Shortage of General Physicians' Impact on Medical Malpractice Deaths, The Case of Quebec

By

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Abstract

In 2012, A study was released showing that more than 40,000 lives were claimed because of medical malpractice in Canada; it is estimated that more than 9,000 of these deaths happened in Quebec in the same year (Charney, 2012). In 2019, The Canadian Patient Safety Institute reported that medical malpractice incidents “are the third leading cause of death in Canada, following cancer and heart disease” (*Strengthening Commitment for Improvement Together: A Policy Framework for Patient Safety*, 2019). Without proper intervention, this number of deaths will most likely increase.

It is assumed that the main reason behind these deaths is the shortage of GPs (General Physicians) in Quebec, as it is about 2.52 GP per 1,000 persons (Wittevrongel & Shaw, 2020), while the threshold of “The Organisation for Economic Co-operation and Development” (OECD) is 3.6 GPs per 1,000 persons (OECD, 2021). This shortage puts GPs under stress and pressure, which will increase the probability of them making medical errors, leading to increased deaths.

Therefore, this thesis aims to study the impact of covering the shortage of GPs in Quebec on the number of deaths caused by medical errors, assuming that excessive workload on GPs puts them under heavy stress leading them to make medical errors, causing more deaths.

A computational model was developed using the System Dynamics approach (SD) representing the GPs supply and demand system in Quebec; in addition to a stress and workload system, both systems are simulated to explain the cause and effect relations between their different parts, in addition to their interactions which impact the number of medical errors deaths over time.

The findings of the study showed that the main hypothesis partially solves the problem at hand; the modified hypothesis states that by covering the shortage of GPs in Quebec and including practicing pharmacists (PP) in the general practice tasks, the stress and workload on GPs will decrease; thus, a decrease in the number of medical error deaths can be expected. By doing so, this study serves as proof of the impact of shortage in GPs and the impact of stressed and exhausted GPs, on the deaths caused by medical errors.

Based on the leverage points found in the system, this thesis can be used for designing policies that can formulate a road map to provide a sustainable GPs Supply system that mainly focuses on the effect of burnout levels of the working GPs on the Medical Malpractice Deaths.

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Abbreviations

GP	General Physician
OECD	Organization for Economic Co-operation and Development
SD	System Dynamics
UK	United Kingdom
USA	United States of America
PP	Practicing Pharmacists
MDC	Malpractice Death Cases
PSQS	Patient Safety and Quality of Service
CLD	Casual Loop Diagram
RW	Relative Workload
BU	Business-As-Usual
Grad_PP	The Medical Schools Students and Practicing Pharmacists Scenario
Grad_Only	Increasing Medical Schools Students Only Scenario

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1. Introduction

Healthcare system performance is one of the most important indicators of a country's level of development. On regular days, most entities that constitute the total healthcare system are under constant pressure as a result of the relatively increasing number of patients, the limited availability of healthcare facilities, and the shortage of healthcare practitioners from all types and specialties (Oleribe et al., 2019). During the COVID-19 pandemic, the global healthcare system suffered from enormous pressure on supplies, accessibility to facilities, limited hospital capacities, and human resources (Liu et al., 2020). As a result, many governments began to question the resilience and sustainability of their countries' healthcare systems. Activities like those taking place within healthcare system processes, when put under a heavy load of medical activities, they start to fail, sometimes rapidly and noticeably, as in Slovenia during the Covid-19 pandemic, and sometimes slowly, as what happened in Turkmenistan (Bethany, 2021), in both cases, the healthcare system was compromised and failing. Furthermore, the increased workload on healthcare systems creates burnout in the medical staff attempting to meet the ongoing high demand for healthcare services (Portoghese et al., 2014); burnout is a significant factor in medical errors.

In the USA alone, there are more than 251,000 deaths caused by medical malpractice (Anderson & Abrahamson, 2017), and this number is increasing year after year; the same is true in many other countries around the world. Therefore, the OECD established a specific threshold to determine whether the number of active medical practitioners in a country is sufficient or not; in a way that increases patient safety and reduces the number of malpractice cases, ultimately reducing death cases.

1.1 Background

1.1.1 Medical Malpractice

In 2016, Makary and Daniel released a study showed that more than 251,000 lives were claimed because of medical malpractice in the USA (Makary & Daniel, 2016). Medical malpractice is considered the third reason for death cases in the USA after heart disease and Cancer; unfortunately, only 5-10% of malpractice errors are reported to authorities (Anderson & Abrahamson, 2017). These numbers are alarming indicators of a deeper complex problem in delivering healthcare services in developed countries like the USA and Canada.

In the healthcare services sector, one of the most exhausting challenges a doctor faces during her/his career is confronting a medical error case; this type of problem usually puts the doctor under excessive pressure, which will be added to her/his normal daily workload. This type of pressure can lead to long-lasting anxiety and continuous tension; in many cases, it might cause serious illness for the doctor (Jafarian et al., 2009).

Medical errors happen when the doctor meets the patient for treatment, putting the doctor as the primary and almost lonely responsible for delivering adequate medical service for the visiting patient. Suppose the doctor could not follow the predetermined standards for medical practice and failed in one or several processes in her/his role as a trusted physician. In that case, a medical error will most probably happen, putting an extra load on the patient's physiological, physical, and financial obligations toward her/himself or their surrounding community (Raeissi et al., 2019). On the other hand, as a result of a medical error occurrence, doctors will also be under stress, which may lead to even more medical errors if no supportive actions are taken toward the patient and the doctor.

Lack of coordination between the different sectors of medical service providers, the excessive workload on medical staff (doctors, nurses, and others), the psychological and physical stress on the medical staff caused by the extreme workload, and the continuous increment in the population (Sheikh Azadi et al., 2007), are considered the main reasons behind the occurrence of repetitive medical errors. In addition, the shortage of medical practitioners, especially GPs, puts the healthcare system under severe pressure.

1.1.2 General Physicians (GP) Burnout

It is well-known from many reports and studies that healthcare professionals are facing the problem of burnout and stress (Arigoni et al., 2010), (Embriaco et al., 2007), (Klein et al., 2010). Doctors are no exception to this; doctors' burnout comes as a result of a continuous heavy to medium workload; it causes several negative emotions that affect the Quality of the medical service provided to patients; in such cases, the doctor will suffer mainly from anxiety, exhaustion, and low aptitude to give more to her/his work (Maslach & Jackson, 1981).

Studies showed that the level of well-being defines burnout. Well-being is a term that describes the current psychological state of a person. Well-being can identify and describe the current feelings of the employee (GP in our case), whether she/he is sad, tired, or exhausted, or whether she/he is happy, satisfied, or initiator (Johnson & Wood, 2017).

It is documented that burnout is one of the main reasons behind the increasing number of suicide cases inside the healthcare society; besides that, it is a significant motivator for the increased cases of drugs misuse, which is registered among some of the healthcare staff who are suffering a severe workload and Burnout (Soler et al., 2008) (Suñer-Soler et al., 2013).

Burnout does not solely cause the aforementioned negative consequences; they also come as a result of harmful organizational practices, like a non-secure work environment, absenteeism, and low levels of patient safety (Hall et al., 2016) (Salyers et al., 2017) (Welp & Manser, 2016).

General Practitioners (GP), as a group of the healthcare staff, are considered one of the most vulnerable groups to the dangerous consequences of burnout and also to having low levels of mental health in many developed countries like the UK and Canada (Arigoni et al., 2009) (B. O'Connor, Rory C. O'Connor, Barb, 2000) (Lee et al., 2008).

Recent researches showed that the rate of GPs that suffer from burnout syndrome is higher than other healthcare practitioners by 2 – 43%; additionally, they are more likely to get psychiatric sickness higher than others by 7 – 22% (Arigoni et al., 2010), (Soler et al., 2008).

In the UK, a survey showed that GPs have been suffering from very high-stress levels and extreme dropped levels of job satisfaction; additionally, since 2012, GPs have an increasing expectation that they will quit their jobs in the healthcare sector anytime within the coming five years (Gibson et al., 2015).

Studies about burnout and well-being are available, and they discuss many jobs within the healthcare sector. However, studies on how GP burnout and well-being affect patient Safety are limited. Furthermore, in many cases, these studies have improper conceptual representations, for example, many studies combined GP's Burnout with other healthcare staff, they are not treated as a separate group, or they ignored their underlying feelings, beliefs, and expectations; this comes as a result of not focusing on the qualitative scientific methods in these studies (Dyrbye et al., 2013) (Linzer et al., 2009), qualitative methods are necessary to investigate the psychological state of the GP.

1.1.3 Doctors Shortage in Quebec

In recent years, the shortage of GPs in Quebec has become more evident for both government and locals. According to the OECD report released in 2021 (OECD, 2021) (Moir, 2021), the average number of required GPs is about 3.6 GP per 1,000 people, and this is higher than the average number of GPs in Canada, which is about 2.7 GP per 1,000 people that is 25% lower than the OECD average number of doctors (*Health Care Resources (Physicians).*, 2019), (OECD, 2021). In Quebec, the ratio drops even less than the current Canadian national number; it is estimated to be around 2.5 Physicians per 1,000 persons (Wittevrongel & Shaw, 2020); Figure (1) shows the historical development of Physicians per 1,000 population in Canada and OECD, between 1961 and 2015 (Globerman et al., 2018).

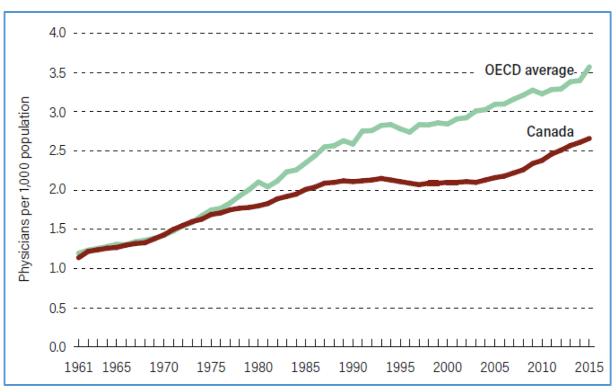

Figure (1): Historical Development of the number of GPs in Canada(Globerman et al., 2018).

In Canada, more than 5 million Canadian do not have an allocated GP or family doctor (Hopper, 2022). In Quebec alone, 1 out of 5 Quebecers is without a GP, causing a long waiting list for them to access healthcare (Lalonde, 2021). It takes around 599 days to get an assigned family doctor in Quebec (Bellerose, 2021); in addition to that, a survey conducted in 2021 showed that 69% of Quebecers suffered from timely access to health services (De Marcellis-Warin & Peignier, 2021), these facts show some of the direct consequences the shortage of GPs is causing in Quebec.

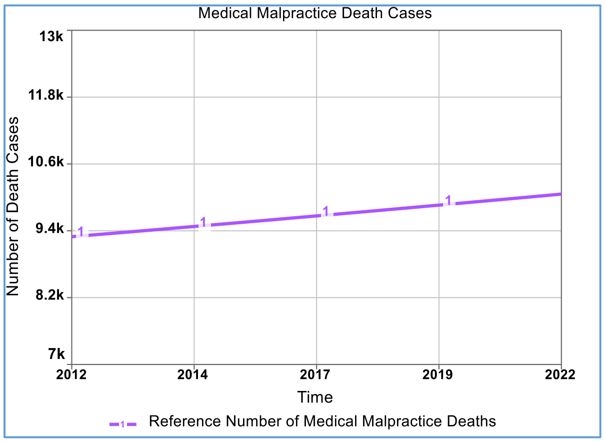

Figure (3): The Estimated Development of MDC from 2012 to 2022(Charney, 2012).

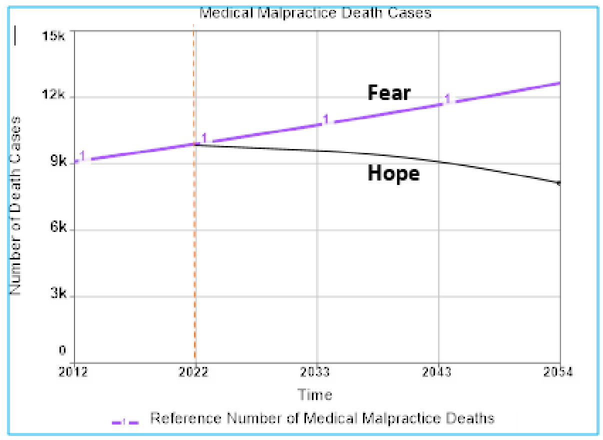

Figure (2): Development of the Number of Death cases caused by Medical Malpractice (MDC) (Charney, 2012)

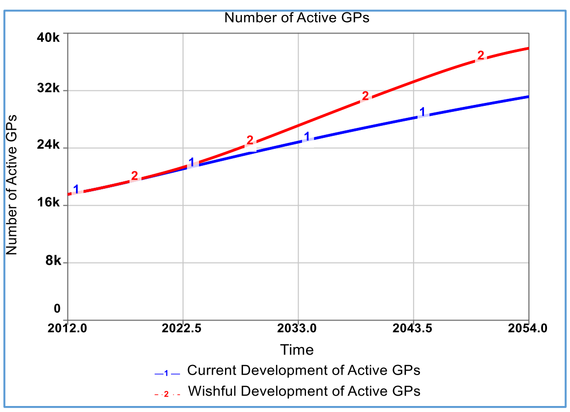

Figure (5): Active GPs reference mode (Wittevrongel & Shaw, 2020), & Wishful number of Active GPs .

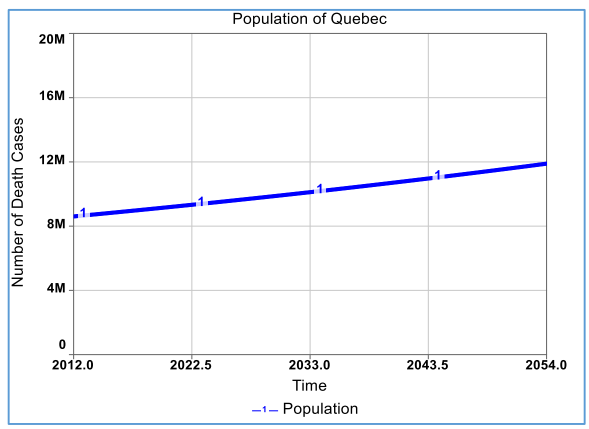

Figure (4): Development of Population in Quebec in (Institut de la Statistique du Québec, 2022).

1.2 Research Objective

In this study, we investigate the underlying factors and feedback processes contributing to medical malpractice deaths in Quebec. In addition, we study 1) the effect of General Practitioner (GP) burnout, 2) the supply and demand mechanism of General Practitioners (GP) in Quebec, and 3) how all these affect the patients' death rate caused by medical malpractice.

Reference modes are graphical representations of the development of problem behavior over time; these representations are built using quantitative data, like time series, or qualitative estimates (Saeed, 2017).

In this study, Figure (2) and Figure (3) illustrate the reference modes in our study for the number of Medical Malpractice Death Cases (MDC) in Quebec and its estimated development over time; Figure (3) shows the development of MDC from 2012 to 2022 (Charney, 2012) while Figure (2) combines the historical development of MDC shown in Figure (3) and the anticipated development of MDC from 2022 up to the end of our study time which is in 2054.

The increasing number of deaths caused by medical malpractice from 2012 to 2054 represents this study's main reference mode (The blue line in Figure (2)). The data in Figure (2) and Figure (3) is deduced from the fact that more than 40,000 Canadians died in 2012 because of medical malpractice (Charney, 2012). However, it is documented that there is a lack of data about the medical malpractice death cases (*MDC)* in Canada generally and Quebec specifically; only less than 10% of these cases are reported (Anderson & Abrahamson, 2017); therefore, we estimated the number of MDC in Quebec using the following calculations:

$$The\ Fraction\ of\ MDC\ in\ Canada\ (2012) = The\ number\ of\ MDC\ in\ Canada\ (2012)\ \div\ The\ Total\ number\ of\ Population\ in\ Canada\ (2012)$$

$$The\ number\ of\ MDC\ in\ Quebec = The\ fraction\ of\ MDC\ in\ Canada\ (2012) \times The\ Total\ Population\ in\ Quebec\ (2012)$$

Where The number of MDC in Canada is around 40,000 cases (Charney, 2012), the total population of Canada was 34,691,878 persons in 2012 (macrotrends.net, 2022), The calculated fraction of MDC in Canada is 0.00115301, the total population of Quebec was 8,061,101 persons in 2012 (Institut de la Statistique du Québec, 2022), hence, the number of MDC in Quebec was around 9,295 deaths in 2012, estimated by the above calculations.

As the population of Quebec is continuously increasing (Figure (4)), then it is expected that the number of MDC will keep increasing, beginning from 9,295 cases in 2012 until it will reach around 12,900 cases in 2054, with an increment of almost 35%; the fear line Figure (2) represents this development. However, we hope to find solutions to decrease the number of MDC over time by testing this study's dynamic hypothesis, which aims to explain the dynamic motivators of this problematic behavior in MDC.

Figure (5) Shows an additional reference mode for the development of the current active GPs shortage; the graph shows the difference between the historical development of the number of active GPs (blue line) and the wishful development of the active GPs number that we seek by the end of this study (red line).

In summary, the major purpose of this study is to conduct model-based hypothesis testing to investigate the impact of the shortage of GPs on the number of medical malpractice deaths that happen in Quebec over time.

1.3 Research Question

1. What are the drivers that increase the number of death cases caused by medical malpractice?
2. What are the key feedback loops that control the changes in malpractice death cases over time?
3. What are the dynamic structures behind these drivers which lead to the Malpractice death cases?
4. What are the leverage points in the model that can lead to a reduction in the number of malpractice death cases (MDC)?
5. What are the main implications related to policy implementation?

2. Methodology

2.1 Research Strategy

The strategy used in this thesis is a mixed research strategy; it is said to be mixed because it uses a combined approach of qualitative and quantitative strategies. System dynamics (SD) is the method that is used to complete this research; SD can easily combine the qualitative and quantitative methods in one frame or model, which allows both types of methodologies to interact with each other in a way that can provide operational insights (Sterman, 2000).

In this research, quantifying was used for representing qualitative constraints, for example, the stress level; this is a qualitative variable that is quantified using SD; this approach allows the researcher to estimate the effect that results from the varying stress level on other related variables and finally on the whole system.

Building on the literature reviewed, the quantitative parameters are usually heavily used, and their values are determined or calibrated during the model development phase of the research.

SD is the appropriate approach that can represent the interaction between qualitative and quantitative parameters; for example, SD can demonstrate the interaction between the parameter representing the current number of active GPs in Quebec (Quantitative Parameter) and their estimated stress level (Qualitative Parameter); thus, insights can be deduced from this interaction for further studies.

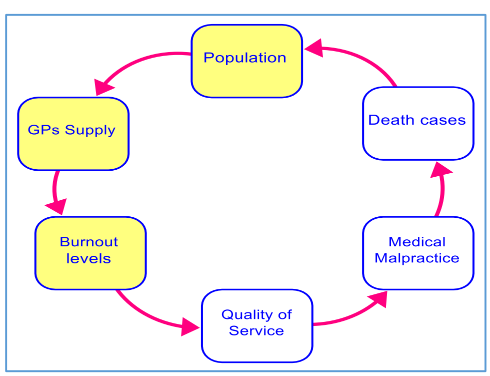

Figure (6): Parts of the proposed system that are included in the model.

2.2 Specific assumptions for this project

Figure (6) shows the concepts that are included in the proposed model; these are the highlighted ones in the same figure, while other concepts were assumed to be converters due to the limited boundaries of the project and will not be represented as a separate structure. Table (8) in appendix (A) shows all the exogenous parameters that are used in the proposed model.

The following are the assumptions that were not represented as a separate structure in the proposed model:

2.2.1 GPs Immigration rate

GPs Immigration rate is a significant factor that could have a noticeable impact on the behavior of the system; however, in this model, the researcher assumed that this factor is an exogenous parameter since it is not included in the scope of the proposed model; which is focusing on the GPs who are graduating from the local schools in Quebec.

2.2.2 Patient Safety and Quality of Service (PSQS)

In this model, Patient Safety and Quality of Service (PSQS) are not included as a separate structure; they are combined in one converter. The reason behind this is that this parameter has many elements that could affect it, and these elements are not feasible to include in this model due to the model's specific boundary, for example, the Quality of medical equipment, the continuous training for medical staff, and many other factors.

2.2.3 Burnout level consideration

In the proposed system, GPs' Burnout is represented using two different but related sectors, the stress level sector and the workload level sector. In this model, the workload level is computed using the number of patients a GP manages yearly; in some research, the workload is computed depending on the average daily duty hours a GP works. However, the researcher preferred to use the number of patients visiting the GP rather than calculating the duty hours because the number of patients visiting the GP can indirectly represent the duty hours a GP works, considering that a GP needs an average of (20) minutes to serve each patient (Mehlmann-Wicks, 2022).

2.2.4 Recruiters' Main Task

The recruiters in this model are deployed to attract the maximum number of qualified students that can qualify to join the medical schools in Quebec province. The model focused only on the output of these recruiters' functionality, ignoring the cost and expenses related to their activities and salaries. The model only focused on their success in attracting the target number of highly qualified candidates for medical schools.

2.2.5 The Stress level

This research assumes that the normal stress level is ten stress units, so if this level is higher than 10, we consider that extra stress affects the working GPs.

2.3 Data collection

The data collected in this research is from secondary resources; no primary data were collected for this project. Instead, the data was collected from related scientific literature that the researcher reviewed for this project. Also, the researcher's personal experience as a data analyst in a healthcare provider was deployed in some parts of the development of this research, particularly in building and validating the structure of the recruitment sector and most of its related parameters. Table (1) summarizes the leading sources for the data used in this project.

Table (1): Primary Data Sources

Data Type	Main Data Source	Collection	Contribution
Numerical Data	(Malko & Huckfeldt, 2017), (Globerman, 2018), (Lagarda-Leyva & Ruiz, 2019)	Literature Review	Parameters Values, Estimations, Calibration, and Validation
GPs population related Qualitative and Quantitative Data	(Hopper, 2022), (Malko & Huckfeldt, 2017), (Bellerose, 2021), (De Marcellis-Warin & Peignier, 2021)	Literature Review focuses on the current situation of the GPs population in Quebec.	Building validated Causal Loops Structure, Parameters Values, estimations, and Formulating Equations related to GPs and Students in Medical Schools
Burnout-related Qualitative and Quantitative Data	(Klein et al., 2010) (Lee et al., 2008), (Maslach & Jackson, 1981), (Dyrbye et al., 2013), (Embriaco et al., 2007), (Hall et al., 2016)	Literature Review, focusing on Burnout causes and Effects	Building validated Causal Loops Structure, Parameters Values, estimations, and Formulating Equations.
Recruitment of Qualified Students, Qualitative and Quantitative Data	(Hovmand, 2020), (Lagarda-Leyva & Ruiz, 2019), (Malko & Huckfeldt, 2017), Author own Experience.	Literature Review with a focus on the university graduate of Medical Schools in Quebec and their journey to graduation.	Building validated Causal Loops Structure, Parameters Values, estimations, and Formulating Equations.
SD models Related to Burnout, Staffing, GP	(Gambardella & Lounsbury, 2017), (Malko & Huckfeldt, 2017), Author own Experience.	Review Existing Models and adapt proper structures after adjusting the adapted structures to fit the proposed model.	Developing causal structures, assumptions, parameter estimation and delay discounting equations

2.4 Research ethics

Since no primary data collection was used in the development of this research, the ethical concerns do not apply to this project; however, general ethical guidelines have been applied in this research to ensure a suitable standardized impact of this research's contribution to the scientific community (*Forskningsetikk.no*, 2022), (Deborah, 2003).

All the data related to this research are available in the appendices; any researcher who wants to check or replicate this research can use the equations, assumptions, and data in these appendices.

Also, the researcher is aware that plagiarism is not accepted or allowed and can lead to serious disciplinary actions against those who copy from other researchers' work without proper referencing or permission. Additionally, the researcher is committed to following the rules of research ethics and modeling ethics and respects the privacy of individuals and groups (Saltelli et al., 2020), (Walker, 2009), (Wallace, 1994).

3. Dynamic Hypothesis and Feedback Loops Analysis

In this section, we will provide a visual representation of the dynamic hypothesis called the Causal Loop Diagram (CLD), which will describe the proposed system structure and the feedback loops that are interacting with each other generating the unwanted behavior (problematic behavior) (Sterman, 2000).

In order to understand the CLD in Figure (7), it is important to mention that the arrow between any two variables represents a link between them; this link is accompanied by a (+) sign or (-) sign. The (+) sign means that the first variable is changing in the same direction as the second variable, while the (-) sign means that the first variable is changing in the opposite direction of the second variable. For example, X → (+) Y, this relation means that Y will increase when X increases, and Y will decrease when X decreases. On the other hand, the following relation, X → (-) Y, means Y will decrease when X increases and Y will increase when X decreases.

