_of_hours_worked_a_week	36/(24*7)		1/Day	The amount of hours worked per day by a nurse.	

	Desired_nurses	Total_patients/Average_complexity_of_recovery_patients		FTE	The amount of FTE desirably needed.	
	Desired_workload	1		Dmnl	The preferred workload per nurse.	
	Effect_on_availability	GRAPH(Normalized_gap_workload) Points: (0,000, 0,0000), (0,200, 0,0500), (0,400, 0,1000), (0,600, 0,1500), (0,800, 0,2000), (1,000, 0,2500), (1,200, 0,3000), (1,400, 0,3500), (1,600, 0,4000), (1,800, 0,4500), (2,000, 0,5000)		Dmnl	The effect of the workload on the availability of nurses.	
	Fraction_of_nurses_not_available_due_to_circumstances	Effect_on_availability		Dmnl	The ratio of nurses that are not available.	
	Gap_workload	Workload-Desired_workload		Dmnl	The difference between current and desired workload.	
	Normalized_gap_workload	Gap_workload/1,5		Dmnl	The normalisation of the workload.	
	Nurse_gap	Nurses_on_shift_at_recovery-Desired_nurses		FTE	The difference between current and desired nurses on duty.	
	Nurse_on_Shift_Initial_Value	INIT(3)		FTE	The base amount of nurses on duty.	
	Nurse_shifts	(IF TIME >= (0,3021) AND TIME <= (720) AND (TIME - (0,3021)) MOD (4) < (1) THEN 1 ELSE 0)+(IF TIME >= (0,3958) AND TIME <= (720) AND (TIME - (0,3958)) MOD (3) < (1) THEN 1 ELSE 0)+(IF TIME >= (0,4792) AND TIME <= (720) AND (TIME - (0,4792)) MOD (2) < (1) THEN 1 ELSE 0)+(IF TIME >= (0,646) AND TIME <= (720) AND (TIME - (0,646)) MOD (2) < (1) THEN 1 ELSE 0)		FTE/Day	The shifts of nurses and the amount of nurses on duty per day.	
	Nurses_leaving_shift	DELAY(Nurses_starting_shift; Shift_duration; 0)		FTE/Day	The rate of nurses that finish their shift.	
	Nurses_on_shift_at_recovery(t)	Nurses_on_shift_at_recovery(t - dt) + (Nurses_starting_shift - Nurses_leaving_shift) * dt	INIT Nurses_on_shift_at_recovery = Nurse_on_S	FTE	The total amount of nurses on duty.	

			hift_Initial_Value			
	Nurses_starting_shift	((IF Nurse_shifts < (Total_FTE*(1-Fraction_of_nurses_not_available_due_to_circumstances)*Average_amount_of_hours_worked_a_week) THEN Nurse_shifts ELSE (Total_FTE*(1-Fraction_of_nurses_not_available_due_to_circumstances)*Average_amount_of_hours_worked_a_week)))*COVID19_PULSE		FTE/Day	The rate of nurses coming to work.	
	Shift_duration	8,5/24		Day	The amount of hours a nurse is on shift during a day.	
	Workload	Total_patients/(Nurses_on_shift_at_recovery*Average_complexity_of_recovery_patients)		Dmnl	The workload a nurse is experiencing. A workload of 1 means being able to handle all patients assigned without pressure.	

Table 18a Model Count

Total	Count	Including Array Elements
Variables	88	88
Sectors	6	
Stocks	7	7
Flows	15	15
Converters	66	66
Constants	43	43
Equations	38	38
Graphicals	1	1

Table 19a Run Specs Overview of the Model.

Run Specs	
Start Time	0
Stop Time	360
DT	0,03125
Fractional DT	False
Save Interval	0,03125
Sim Duration	0
Time Units	Day
Pause Interval	0
Integration Method	Euler
Keep all variable results	True
Run By	Run
Calculate loop dominance information	False