# The impact of shifting priorities during COVID-19 with aging population: exploring the importance of the PACU unit.

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**Abstract**

Postanesthetic care unit (PACU) employees have a key role in the surgery center of a hospital; they take care of patients directly after receiving surgical procedures. In this situation scheduling of both staff and patients is very dynamic and complex. The nature of the PACU employees skillset contributes strongly to upscaling the intensive care unit during the covid pandemic. Consequently, the short-term gain of the higher intensive care unit (ICU) capacity may have a long-term downside. Non-critical surgical procedures will be postponed and may cause deterioration of patient’s heath. Overtime non-critical becomes critical. According to our exploratory research, employee wellbeing and PACU capacity decisions may directly influence hospital performance. Although further research is needed, our research suggests that shifting priorities by upscaling the ICU capacity at the expense of the PACU capacity may have far reaching consequences.

## 1. Introduction

### *1.1 Research motivation*

During the COVID-19 pandemic healthcare capacity issues are prominent on the national news and monitored (Mathieu, 2020). Especially COVID-19 care units and intensive care capacity are often measured. In this period intensive care unit (ICU) capacity was scaled up to cover the increasing demand of COVID-19 patients. Resulting the number of patients exceeded the normal capacity of ICU. Therefore, extra personnel were needed to deliver the required medical care to the ICU patients. In order to match the different specialized tasks of ICU nurses these tasks were reallocated over a wide variety of capable hospital personnel. The postanesthetic care unit (PACU) has a vital role in scaling up or down the ICU capacity because PACU and ICU workforce have certain equivalent skills and capabilities (Maves et al. 2019).

In certain countries non-critical healthcare has been scaled down in favor of providing higher COVID-19 care and ICU capacity (Al Omar et al., 2020). In the long term this may have huge consequences on national health of society. Postponed non-critical healthcare will become more critical over time (Shehata et al., 2020). Consequently, more intense treatment and care might be needed to resolve these deteriorating health effects of the postponed non-critical care (Rajasekaran et al., 2020). This may impact the future capacity of the healthcare system. Therefore, we investigated the dynamic nature of the PACU capacity.

### *1.2 Research approach*

The complex and dynamic nature of healthcare is well known (Davahli et al., 2020). Healthcare operations can be recognized as a complex dynamic system. Dynamic complexity is the counterintuitive behavior of complex systems that arises from the interactions between its many components and agents over time (Sterman, 2006; Forrester, 1971), which involves multiple feedback mechanisms and time delays. Its dynamic nature can be recognized in changing the employee base, patients flow, workforce dynamics, specific patients' journeys that require specific medical disciplines, dependency on logistics and healthcare technology (Davahli et al., 2020). In our research, we used a system dynamics and group model building approach to capture the systemic structure relevant to the PACU capacity by utilizing mathematical equations to make a simulation and simulated different relevant scenarios about PACU capacity development. Our exploratory research is a case study in a large top clinical hospital with a large oncology center and specialized trauma care, anonymized as Pacu Care Centre inc.

### *1.3 Research contribution*

According to the meta study of Davahli et al. (2020) healthcare is a well-covered topic in system dynamics research, where in terms of healthcare operations there is a focus on patients flows and emergency departments. Although other scientific research areas recognize PACU scheduling issues (Abedini et al., 2017; Bai et al., 2017; Abdelrasol et al., 2013; Weinbroum et al., 2003), limited research can be found in the field of system dynamics. This is an interesting observation because PACU capacity is complex and dynamic in nature while shortage can have a significant impact on hospital function and even eventually on the health of the population in the region. Our research is a first attempt to have a detailed understanding about the systemic structure that drives the PACU capacity development. Another observation is that limited research attention is found on PACU efficiency (Debats et al., 2021) while improvement in this area significantly contributes to the overall performance of a hospital in terms of beds occupancy and patients' wellbeing (Latorre-Núñez et al., 2016; Wang et al., 2015).

Our paper is organized as follows: First, we review the relevant literature and theoretical background information. Second, we present our research methodology including an explanation of the model structure and the justification of why we can rely on its output, followed by results of the policy analyses, conclusion, and future research directions.

## 2. Theoretical background

Given the fact that the PACU is core of our systemic model we briefly explain how the PACU is positioned in our case study organization and explain its dynamic nature with relevant literature.

### *2.1 Positioning the surgical center in the context of Pacu Care Centre inc.*

The core of many hospitals is created by the units that focus on acute and complex care such as the accident & emergency unit, the birth care unit, the acute care unit, the surgery unit, the PACU and the ICU. All these units combined; it is often referred to as the acute care ward. Emerging patients with acute healthcare issues are assessed and treated in this ward. Some of these emergency patients need surgery or intensive care, like life threatening situations. Besides emergency and acute care, the surgery center, which consist of the surgery unit and the PACU, also delivers planned or scheduled care.

### *2.2 Positioning PACU in the context of the surgical center.*

The PACU provides staff capacity for both postanesthetic care as well as preparation phase before entering surgery. There is a three-step route (like an aging chain) for preparation, surgery to postanesthetic care (see Figure 1). When the demand for care exceeds capacity to deliver this care there will be delays through the chain. While generally employable anesthesiologists and specialized nurses take part in the process, the surgery itself depends on specific specialist surgeons driven by the patient flow. This patient flow can only be partially controlled through scheduling because of emerging patients for emergency surgery. Examples of emerging patients are the ones coming for lifesaving surgery after a disaster, trauma care after an accident, or giving birth by lifesaving caesarean section.

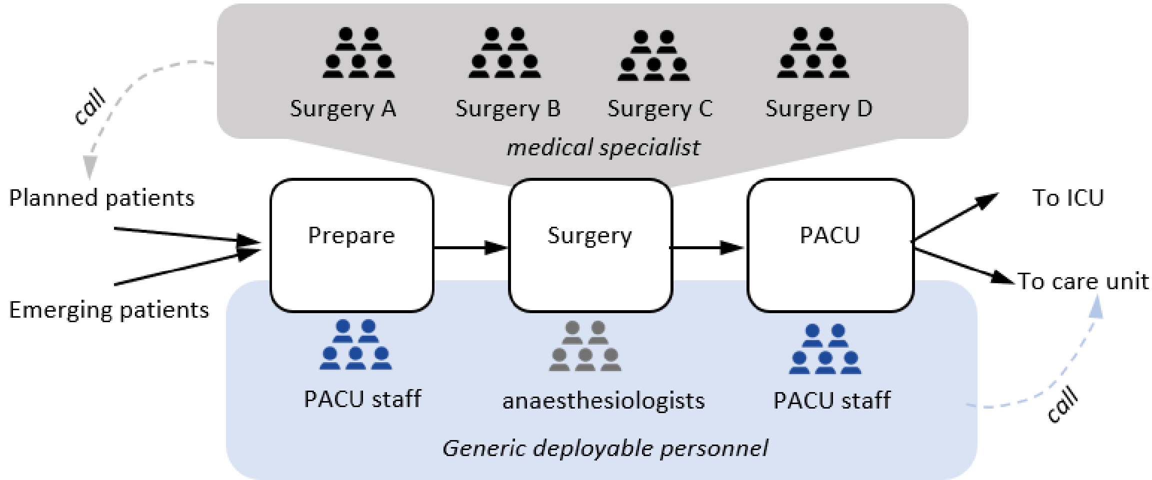


*Figure 1 Positioning of the PACU in Pacu Care Centre inc.*

PACU rooms represent the last phase of a three-step operation route where patients already have passed through a preparation phase (in Pacu Care Centre inc. this room is called the holding unit) and the operation itself. Different specialist surgeons or generally employable anesthesiologists and nurses take part in this chain (see Figure 1). In this sense, if the demand for care exceeds PACU's capacity, this could result in delays throughout the chain. Delays can also be caused by: (i) staff (i.e., doctors, operating teams and nurses) availability; (ii) the workload required by patients complexity, which is identified according to the American Society of Anesthesiologists (ASA) classification; (iii) increased requirements in terms of emergencies; (iv) the scheduling of the various surgical programs and patients dismissal; (v) unpredictable conditions related to patients inflows (e.g., last-minute patients' complications) and outflows (e.g., delays of the pick-up department) (see Appendix 1 of the supportive documents). Similar issues are also supported by literature (Conti et al., 2014; Schoenmeyr et al., 2009; Simoens et al., 2005).