Based on the available literature and the reference modes (Figure (2), Figure (3), and Figure (5)), the Casual Loop Diagram (CLD) in Figure (7) was developed. This CLD represents the dynamics hypothesis that this study will test and validate; *it suggests that one of the main reasons for the deaths caused by medical malpractice errors is the shortage of GPs in Quebec, which compromises patient safety and quality of service, leading to potential injuries causing deaths. Therefore, covering the shortage of GPs in Quebec should solve the problem*.

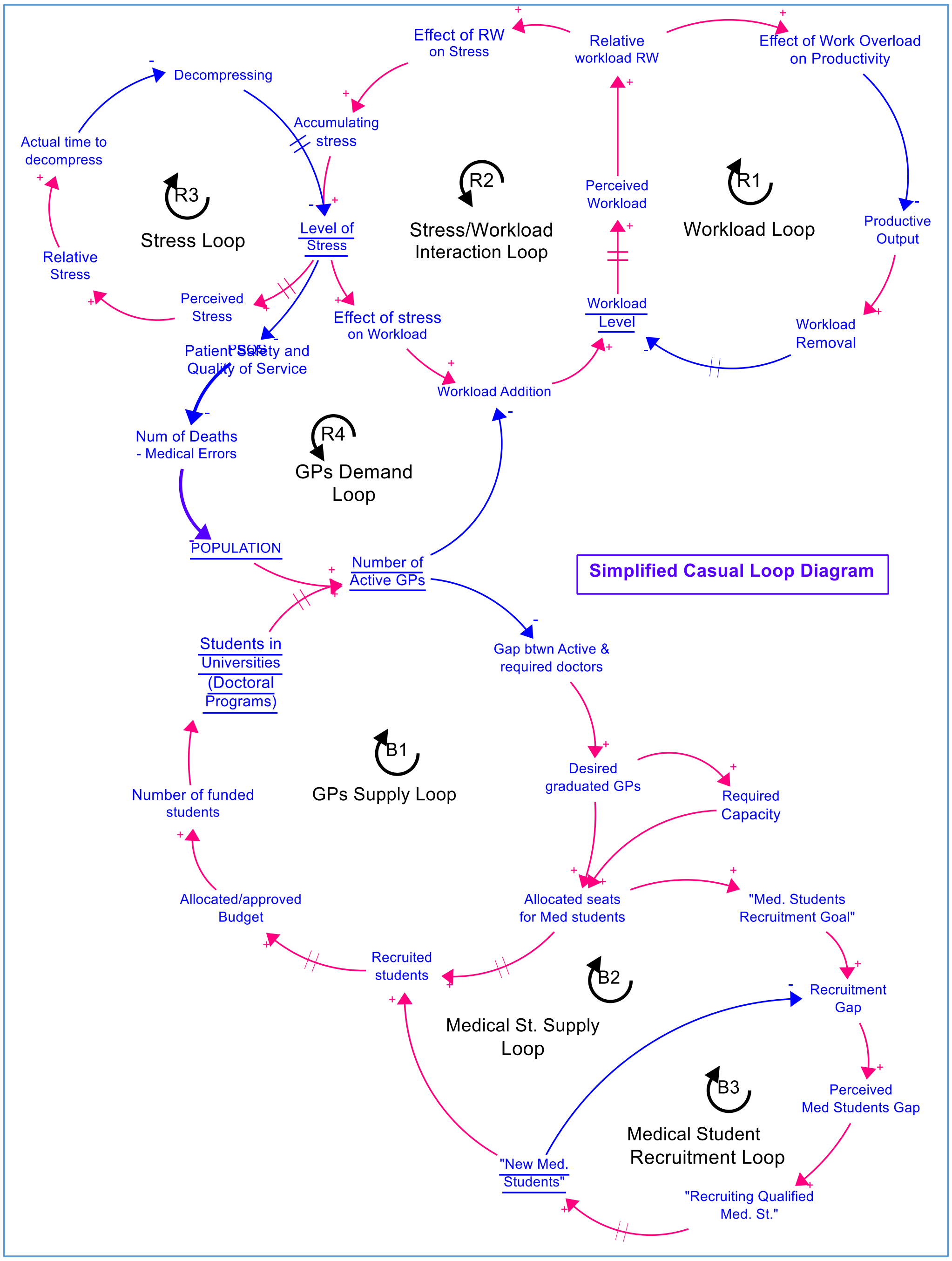

Figure (7): CLD that describes the proposed hypothesis

3.1 Loops Description

The central hypothesis involves about how the demand and supply of GPs, along with the burnout factors (stress level and workload level), all interact with each other affecting the number of medical malpractice death cases (MDC), which is one of the leading key performance indicator (KPI) in the proposed system.

The following are the main feedback loops of the dynamic hypothesis for the proposed system:

3.1.1 GP Demand Loop (R4)

***Loop (R4) pathway**: Population → (+) Number of Active GPs → (-) Workload Addition → (+) Workload Level→ (+) Perceived Workload → (+) Relative Workload → (+) Effect of Relative Workload on Stress→ (+) Accumulating Stress→ (+) Level of Stress → (-) Patient Safety & Quality of Service (PSQS) → (-) Num of Deaths- Medical Errors → (-) Population*

The GP demand reinforcement loop is activated by the required number of GPs that are needed to sufficiently provide healthcare services to the people of Quebec; since the population of Quebec is increasing every year (Institut de la Statistique du Québec, 2022), the need for more GPs is increasing. When a sufficient number of GPs are providing healthcare services to the people of Quebec, the number of patients a GP will see every day will be around the safe number of patients a GP can manage safely without extra pressure on her or him, which means less workload addition on the working GP. When the level of workload goes down, the stress related to workload will go down as well. An unstressed GP with a decent workload will be more alert and focused, which means a higher level of healthcare service quality and more safe environment for the patients (PSQS); it is found that a stressed GP is more likely to make a medical error twice higher than an unstressed one (Motluk, 2018). With a high level of service quality, the number of MDC will go down, saving more lives and reducing the death fraction of Quebec, increasing the population.

3.1.2 GP Supply Loop (B1)

***Loop (B1) pathway**: Number of Active GPs→ (-) Gap btwn Active & required doctors→ (+) Desired graduated GPs→ (+) Allocated seats for Med students→ (+) Recruited students→ (+) Allocated/approved Budget→ (+) number of funded Students→ (+) Students in Universities (Doctoral Programs) → (+) Number of Active GPs*

This loop is pushed by the direction of the change In the population of Quebec; when it is increasing, more active GPs will be required to serve the expanding population of Quebec; if it is decreasing *or* the gap between the active and required GPs is small or equal to zero, then few or no more GPs will be required, and the new GPs who are joining the active GPs pool will be allocated for providing sustainability for the workforce count all the time.

When the number of active GPs increases by the newly trained medical students, the gap between the required number of GPs and the current number of GPs will get smaller and smaller over time. This gap is controlled by the threshold of active GPs that the OECD determined for its members, which is 3.6 GPs for every 1,000 persons (OECD, 2021), while the current number of GPs per 1,000 persons in Quebec does not exceed 2.5 GPs per 1,000 persons (Wittevrongel & Shaw, 2020).

While closing the gap mentioned above, the number of desired new GPs will get smaller over time; this will be accompanied by a change in the allocated number of seats for the new medical schools, which is determined yearly, as the gap is shrinking, the number of seats for medical students will get fewer also. Because of the highly challenging requirements of medical schools' admission, these schools are suffering from a very low admission rate which does not exceed 9% of the submitted applications (Barber, 2016). Therefore, a recruitment process is required to attract highly qualified applicants to join the medical schools in Quebec; attracting these qualified applicants will require funds; however, because the target of the recruiters is getting lower over time as the gap is shrinking, the funding for these students will be decreasing. The number of newly recruited medical students' number will depend on the previously approved funds; by a decreased fund, fewer new medical students will join the medical schools in Quebec, which means fewer graduates from these schools after seven years of study and training (Lagarda-Leyva and Ruiz, 2019). As a result, fewer new GPs will be added to the currently active GPs in Quebec.

3.1.3 Medical Students Supply Loop (B2)

Loop (B2) pathway: *Number of Active GPs→ (-) Gap btwn Active & required doctors→ (+) Desired graduated GPs→ (+) Allocated seats for Med students→ (+) "Med. Students Recruitment Goal"→ (+) Recruitment Gap→ (+) Perceived Med Students Gap→ (+) "Recruiting Qualified Med. St." → (+) "New Med. Students"→ (+) Recruited Students→ (+) Allocated/approved Budget→ (+) Number of funded Students→ (+) Students in Universities (Doctoral Programs) → (+) Number of Active GPs*

This balancing loop is working with loop (B1) to reach the goal of the number of GPs added to the healthcare system; it is using the allocated seats for the new medical students as a base to set the gap size between the current admitted number of medical students and the desired number of new medical students. Here, the recruitment of qualified new medical students will take place, increasing the potential number of these students who will join the medical schools; the number of these recruited medical students will be used to calculate the potential budget that is required to be approved and allocated before joining the medical schools, the approved fund will determine the number of medical students that the Quebec authorities will sponsor, then they will join the medical school, and after graduation, these recruited students will be added to the number of registered active GPs in Quebec, the loops B2 and B1 will keep feeding each other until the gaps in the two loop are covered.

3.1.4 Medical Students Recruiting loop (B3)

Loop (B3) pathway: *"New Med. Students" → (-) Recruitment Gap→ (+) Perceived Med Students Gap→ (+) "Recruiting Qualified Med. St." → (+) "New Med. Students"*

Loop (B3) is the backbone for loop (B2) and an indirect influencer for the supply of GPs in the loop (B1). Loop (B3) supplies new medical students for loop (B1) and controls the activity and power of loop (B2).

By admitting new students into the medical schools in Quebec, the gap between the desired number of medical students generating new GPs and the current number of admitted new medical students will decrease; as a result, the perceived number of new medical students will decrease, this will decrease the recruitment activity, which means less new students will join the medical schools in Quebec. However, the opposite also applies here; if the number of new medical students is less than the required number, the gap between admitted and desired new medical students will increase, which will push on the recruitment process to attract more highly qualified medical students, which will increase the number of new medical students that will join the medical schools of Quebec.

3.1.5 Workload Loop (R1)

Loop (R1) pathway: *Workload Level → (+) Perceived Workload → (+) Relative Workload → (+) Effect of Work Overload on Productivity → (-) Productivity Output→ (+) Workload Removal → (-) Workload Level*

This reinforcement loop represents simplified workload dynamics; it demonstrates the amplifying effect of workload addition on workload level. Workload addition is triggered by the number of the current active GPs; so when this number increases, the workload addition will decrease; this is because the number of patients a GP will see will be distributed between more active GPs and vice versa; if there is a shortage in GPs, then a GP will have to see more than the average safe number of patients, this will increase the workload addition rate which will increase the workload level. The relative workload determines the relationship between the current workload level and the normal-safe workload, which is around 5,980 patients yearly per GP (Mehlmann-Wicks, 2022). Relative workload will also quantify the effect of workload on work productivity which behaves in the opposite direction of the relative workload; when one increases, the other will decrease, and vice versa. Productivity will determine the rate of workload removal, higher productivity means higher workload removal that leads to a lower workload level, and the opposite scenario also applies.

3.1.6 Stress-Workload Interaction Loop (R2)

Loop (R2) pathway: *Workload Addition→ (+) Workload Level → (+) Perceived Workload→ (+) Relative Workload→ (+) Effect of RW on Stress→ (+) Accumulating stress→ (+) Level of Stress→ (+) Effect of stress on Workload→ (+) Workload Addition*

Loop (R2) is stimulated by the number of active GPs serving in Quebec's healthcare system. When the number of active GPs is lower than the needed number of GPs, the workload will increase because a GP will deal with more patients than the safe-normal number of GPs mentioned earlier. Increasing workload will add more mental pressure and fatigue to the working GP, increasing her/his stress level. More stress will decrease productivity leading to more workload addition. On the other hand, a sufficient number of GPs serving Quebecers will create low workload addition on GPs, which means less stress on them, enhancing service quality and patient Safety (Lyndon, 2015) (Motluk, 2018).

3.1.7 Stress Loop (R3)

Loop (R3) pathway: *Level of Stress→ (+) Perceived Stress→ (+) Relative Stress→ (+) Actual time to Decompress→ (-) Decompressing→ (-) Level of Stress*

This reinforcement loop represents the stress-releasing mechanism. An increasing stress level, pushed by an increased workload, will keep accumulating, requiring a longer time to decompress, which means a longer time for stress to stay draining the mental health of the overloaded GPs. Therefore, this loop is important to determine the level of patient safety and quality of service (PSQS) (Anderson & Abrahamson, 2017).

3.2 Feedback Loops Interactions summary

Currently, the number of GPs in Quebec is less than the OCED-specified threshold, which is 3.6 per 1,000 persons (OECD, 2021); the current ratio in Quebec is 2.5 per 1,000 persons (Wittevrongel & Shaw, 2020). So the population of Quebec is activating the reinforcement loop (R4) to increase the number of active GPs; by that, the gap between the desired number of GPs and the currently active GPs will be closed; the main goal of loops (B1 and B2) is to increase the number of GPs by increasing the number of new medical students aiming to reach the OECD threshold (goal).

When the desired number of medical students increases, the gap between this number and the number of current medical students will increase, this will initiate the recruitment loops (loops B2 and B3), which represent the engine of the GP supply dynamics; these loops will close the mentioned gap and add more new medical students to the universities in Quebec, leading to more graduated GPs.

To control the increasing number of graduated GPs and new medical students, the three balancing loops (B1, B2, and B3) will limit the growth of these stocks and stabilize it when the number of active GPs reaches the threshold of OECD, which means that the balancing loops are reaching their goals.

So when there is a shortage of GPs in Quebec, the reinforcement loops (R1, R2, R3, and R4) dominate, and the number of GPs will increase up to the OECD threshold; once the system approaches the desired threshold, the balancing loops dominate the system

When the number of active GPs increases, the burnout levels of active GPs decrease (stress and workload), and as a result, the Patient Safety and Quality of Service (PSQS) increases; this will decrease the probability of the occurrence of medical malpractice death cases. s

4. Model Description

This chapter will discuss the major parts of the model's structure, mainly stocks, flows, equations, and parameters' values. A complete documentation about the model structure is available in appendix (C).

4.1 Population Sector

In this sector, the researcher represents the development of the population of Quebec Province from 2012 up to 2054 (Institut de la Statistique du Québec, 2022). The population stock will increase with the birth

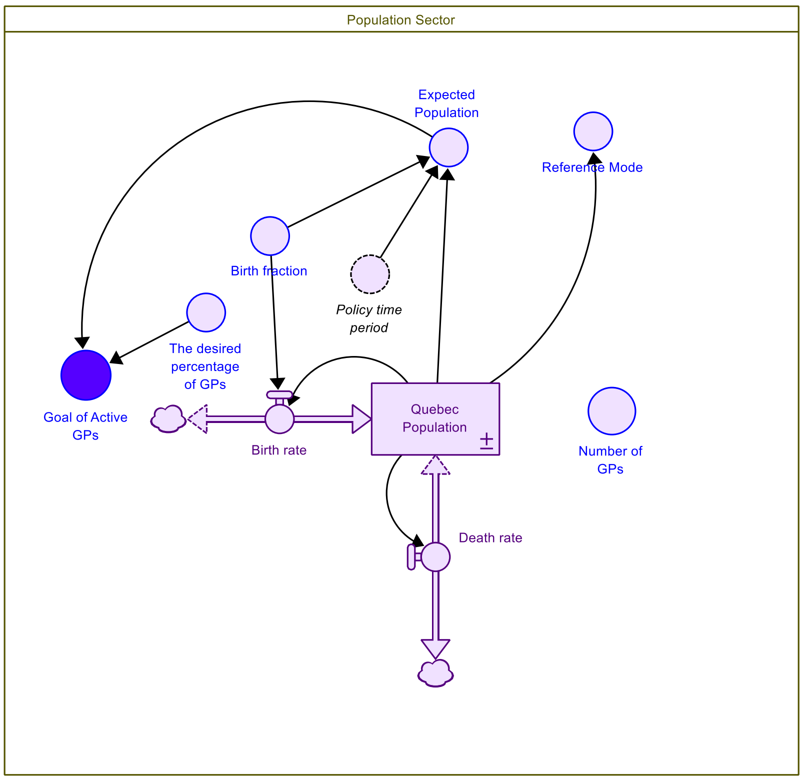

Figure (8): The population sector.

rate and decrease with the death rate; Figure (8) illustrates the population structure. With the development of the population in Quebec, the number of required GPs will be increasing; this factor will be represented as a goal for the entire model. It is the major output of this sector, and it will be denoted by the converter "***Goal of Active GPs"***. This output is vital for other model structures, mainly *The Active GPs Sector*.

The "*Goal of Active GPs"* was calculated as follows:

*Goal of Active GPs = The_desired_percentage_of_GPs*Expected_Population*

The OECD identifies "***The desired percentage of GPs"*** by the value of 3. 6 GPs for every 1,000 persons (OECD, 2021). The ***"Expected Population***" is determined by the future change of the population in Quebec, starting in 2012 up to 2054; **FORCST** is a built-in function in STELLA Architect that can estimate the future growth in the population of Quebec using the following formula:

FORCST (Population, Policy_time_period, Birth_fraction)

Using ***"FORCST,"*** the ***Goal of Active GPs*** value will be determined and forecasted in the future.

4.2 Active GPs Sector

Figure (9) shows the model structure that captures the dynamics which control the population of Active GPs in Quebec. Two inputs for this sector come from the population sector; the initial value for the ***"Number of Active GPs"*** stock and the "***Goal of Active GPs***" converter**.** The purpose of this sector is to close the gap between these two inputs in (32) years' period. Two inflows are adding more active GPs to the ***"Number of Active GPs"*** stock; the "***Immigrant GPs"*** inflow and the "***New Graduates New GPs"*** inflow; the purpose of this model is to depend entirely on the local GPs that graduate from the four local medical schools in Quebec; therefore, the "***New Graduates New GPs"*** inflow is a critical part of this research and structure. In Quebec, it is estimated that the retiring age of GPs is 68 years (Racine, 2012); this is represented in this sector by the "***Retiring GPs* rate"** outflow**.** The "***New Graduates New GPs"*** inflow will supply GPs to cover the gap mentioned above and compensate both the "***Retiring GPs"*** and the Medical Students who are "***dropping out"*** from their studies and medical training while in medical schools (Glauser, 2019).

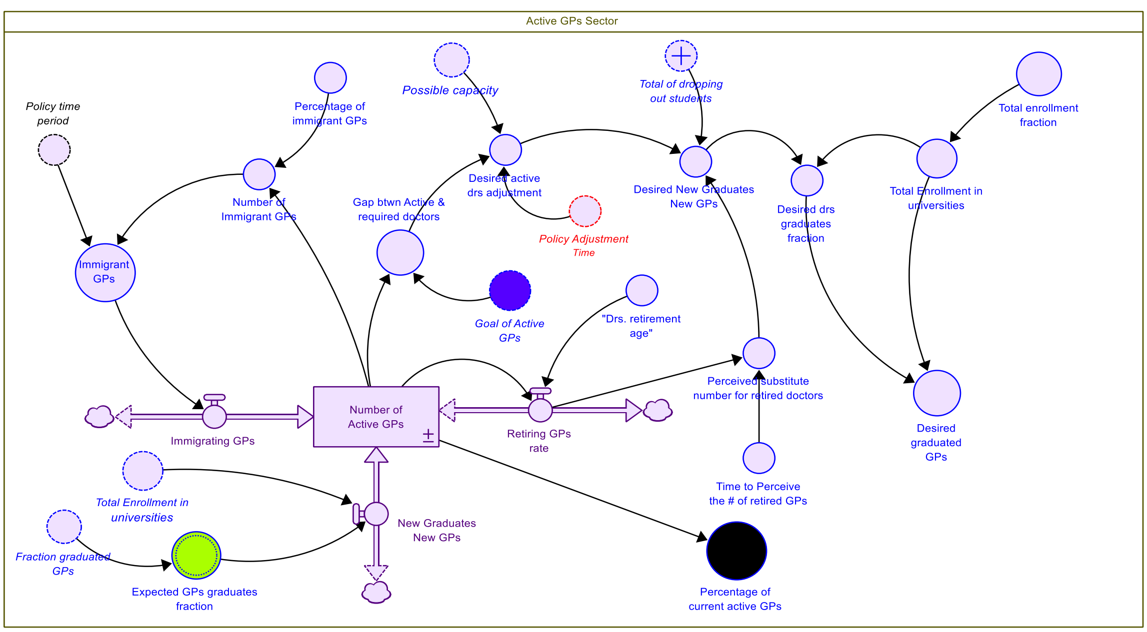

Figure (9): Active GPs Sector.

The "***New Graduates New GPs"*** rate is a result of the multiplication of the ***"Faction of Graduated GPs"*** with the "***Total Enrollment in Universities"*** (*Enrolment by University - Universities Canada*, 2021), the "***Fraction of Graduated GPs"*** comes from the number of medical students that graduate from the medical schools in Quebec every year. The primary outputs of this sector are The "***Desired Graduated GPs"***, which is an essential input for the Funds sector and the University Capacity Sector, and the "***Percentage of current active GPs",*** which is a major input for the Burnout and the Workload sectors, as it will determine the workload and stress levels on the current working GPs in Quebec.

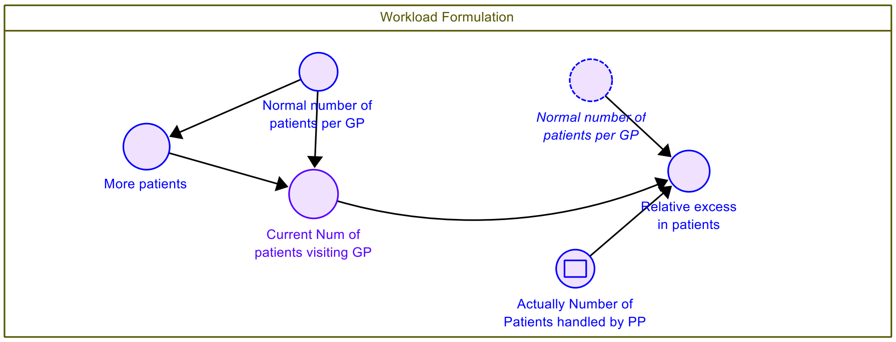

Figure (10): Workload Formulation Sector.

4.3 Workload Formulation Sector

This sector represents the workload generated due to the shortage of GPs in Quebec (Figure (10)); the workload is measured by the number of patients a GP handles yearly. The excessive number of patients is represented in this sector by the converter "***More patients"***; this converter and the "***Normal number of patients per GP"*** converter are added to each other, generating the "***Current number of patients visiting GP,"***; which represents the current pressure of workload that will be transferred to the working GPs in the Workload Sector. In order to pass this workload effect, the ***Relative excess in patients*** converter is used to find out the multiplying factor that represents the relation between the ***"Normal number of patients per GP"*** and the ***"Current Num of patients visiting GP".*** The value of the "***Relative excess in patients"*** converter is the major output of this sector that will be passed to other sectors.

4.4 Workload Sector

This structure is adapted from (*isee Exchange*^{TM}, 2022) "Battle Burnout, Take a vacation"; it is built to investigate the effects of various workloads on GPs. The amount of workload which is added or removed by this sector depends on the output from the Workload Formulation Sector, specifically by the ***"Relative excess in patients"*** converter.

The workload increases when the number of patients increases; if the number of active GPs does not counterpart the increasing number of patients, the workload will also increase, causing extra stress on the working GPs. This structure interacts directly with the Burnout (Stress) sector because, conceptually, these structures mutually affect each other. When the workload on a GP is getting higher, she/ he will see more patients than her/his normal capability causing excessive stress on her/him, which will accumulate over time, increasing the probability of causing a malpractice incident (Sheikh Azadi et al., 2007).

The main output from this structure is the level of workload generated by the excess number of patients a GP must see every year; it is represented by the "***Relative workload converter"***, which will transfer the effect of workload to the Burnout (Stress) Sector. Figure (11) shows the structure details.

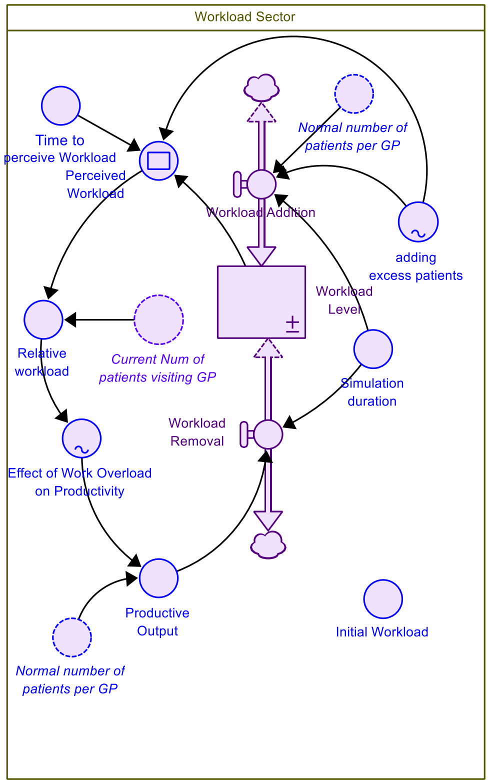

Figure (11): Workload Sector.