### *2.3 Dynamics in healthcare operations – a PACU perspective*

The healthcare sector in the region of our case study copes with a shortage of staff and declining labor market potential (Simoens et al. 2005). Lowering contract hours because of increasing workload and aging population reinforces this effect (Landman 2021). The aging population has also another effect because it increases complexity and severity in required hospital care (ASA) (Umekawa et al.,2019; Soyalp et al., 2018). The combination of a decrease in available labor and an increase in complexity is even more concerning for the PACU because this unit has required specialized staff with dedicated training and experience, this requires time.

## 3. Methods

In this section we explain more about the model structure, our modelling approach and the performed tests and procedures for validation.

### *3.1 Our modelling approaches*

We used a group model building (GMB) approach to construct the model. GMB is known for addressing strategic problems and learning about the issue at hand while achieving consensus and work towards commitment on joint actions (Vennix, 1996, 1999; Ackermann et al., 2010). In Table 1 below, the experts and their participation in modelling activities are shown. The table shows that two modelling sessions with experts for model structure design. During these GMB sessions, the GMB protocols as provided by the Radboud University and the System Dynamics Society were followed. The table also shows that one validation session was held. During this session, a walkthrough through the model structure was done and the boundary of the model was validated with the experts.

*Table 1 Overview of model building activities and participation.*

| | Session 1 | Session 2 | Validation Session |
|---|---|---|---|
| PACU nurse | x | x | |
| Scheduler | x | x | |
| Data specialist I | x | x | x |
| Data specialist II | | | x |
| Head of PACU | x | x | x |
| Head of surgery | | x | |
| Researcher | x | | |

### *3.2 Subsector overview*

In our simulation model three important sub-structures can be recognized: 1) PACU capacity and patient flows, 2) workload dynamics, and 3) workforce dynamics. The PACU capacity and patient flow substructure represents the aging chain of patients receiving and recovering from surgery. While planned and emerging patients drive the demand of patients, the available nurses provide bounded capacity that can provide care for these patients. When required staff capacity exceeds the availability, staff capacity workload may increase and generate pressure to work harder. Consequently, staff may skip procedures and make more errors. Ultimately, in the long run it may affect staff capacity due to work pressure related health issues, staff starting to lower their contract hours, or even leaving the organization. This is the core of the workload dynamics substructure. The workforce dynamics substructure considers the available nurses considering, recruitment, staff turnover, training and educating specialized nurses. In the next three sections the most important feedback loops per substructure are explained.

*3.2.1 PACU and patient's flow*

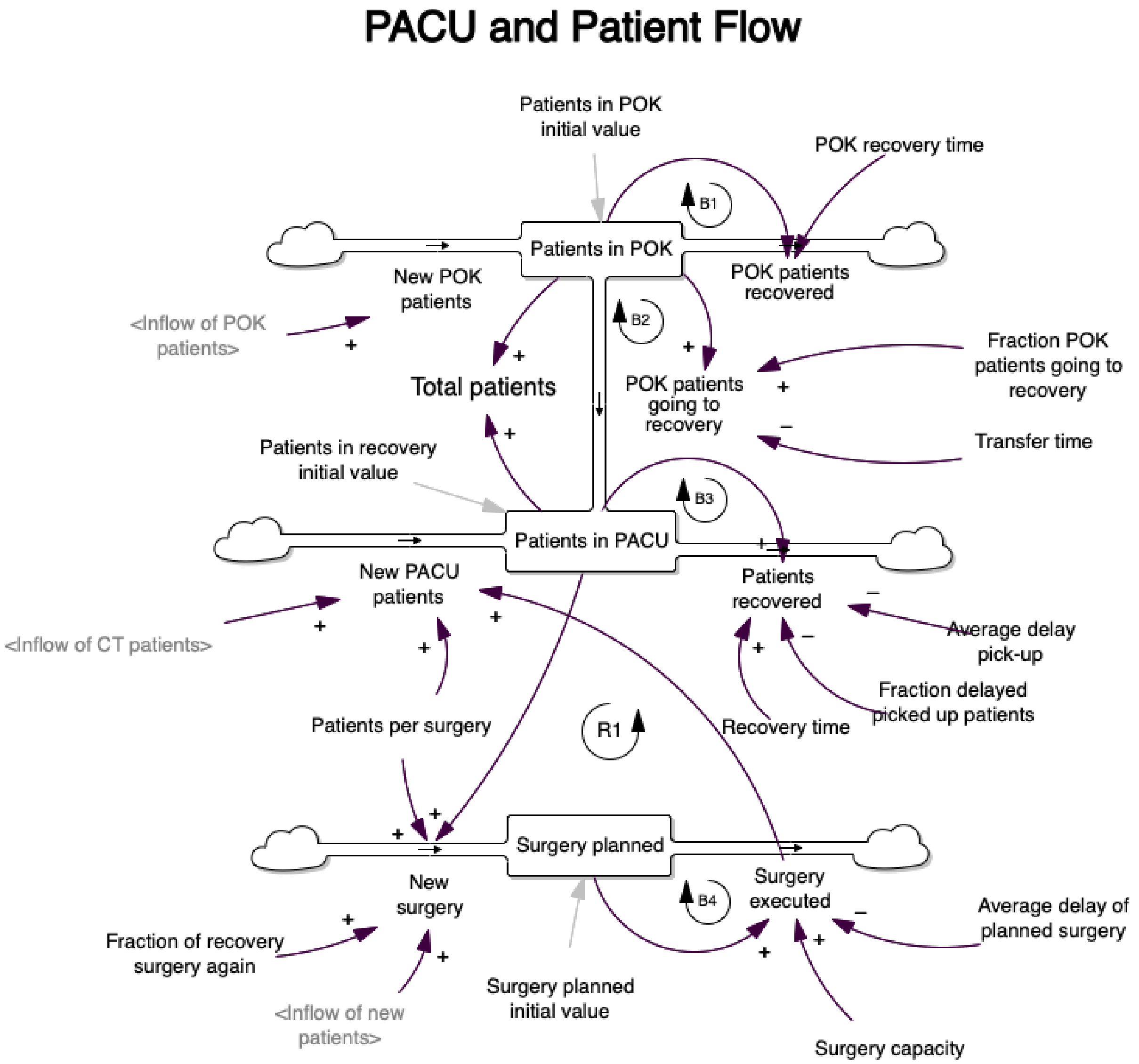


*Figure 2 Stock and Flow Diagram PACU and Patient flow.*

Our patient flow structure (Figure 2) differs from the one shown in Figure 1 in two ways. Because the allocation of nurses to the preparation phase is independent of the number of patients, it was first merged with the influx of new patients. Second, Pacu Care Centre Inc. has two operating locations with the identical challenges as our case study. In our case study, the PACU units are known as POK and PACU. Depending on their recuperation time following surgery, a subset of patients will be transferred from the POK to the PACU.

Four balancing and one reinforcing loop can be distinguished in Figure 2 determining the patients flowing through surgery, PACU and POK. All four balancing loops drain the stocks and are goal seeking. Loops B1, B3 and B4 represent a first order material delay. The stock 'Patients in POK' is drained by a fraction of patients leaving daily to the PACU.