4.5 Burnout (Stress) Sector

The Burnout sector is adapted from (*isee Exchange*^{TM}, 2022) "Battle Burnout (Figure (12)), Take a vacation"; it represents the level of stress generated as a result of the current workload; the workload is measured by the average number of patients who visit a GP yearly, assuming that the safe average number a GP can see every year is 5,980 patients (Mehlmann-Wicks, 2022).

The main input for this structure comes from the workload sector, precisely, the "***Effect of RW on Stress"*** converter; this variable transfers the effect of the number of excess patients that a GP meets yearly to the entire sector; this excess in patients comes as a result of the shortage of GPs in Quebec; as mentioned before.

The stress level will keep accumulating as long as there is a workload generated inside the system. If the accumulated stress is not well managed, then the more stress on GPs, the lower levels of service quality will be provided to patients; (Farid et al., 2020).

The Burnout sector aims to provide the model with two main outputs; the first one is the level of Patient Safety and Service Quality (PSQS) provided to patients, which affects the number of medical malpractice deaths. The second output is the ***"effect of Stress on workload"***; this output transfers the stress effect on the workload addition rate inside the workload sector; accumulated stress will decrease the productivity of the GP, leading to more patients being added to the waiting list, increasing the workload.

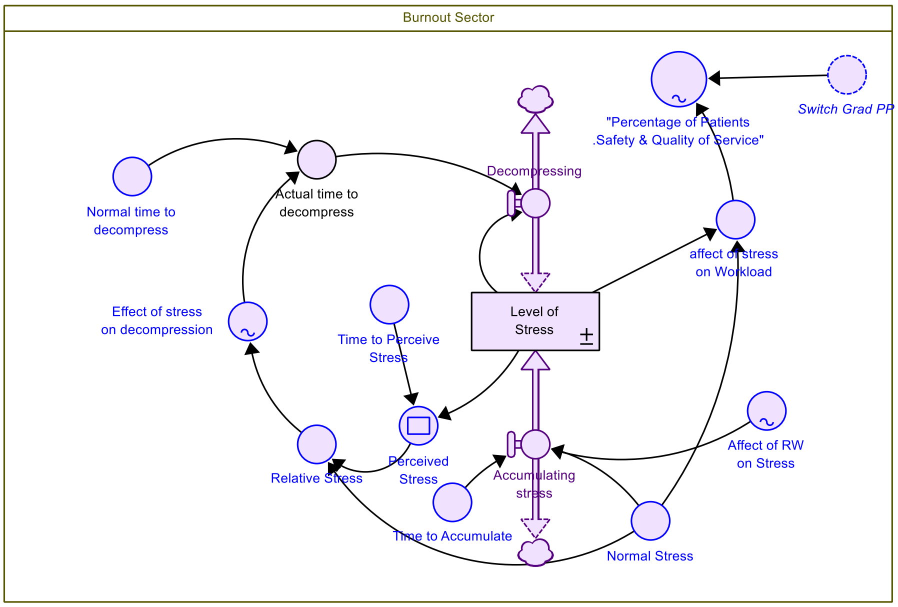

Figure (12):The Burnout (Stress) Sector

It is essential to mention that the author estimated the "***Percentage of Patient Safety and Quality of Service" (PSQS)*** graphical function due to the lack of accurate data relating QSPS with the malpractice death cases; however, the main resource that reflected on this relationship was explained by (Anderson and Abrahamson, 2017), they estimated that stress and burnout factors contribute with about 30% of the total level of PSQS.

4.6 Malpractice and Death Sector

Figure (13) shows the Malpractice and Death Sector; this part of the model is built to calculate the main results of the whole model interactions; it calculates the change in the number of death cases caused by

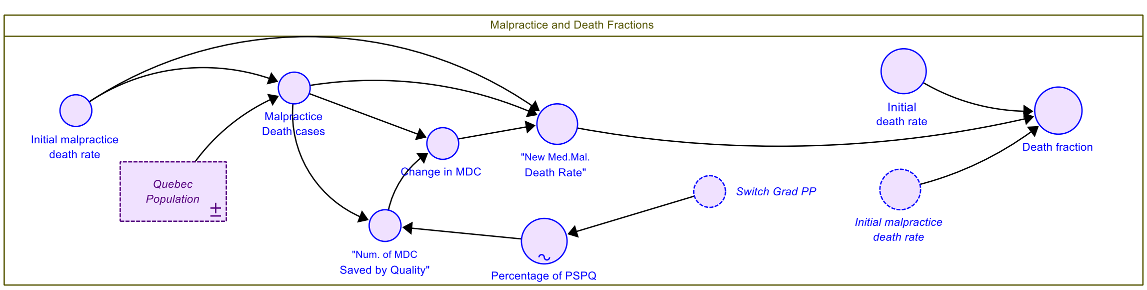

Figure (13): Malpractice and Death Sector malpractice errors, and it also captures the change in the whole death fraction affected by the change of malpractice death fraction. This structure's main input is the level of patient safety and quality service (PSQS) from the Burnout sector; it is also used to compare the historical malpractice deaths with the anticipated number of malpractice deaths generated by the proposed system.

4.7 Universities' Capacity Sector

The structure shown in Figure (14) represents the Universities' capacity in Quebec; four universities in Quebec provide medical study and training with a total of 928 new medical students yearly (Lagarda-Leyva & Ruiz, 2019).

The possible capacity represents the maximum and the current capacity that the medical schools in Quebec can admit yearly; it is the main output of this structure.

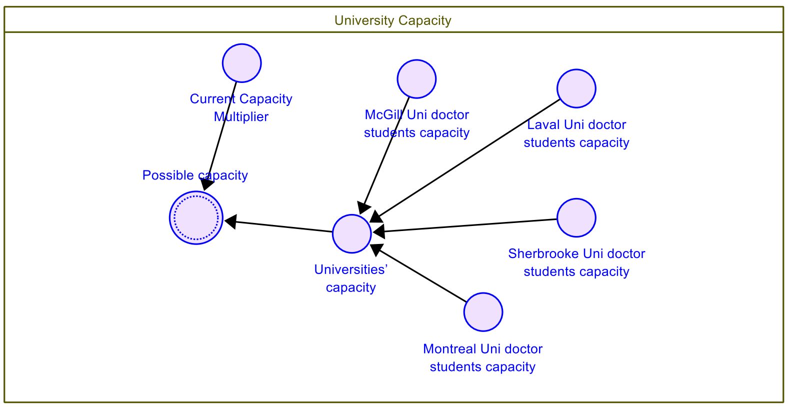

Figure (14): Universities Medical Schools Capacity.

4.8 Funds Sector

Figure (15) shows the funds sector; this sector catches the budget that might be approved by authorities in Quebec to encourage new applicants to apply to medical schools in Quebec. The budget will be allocated to pay the medical school tuition fees, and a monthly stipend for each student admitted to a medical school in Quebec.

The main inputs for this sector are 1) the "***Desired graduated GPs"***, which represent the gap between the current active GPs and the required number of active GPs. 2) The "***Possible capacity"***; this parameter shows the current number of seats that the medical schools in Quebec can admit annually. 3) The "***Fraction of recruited students"*** shows the number of recruited students joining the medical schools in Quebec.

By defining a target number of new medical students, the budget to encourage these students will be calculated and determined. However, this budget must be approved by the educational authorities in

Quebec; therefore, this sector included three scenarios for the output (decision) that might come out of the anticipated debate about approving the required budget. Table (2) shows a summary of these scenarios.

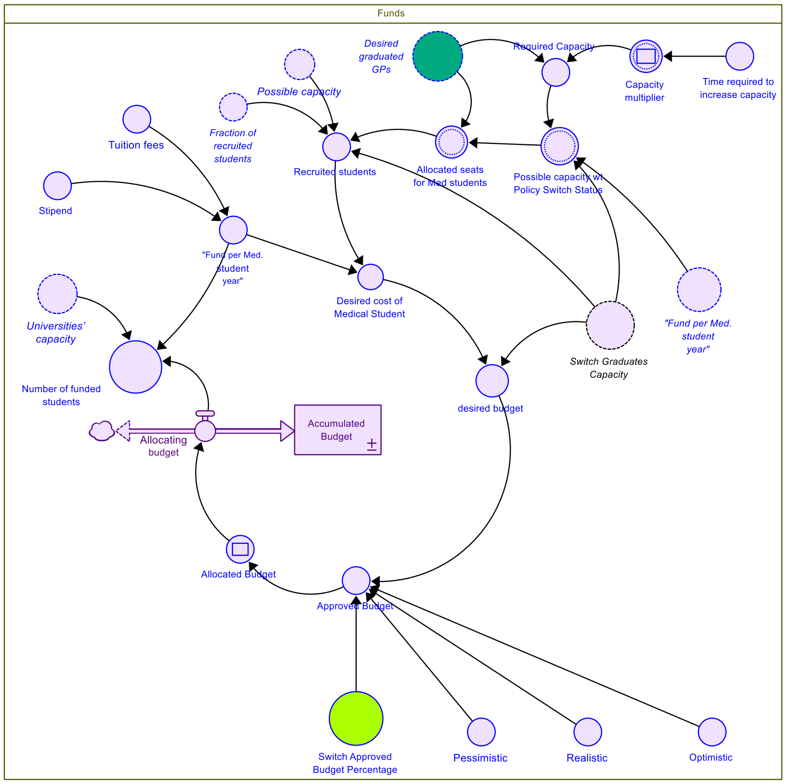

Figure (15): Fund Sector.

Table (2): Budget Switch values.

Switch Value	Percentage of Approved Budget	Effect on Achieving Goal
1 (Optimistic)	Fully approved budget 100%	Fully cover the gap between current and required GPs (100%).
2 (Realistic)	Partially approved budget 85%	Covers 92% of the gap between current and required GPs
3 (Pessimistic)	Partially approved budget, but not enough to impact	Covers 89% of the gap between current and required GPs

4.9 Recruiting Qualified Medical Students Sector

This sector was built to capture the dynamics that describe the processes of recruiting qualified medical students in a simplified representation (Figure (16)); this structure was adapted from (Hovmand, 2020)

The input for this sector comes from the Universities' Capacity sector, namely the "***Allocated seats for the Med. Students"*** converter; this converter represents the goal that the recruitment sector shall achieve, assuming that; by a specific delay time, the recruitment process achieves its goal, and the gap will be closed.

However, there is always a probability that some students change their minds after a while and withdraw their admission from medical school; this is what the outflow represents in this sector.

The main outputs of the sector are the ***"New Med. Students"*** and the "***Fraction of recruited students"***; these two outputs will be the inputs for the funds' sector.

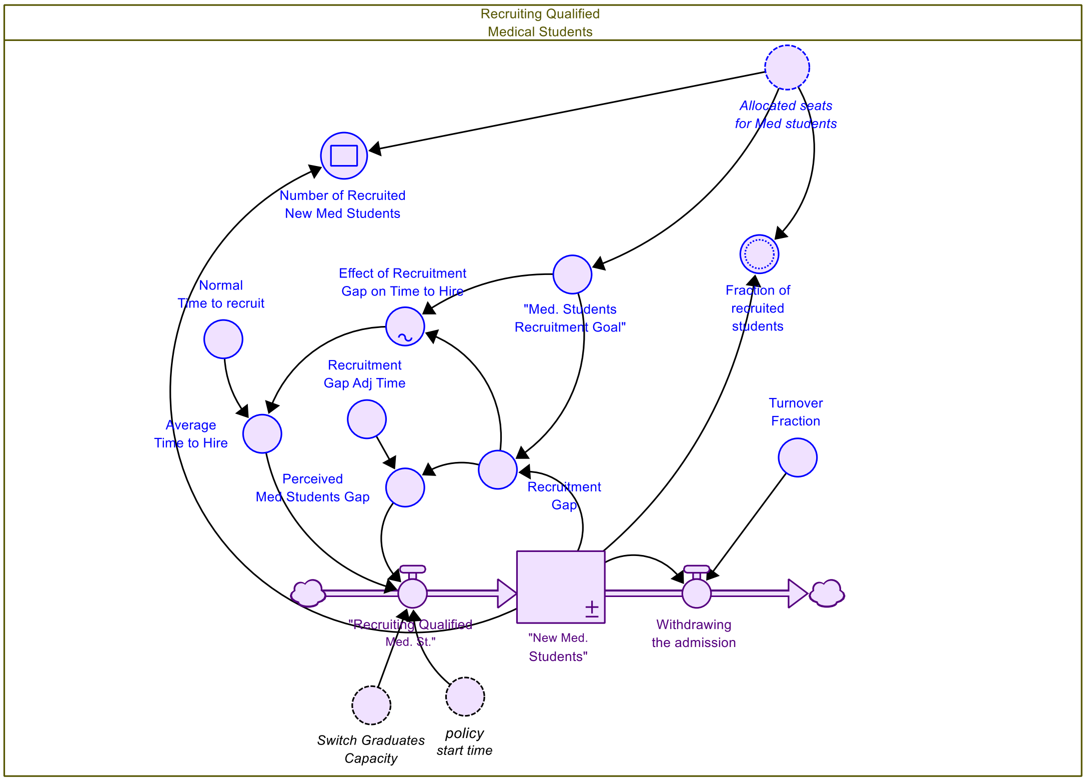

Figure (16): Recruiting Qualified Medical Students

4.10 Medical Education at University

The Medical Education Sector is adapted from (Lagarda-Leyva & Ruiz, 2019); it is shown in Figure (17). In this sector, the input comes from the recruitment of qualified medical students and the funds' sectors; the converter "***Number of funded students***" represents this input**.** The recruited students join the medical school for 4 to 5 years of study; then, they will be transferred to the residency program in which they receive practical training. After that, they either graduate or take more training for a specialty degree; in both cases, the doctor will hold a GP rank. Therefore, the total number of graduating medical students will enforce the effect of the inflow of "***New graduate GPs"*** in the active GPs sector, increasing the number of GPs who are currently practicing medicine. There is always a probability that medical students abandon their studies or training for many reasons; however, the number of these students does not exceed 5% of the medical students in each studying stage (Glauser, 2019). The dropping students are represented with outflows in each stage, and the total is calculated and passed to the active GPs sector to be added to the goal of desired GPs; this will compensate these dropping out students.

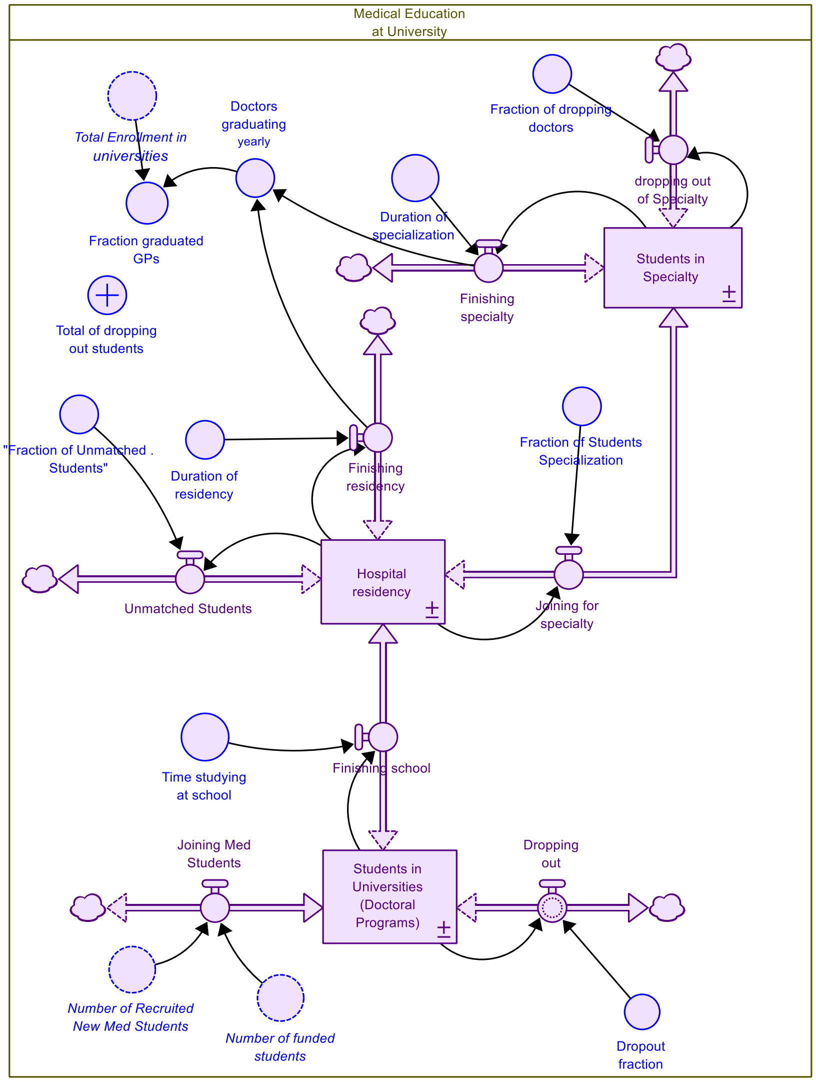

Figure (17): Medical Education Sector.

4.11 Practicing Pharmacists (PP) Sector

The main purpose of this sector (Figure (18)) is to represent a potential intervention point in which we can design a policy to tackle the problem of excess Stress and Workload while the new graduates of medical schools are in the process of studying to join the active GPs pool every year, covering the shortage in the GPs' workforce.

The proposed intervention is evolving about providing help to the GPs' practice by performing several administration duties and prescribing tasks, which will release GP's time and give her/him the ability to enhance her/his productivity level. It is reported that: with the support of a Practicing Pharmacist in prescribing, a GP can have an extra 4.9 hours every 40 hours weekly (Maskrey et al., 2018). This intervention was tested and applied in the United Kingdom and reported by (Maskrey et al., 2018). The same study reported a significant reduction in the stress caused by the workload on GPs who participated in this initiative (Maskrey et al., 2018). The described intervention is quantified and calculated in this sector, putting in mind that this intervention is time limited and will be terminated once the gap in GPs shortage is covered. Also, this intervention is changing relatively with the change in the number of excess patients visiting a GP. So when the gap between active and required GPs is large, the pharmacists' support will be significant, and this support will decrease when the gap decreases.

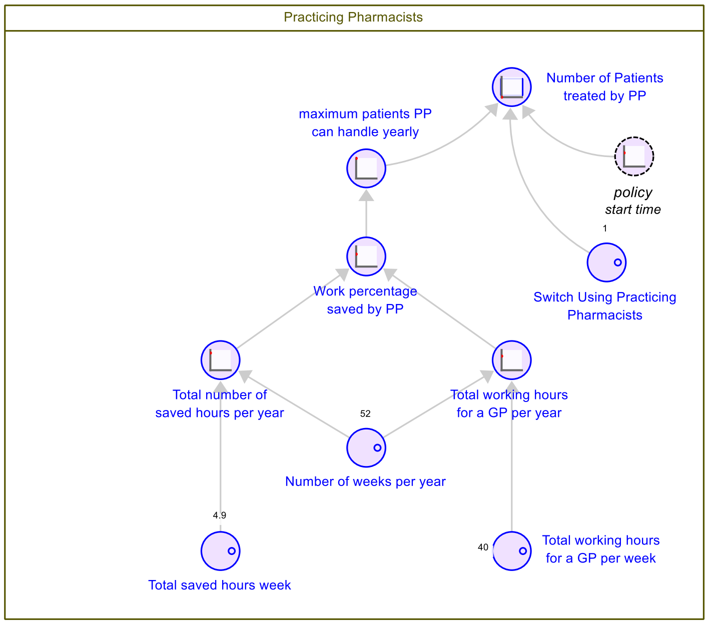

Figure (18): Practicing Pharmacists Sector.

5. Validation Tests

A model was developed in order to test the dynamic hypothesis described in chapter (2). This model was validated by running structural and behavior tests to build confidence in its outcomes; these tests ensure that the proposed system's behavior and structure align with the existing and verified knowledge (Homer, 2012).

In this chapter, the validation tests (structural tests and behavior tests) described by (Forrester & Senge, 1980) and (Barlas, 1996) will be summarized, and their results will be reported accordingly.

5.1 Direct Structure validation test

The objective of these tests is to compare the proposed model with the existing knowledge; when put under these tests, the model's behavior should relatively match the real-world system's behavior if we also put it under the same tests. In these tests, the relationships between the variables are compared with the existing literature or other available sources in order to validate them (Homer, 2012).

The structure validation tests are essential to give creditability to the links between the parts and structures of the proposed model; without passing these tests, the model will not be eligible to go further with the other tests.

5.1.1 Structure Verification Test

In this test, the structure of the model is verified by comparing its component with the existing verified knowledge; this is done by comparing the links and equations of the proposed model with real-world knowledge. The knowledge deployed to develop the proposed model is deduced from the literature reviewed, and the model described in chapters (1 and 4). Therefore, the proposed model passed this test successfully.

5.1.2 Parameter Verification Test

Verifying exogenous parameters and ensuring that their values are within the reasonable range as in real systems adds significant credibility to the proposed model (Forrester & Senge, 1980) (Barlas, 1996); this is what "Parameter Verification" is about.

Most values of the parameters in the model are obtained from the literature and modeling researches. For some parameters, their values were estimated by the researcher; however, the estimation was not random; the researcher's experience as a data analyst for a healthcare facility was the basis for estimating the reported values for a few parameters; for example, some parameters in the Recruiting New Medical Students sector. Appendix (A) shows the details of every parameter used in the model with the source of their values.

For the Burnout sector, the main structure was adapted from (Gambardella & Lounsbury, 2017), who used (Richmond, 2001) and *(isee Exchange™*, 2022). Therefore, the parameters in this sector were mainly deduced from that model. The main challenge in this adaption was converting the values of the parameters that are related to time from weeks to years; this is because the time unit for the proposed model is in years while the units in the burnout model were in weeks, the behavior in this sector, when transformed from weeks to years, will be less detailed which may hide some important information beneath it. The uncertainty concerns of using estimated and converted parameters in the model are further evaluated using sensitivity analysis tests later in this chapter and detailed in appendix (B); in these tests, if the values of the parameters are found to cause a slight change in the model behavior, then the *uncertainty* of these parameters will be significantly reduced and vice versa.

5.1.3 Direct Extreme Conditions Test

Each equation in the proposed model was tested using the direct extreme conditions, ensuring that the examined equations work correctly when put under these conditions. In addition, MAX or MIN functions were used, where needed, to control variables' values during simulation; these functions guarantee that these variables will remain within reasonable ranges, avoiding any computational errors. Finally, the upper and lower values were estimated and tested under extreme direct conditions for the table functions.

Using all these preventive measures, the proposed model showed no computational errors, and the model's output assured that the variables' values were within the logical boundaries.

5.1.4 Dimensional Consistency Test

This test is completed automatically using the simulation software (Stella Architect version 3.0.2); no inconsistencies were found in all the units associated with the variables and constants used in the proposed model. This test ensures that all the variables are conceptually and mathematically consistent and reflect real-world values (Barlas, 1996; Sterman, 2000).

5.1.5 Boundary Adequacy Test

To evaluate the adequacy of the model's boundaries, we need to consider the model objectives (Forrester & Senge, 1980). The main objective of the model is to provide a proof of concept for the causal theory on the impact of the shortage of GPs on the Patient Safety and Quality of Medical Services (PSQS) in Quebec, Canada, which will affect the number of deaths caused by medical malpractice.

The proposed model included a simplified population structure representing the demand for healthcare services. The Active GPs sector includes the GPs Supply structure, which represents the current dynamics of the GPs who will join the working GPs group after they complete their studies and training; the supply of GPs shows the medical student's journey from admission into medical schools until her/his graduation and then becoming an active GP in the community. The model also shows the structure for the fund required to finance the recruitment of qualified medical students and the fund required to attract them to join the medical school; this structure is simplified because the goal of this structure is to estimate an approximate budget for funding the successful deployment of highly qualified medical students in medical schools in Quebec.

To illustrate the impact of the shortage of GPs, the researcher included a simplified structure to represent the Burnout syndrome initiated by the shortage of GPs. Since the model focuses on the dynamics of supply and demand of GPs in Quebec, the structure of the Burnout sector was simplified to reflect the accumulated stress level caused by the sufficiency or insufficiency of the currently active GPs.

The boundary of the proposed model is additionally validated by reviewing related literature and its ability to describe the entire process of providing qualified GPs to the active GPs group serving the people of Quebec. Therefore, to summarize, the model is considered adequate. Figure (6) shows the structures that are included in the proposed model, and Table (8) lists the most important exogenous parameters with their related resources.

5.2 Structure-Oriented Behavior Tests

5.2.1 Integration Errors

(Schwaninger & Groesser, 2009) described the success of the integration error test by showing that the model behavior will not be affected by the change of the integration method or interval. The researcher used the RK4 integration method in the proposed model and a time step of (1/72) years. The model behavior showed no sensitivity to time intervals (time steps) which were multiplied by (2) and divided by (2); also, it was not sensitive to the change of the alternative integration methods, like Euler and RK2.

5.2.2 Indirect Extreme Conditions

Unlike the direct test, where each parameter is examined under extreme conditions, the indirect test examines the entire system's behavior when putting specific parameters' values under unlikely extreme conditions. To pass this test, the model should generate behavior that will mimic the behavior of the actual system if put under the same conditions (Schwaninger & Groesser, 2009). To perform this test, we will assume that we have no enrollment to universities at all, no budget will be provided to fund the study costs of medical students, no patients visiting GPs, and no new medical students will be admitted to medical schools in Quebec. Table (3) shows the parameters used for this test.

Table (3): Parameters values under extreme conditions

Parameter	Sector/ Module	Extreme Condition
Total enrollment in universities	Active GPs Sector	0
"Fund per Med. Student year"	Funds	0
Normal number of patients per GP	Workload Formulation	0
Current Capacity Multiplier	University Capacity	0

It was observed that the model behavior aligns successfully with the expectations about the system's behavior. When no students enroll in universities, the number of Active GPs will keep decreasing yearly because the inflow for the active GPs stock will add nothing to the stock (Zero GPs). However, the outflow will keep decreasing the number of Active GPs due to the continuous retirement of aged GPs. The active GPs stock has an initial value of (17,550) Active GP (Canadian Medical Association, 2012); this is why it is declining to (10,500) Active GP and will keep declining until it reaches zero value. Other stocks, like the Burnout stock, will increase to 34 stress units, and the workload stock will reach up to 15,400 patients; due to the absence of new enrollment to medical schools. Also, no budget will be allocated to new medical students; the entire GP supply will be deactivated in this extreme condition. The remaining addition of the inflow to the Active GPs stock will come from the immigrant GPs, who are not generating from Quebec Universities.

The logical expectation is that when no patients are visiting GPs, the Burnout sector will be deactivated; this is because there is no work pressure on GPs, so they will not become burnout; however, other parts of the system will keep running because the number of active GPs is activated depending on the OECD threshold which is 3.6 physicians per 1,000 persons (OECD, 2021).

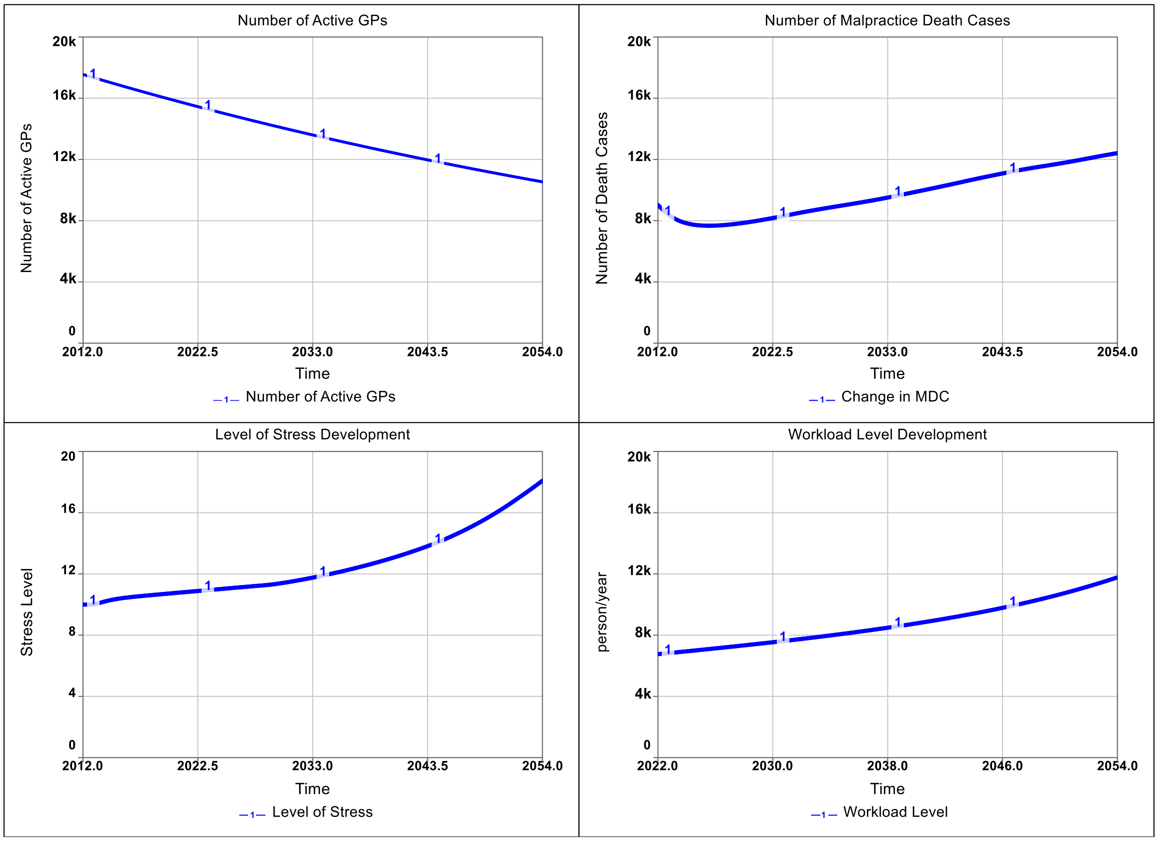

Figure (19): Model Behavior when The Total Enrollment Fraction is set to zero.

If the authorities, for unexpected reasons, decided to stop funding the new highly qualified medical school students, a rational expectation would be that most prospective medical students would not join the medical schools. So when we assume that tuition fees and stipends are no more funded, the recruiters will have nothing to help them attract new prospective students; therefore, the operation will be automatically halted; this is precisely how the system reacts when the funding is not provided to the medical students' expenses. No more budgets will be allocated; the budget sector variables will remain at their initial value. Also, no more students will be recruited, and the stress stock in the Burnout sector will reach its highest limits because no more newer GPs will be joining the Active GPs stock; in addition, the Medical Education Sector represents the medical study process in the universities will be going towards zero students. Some stocks' values will decline as their inflows are cut off; this behavior is because they have an initial value other than zero to push the system out of its equilibrium state when the simulation is tested. Figure (19) shows the system's behavior when the enrollment fraction is set to zero.

Parameter	Values	Unit	Sensitivity	Uncertainty	Source
Current fraction of GPs per person	0.00252	Dimensionless	High (Numerical)	Low, Data from validated resources	(*Health Resources - Doctors - OECD Data*, 2022), (*Quebec Needs at Least 10,000 New Doctors to Solve Shortage | News*, 2022)
Initial death rate	0.0081	1/year	High (Numerical)	Low, Data from validated resources	(Government of Canada, 2022)
Initial malpractice death rate	0.00115	1/year	High (Numerical)	Low, Data from validated resources	(Charney, 2012)
Initial Workload	7.48k	person/year	High (Numerical)	Low, Data from validated resources	(Gambardella & Lounsbury, 2017)
The desired percentage of GPs	0.0036	Dimensionless	High (Numerical)	Low, Data from validated resources	(OECD, 2021)
Normal number of patients per GP	5.98k	person/year	High (Numerical)	Related to Leverage Point	(Mehlmann-Wicks, 2022)
Time to Accumulate Stress	1	year	High (Numerical)	Moderate	estimated by author
Normal time to decompress	1	year	High (Numerical)	Low, Data from validated resources	(isee ExchangeTM, 2022)
Hospital residency	3,600	person	Moderate (Numerical)	Low, Data from validated resources	(*Quebec Medical Residents Vote to Strike If Contract Negotiations Break down | CBC News*, 2015)
Laval Uni doctor students capacity	223	person/year	Moderate (Numerical)	Low, Data from validated resources	(*Laval University Faculty of Medicine Admission Requirements*, 2020)
McGill Uni doctor students capacity	215	person/year	Moderate (Numerical)	Low, Data from validated resources	(Master Student, 2021)
Montreal Uni doctor students capacity	291	person/year	Moderate (Numerical)	Low, Data from validated resources	(*Enrolment by University - Universities Canada*, 2021)
Normal Capacity Multiplier	1	Dimensionless	Moderate (Numerical)	Related to leverage point, assumption, expected Behavior	estimated by author
Total saved hours per week by PP	4.9	hrs/Weeks	Moderate (Numerical)	Low, Data from validated resources	(Maskrey et al., 2018)
Sherbrooke Uni doctor students capacity	199	person/year	Moderate (Numerical)	Low, Data from validated resources	(*Sherbrooke University Medical School Admission Requirements*, 2020)

Students in Universities (Doctoral Programs)	928	person	Moderate (Numerical)	Low, Data from validated resources	(Lagarda-Leyva & Ruiz, 2019)
Time studying at school	5	year	Moderate (Numerical)	Low, Data from validated resources	(Montreal Gazette, 2020), (Lagarda-Leyva & Ruiz, 2019)

Table (4): Sensitivity analysis results of some exogenous parameters in the model.

One last test of the indirect extreme conditions tests was assuming that no medical students are admitted to medical schools at all; this assumption is tested by assigning zero to the *Current Capacity Multiplier* converter. The observation of the system behavior matched the expectations of the real-world behavior if put under the same test. The system's behavior was the same behavior observed when we put the funds for new medical students equal to zero, which was described above.

5.2.3 Behavior Sensitivity

Sensitivity analysis tests the numerical and behavioral model response to changing and calibrating the values of the exogenous parameters in the system. Suppose the model sensitivity is not similar to the expected sensitivity in the real system; in that case, we conclude that the tested structure confidence is insufficient and requires more study and validation through collecting more validated data about these parameters, which causes the unexpected behavior (Barlas, 1996). The sensitivity of the exogenous parameters was tested against the key performance indicators of the proposed model: the number of medical malpractice death cases, the active GPs stock, the level of workload, and the level of stress.

Table (4) summarizes the sensitivity analysis results performed on the model's exogenous parameters; it only shows the high and moderate sensitive parameters. This table did not report the parameters that showed low or no sensitivity. The bottom line of the sensitivity analysis for the model is that the model showed sensitivity to some parameters that are also sensitive in the real-world system; in addition to that, the model was sensitive to some initial values of some parameters and stocks—details of the sensitivity analysis performed in the proposed model are reported in appendix (B).

5.3 Behavior Reproduction Test

This test is performed on the model using the Business-as-Usual (BU) Scenario; the generated behavior of the model is compared to the available data about the medical malpractice deaths in Quebec, and the number of active GPs serving the local community of Quebec, Figure (20), shows both variables in two behaviors (lines) one represents the historical data, and the other represents the simulated behavior from the proposed model. (Barlas, 1996) indicated clearly that the importance of this type of tests is the pattern of behavior, which includes the trend and the formation of the behavior. The result of this test showed that the proposed model generated a similar behavior with a similar trend and shape of the behavior that is produced using the historical data for both medical malpractice deaths (Charney, 2012) and the number of active GPs in Quebec (Globerman et al., 2018)

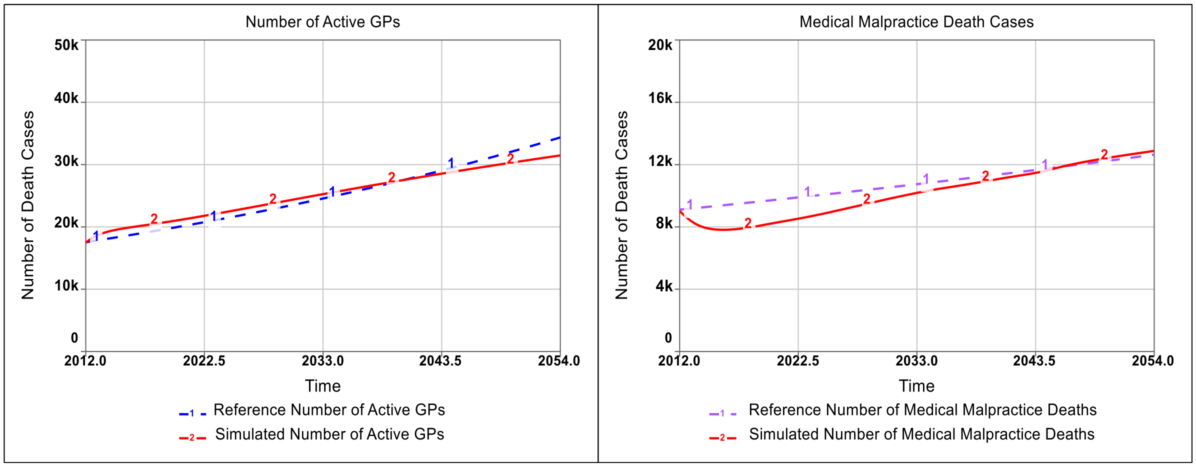

Figure (20): Simulated behavior VS Historical behavior.

6. Scenario Analysis

In this chapter, we will show the various behaviors of the proposed system that are generated by applying three (3) particular scenarios: 1) The Business as Usual Scenario (BU), 2) The Expansion of Medical Schools Capacities Scenario (Grad_Only), and 3) The Expansion of Medical Schools Capacities and Deploying Practicing Pharmacists Scenario (Grad_PP). We will evaluate the results of these scenarios by observing their effects on the key performance indicators, namely, 1) Number of Malpractice Deaths, 2) Number of Active GPs, 3) Level of Stress, and 4) Workload Level. After each scenario, an explanation for the generated behavior will be discussed.

6.1 Business as Usual (BU)

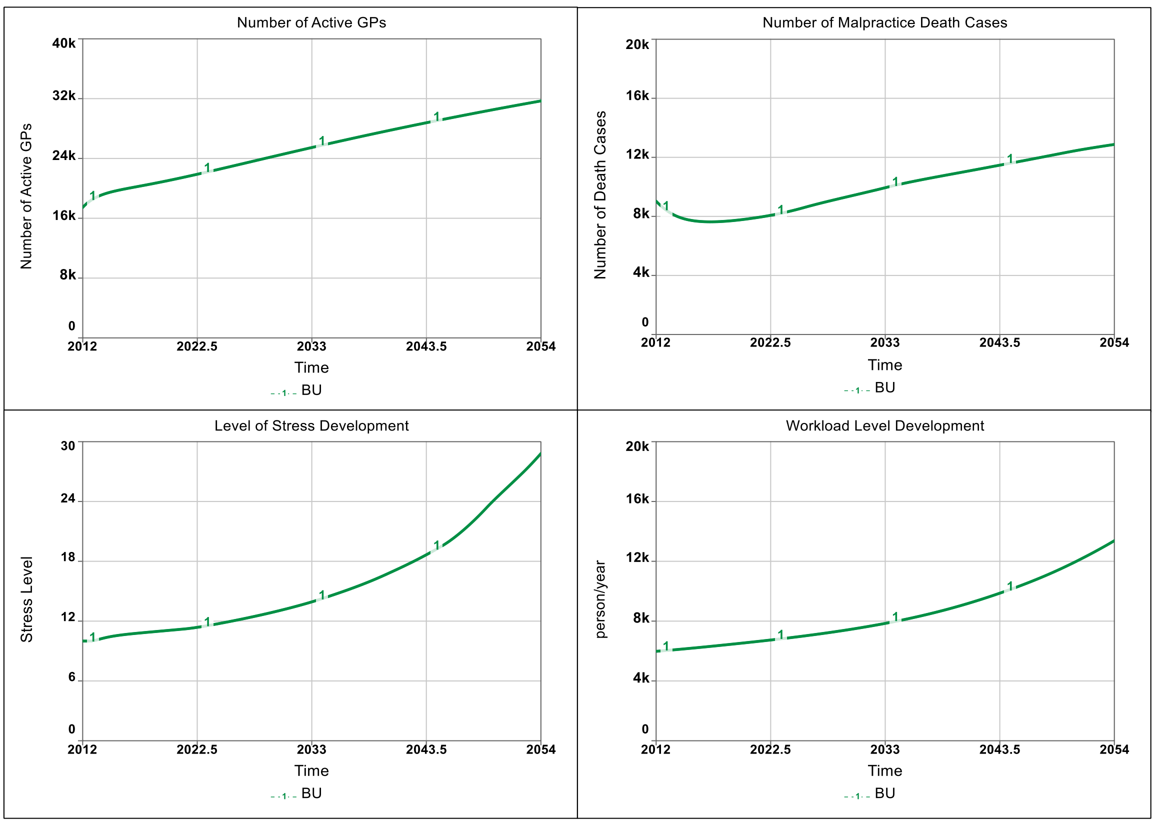

Figure (21): Results of Key Indicators with Business as Usual

6.1.1 Experiment Setup

In this scenario, the medical schools in Quebec are nearly accepting the same number of new students each year, around 928 medical students (Lagarda-Leyva & Ruiz, 2019); this setting is represented by assigning the value of zero (0) to "Switch Graduation Capacity" Converter. Additionally, in this scenario, no corrective actions are taken to decrease the workload and stress on the current active GPs; this is represented by assigning zero (0) to the "Switch Practicing Pharmacists" converter. A 928 new medical students every year will keep the gap between the active GPs in Quebec and the required number of GPs almost stable, and this will remain applied until the year 2054; after that, the gap will increase increasingly. However, this will happen at a time that is out of our model simulation.

6.1.2 Experiment Results

Figure (21) shows the results of the Business as Usual simulation; the number of active GPs is increasing almost steadily from the year 2012 up to 2054; as explained earlier, the gap between the number of active GPs and the number of the required GPs will be rounding at the same average up to the year 2054 (Figure (22)). The number of the current active GPs in 2022 is calculated as follows:

*(2.52/1,000) * 8,604,495 = 21,684 active GPs (OECD, 2021)*

While the ideal number of GPs, as per OECD, should be as follows:

*(3.6/1,000) * 8,604,495 = 30,976 GPs (OECD, 2021)*

So the initial gap in 2022 is about 8,431 GPs.

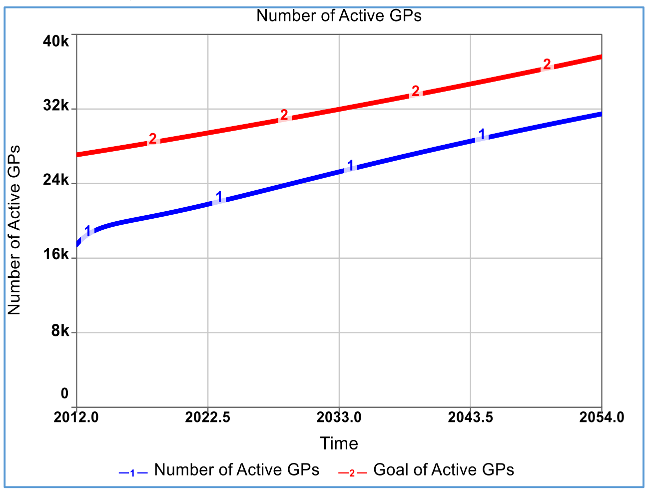

Figure (22): Current Active GPs vs. Goal of Active GPs

As a result of this Gap, an extra workload is put on the healthcare system of Quebec, which appears in Figure (21), where the workload level is increasing almost increasingly because of the continuous shortage of the GPs, which causes more patients to be seen by a GP. It is estimated that a GP will handle around 6,800 patients in 2022 and will have to deal with around 13,500 patients in 2054, which is almost double the number of patients in 2012; the average number of patients a GP should see to maintain the Quality of service and the Safety of the patients is about 5,980 patients daily (Mehlmann-Wicks, 2022).

The increasing number of patients is mainly related to the increasing population of Quebec (see Figure (23)), with about 8,061,101 people in 2012 and will reach 11,200,00 people in 2054 (Institut de la Statistique du Québec, 2022). In addition, the continuous load on GPs generates stress; this stress is quantified and shown in Figure (21) with a behavior that is similar to the workload level; it is observed that all of the key indicators are increasing over time, linearly or increasingly; in this model, the normal stress is assumed to be ten stress units.

Lastly, the stress in the model represents the level of Burnout the GP is suffering because of the extra load she or he is facing continuously; this stress will decrease the level of patient safety and service quality, causing more and more malpractice errors; this is because GPs will suffer from fatigue and anxiety, which will distract the GP, leading to an increasing number of death cases as shown in the upper right graph in Figure (21), where the number of death cases in 2012 is around 9,000 cases. It is estimated to reach up to 12,900 cases in 2054, as shown in the same graph.

6.1.3 Behavior Analysis and explanation

The population in Quebec is suffering from a shortage in GPs with around 8000 GPs, as mentioned previously; the population requires about 30,000 GPs while the currently active number of GPs is about 21,700 GPs; this will activate loop R4 (GPs Demand Loop); this shortage is translated into an excessive workload on GPs measured by the number of patients a GP will meet every year. Furthermore, since the population of Quebec is increasing and will keep increasing every year with a growth rate of 0.158 (*Bouncing Babies: Quebec's Birth Rate Has Returned to Pre-Pandemic Levels | Montreal Gazette*, 2022), the number of patients and the shortage of GPs will keep increasing and expanding, which will keep adding more pressure on the healthcare system of Quebec.

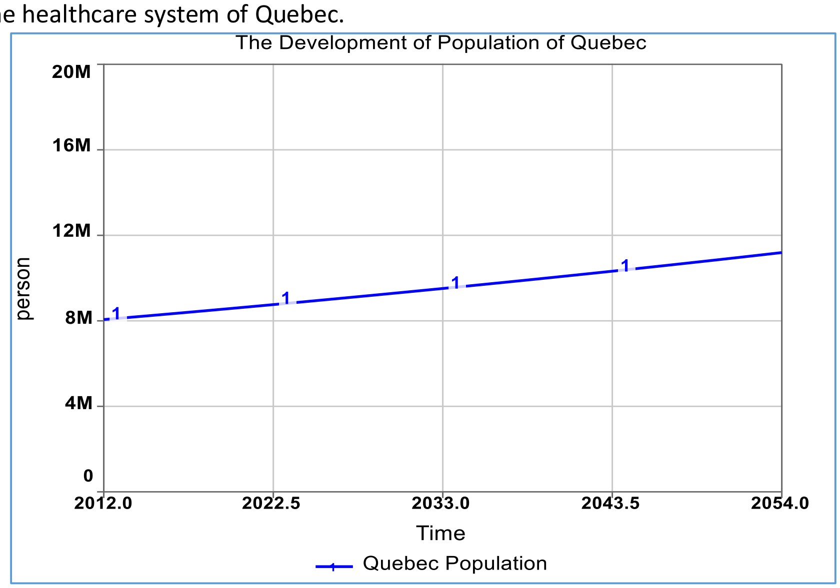

Figure (23): The Development of The Population of Quebec (Institut de la Statistique du Québec, 2022)

The accumulating number of patients pushes the level of the workload from 6,740 in 2022 to 13,400 patients yearly in 2054; the increasing number of patients stimulates loop R2 (Stress/Workload Interaction Loop), which is driven by the influence of loop R4 (GPs Demand Loop). Therefore, by changing the workload level in the same direction, the patients' number is changing; the stress level will respond to this increased workload and will also increase.

The relative workload affects the efficiency of productivity; Figure (24) shows the significant difference between the inflow and outflow of the workload level in the current scenario; the excess workload decreases the efficiency of productivity, which will decrease the removal of workload by weakening the

Workload Loop (loop R1) and increases the addition of workload by reinforcing the Stress/Workload Interaction Loop (loop R2), this will increase workload level and as a consequence increasing the Stress level.

In this scenario, the effect of workload on stress is quantified and translated into stress units; in the year 2012, the stress level is initiated in a value of 10 stress units, and it increases increasingly as the workload increases, it will reach a value of 28.8 stress units in 2054, this is because of the significant increment in the number of patients a GP will see every year, this is a translation of loops R2 and R4 activities.

The high level of stress has terrible consequences on the level of patient safety and service quality; both will decrease as long as the stress on GPs increases; it is estimated that the level of safety and service quality decreases by around 30% in total when the stress is high or doubled (Motluk, 2018). Therefore, in the Business-As-Usual scenario, the value of the patient's safety and service quality (PSQS) is assumed to be almost 0% and will reach a maximum of 30% in best scenarios; this is because of other factors that affect

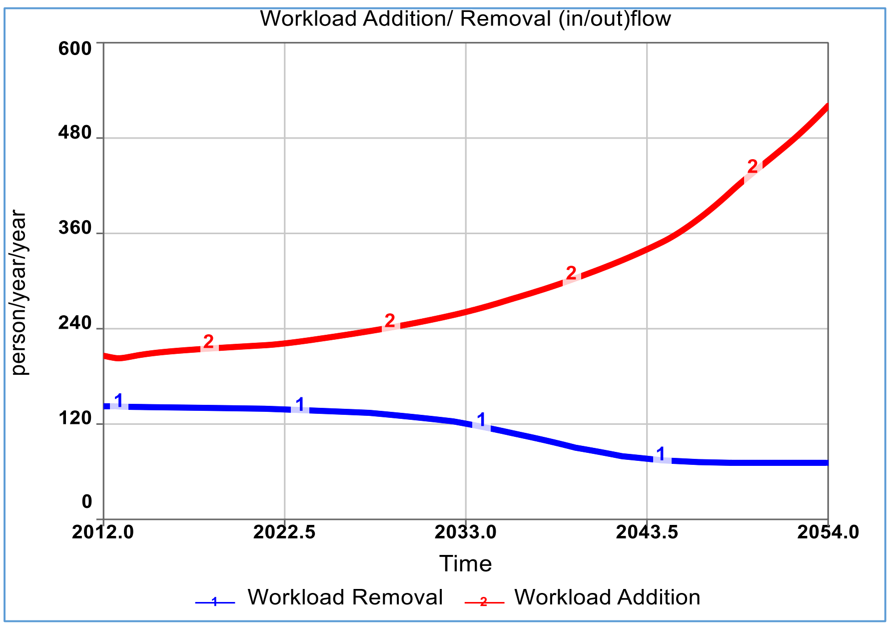

Figure (24): Workload Addition/ Removal (in/out) flow.

the level of Safety and Quality that are not covered by this research. These factors constitute 70% of the level of Patient Safety and Quality of Service (PSQS), such as organizational change factor, material Quality, equipment functionality factor, and many other factors that are not included in the model (Charney, 2012).