### *3.2.2 Workload dynamics*

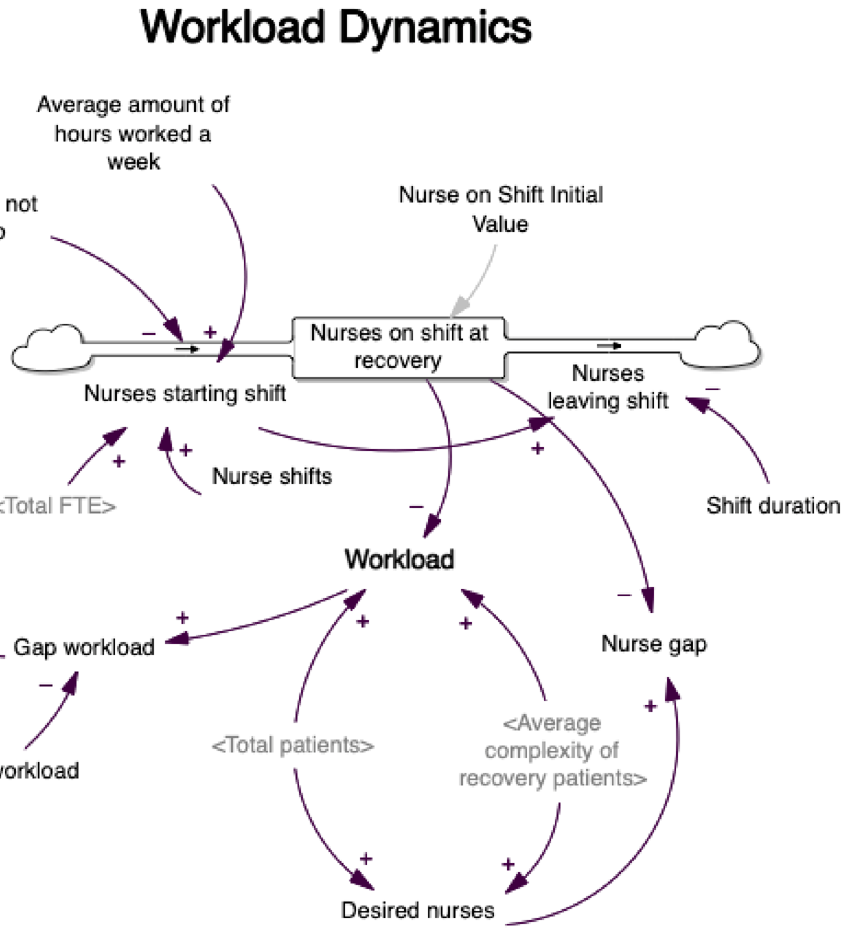


*Figure 3 Stock and Flow Diagram Workload dynamics.*

Figure 3 displays the structure determining the workload a nurse is experiencing on a daily basis over time. Reinforcing feedback loop 2 is indicating an exponential increase or decay in the workload. In case the workload is too high, it negatively effects nurses' availability on future shifts. Besides the calculation of the workload, the number of desired nurses is determined. The difference between desired nurses and nurses on shift is the nurse gap. The nurse gap is important for knowing the bottleneck in terms of nurses. ICU research indicate too high workload cause higher mortality (Lee et al., 2017).

*3.2.3 Workforce dynamics*

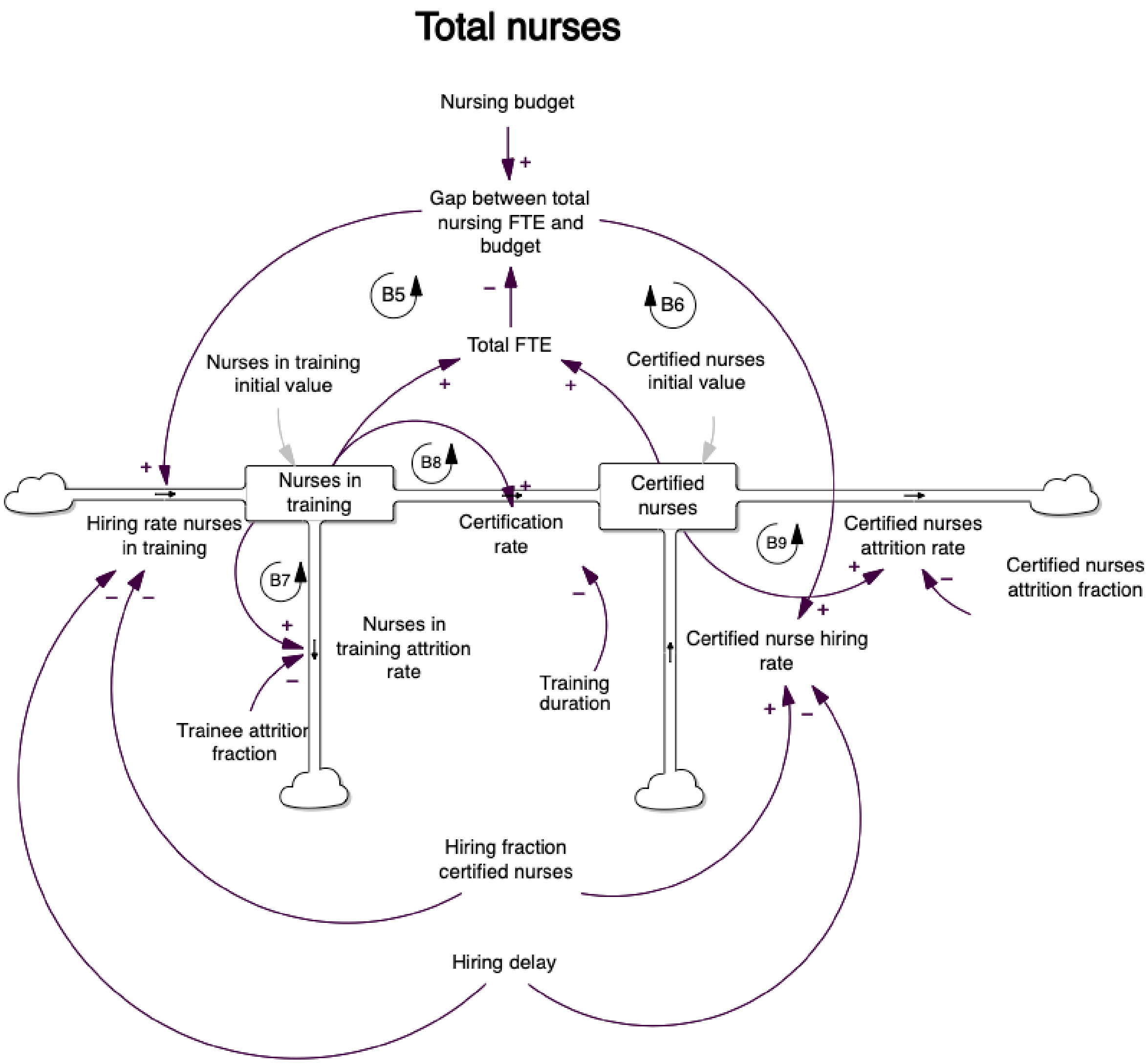


*Figure 4 Stock and Flow Diagram Total Nurses.*

The nurses in training and certified nurses are forming an aging chain. Uncertified and certified nurses can be hired, determining where they flow into the system. The uncertified nurses need to go into training where after they can become a certified nurse as well. In the meantime, they are allowed to nurse patients, however, they are not allowed to do the same tasks.

Balancing feedback loops B7, B8 and B9 are draining the stocks through either a first order material delay or by multiplying with a fraction. Balancing feedback loops B5 and B6 are goal seeking to decrease the nurses gap based on the budget being set.

## *3.3 Validation and testing procedures*

The validation and testing procedures involve three crucial elements: testing structure of the model and evaluating the output of the model; both in terms of behavior and patterns (Forrester & Senge, 1980; Barlas, 1996; Sterman, 2000). It was determined that the model is adequate to support the conclusion.

The model is robust. The chosen timestep is smaller than the smallest constant within the model (Sterman, 2000). This makes the simulation runs accurate. In addition, the model passes the extreme condition test. Some variables (Average Delay of Planned operations, Fraction Delayed Pick-Up Patients and Recovery Time) within the model are sensitive, within a reasonable range. These variables are out of scope to have direct influence on. Details on testing of sensitivity, extreme condition and behavior reproduction can be found in Appendix 1 of the supportive documents.

## 4. Results of the policy analysis

For the policy analysis we included the base run based of Pacu Care Centre inc.'s input data. The results of the base run contributed to their staff planning and cycle. The second and third scenario are more exploratory in nature and are about the impact of aging on workload related patient complexity and staff reallocation caused by COVID19. Details on parameter used in the simulation are included in Appendix 2 of the supportive documents.

### *4.1 Base run*

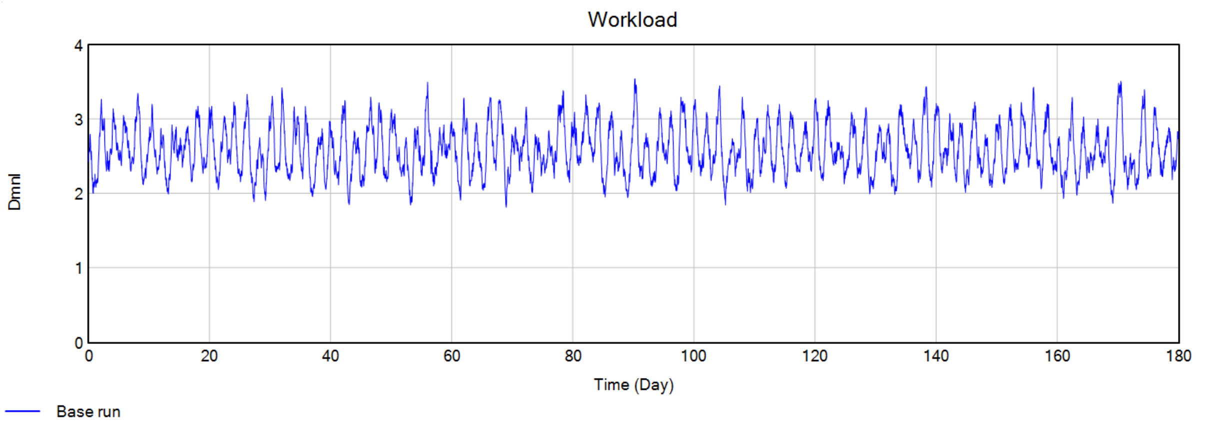


*Figure 5 Workload Base Run.*

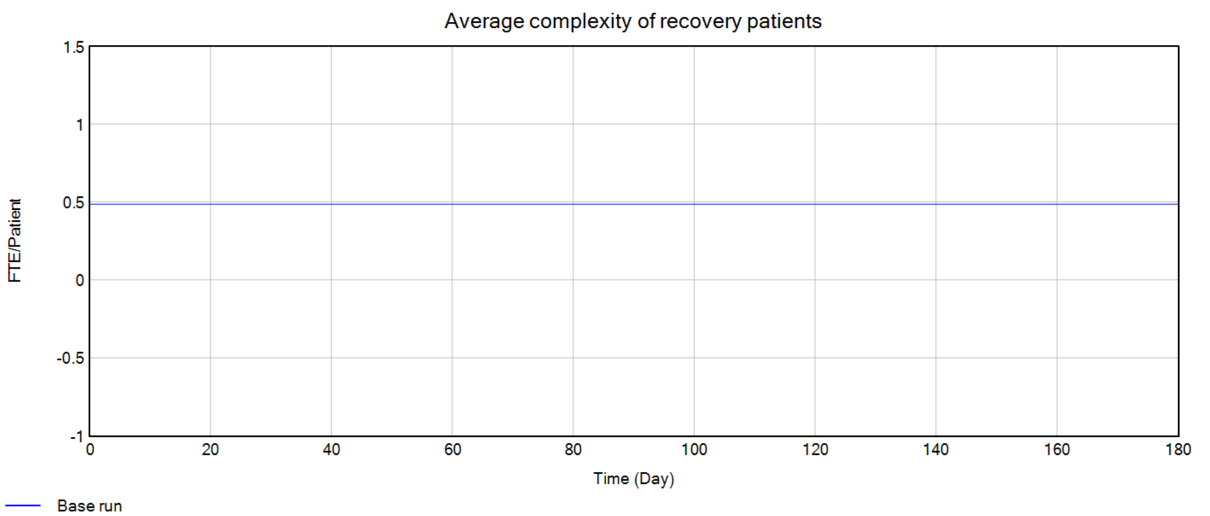


*Figure 6 Average complexity of recovery patients base run.*

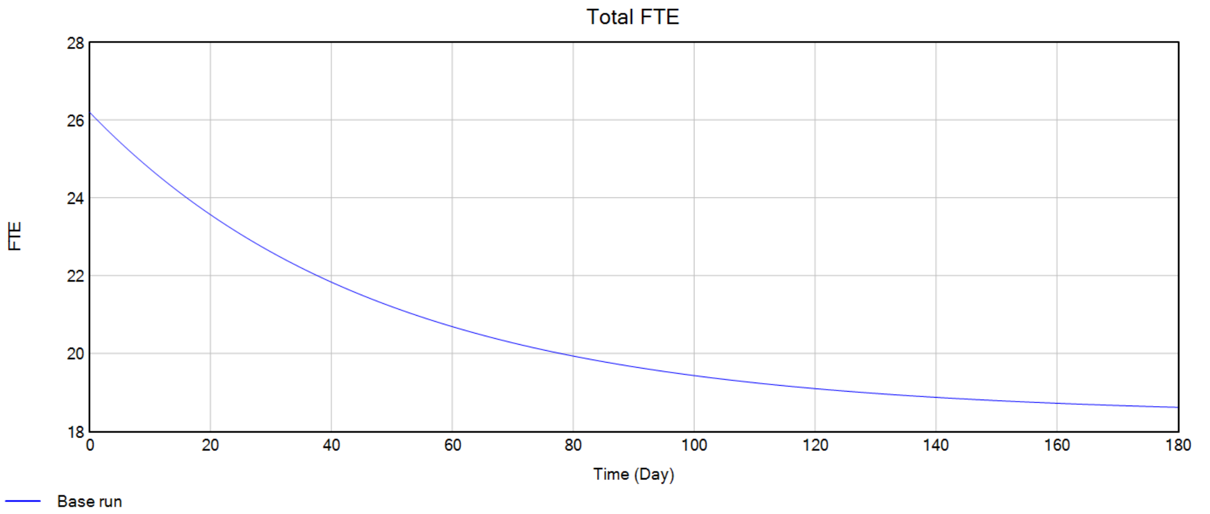


*Figure 7 Total FTE base run.*

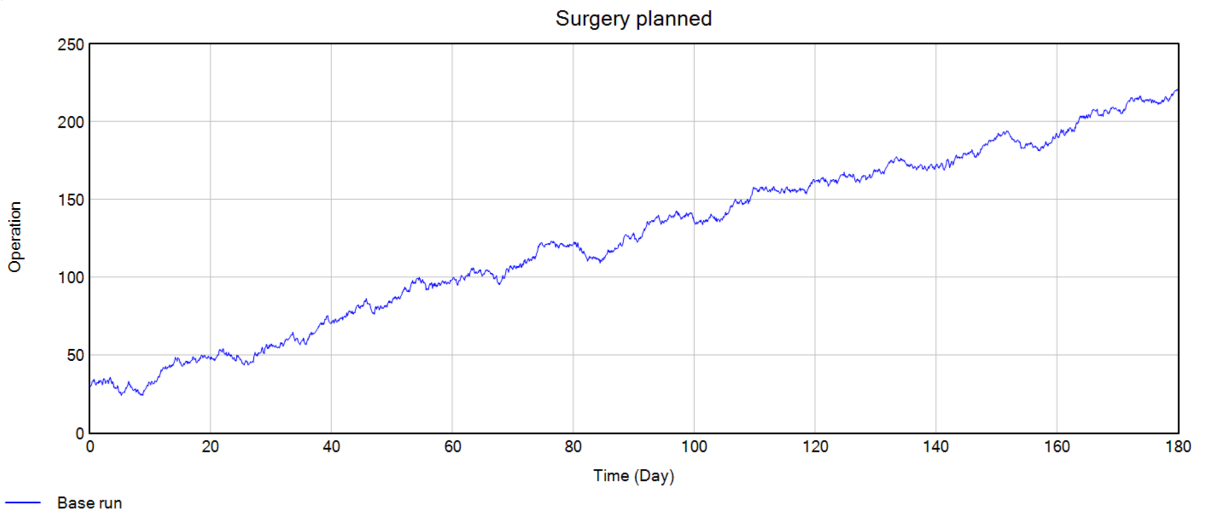


*Figure 8 Surgery planned base run.*

For the base run, depicting in Figure 5 to Figure 8, it is assumed that the average complexity of patients remains equal throughout the simulation, indicating the number of patients that can be treated by a nurse. Furthermore, the inflow of patients is based on random variations drawn by the model based on a normal distribution, leading to a stochastic inflow. This affects the model throughout and is visible in the behaviour of workload as well - it deviates over time. However, it is at all times above the desired level of one. A desired workload of one assumes that the nurses can treat all patients. Whenever the workload is higher than one, the pressure builds up for the nurses and will have a harder time handling the patients. The number of nurses is decreasing over time, because of internal stress availability factors and external attrition rates. Fewer nurses and uncertain inflow of patients results in a delay of surgeries, meaning the planned surgeries are building up over time. Patients cannot be treated right away and a backlog is created for them.