Because of the compromised level of Safety and Quality of Service, the number of medical errors will increase, leading to an increasing number of death cases, decreasing, slightly, Quebec's population by 12,900 persons in 2054 alone.

6.2 Expansion of Medical Schools Capacities Scenario (Grad_Only)

6.2.1 Experiment Setup

In this experiment, we will expand the medical schools' capacity in order to admit more new medical students to increase the number of graduating GPs in Quebec; this is supposed to mean more active GPs, lower workload and stress, better service, and safer patient treatment.

To set up this scenario, we assign the value of one (1) to the "*Switch Graduation Capacity*" Converter and the value of zero (0) to the "*Switch Using Practicing Pharmacists*" Converter, leaving the budget switch on the value of one (1); assuming that the authorities will approve the total amount of the required budget to provide funds for the new medical students, by this, we guarantee having the full effect of this intervention.

6.2.2 Experiment Results

The "Expansion of Medical Schools Capacities" intervention will noticeably affect all the key indicators. However, since medical students must spend at least seven years studying and training before being allowed to practice medicine, the effect of admitting more new medical students will not appear as quickly as expected; it will take years to observe a significant change in the KPI's; this means that the workload will remain higher than the normal level, especially in the first few years of the simulation, and this will be reflected on the stress level as well, leading to a lower patients' safety and service quality (Figure (25)).

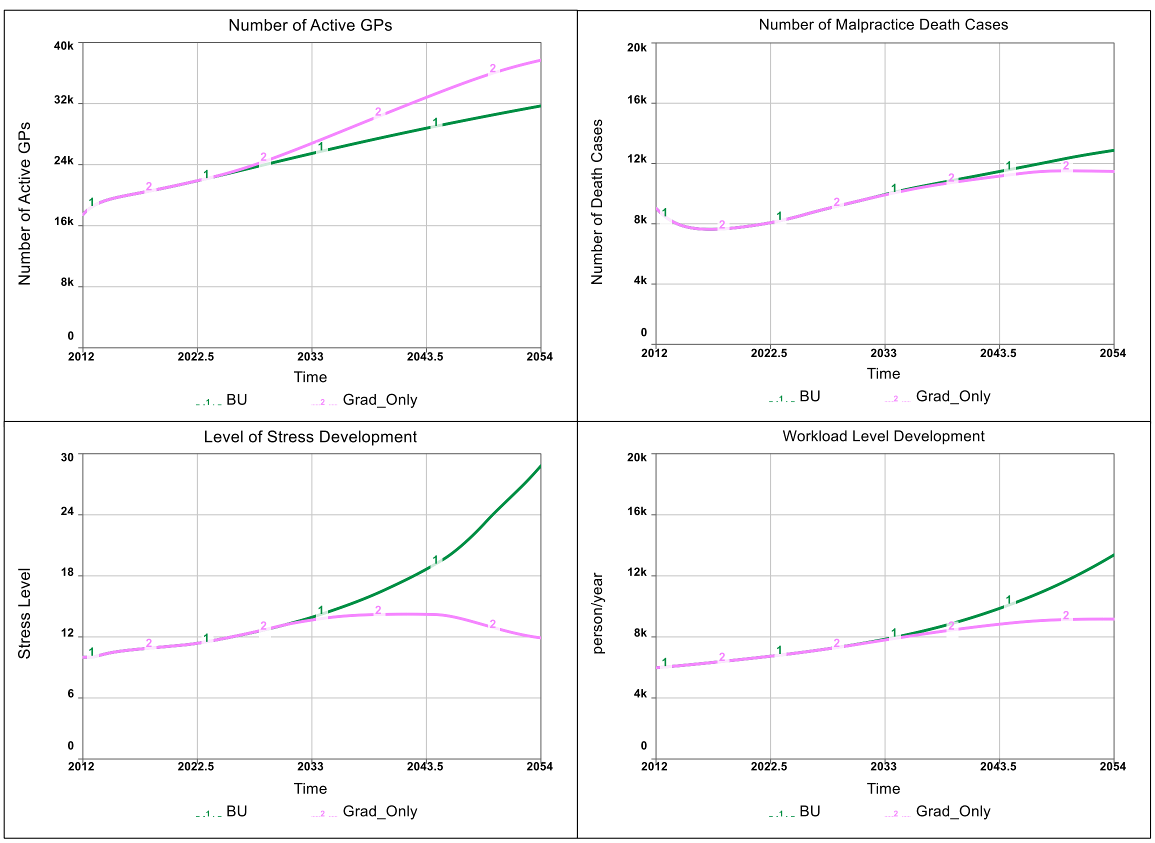

Figure (25): Results of BU vs. Grad_Only Scenarios.

This intervention will increase the number of new medical graduates joining the active GPs pool, and the gap between the active GPs and the required GPs will be covered at the end of the simulation, as shown in (Figure (27)). However, the workload will remain higher than the average level during the simulation duration due to the medical students' delay in graduating; the workload will be around 9,170 patients 0n 2054. Also, while waiting for the new GPs to start practicing medicine in Quebec, the currently working GPs will remain under stress and pressure for a long time because of the consistently high workload. Covering the GPs shortage will reduce the stress towards the average level, but it will not reach it during our simulation time; however, this drop in the stress level will appear partially in our simulation.

As mentioned above, the excessive workload will add more stress on the working GPs, meaning less patient safety and service quality, which may cause more death cases related to medical malpractice (Figure (25). Table (5) summarizes the results of BU and Grad_only scenarios.

Table (5): Numerical Simulation Results in 2054 for BU and Grad_Only

Indicator (year 2054)	**Business As Usual (BU)**	**Grad_Only Intervention**
Number of MDC	12,900 Person/Year	11,500 Person/year
Number of Active GPs	31,700 GP	37,700 GP
Workload Level	13,400 person/year	9,170 person/year
Stress Level	28.8 Stress Unit	11.9 Stress Unit

6.2.3 Behavior Analysis and explanation

In the Grad_Only scenario, the intervention will be initiated by the expansion of the universities capacity to admit more new medical students. It is estimated that the maximum expansion of the universities capacity will not exceed 41% to achieve the goal of this simulation; this expansion is estimated to take about six years to implement (*Quebec Expands Admissions to Medical Schools by More than 100 | Montreal Gazette*, 2020); this is due to the technical, fiscal, and social challenges that come with this expansion (Wheat & Bardach, 2018). With this intended expansion, the Medical Students Recruitment Loop (loop B3) will be activated, adding new qualified medical students to universities; after years of study and training, the recruited medical students will graduate and join the active GPs society (Loops B1 and B2). The interaction between (loops B2 and B3) will keep adding more medical students to medical schools and more GPs to the active GPs community until the gap between active and desired GPs approaches zero; before reaching this value, the universities' capacity will shrink and adjust according to the changing goal, which will be getting smaller and smaller in this scenario. The amount of workload will not be changed quickly, as mentioned before; this will keep the workload accumulating at a high rate because of the power of (loop R2) and the weakening of (loop R1), as (loop R2) will be enforced by the time and volume of the GPs shortage; this behavior is observed between the years 2022 and 2032, after 2032 the workload will start decreasing in the next 20 years until 2054, here (loops R1) starts to be more potent than (loop R2). In 2034, the increasing number of GPs will cause a weakening in the workload addition (loop R2), and it will empower the work removal loop (R1); meanwhile, (loop R4) will keep demanding more active GPs as long as the gap between current and required GPs is not covered.

The dynamics in workload developments loops (R1, R2, R4) are affecting the stress development loops (R2, R3); by adding more workload to the system due to the shortage of GPs, the stress level will keep increasing increasingly, as seen in Figure (25) between the years 2022 and 2032 (loopR2), after that, from 2033 until 2045 the stress level will start increasing decreasingly slowly, we can say it is almost stable in this period; because the amount of added stress is equal to the amount of decompressed stress due to the balance between loops (loop R2) and (loop R3), also the weakening of loop (R4) this is because the gap between the active and required GPs will be shrinking significantly, which means a decreasing demand of new GPs. Between 2045 and 2054, the stress level will decrease almost linearly because the effect of the new joining GPs who are covering the gap is removing the workload on current working GPs; this will enforce (loop R3), releasing GPs from stress, weakening (loop R2) and enforcing (loop R1), as (loop R2) is empowered by the demand on GPs that is influenced by the power of (loop R4); which becomes weaker when the gap in current and required GPs become small.

As a GP, a high workload means more patients to handle every day; more patients mean more stress, and with more stress, the probability of medical malpractice errors will increase, leading to more death cases related to medical malpractice. In the Grad_Only intervention, the stress level will be higher than the normal stress in most of the simulation duration; because the working GPs' stress and workload will not be treated quickly; it will be delayed until a sufficient number of new GP graduates will join the active GPs pool. In Figure (25), it is observed that medical malpractice death cases (MDC) will keep increasing in the same pattern as the BU scenario until the year 2034; after that, the number of MDC will start increasing decreasingly because new GPs will start to join the active GPs community, MDC will be decreasing in comparison with BU scenario; however, it will stop increasing in 2047, and it will stabilize until the end of the simulation.

Due to the stress and workload that accumulate all the years (loop R2, R4), the efficiency of this intervention will have less impact on the number of medical malpractice death cases (Figure (25)); it is expected that the effect of this intervention will take longer time than our simulation end time in order to reach a limit which is near the normal levels of stress and workloads.

6.3 Expansion of Medical Schools Capacities and Deploying Practicing Pharmacists Scenario (Grad_PP)

6.3.1 Experiment Setup

In this scenario, two leverage points are used to tackle the problem in this study. The first one is by changing the medical schools' capacity in order to admit more new medical students every year; the standard capacity for the medical schools is about 928 new students yearly (Lagarda-Leyva & Ruiz, 2019); this intervention will increase the capacity to reach a maximum of 1,390 new medical students each year, with an increment of 460 students. A previous expansion in Quebec medical schools was applied two years ago, and it took almost three years to add 140 new seats to the medical schools' capacity (*Quebec Expands Admissions to Medical Schools by More than 100 | Montreal Gazette*, 2020). This intervention is represented by assigning the value of one (1) to the "Switch Graduation Capacity" Converter.

The second leverage point is proposed to decrease the workload on a GP by using the aid of clinical pharmacists saving the GP almost 4.9 hours of work every week (Maskrey et al., 2018); this will be translated into more patients a GP can treat, decreasing the workload on her/him; this setting is applied by assigning the value of one (1) to "Switch Using Practicing Pharmacists" Converter.

This scenario's main objectives are to cover the shortage in the current number of active GPs in Quebec through the coming (32) years; however, covering the shortage of active GPs will take a long time, leaving the current active GPs stressed and overloaded for a significant period of time, which will negatively impact the Patients' Safety and Quality of Service. Therefore, immediate action is required to help the currently stressed working GPs, by deploying Practicing Pharmacists (PP) who will release them from a portion of the exhausting overload of patients.

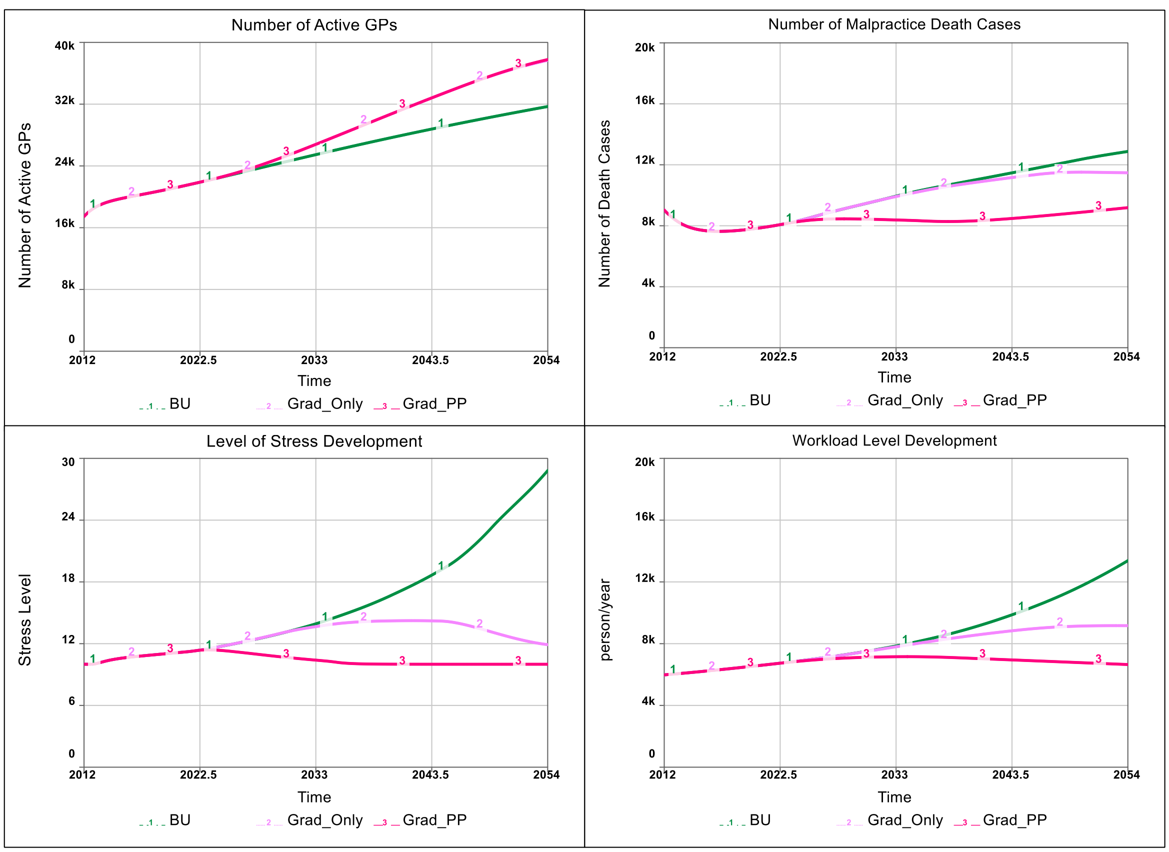

Figure (26): Results of Grad_PP Scenario.

6.3.2 Experiment Results

Figure (26) shows the response of the key indicators to the expansion of the medical students' capacity in the universities and including practicing pharmacists in the GPs' general practice.

The expansion of the medical schools' capacity in Quebec

As mentioned earlier, the average number of newly admitted medical students is about 928 yearly (Lagarda-Leyva & Ruiz, 2019); by The expansion of the medical schools' capacity intervention, we will increase the medical schools' capacity to reach a level that will cover the gap between the current number of active GPs and the required number of GPs. Admitting new medical students will eventually lead to the graduation of more GPs; this will shrink the gap mentioned earlier. Figure (27) shows the effect of admitting new medical students into medical schools on the gap between the goal number of GPs and the current number of GPs.

The workload on GPs will be spread between the current and new GPs joining the health service; this will decrease the workload on each GP. However, in this scenario, the workload is also mainly affected by the deployment of practicing pharmacists; they are the main reason for the stable workload that appears in Figure (26); this is because of the effect of the practicing pharmacist (PP) on the workload which will appear relatively quickly while waiting for the new GPs to graduate which will take almost seven years to join the active GPs community, which showed a slower effect on the workload in the Grad_Only scenario. Because of the stabilized workload, the stress level will also be stabilized. A stabilized stress on a normal level means that we accomplished an increment of 30% in Patient Safety and Quality of Service (PSQS); this is the reason that the number of death cases caused by medical malpractice decreased from 12,900 cases to almost 9,190 deaths in 2054.

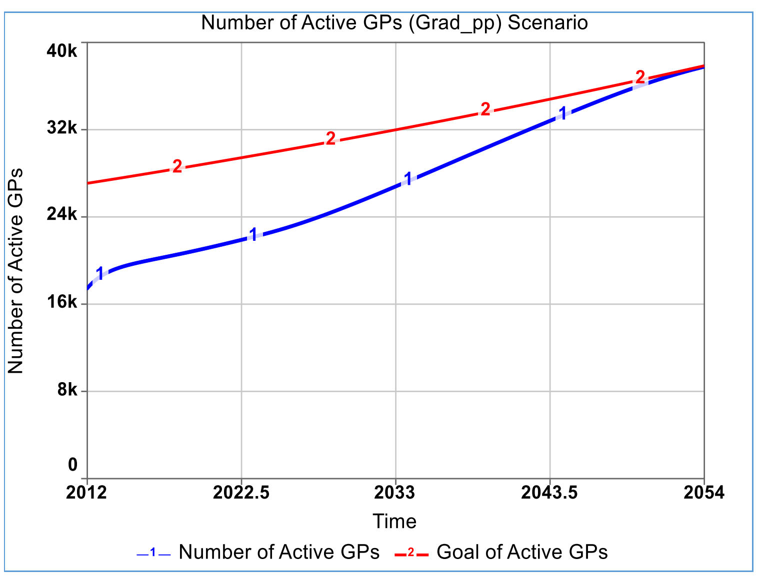

Figure (27): The Development of active GPs (Grad_PP & Grad_Only) Scenarios.

In order to attract highly qualified students from schools to apply for medical schools in Quebec instead of other schools in other provinces, a fund is allocated to cover the tuition fees of medical study at these schools, which is about 5,000 CAD yearly (*Medical Schools in Quebec in 2022*, 2022), and a stipend of 1,000 CAD monthly is paid for each admitted medical students. The Education Ministry or any other authorized government body must approve this added budget; for this reason, a switch was added in order to give a possibility that 1) the budget will be fully approved, 2) the budget will partly be approved, or 3) the budget will not be approved at all, which means that the *"The expansion of the medical schools' capacity in Quebec"* intervention will not be activated at all, this will return the simulation to the Business as usual (BU) scenario. The default value for the converter "Switch Approved Budget Percentage" is set to one. It is essential to mention that the approved percentage of the budget should not be less than 85% of the total budget in order to be effective within the simulation timeline. If the budget switch is set to zero then the simulation will be the same as the BU scenario; if the value of the witch is set to 2, then it will approve 85% of the required budget, shrinking the gap between the current and the required number of GPs to some sufficient level.

Deploying Practicing Pharmacists to help GPs in their daily tasks intervention

Deploying practicing pharmacists to help the GP with her/his daily tasks saves around 4.9 hours of work every week (Maskrey et al., 2018); this time is enough to treat about 14 extra patients every week per GP, and more than 740 patients every year, which constitute more than 12% of extra productivity for a GP, this number of patients will be subtracted from the excess number of patients a GP should see, releasing the GP from the extra workload and stress leading to fewer death cases because of medical malpractice errors by 30%. Together, this intervention and the abovementioned intervention will achieve the results discussed earlier in Figure (26). Table (6) summarize the results of BU, Grad_Only, and Grad_PP scenarios.

*Table (6): Numerical Simulation Results in **2054** for BU, Grad_Only, and Grad_PP*

Indicator (2054)	Business As Usual (BU)	Grad_Only Intervention	Grad_PP Intervention
Number of MDC	12,900 Person/Year	11,500 Person/year	9,190 Person/year
Number of Active GPs	31,700 GP	37,700 GP	37,700 GP
Workload Level	13,400 person/year	9,160 person/year	6,390 Person/year
Stress Level	28.8 Stress Unit	11.9 Stress Unit	10.1 Stress Unit

6.3.3 Behavior Analysis and explanation

By expanding the medical schools capacity, a new goal will be set for recruiting new medical school students; this will activate *The Medical Students Recruitment* Loop (loop B3), increasing the new medical schools' students from 928 students to 1,330 starting in 2022 up to 2043; after this year the recruitment will decrease decreasingly up to 2054, this is because the recruitment gap between the goal and the desired new medical students will be closing (Figure (28)).

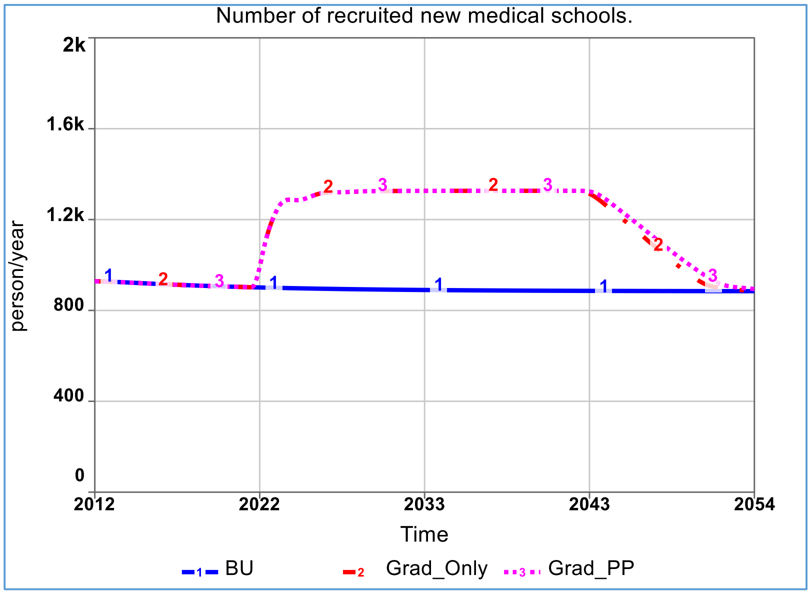

Figure (28): Number of Recruited New Medical Students

Recruiting more new medical students will increase the power of the Medical St. Supply Loop (loop B2), causing more GPs to graduate, which will empower the GPs Supply Loop (loop B1), eliminating the shortage in GPs by the year 2054.

Figure (27) shows the development of the active GPs community when we apply the Grad_PP scenario; this scenario will take place in our simulation starting in 2022. It is noticed that the number of active GPs will increase in the same slope it is increasing in the BU scenario between the years 2022 and 2027; this is because of the delay in the increasing number of recruited new medical students (Medical students Recruitment Loop B3), also, because each student will need about seven years to graduate and finish the medical training before joining the pool of the active GPs (loops B1, B2). Starting in 2030, after nearly 7 to 8 years, the number of active GPs will increase increasingly until 2050; then, it will start to increase decreasingly because it will be approaching the value of the required number of active GPs (the goal); in the last four years, the goal will be almost reached (Figure (27)).

The effect of deploying practicing pharmacists is significant on the workload on GPs; this is the reason why the workload is around the normal value of 10 stress units from the beginning of the simulation (see Figure (26)).

Table (7): The Development of Medical Malpractice Deaths (BU, Grad_Only, and Grad_PP)

Years	BU Scenario	Grad_Only Scenario	Grad_PP Scenario	Potential Saved Lives (*Grad_Only)*	Potential Saved Lives (*Grad_PP)*
2012	9.03K	9.03K	9.03K	0	0
2018	7.66K	7.66K	7.66K	0	0
2024	8.30K	8.30K	8.26K	0	40
2030	9.41K	9.41K	8.44K	0	970
2036	10.4K	10.4K	8.30K	0	2,100
2042	11.30K	11.00K	8.40K	300	2,900
2048	12.10K	11.50K	8.76K	600	3,340
2054	12.90K	11.50K	9.19K	1,400	3,710

Practicing Pharmacists (PP) will take care of the excessive number of patients who are identified as the number of patients that *exceeds* the maximum average number of patients a GP can treat daily, which is around 23 patients daily, which equals 5,980 patients every year (Mehlmann-Wicks, 2022). The number of patients a practicing pharmacist can manage is shown in Figure (29). The mechanism that is used in this intervention is that in 2022 the practicing pharmacists (PP) will start their duties in helping GPs in managing the excess number of patients; the maximum number the PP will manage will be at its highest in 2033 after that it will start decreasing (see Figure (29)), this is because new GPs will start joining the active GPs increasingly after around seven years of study and training. After 2040, the number of patients handled by PP will start decreasing increasingly until 2050; it is observed that the number of excess patients a PP is managing will drop rapidly in this period of time because many new GPs will be graduating and joining the active GPs pool (Figure (29)). In this scenario, we assumed that the new GPs will always replace the working PP, which is why the number of patients a PP is managing will drop after 2040.