### *4.2 Aging population*

The region of our case study organization has an aging population. Aging results in higher care demand and therefore on average a higher ASA classification (Umekawa et al.,2019; Soyalp et al., 2018). For this scenario we activated an equation that increased the average ASA score with 0,00015 per day. The workload grows in tandem with the ASA score. Figure 9 shows that the workload has peaks that exceed the base run, particularly between days 120 and 180. This suggests workload increase due to aging may continue in the future.

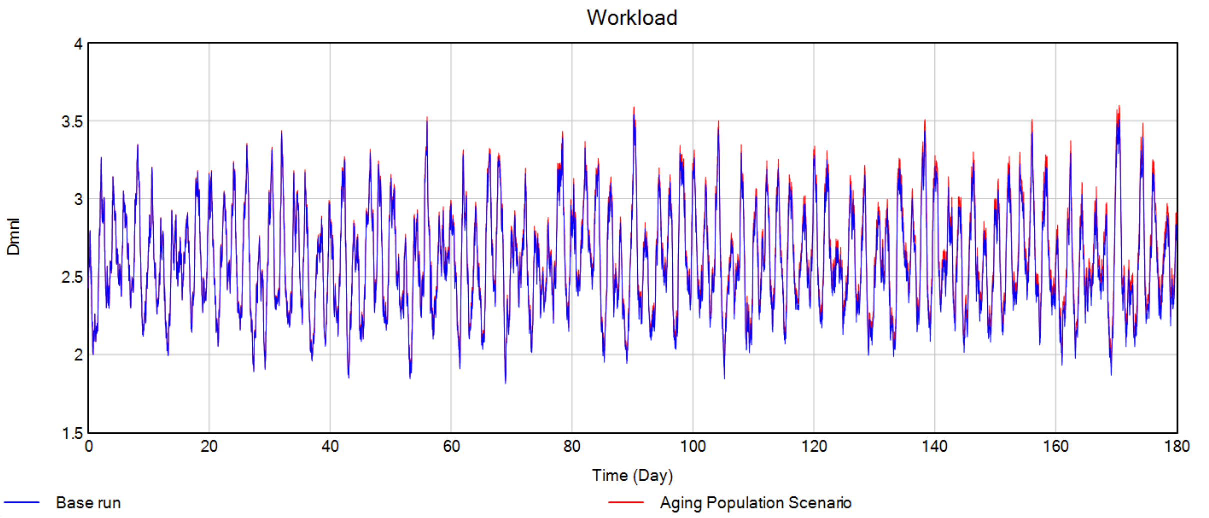


*Figure 9 Workload of base run compared with aging population scenario.*

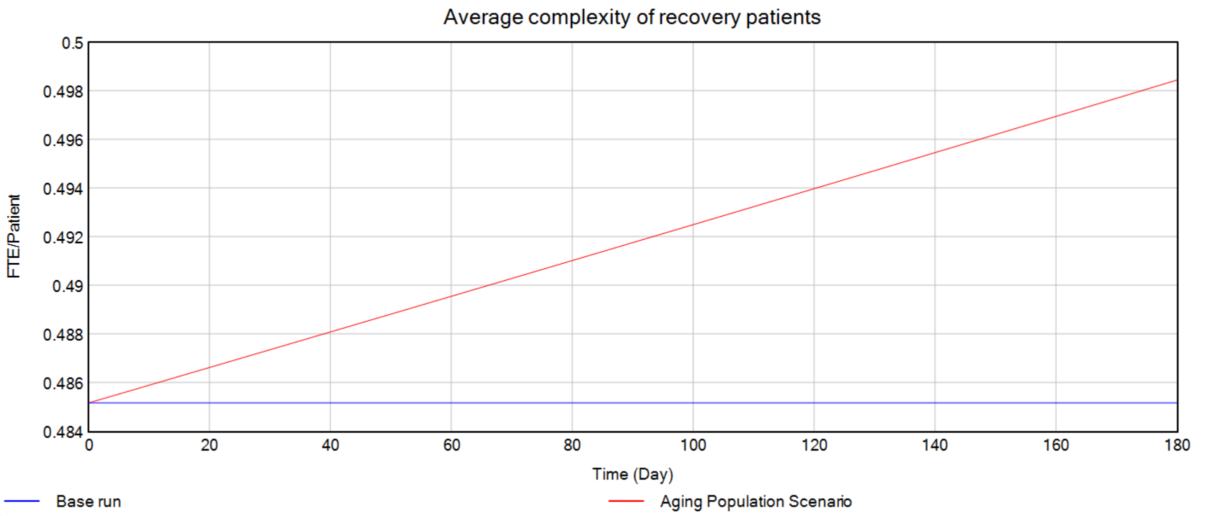


*Figure 10 Average complexity of recovery patients of base run compared with aging population scenario.*

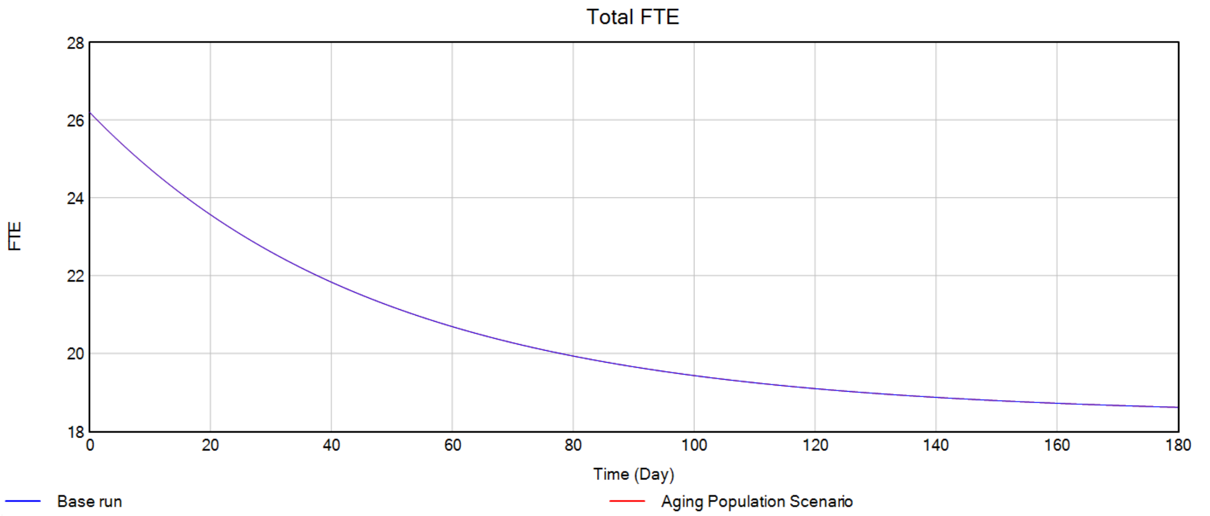


*Figure 11 Total FTE of base run compared with aging population scenario.*

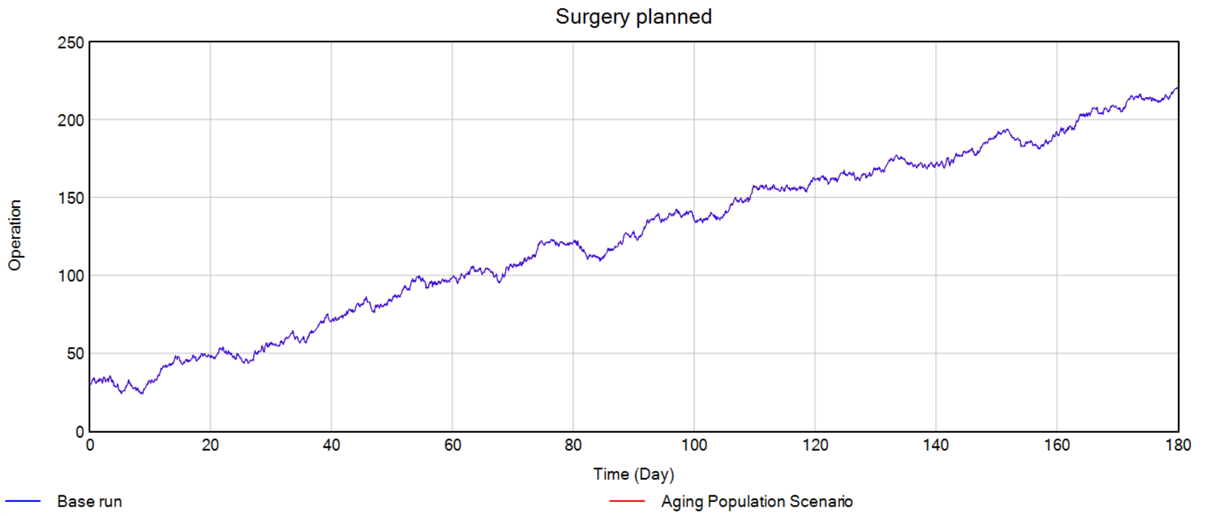


*Figure 12 Surgery planned of base run compared with aging population scenario.*

As can be seen in Figure 10, the average complexity of recovery patients increases linearly with a slow pace, because the number of patients that can be treated by one nurse is less than before. The deviation from the base run for the workload is small, because of the small increase in complexity. No changes occur for the number of nurses available, and the number of surgeries planned, as seen in Figure 11 and Figure 12 respectively. Due to the slight increase in average complexity and the other factors remaining constant, the workload does increase and deviates more over time than visible in the base run of Figure 9.

## *4.3 Shifting priorities; COVID-19*

During the COVID-19 pandemic PACU staff was moved for a longer period to the ICU to temporarily increase the ICU capacity. As a result, less nurses were available at the PACU, and non-critical care was postponed. Adjournment of care may erose of personal health and therefore increase the severity of treatment and care that is needed later. Rajasekaran et al. (2020) provided notions that under certain conditions patients with higher ASA scores receive additional complications. In the forthcoming scenarios we simulate increasing accumulating complexity of care because of aging and covid

For this scenario we assumed that after the 2nd week (day 14) 50% of the nurses will work at the ICU for 21 days. Consequently, surgery rooms will be closed, and average patient inflow will be 50% less as well. The values for minimum, maximum and standard deviation remain the same in order to reflect the flow of emerging patients. This flow might be higher because of erosion of personal health that takes place during the postponement of non-critical care.

Due to the possibility of emerging patients for emergency surgery standard deviation and maximum values are not changed. As a consequence of the perceived stress and massive workload during the COVID-19 pandemic willingness to leave increases significantly (Zhang et al., 2021; Labrague & De los Santos, 2020)

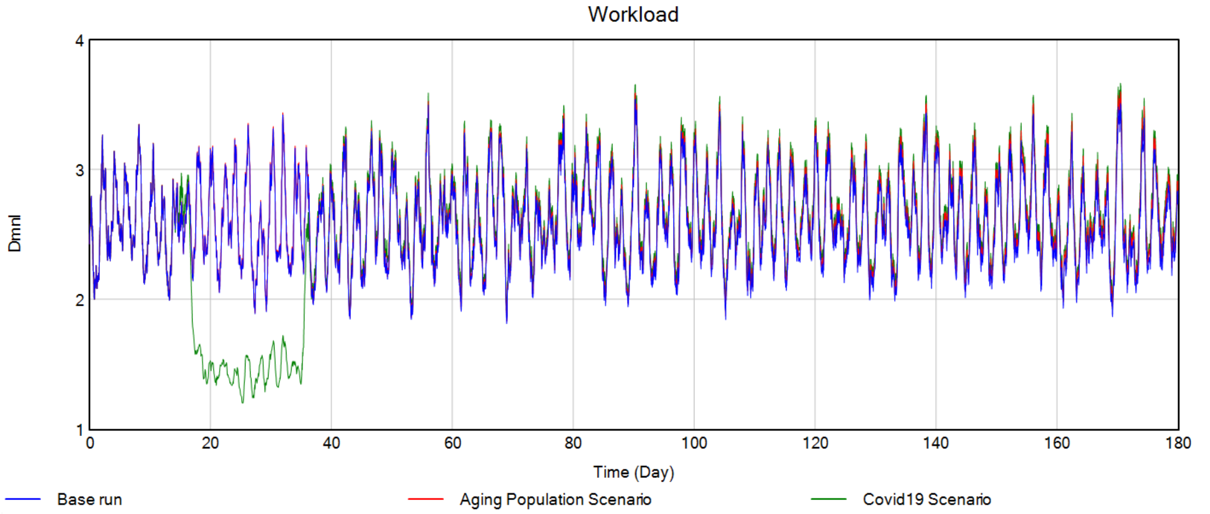


*Figure 13 Workload of base run compared with aging population and COVID-19 scenarios.*

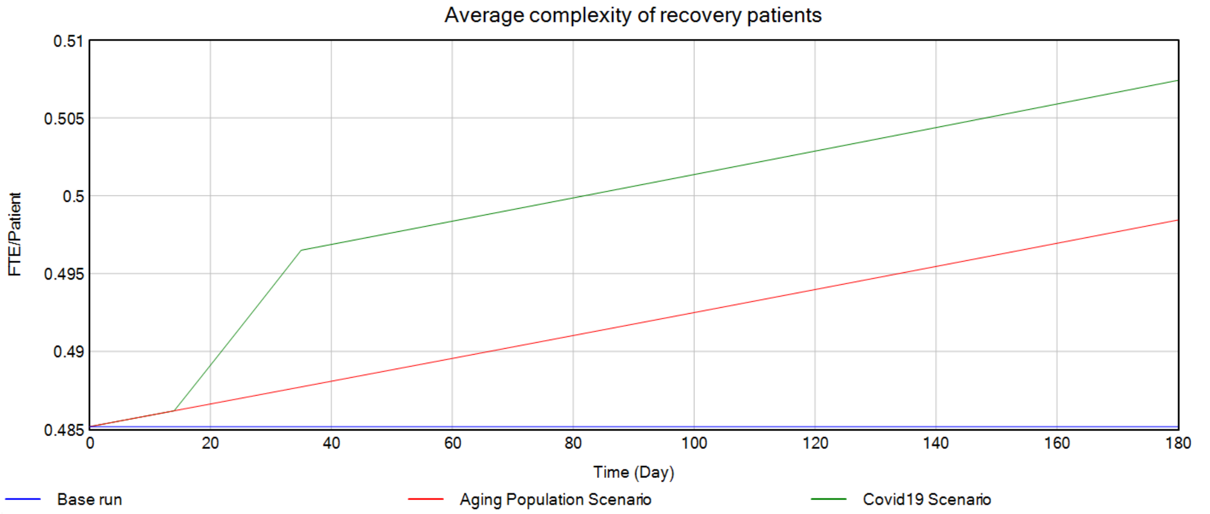


*Figure 14 Average complexity of recovery patients of base run compared with aging population and COVID-19 scenarios.*

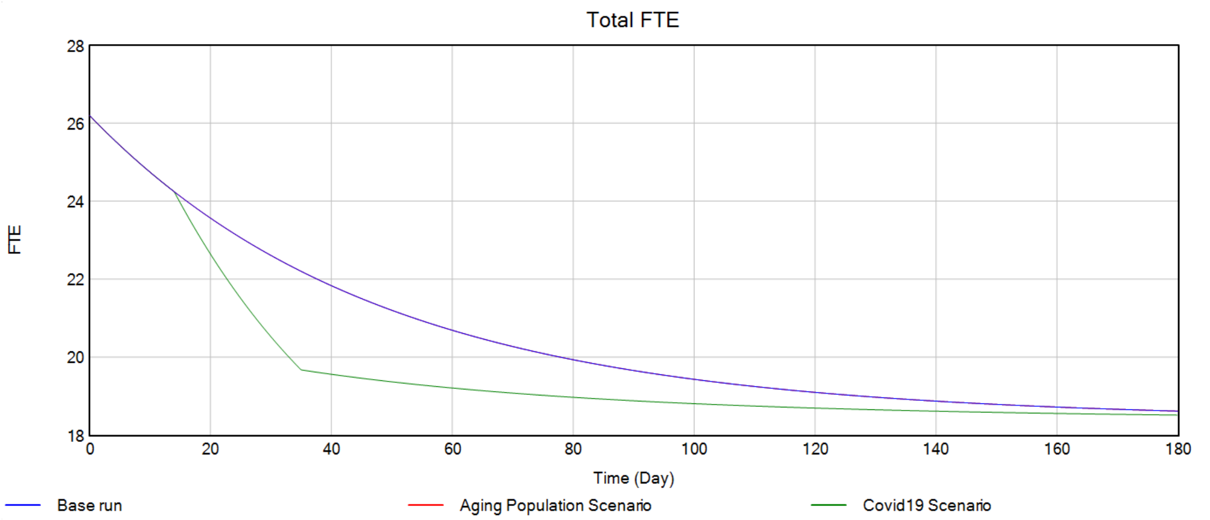


*Figure 15 Total FTE of base run compared with aging population and COVID-19 scenarios.*