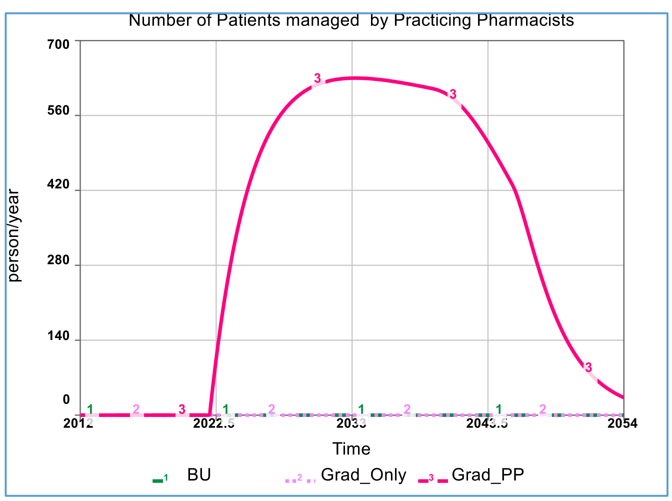

Figure (29): The number of Patients a PP can manage

Between 2050 and 2054, a drop in the number of patients managed by PP will smoothly take place; this is because it is assumed (in the model) that when the excessive number of patients becomes less than 250 patients every year, the need for PP will vanish; we assumed that it would take three years (delay) to deactivate the use of the remaining working PP, and entirely depend on GPs (Figure (29)). Deploying PP will regulate the workload, which will regulate the stress level around the normal levels, increasing the patient's safety and quality of service to a maximum of 30% and reducing the number of deaths caused by medical practice, as detailed in Table (7).

7. Conclusion and Discussion

In this chapter, we will summarize the findings of this study; and relate them to the research objectives and questions. Also, we will describe the study's contributions and list the main limitations of this study in addition to the recommendation for future work on this research.

7.1 Summary of chapters and Answers to Research Questions

Chapter (1) describes the problem of the increasing number of medical malpractice deaths in Quebec by providing a comprehensive background about the current situation generally in Canada and particularly in Quebec, with a brief about the situation in other OECD member countries like USA and UK. Also, chapter (1) describes the framework in which this research will investigate; this framework will cover the key drivers which cause the increasing number of MDC; these drivers are the current number of active and working GPs, and their burnout level, which is represented by workload and stress levels on active GPs.

In addition to research questions, this chapter included the research objective, which is capturing the main structure that causes the problem of the increasing number of death cases caused by medical malpractice in Quebec, and revealing the underlying dynamic relations using the System Dynamics (SD) approach.

Chapter (1) answers *the* first question in this study, which is,

What are the drivers that increase the number of death cases caused by medical malpractice?

As mentioned above, the critical drivers found by reviewing literature are the shortage of active working GPs, their current workload, and the stress generated due to excessive workloads, altogether causing a significant drop in patient safety and quality of service provided to patients, causing more medical errors, leading to more MDCs.

In order to combine qualitative concepts with quantitative concepts in one frame or model, we used Systems Dynamics (SD); SD is a unique approach that allows us to study the interactions between these two types of variables. Chapter (2) summarize the methodology used in this study, along with assumptions and research ethics applied in the research; it also explains why using SD is a feasible approach to achieve the objective of this study.

After identifying the main drivers for this study problem and determining the methodology, we proposed a dynamic hypothesis, which is explained in chapter (3); this hypothesis is presented using a CLD that helped us to develop an operational model; additionally, this CLD allowed us to determine and describe the main feedback loops that formulate the proposed dynamic hypothesis.

The Stress feedback loop (loop R3) and its interaction with the workload loop (loop R1) are the direct motivators for the change in patient safety and quality of service, which in turn affect the change in MDCs. The GP demand loop (loop R4) transfers the pressure caused by the shortage of GPs to the loops mentioned above. The GP demand loop (loop R4) will be weakened only if the GP supply loop (loop B1) is highly activated to provide it with the required graduated GPs. Inside this dynamic mechanism, there is an internal engine that powers other loops; it is the recruitment of new medical student's loop (loop B3), which provides new highly qualified medical students to universities, who will eventually become registered working GPs in Quebec.

Thus, chapter (3) answers the second question in this study, which is:

What are the key feedback loops that control the changes in malpractice death cases over time?

By defining the feedback loops that represent the proposed dynamic hypothesis, we conceptualize them along with the variables and parameters connected to them; we used the reviewed secondary literature for this purpose. After developing an operationalized computational model, we described the different structures of this model, specifying the literature and logic used to build these dynamic structures. Chapter (4) details the whole model and its sectors, answering the third question of the study:

What are the dynamic structures behind these drivers which lead to the Malpractice Death Cases?

In order to add creditability to the developed model and its components, we put the proposed model under different tests; these tests and their results are explained in detail in chapter (5). The results of these tests confirmed the presence of adequate confidence in the proposed model; however, the stress structure and its effect on patient safety and quality of service, which in its turn affects medical malpractice deaths, produced a level of uncertainty because of its qualitative nature that can be quantified under various rules and conditions. However, this part of the model successfully demonstrated an acceptable level of parameter representation; this is proved by its contribution to regenerating the reference mode that is presented in chapter (1)—completing all the validation tests showed that the proposed model had captured the required dynamics of the problem at hand with acceptable and reasonable confidence.

In Chapter (6), we described, in detail, the simulations that were run using the computational model; it started with the simulations setup, followed by the results of the simulations, which were used to construct the analysis of these results.

The findings from these simulations support the dynamic hypothesis explained in chapter (3), which suggests that *one of the main reasons for the deaths caused by medical malpractice errors is the shortage of GPs in Quebec, as this shortage compromises patient safety and quality of service, leading to potential injuries causing deaths. Therefore, covering the shortage of GPs in Quebec is supposed to solve the problem*.

It was observed that in all the experiments, an increase in the number of GPs will decrease the workload on them, which will decrease their stress level; a decreased level of stress means better patient safety and service quality, which will lead to less number of death cases caused by medical malpractice errors. However, the results of the simulations revealed an important key finding: the decrease in medical malpractice deaths depends not only on the number of active GPs in Quebec but also depends on the level of the *current* GP's Stress; this stress needs to be decompressed as quick as possible; with proposing the inclusion of the practicing pharmacists (PP) in the general medical practice, Stress on GPs will start to decompress, as the PP will take care of some of the GPs tasks releasing these GPs from extra workload, decreasing their stress level; this proposal will formulate a significant milestone in this study. PP's contribution takes place from the beginning of applying the Grad_PP scenario in 2022, which will release the *currently* active, stressed GPs from excessive workload; rather than waiting for the new graduating GPs who will start to join the active GPs after many years. By the time waiting for new GPs to graduate, the workload will stay high, and the stress will keep accumulating for a long time year after year; this consequence was observed in the Grad_Only scenario, while in the Grad_PP scenario, the results were more promising because of the deployment of PP.

Therefore, to reflect this finding, we modify the hypothesis to the following: *by increasing the number of active GPs and the support of practicing pharmacists for the current active GPs, the number of medical malpractice deaths will decrease significantly.*

The proposed model serves as proof of the impact of increasing the number of active GPs with the support of practicing pharmacists on saving the lives of patients who might be in danger of medical malpractice errors which occur because of the high levels of stress GPs suffer from due to the high workload.

7.2 Model-Based Policy Insights

In chapter (6), the different simulation scenarios were tested and analyzed; based on the analyzed results, we identified the universities capacity as a leverage point as the model showed a high behavioral variation when changing the value of this capacity. By increasing the value of the universities' capacity, we observe an increasing number of graduating GPs joining the active GPs community; this will decrease the GPs' workload and stress, which will be followed by a decreased number of deaths caused by medical malpractice errors. However, the stress will be higher than normal levels by using the universities' capacity alone as an intervention, which means that the quality of service is still in a low level which reflects on the medical malpractice deaths; therefore, through the analysis of simulations in chapter (6) and the sensitivity analysis performed in chapter (5), we found another leverage point that has a significant impact on the system, which is the number of patients a GP manages every year, here, we decrease this number by adding a simplified intervention structure; this structure represents the deployment of practicing pharmacists (PP) who will help the GPs in some of their tasks towards their patients; this will release the GPs from the burden of the excessive number of patients, decreasing the number of patients a GP will see to the normal levels; by doing so, the workload will decrease – *workload represents the number of patients a GP handles every year*- decreasing the stress on GPs, enhancing the service quality and patients safety, decreasing the number of lives that might be lost due to medical malpractice errors caused by the GPs' burnout. Thus, this description represents the answer to the fourth question of this study which is:

What are the leverage points in the model that can lead to a reduction in the number of malpractice death cases (MDC)?

The answer to the fourth research question specified the leverage points found in the system; based on that, we will deliberate on their implications for policy design. We will infer the insights from the developed model regarding expanding the medical schools' capacity; also discuss the implications of deploying practicing pharmacists as assistants for the currently working GPs.

In the beginning, we reflect on the need to expand the medical schools' capacity for admitting new medical students every year, which will empower the GPs' supply loop, enabling the number of active GPs to grow year after year. After that, we consider the need for the practicing pharmacists' intervention since the number of patients a GP must manage every year exceeds the safe number of patients she/he should see, even when the medical schools' capacity is already expanded.

7.2.1 Medical Schools' Capacity

The medical schools' capacity showed that the regular capacity (928 medical students yearly) is insufficient to graduate an adequate number of new medical students that will cover the shortage of GPs in Quebec (BU scenario). Therefore, shedding light on this leverage point advises the decision-makers to consider a policy design that controls the mentioned capacity in order to adapt to the changing number of active GPs in Quebec; the experiments in chapter (6) are proof of the validity of this expected implication.

7.2.2 Practicing Pharmacists' Intervention (PP)

Proposing the inclusion of practicing pharmacists into the general medical practice in Quebec opens new dimensions for more innovative policy design; the main expected implication of this leverage point is that the policymakers in Quebec can deploy healthcare practitioners other than GPs in the general medical practice in order to reduce workload and stress on the working GPs, this will need a deep technical study about the GPs' tasks that can be delegated to other healthcare practitioners.

The aim of deploying healthcare practitioners is to help GPs in their daily work, leading to lower workload and stress in a shorter time as possible, by this policymakers can focus on another potential solution, which is considering activities that can speed up the decompressing of stress, the time of decompressing was identified as a potential leverage point that can affect the stress accumulated on GPs, therefore, as an implication of this study, the decompressing of stress can be further studied looking for reasonable policies to tackle the problem of accumulated stress on GPs.

The above three paragraphs answer the last question of this study which is:

What are the main implications related to policy implementation?

7.3 Limitations and Future work

7.3.1 Limitations

In this study, we identified the major leverage points that could influence the proposed system behavior; these points suggest potential starting points for intervention; however, this system has some reasonable uncertainties that prevent proper policy implementation. Moreover, the proposed mode is meant to help the decision-makers to focus on the found leverage points; it is not meant to include any policy implementation structure; therefore, it is not possible, using this study, to discuss the policy implementation efficiency, neither suggesting any expectations about future policy resistance. As a result, this study can help only in designing policies, encouraging additional modeling for structures that might be policy implementation, or stimulating more policy research.

Policy implementation has several feasibility-related challenges, such as political, technical, and administrative feasibilities (Wheat and Bardach, 2018). In the context of this study, it is expected to have costs for expanding the medical schools' capacity; these costs might be required for recruiting more faculty members or for expanding or preparing new buildings for medical study and training. Moreover, new GPs graduating from medical schools require salaries and compensation plans to work within the healthcare system; the same applies to practicing pharmacists (PP) who will be deployed within the general practice in Quebec. PP will also need extra training for their new tasks, which means extra cost, not to mention the time required for deploying them properly inside the general practice system. These costs and delays are only a short brief of the expenses that might be required when considering the policy implantation, and they are not captured in this study, which reflects an important limitation of the study.

A critical limitation in this study is the lack of updated, accurate data about medical malpractice death cases not only in Quebec- Canada but in many other countries, including the members of the OECD; it is estimated that only 10% of these deaths are reported (Anderson & Abrahamson, 2017), therefore more trusted data sources are required to add more confidence in the proposed model.

The uncertainty that exists in some parts of the proposed model is formulating a fundamental limitation, specifically in the structures that represent the stress level and its effect on patient safety and quality of service; the data about this part of the study is extremely limited; which challenges the validity of this particular structure.

7.3.2 Future work

This study has suggested a theoretical solution for the causes responsible for about 30% of deaths related to medical malpractice errors. However, as mentioned above, this study has limitations that can be used as a kick-start for future work. Some of the suggested ideas that are recommended for additional research are as follows:

- This study can be extended to include the effect of immigrant GPs as an additional inflow for the active GPs community. By studying the dynamics of immigrant GPs, it will be possible to find ways to encourage them to immigrate to Quebec, saving time and costs for the authorities in Quebec.
- Extending the model to add structure for implementing policies that are related to the leverage points discussed in chapter (6).
- As mentioned in this study, our proposed model is meant to address only 30% of the deaths caused by medical malpractice errors; therefore, it is reasonable to extend this study to include other factors that contribute to this type of death (Anderson & Abrahamson, 2017). These factors include the organizational change in response to medical malpractice errors, enhanced medical equipment and materials, and continued training for GPs and other healthcare practitioners.
- In this study, a simplified structure of stress and workload was developed; an in-depth study for stress and burnout, searching for the endogenous reasons inside its dynamics, can be a significant contribution to this study.
- By further research, this study can be used to plan for a more resilient and sustainable healthcare workforce for Quebec in the future.
- The proposed model in this study can be modified to be used for other provinces or countries that might suffer from a similar problem.

At last, this study proposed a simplified model representing the complex problem of medical malpractice deaths, GP working conditions, and their supply/ demand dynamics; it provides a deeper understanding of the problem using the System Dynamics approach, shedding light on where to look for solutions for this problem.

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Appendices

A. Simulation Experiment Setup Report

This appendix is prepared to provide the guidelines for the replication of the simulations in chapter (6).

The software used for developing the model is:	Stella Architect 3.0.2
Integration Method:	RK4 Integration
Simulation Start Time:	2012
Simulation End Time:	2054
DT = 1/72 Time Units:	Years

Business as Usual Scenario (BU)

Table (8): Parameters Values and Units for BU Scenario.

Parameter	Values	Unit
"New_Med._Students"(t)	INIT "New_Med._Students" = 928	person/year
Accumulated_Budget(t)	INIT Accumulated_Budget = 5000000	CAD/year
Hospital_residency(t)	INIT Hospital_residency = 3600	person
Quebec_Population(t)	INIT Quebec_Population = 8061101	person
Reference_Number_of_GP_in_Quebec(t)	INIT Reference_Number_of_GP_in_Quebec = 17550	GP
Students_in_Specialty(t)	INIT Students_in_Specialty = 130	person
"Students_in_Universities_(Doctoral_Progr ams)"(t)	INIT "Students_in_Universities_(Doctoral_Progr ams)" = 928	person
"Drs._retirement_age"	68	year
"Fraction_of_Unmatched_._Students"	1.2/100	dmnl/year
"Growth_Rate_in._GPs_in_Quebec"	1.6/100	dmnl/year
Birth_fraction	0.0158	1/year
Current_Capacity_Multiplier	1	dmnl
Daily_working_hours	8	hrs/day
Dropout_fraction	0.05	1/year
Duration_of_residency	2	year
Duration_of_specialization	7	year
Fraction_of_dropping_doctors	0.05	dmnl/year
Fraction_of_Students_Specialization	0.2	1/year
Initial_death_rate	8.1/1000	1/year
Initial_malpractice_death_rate	0.00115301	1/year

Initial_Workload	5980	person/year
Laval_Uni_doctor_students_capacity	223	person/year
McGill_Uni_doctor_students_capacity	215	person/year
Montreal_Uni_doctor_students_capacity	291	person/year
Normal_number_of_patients_per_GP	23*5*52	person/year
Normal_Stress	10	stress unit
Normal_time_to_decompress	1	year
Normal_Time_to_recruit	0.5	year
Normalization_Factor	10	dmnl
Number_of_GPs	17454	person
Number_of_saved_hours_by_PP_per_day	0.9	hrs/day
Number_of_weeks_per_year	52	week/year
Optimistic	1	dmnl
Percentage_of_immigrant_GPs	0.082	dmnl
Pessimistic	0.75	dmnl
Realistic	0.85	dmnl
Recruitment_Gap_Adj_Time	0.5	year
Sherbrooke_Uni_doctor_students_capacity	199	person/year
Stipend	12000	CAD/person/year
Switch_Approved_Budget_Percentage	1	dmnl
Switch_Graduates_Capacity	0	dmnl
Switch_Using_Practicing_Pharmacists	0	dmnl
The_desired_percentage_of_GPs	336/100000	dmnl
Time_required_to_increase_capacity	6	year
Time_studying_at_school	5	year
Time_to_Accumulate	1	year
Time_to_Perceive_Stress	1	year
Time_to_Perceive_the_#_of_retired_GPs	0.5	year
Time_to_perceive_Workload	0.5	year
Total_enrollment_fraction	0.018126572	1/year
Tuition_fees	5000	CAD/person/year

Turnover_Fraction	0.1	1/year
Total saved hours per week by PP	4.9	hrs/week
Weekly_working_days	5	day/week

Expansion of Medical Schools Capacities Scenario (Grad_Only)

The parameters' values in this scenario will remain the same except for the following:

Table (9): The Parameters that should be changed to activate Grad_Only Scenario.

Switch_Approved_Budget_Percentage	1	dmnl
Switch_Graduates_Capacity	1	dmnl
Switch_Using_Practicing_Pharmacists	0	dmnl

Expansion of Medical Schools Capacities and Deploying Practicing Pharmacists Scenario (Grad_PP)

Table (10): The Parameters that should be changed to activate Grad_PP Scenario.

Switch_Approved_Budget_Percentage	1	dmnl
Switch_Graduates_Capacity	1	dmnl
Switch_Using_Practicing_Pharmacists	1	dmnl

B. Sensitivity Analysis

In this appendix, we will present the sensitivity analysis tests for the parameters of the proposed model. We will only present the parameters that showed significant sensitivity; the parameters with very low or no sensitivity will not be included here in this appendix. The model was tested using the Grad_Only scenario settings except for the "*Weekly saved hours by PP"* parameter, which was tested using the Grad_PP scenario because this parameter is a part of a structure that cannot be activated without configuring the system using this scenario.

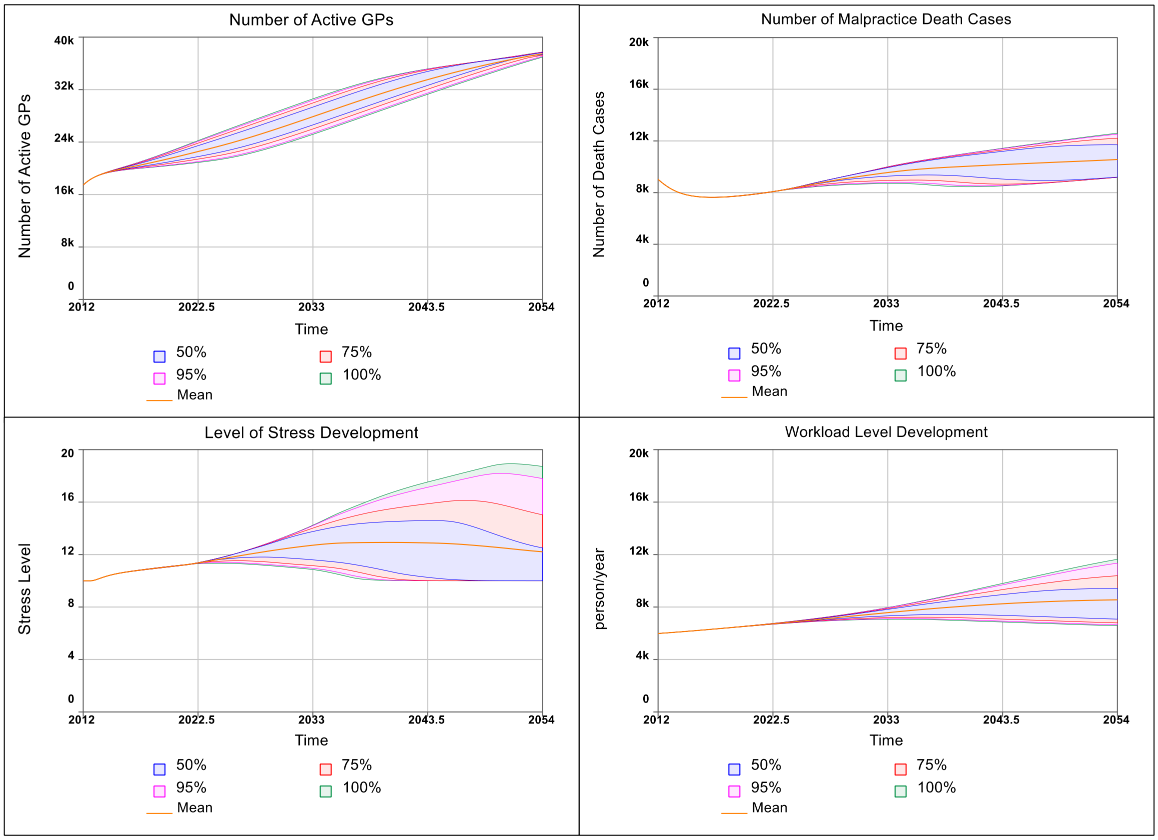

Figure (30): New Med. Students Sensitivity Test.

Table (11): New Med. Students' Sensitivity Test Results.

Runs	New Med. Students	#Malpractice Death Cases	Number of Active GPs
Run 1	450	12,706	36,653
Run 2	838	11,973	37,587
Run 3	1,225	9,734	37,730
Run 4	1,613	9,186	37,456
Run 5	2,000	9,188	37,195

The New Med. Students parameter is highly sensitive; therefore, it was meant to increase the number of new med students enrolling in medical students by regulating the inflow of the new medical students' stock. It is essential to mention that the system's behavior in this test is as expected (see Figure (30), Table (11)) .

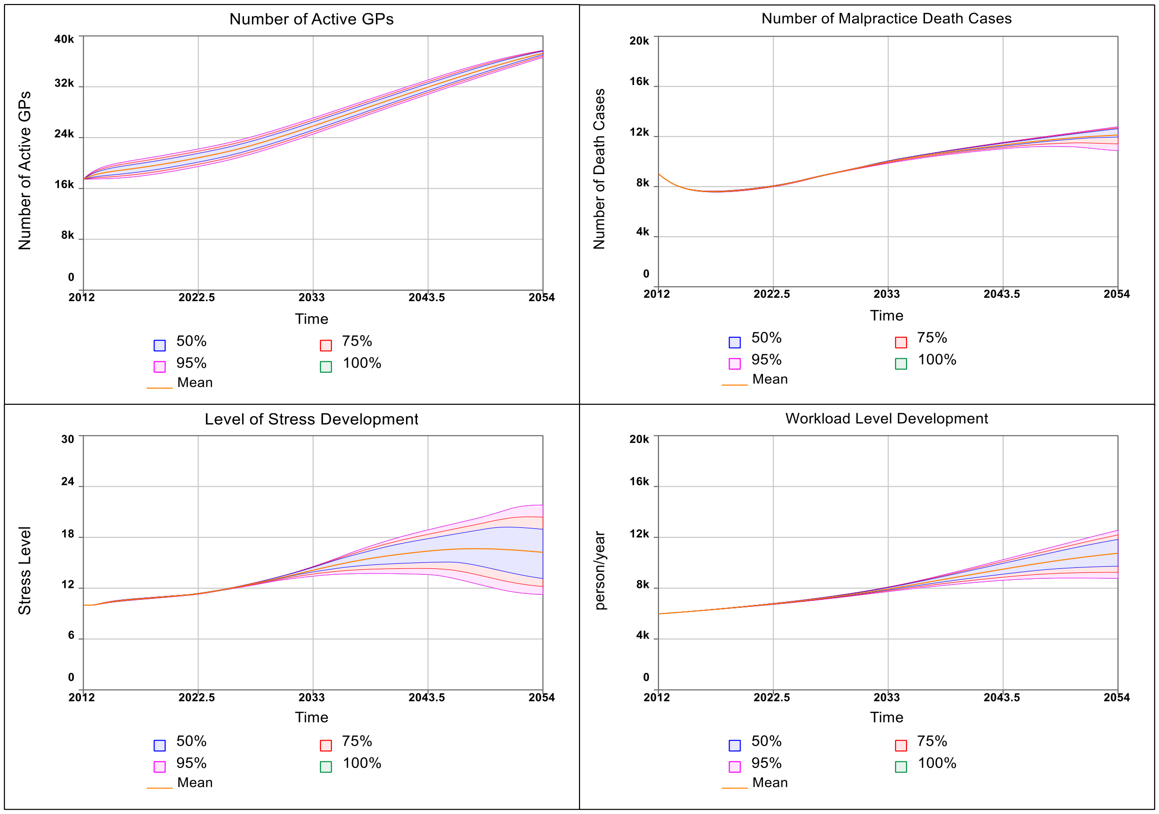

Figure (31): Hospital Residency Initial Value Sensitivity.

Table (12): Hospital Residency Initial Value Sensitivity.

	Hospital residency	Number of Active GPs	#Malpractice Death Cases
Run 1	500	36,607	12,775
Run 2	1375	37,038	12,622
Run 3	2250	37,380	12,378
Run 4	3125	37,607	11,954
Run 5	4000	37,721	10,869

The initial number of medical students in the residency stage is found sensitive because they will graduate and be a significant addition to the number of GPs who will serve the local community of Quebec. So if the number is high, then the impact will be high, even before applying the interventions mentioned in chapter (6) (see Figure (31) Table (12)).

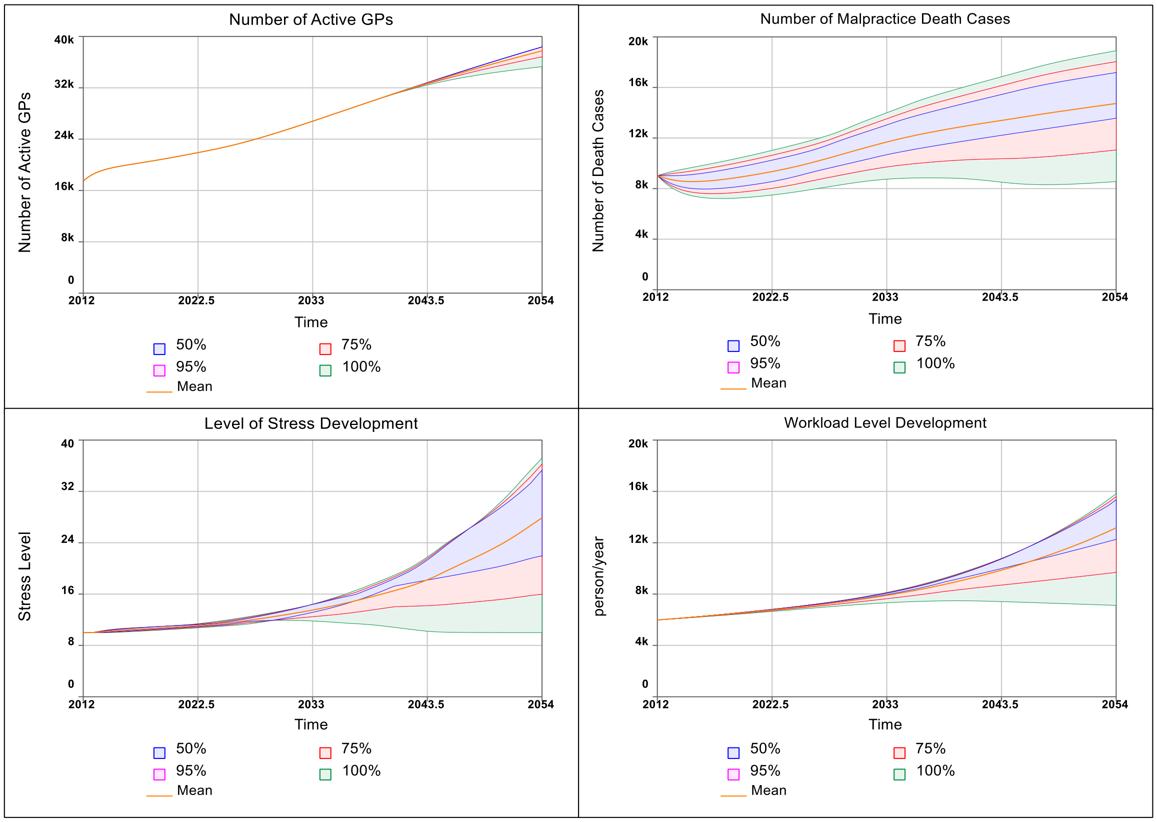

Figure (32): Quebec Population Sensitivity Test.

Table (13): Quebec Population Sensitivity Test Results.

	Quebec Population	Number of Active GPs	#Malpractice Death Cases
Run 1	7,500,000	35,290	8,555
Run 2	8,575,000	38,371	13,564
Run 3	9,650,000	38,371	15,449
Run 4	10,725,000	38,371	17,180
Run 5	11,800,000	38,371	18,907

It is expected to notice an increase in the number of medical malpractice death cases when the population is getting higher; this is because the number of patients will increase as well. However, the change in population is usually limited; therefore, this parameter is not conceptually significant to be considered for further investigation in the context of our study (see (Figure (32), Table (12)).

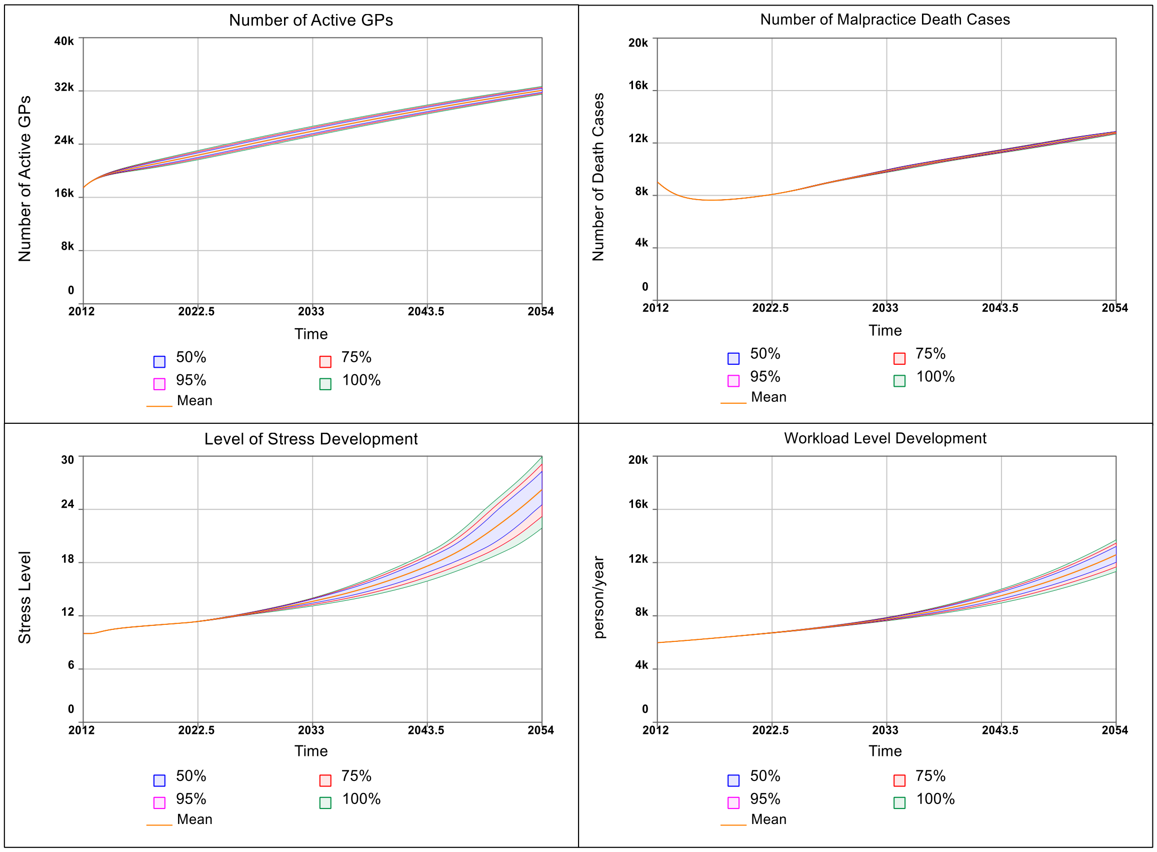

Figure (33): Students in Universities Sensitivity Test

Table (14): Students in Universities Sensitivity Test Results

	Students in Universities (Doctoral Programs)	Number of Active GPs	#Malpractice Death Cases
Run 1	500	31,490	12,881
Run 2	1,125	31,787	12,870
Run 3	1,750	32,083	12,847
Run 4	2,375	32,380	12,793
Run 5	3,000	32,676	12,680

The system's behavior in this test is expected because the number of students in universities will need time to cause a significant impact on the number of medical malpractice deaths. The number of students in the universities will initially impact the workload, but after some time, this will impact the stress level also after a significant time. Therefore, the number of MDC will not be affected within the time boundary of our simulation (see Figure (33), Table (14)).

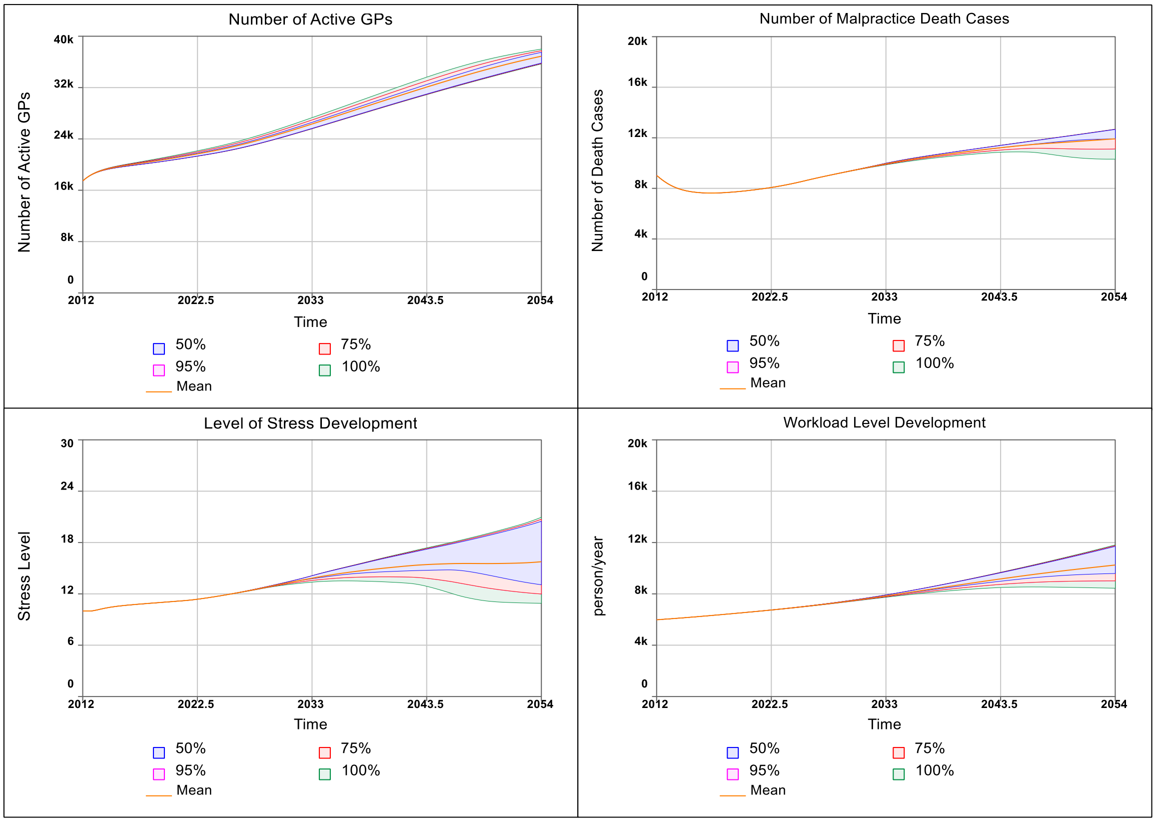

Figure (34): Doctors Retirement Age Sensitivity Test .

Table (15): Doctors Retirement Age Sensitivity Test Results

	Drs. retirement age	Number of Active GPs	#Malpractice Death Cases
Run 1	56	35,682	12,685
Run 2	65	37,442	12,019
Run 3	57	35,822	12,662
Run 4	66	37,494	11,921
Run 5	74	37,998	10,314

The moderate sensitivity here is a result of changing the age of retirement for active GPs, s when the retirement age increases, the number of MDC will decrease. The system behaves as expected using this parameter (see Figure (34), Table (15)).

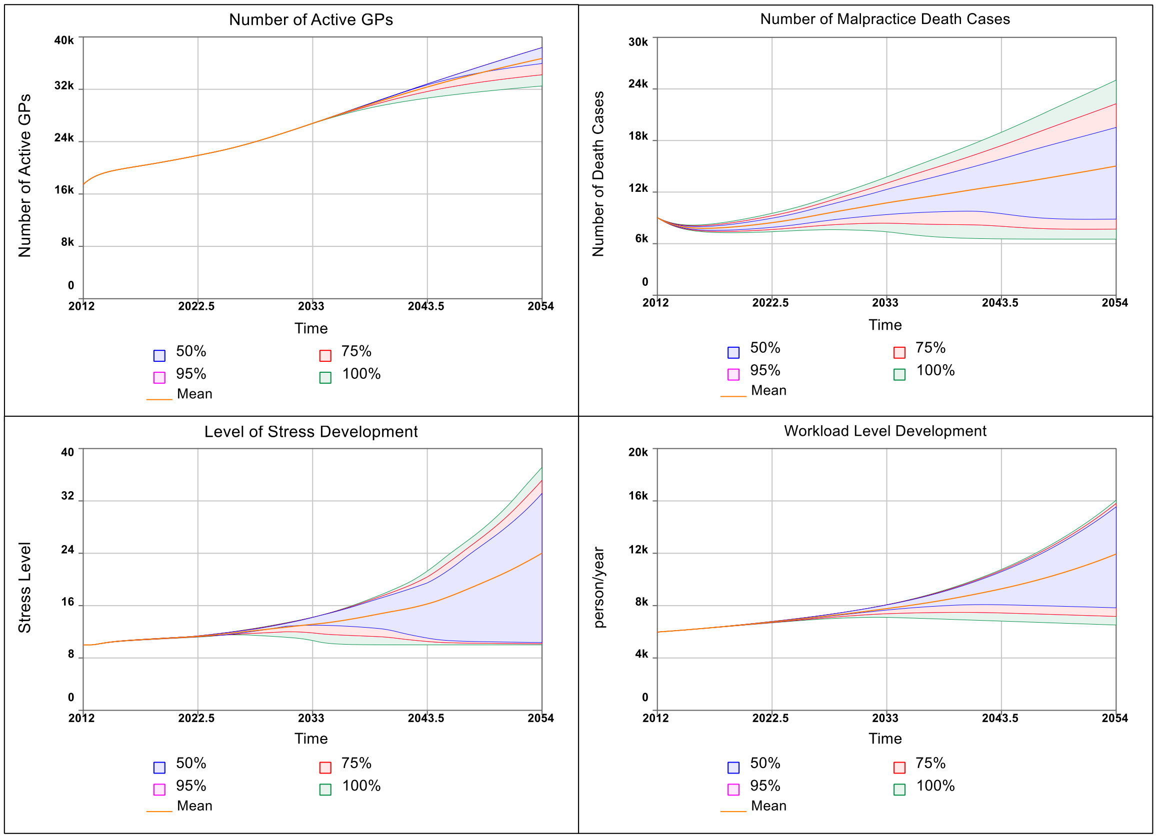

Figure (35): Birth Fraction Sensitivity Tests.

Table (16): Birth Fraction Sensitivity Tests.

	Birth fraction	Number of Active GPs	#Malpractice Death Cases
Run 1	0.008	32,507	6,528
Run 2	0.014	35,935	8,861
Run 3	0.020	38,371	15,208
Run 4	0.026	38,371	19,522
Run 5	0.032	38,371	25,031

The behavior in the above figure is expected; this is because the birth rate has a direct impact to the population, which causes the observed behavior. However, the birth fraction is not an easily changeable parameter in real life, so there will be no meaning in further discussing this parameter (see Figure (35), Table (16)).

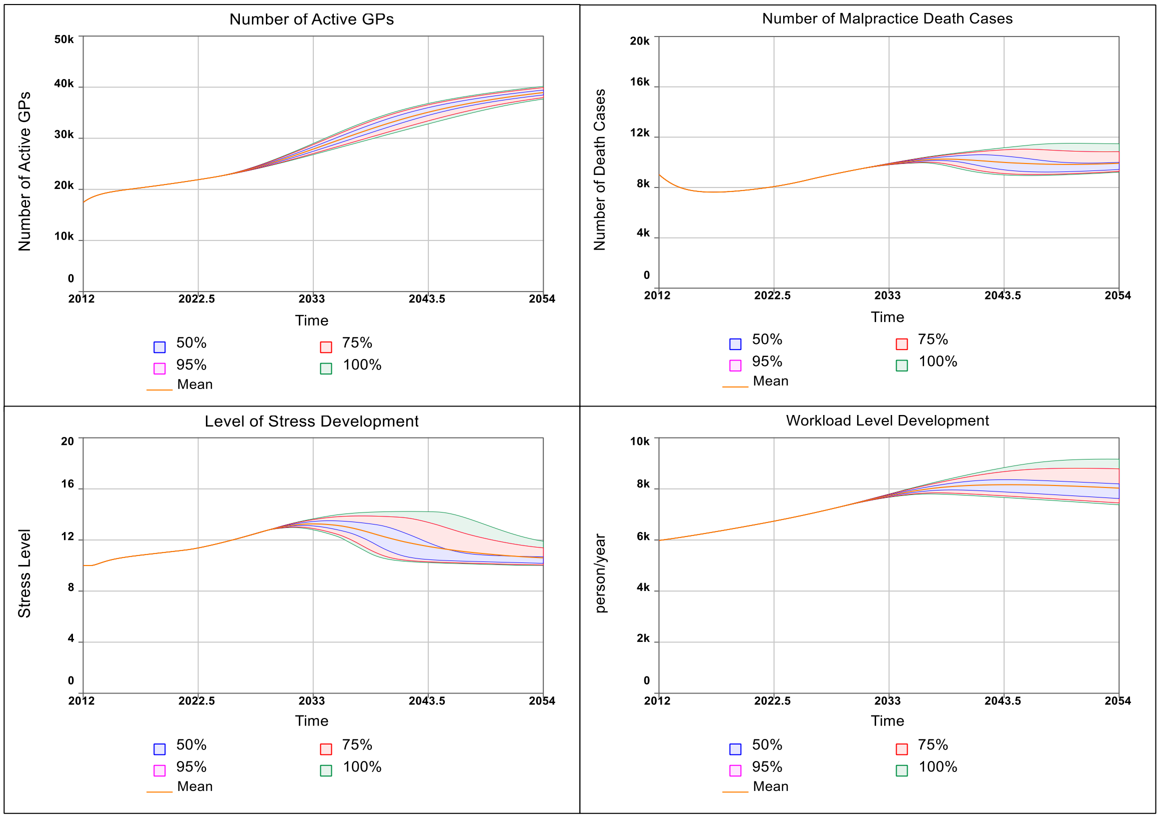

Figure (36): Current Capacity Multiplier Sensitivity Test.

Table (17): Current Capacity Multiplier Sensitivity Test.

	Current Capacity Multiplier	Number of Active GPs	#Malpractice Death Cases
Run 1	1	37,681	11,474
Run 2	1.1	38,234	10,219
Run 3	1.2	38,709	9,779
Run 4	1.3	39,194	9,520
Run 5	1.4	39,685	9,341
Run 6	1.5	40,158	9,222

This parameter significantly impacts the number of MDC; it is used as a leverage point to intervene in this study; it is the starting point for both Grad_Only and Grad_PP scenarios (see Figure (36), Table (17)).

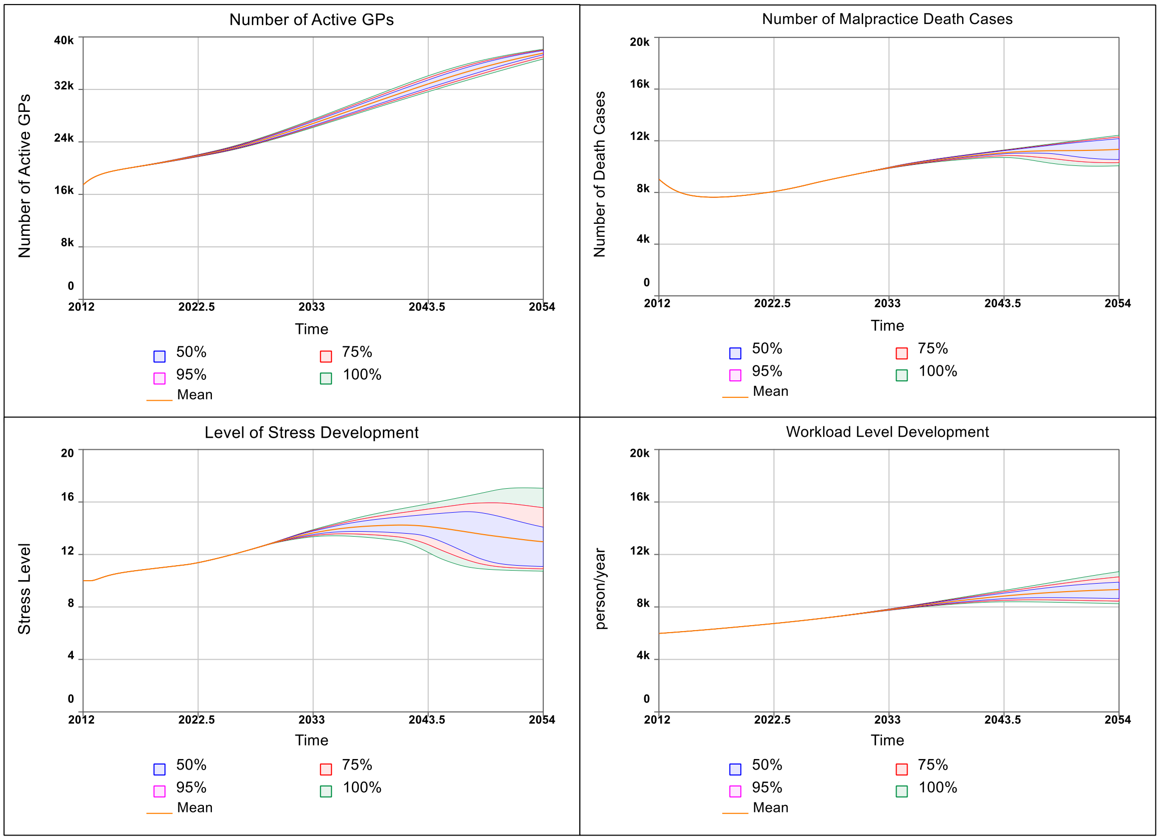

Figure (37): Dropout Fraction Sensitivity Test.

Table (18): Dropout Fraction Sensitivity Test.

	Dropout fraction	Number of Active GPs	#Malpractice Death Cases
Run 1	0.03	38,136	10,066
Run 2	0.04	37,938	10,548
Run 3	0.05	37,681	11,474
Run 4	0.06	37,276	12,166
Run 5	0.07	36,634	12,428

The dropout fraction showed a significant sensitivity in the KPIs of the proposed model. Therefore, this parameter can suggest an auxiliary intervention point to decrease the dropping out of students by addressing the root causes of this case; using professional recruiters to attract highly qualified new medical students is one way to decrease the number of dropping out medical students (see Figure (37), Table (18)).

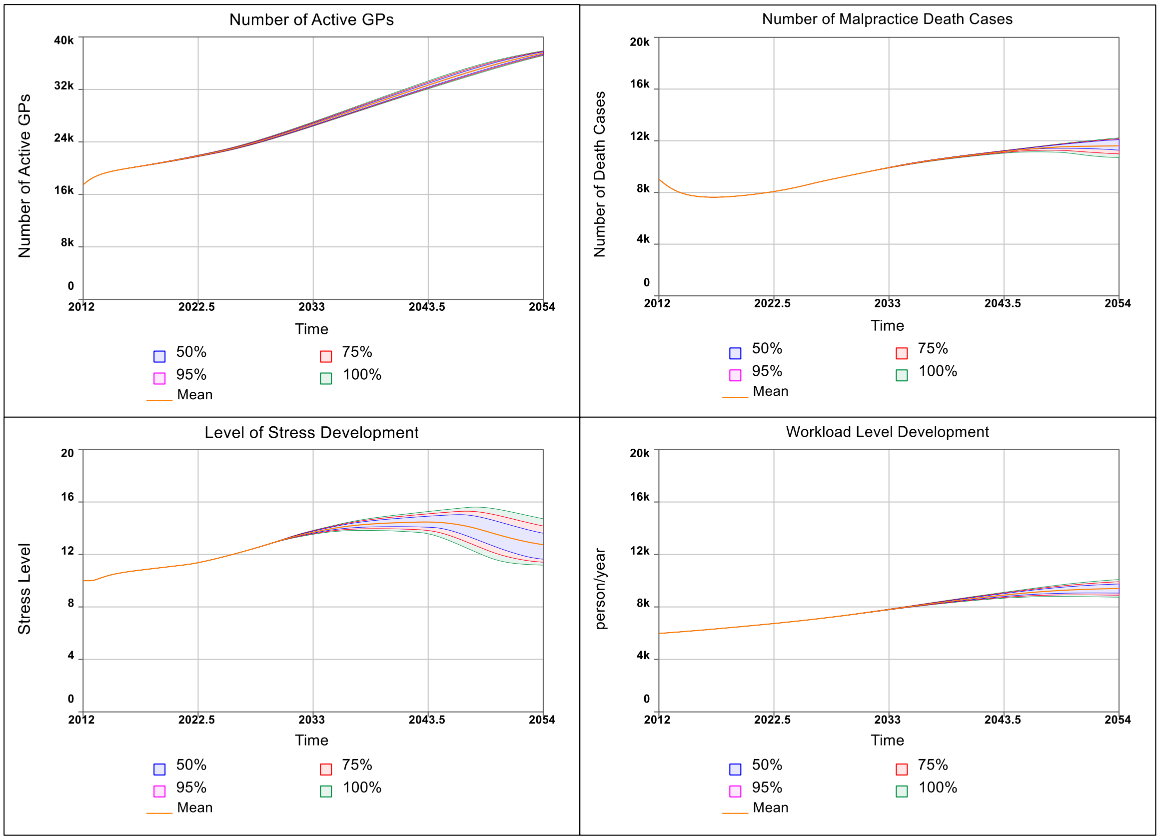

Figure (38): Fraction_of_Dropping_Doctors Sensitivity Test.