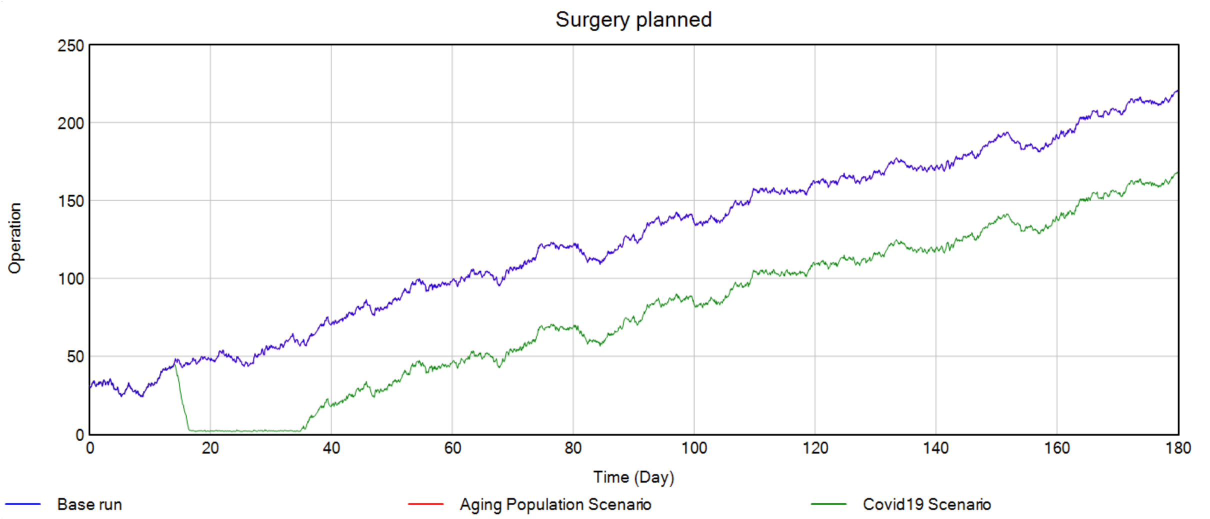


*Figure 16 Surgery planned of base run compared with aging population and COVID-19 scenarios.*

COVID-19 affects the model parameters in multiple places as visualised in Figure 13 to Figure 16. The number of total patients and nurses on shift drops by half for 21 days after day 14. As a combination of a decreasing number of patients and nurses, as well as a slight increase in complexity, does change the workload. As the change in patients is more significant than in nurses or complexity, a decrease in workload still occurs. Be aware that the workload at the ICU is not visualised or represented in this model and the model assumes an average of workload. Therefore, the above average complexity of patients that was present in a similar real life scenario is not fully represented in the model nor the figures. Furthermore, the substructure does not consider task transfers and handovers. On account of lower number of nurses available, the surgeries planned drop significantly then it builds up over time with a similar pattern as the base run. Also note that, these are only the planned surgeries whereas the unplanned surgeries that increased were not included in the model. Unplanned surgeries represents the people that have a need for surgery. This suggests a latent demand for surgery is building up in society.

### *4.4 Shifting priorities; COVID-19*

In certain countries there is a cyclic pattern of increasing COVID-19 infectivity. As a result, on multiple occasions PACU staff was moved for a longer period to the ICU aiming to temporarily increase the ICU capacity. For this scenario we use the same assumptions as stated in section 4.3 with a recurring pattern for every 90 days.

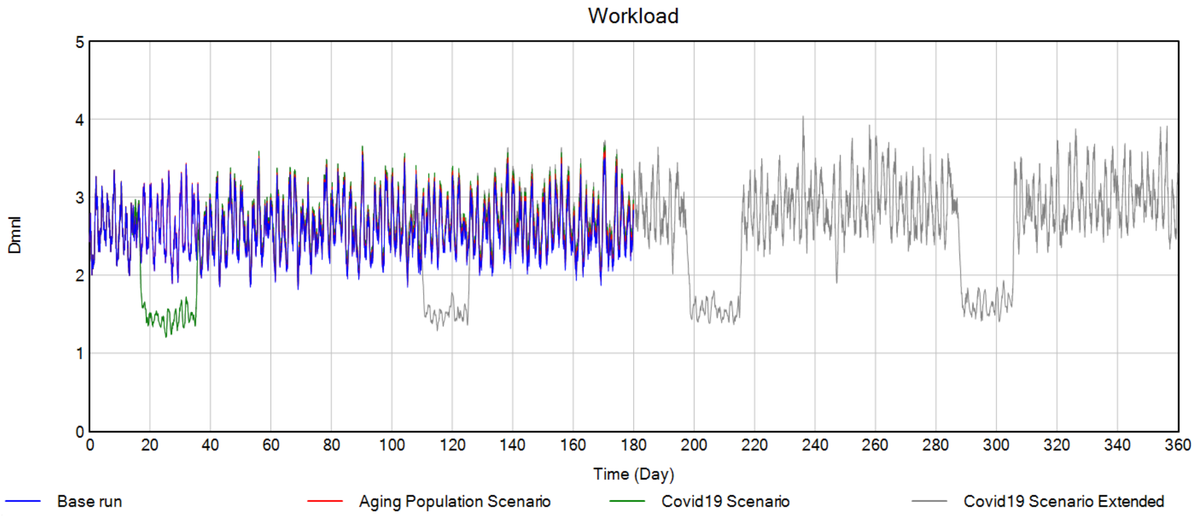


*Figure 17 Workload of base run compared with aging population, COVID-19 and COVID-19 extended scenarios.*

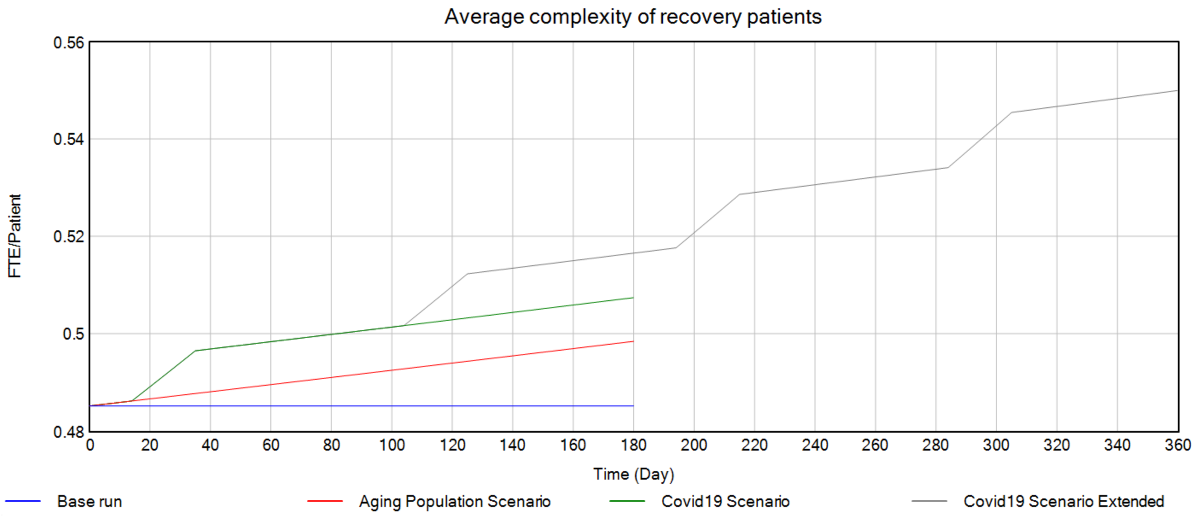


*Figure 18 Average complexity of recovery patients of base run compared with aging population, COVID-19 and COVID-19 extended scenarios.*

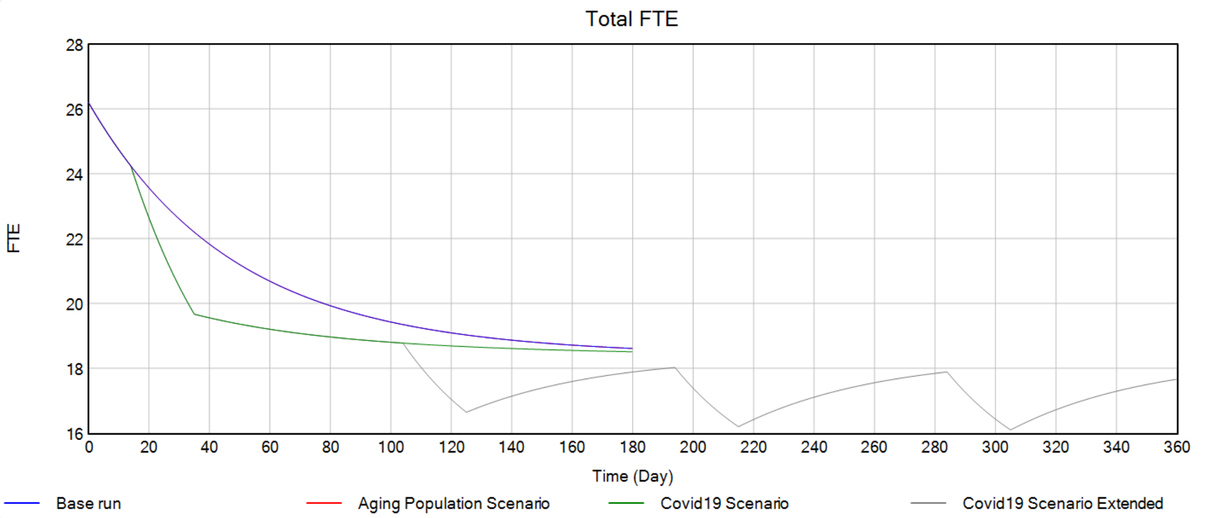


*Figure 19 Total FTE of base run compared with aging population, COVID-19 and COVID-19 extended scenarios.*

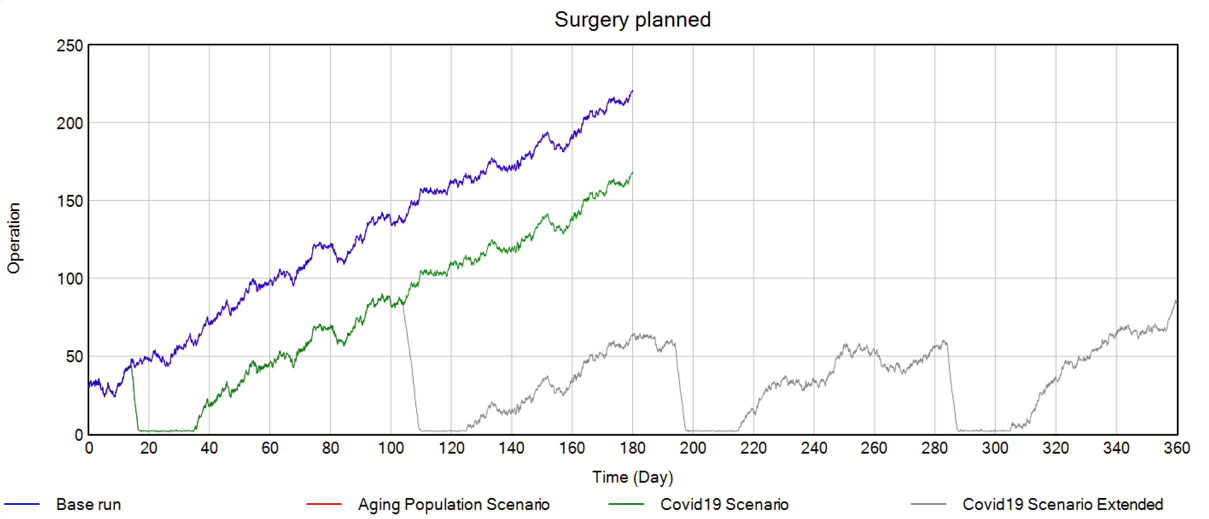


*Figure 20 Surgery planned of base run compared with aging population, COVID-19 and COVID-19 extended scenarios.*

The same behaviour as presented in Subsection 4.3 occurs for the workload in Figure 17. However, the timespan is larger and thus the behaviour returns over time. The complexity of patients is increasing – in terms of the average number of patients treated per nurse – more than before because of the returning COVID-19 waves. This also influences surgeries planned and total FTE. These two variables show an increase after the waves, however, will not be able to increase to the level as before. This is due to the recurring infectivity of COVID and is the societal problem. Less patients can be treated and fewer personal is available. It takes more time to recover from COVID-19 and catch up again. This oscillating pattern is more concerning and may cause a significant latent demand for future surgery in society. The unequal distribution of healthcare professionals across regions and countries (Winkelman et al., 2020) will make it very difficult to fulfil these demands.

### *4.5 Comparison of results*

The workload remains circling around the same level for each scenario, thus it can be concluded that an increase in workload is not directly affecting the PACU nurses, when the workload or replacement to the ICU is not considered. A bigger behavior difference is found in the other graphs like Total FTE, Average complexity of patients and Surgery planned. The number of surgeries planned is crucial for treating life threatening diseases or taking well care of patients. Because of the COVID-19 waves, fewer surgeries were executed by the end of the simulation run (180 days) as shown in Table 2. The aging of the nurses is taking less of an effect on the number of surgeries executed or the available nurses. Being able to execute 643.8 fewer surgeries in half a year time, it might have a tremendous effect on the population and even a more tremendous effect if this situation continues for a longer time than 180 days. This results in an even higher backlog and delay. Another observation is that total executed surgeries are more impacted that the staff at PACU in case of oscillation pattern of PACU staff reallocation due to COVID. Given our aforementioned model limitations we think that these insights are prudent and that in real life situations the effects are more poignant.

*Table 2 Scenario and total surgery executed comparison.*

| Scenario | Total surgeries executed | Average FTE nurses PACU |
|---|---|---|
| Base run | 6783.5 (100%) | 20.5 (100%) |
| Aging Population Scenario | 6783.5 (100%) | 20.5 (100%) |
| Covid19 Scenario | 6434.7 (95%) | 19.7 (96%) |
| Covid19 Scenario Extended | 6139.6 (91%) | 19.2 (94%) |

## 5. Conclusion and future research directions

During the COVID-19 pandemic, health-care capacity was reduced, resulting in a higher number of patients in the ICU, prompting the PACU nurses to be transferred to the ICU. Another consequence of the COVID-19 pandemic was the downscaling of non-critical health care, which could potentially become severe. The degree of care that may be provided to patients is determined by the number of nurses present in the PACU. The unpredictability of patient inflows in the absence of COVID-19 is already putting a strain on nurses' workload, which is already higher than desired and manageable. In addition, as the population ages, the number of patients a PACU nurse can treat decreases, resulting in a minor increase in workload.  As COVID-19 waves hit stronger, the workload increases, the number of FTE available decreases, and the number of surgeries that can be performed decreases, producing greater problems. Nevertheless, the workload in the COVID-19 scenario appears to be too low, and this is overly optimistic when compared to reality.

Because this study only looked at the PACU, the ICU capacity, ICU workload, and available ICU FTE were not examined. There are dynamics that can be examined between the PACU and the ICU on long and short term. The various staff groups can have a role in the dynamics between the different departments. Furthermore, insufficient study is being done on the reasons and consequences of the unpredictable patient inflows. To gain a better understanding of these dynamics, future studies should focus on both processes. Heavy workload also has an impact on error production, personal health, and turnover, according to Sterman (2006). These effects should be given more weight in a future edition of our model. Additionally, this study only covers the dynamics within one specific hospital. To be able to generalize and being able to get a good understanding of the broader system, elements from outside the hospital should be included as well. Our theoretical scenarios underestimate the workload impacts during COVID-19, indicating that the model has to be improved.

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