Table (19): Fraction of Dropping Doctors Sensitivity Test.

	Fraction of dropping doctors	Number of Active GPs	#Malpractice Death Cases
Run 1	0.025	37,889	10,700
Run 2	0.04375	37,735	11,276
Run 3	0.0625	37,567	11,742
Run 4	0.08125	37,376	12,085
Run 5	0.1	37,163	12,229

Dropping out doctors from the specialty phase of the study has a moderate impact on the number of MDC; fewer dropping out means more GPs and doctors, which will decrease the MDCs over time. The model's behavior in this test is expected (see Figure (38), Table (19)).

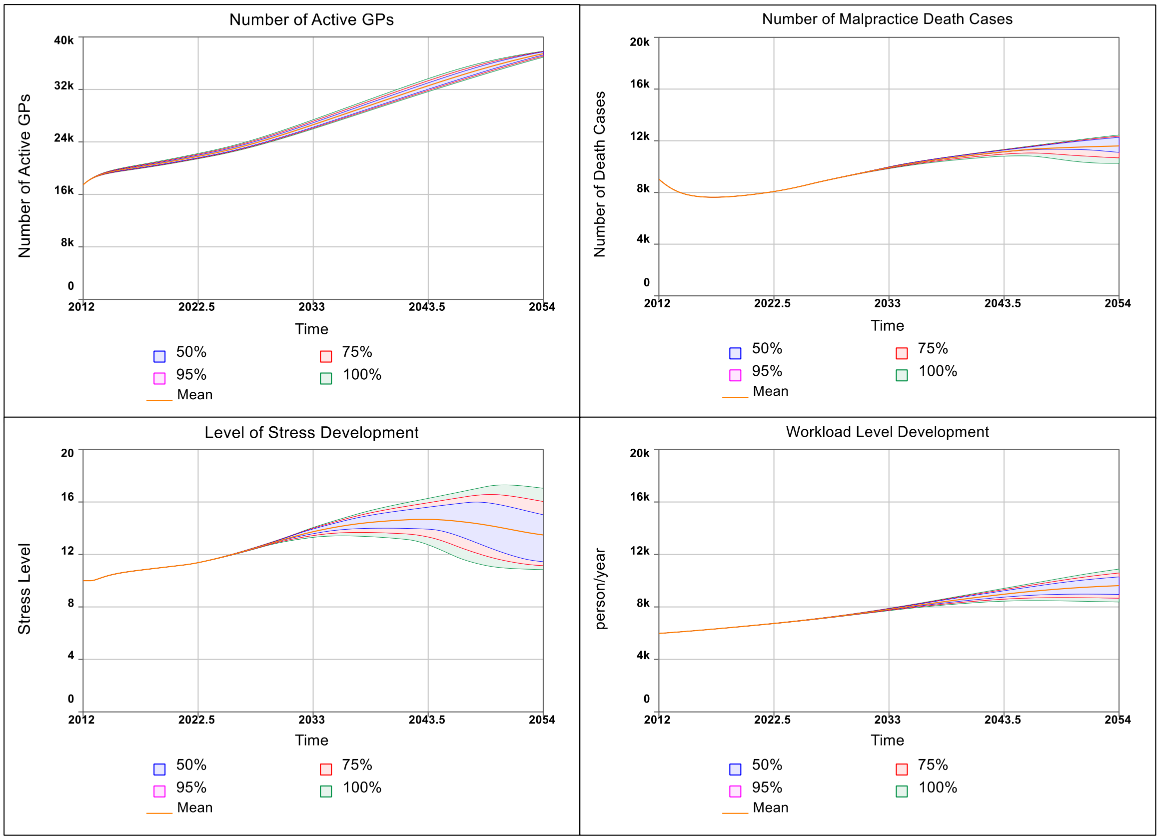

Figure (39): Fraction_of_Students_Specialization Sensitivity Test.

Table (20): Fraction_of_Students_Specialization Sensitivity Test.

	Fraction of Students' Specialization	Number of Active GPs	#Malpractice Death Cases
Run 1	0.1	37,835	10,254
Run 2	0.175	37,737	11,106
Run 3	0.25	37,536	11,928
Run 4	0.325	37,246	12,267
Run 5	0.4	36,907	12,448

Increasing the fraction of students who enroll in the specialty programs will increase MDCs because the doctors require 5 to 7 years to graduate from this program in addition to the period which will be spent on the universities, which is around another five years, delaying the impact on the workload, stress, and active GPs count, causing more MDCs in the time frame of our study (see Figure (39), Table (20)).

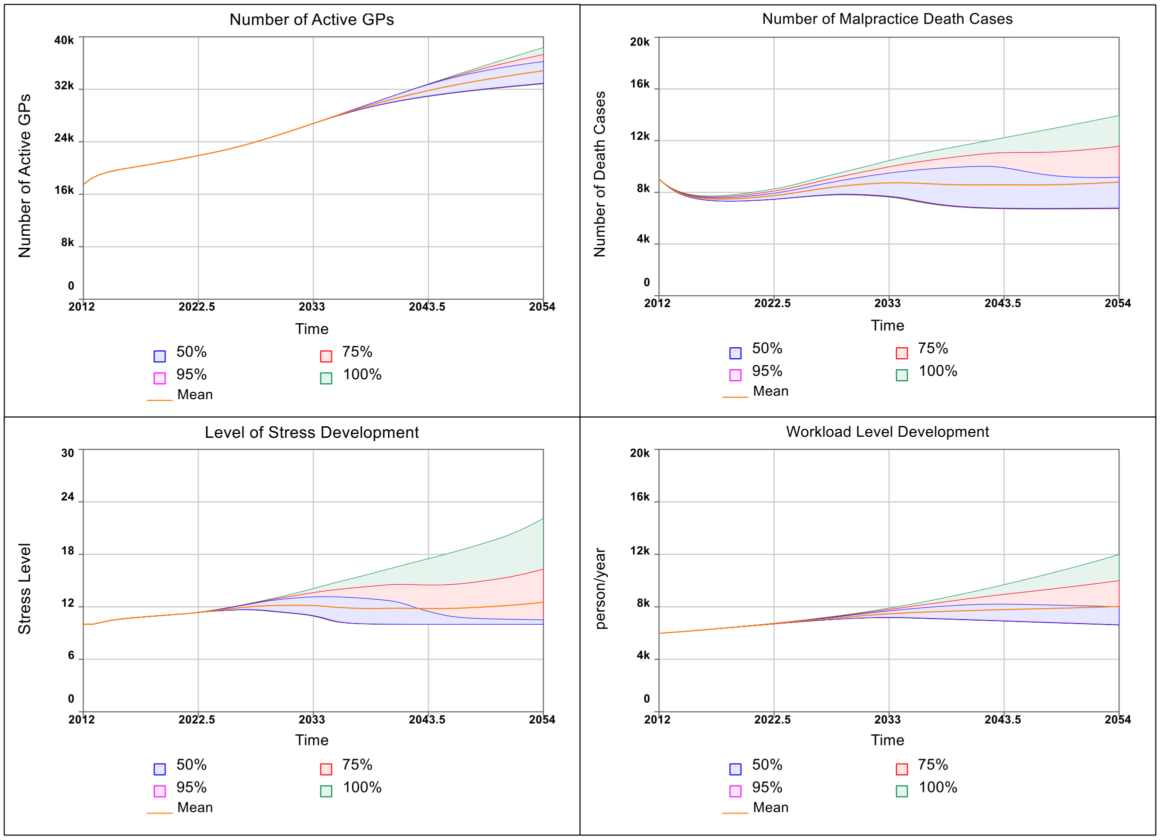

Figure (40): Initial_death_rate Sensitivity Test.

Table (21): Initial_death_rate Sensitivity Test Results.

	Initial death rate	Number of Active GPs	#Malpractice Death Cases
Run 1	0.015093242	32,921	6,788
Run 2	0.009705622	36,239	9,165
Run 3	0.015282301	32,832	6,733
Run 4	0.013315399	33,806	7,329
Run 5	0.005920563	38,371	13,952

The model behaves as expected to the change in the initial death rate; when the death rate is low, the population increases; by the increase of population, the number of MDC increases as we are facing the problem of shortage of GPs and the GPs burnout. For example, a 30% percentage of 10,000 deaths is lower than 30% of 15,000 deaths; this is why we notice an increase in MDC when the death rate is low and the opposite when the death rate is high (see Figure (40), Table (21)).

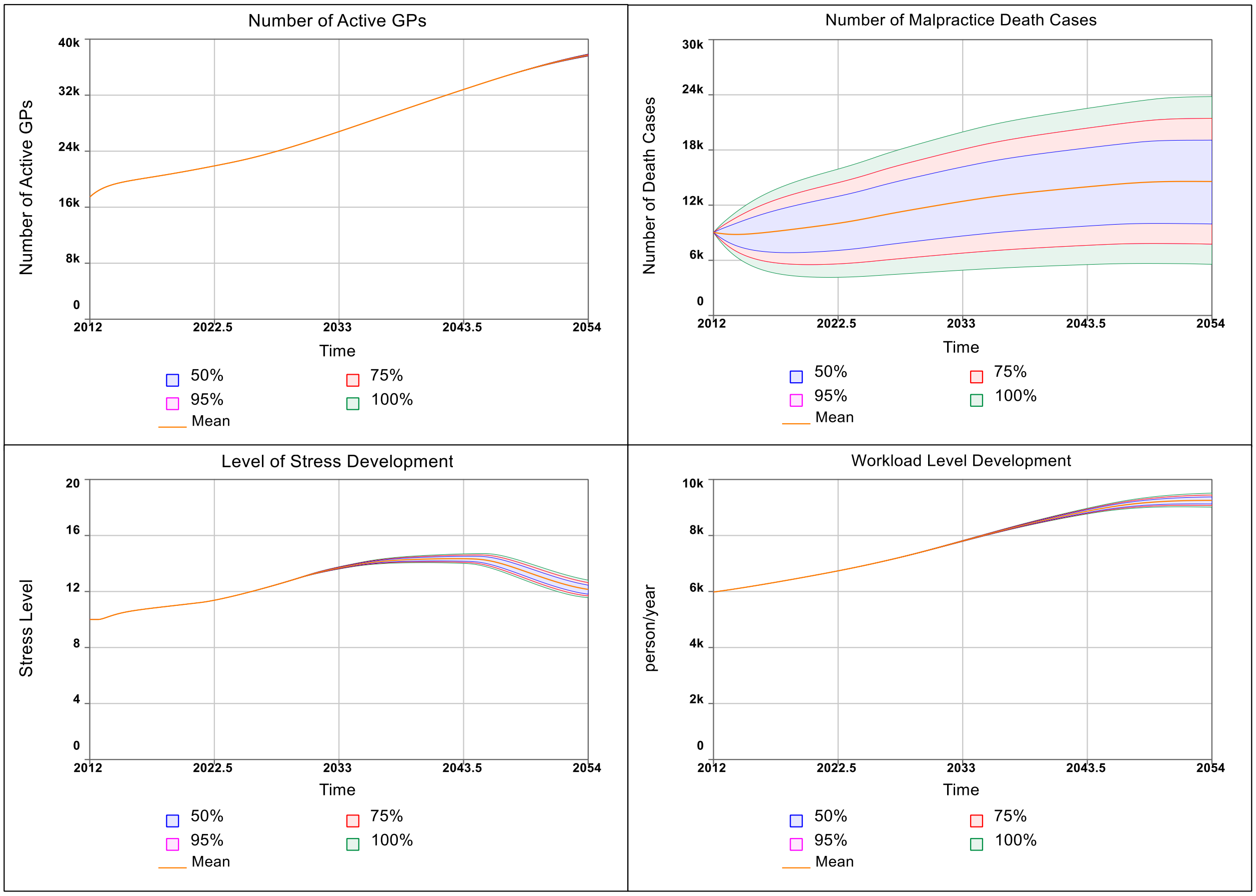

Figure (41): Initial_malpractice_death_rate Sensitivity Test.

Table (22): Initial malpractice death rate Sensitivity Test Results.

	Initial malpractice death rate	Number of Active GPs	#Malpractice Death Cases
Run 1	0.000575	37,567	5,564
Run 2	0.00100625	37,653	9,949
Run 3	0.0014375	37,735	14,453
Run 4	0.00186875	37,813	19,069
Run 5	0.0023	37,887	23,816

The response of the mode to the changing values of the initial malpractice death rate is expected because it will directly affect the number of malpractice deaths. This parameter's value is determined depending on literature and author calculations; it will not add value to our study if we further try to affect this value (see Figure (41), Table (22)).

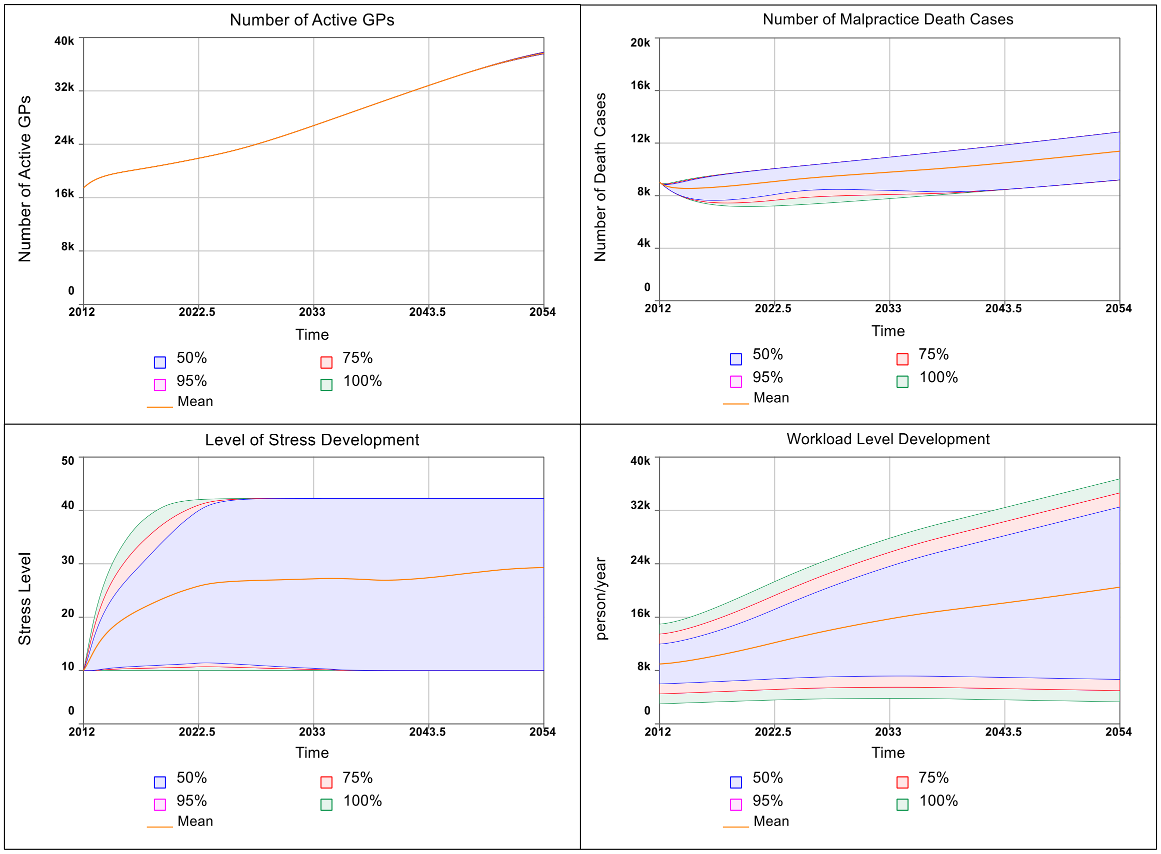

Figure (42): Initial Workload Sensitivity Test.

Table (23): Initial Workload Sensitivity Test Results.

	Initial Workload	Number of Active GPs	#Malpractice Death Cases
Run 1	3000	37,824	9,203
Run 2	5990	37,778	9,187
Run 3	8980	37,560	12,851
Run 4	11970	37,551	12,847
Run 5	14960	37,549	12,846

The initial value of workload is vital in our study; it shows high sensitivity in our model when its value changes; this is because the workload level determines the number of patients a GP will handle, so when it increases, the medical death cases increase as well, and when it decreases the MDC will decrease, as shown in the table and the figure above. Therefore, if we manage the workload, we can decrease the number of MDCs; this is what was suggested in the Grad_PP scenario; by deploying PP to help GPs, the workload will decrease, and therefore, the number of MDC will decrease (see Figure (42), Table (23)).

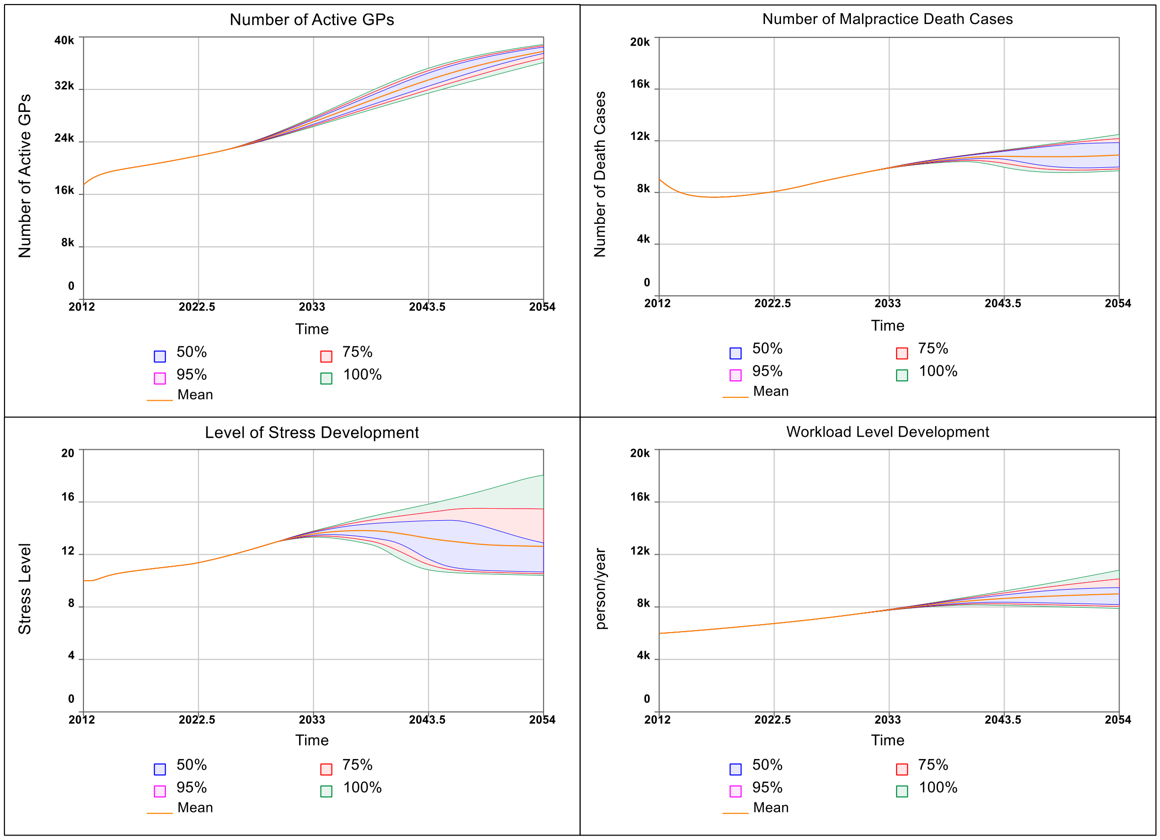

Figure (43): Laval New Medical Students join yearly , Sensitivity Test.

Table (24): Laval New Medical Students join yearly , Sensitivity Test.

	Laval Uni doctor students capacity	Number of Active GPs	#Malpractice Death Cases
Run 1	120	36,107	12,488
Run 2	200	37,479	11,855
Run 3	280	38,042	10,506
Run 4	360	38,462	9,974
Run 5	440	38,869	9,679

Changing the number of new medical students who can enroll every year will change the number of MDC in the same direction. It is expected that when we increase the number of new medical students, MDC will decrease, and the opposite is true also. The same description applies to the change in the number of medical students in other universities in Quebec (see Figure (43), Table (24)).

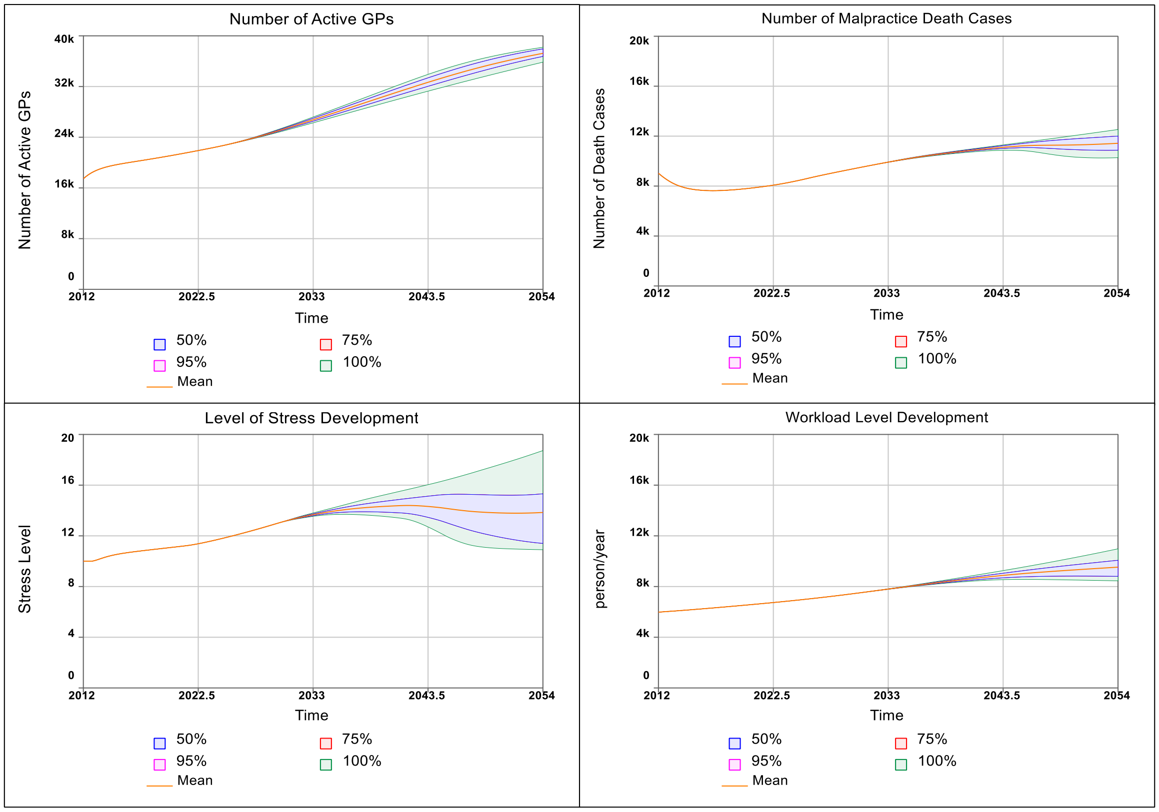

Figure (44): McGill Uni. New Medical Students join yearly , Sensitivity Test.

Table (25): McGill Uni. New Medical Students join yearly , Sensitivity Test.

	McGill Uni doctor students capacity	Number of Active GPs	#Malpractice Death Cases
Run 1	100	35,844	12,532
Run 2	182.5	37,374	12,011
Run 3	265	38,003	10,579
Run 4	347.5	38,439	9,996
Run 5	430	38,859	9,685

Changing the number of new medical students who can enroll every year will change the number of MDC in the same direction. It is expected that when we increase the number of new medical students, MDC will decrease, and the opposite is true also. The same description applies to the change in the number of medical students in other universities in Quebec (see Figure (44), Table (25)).

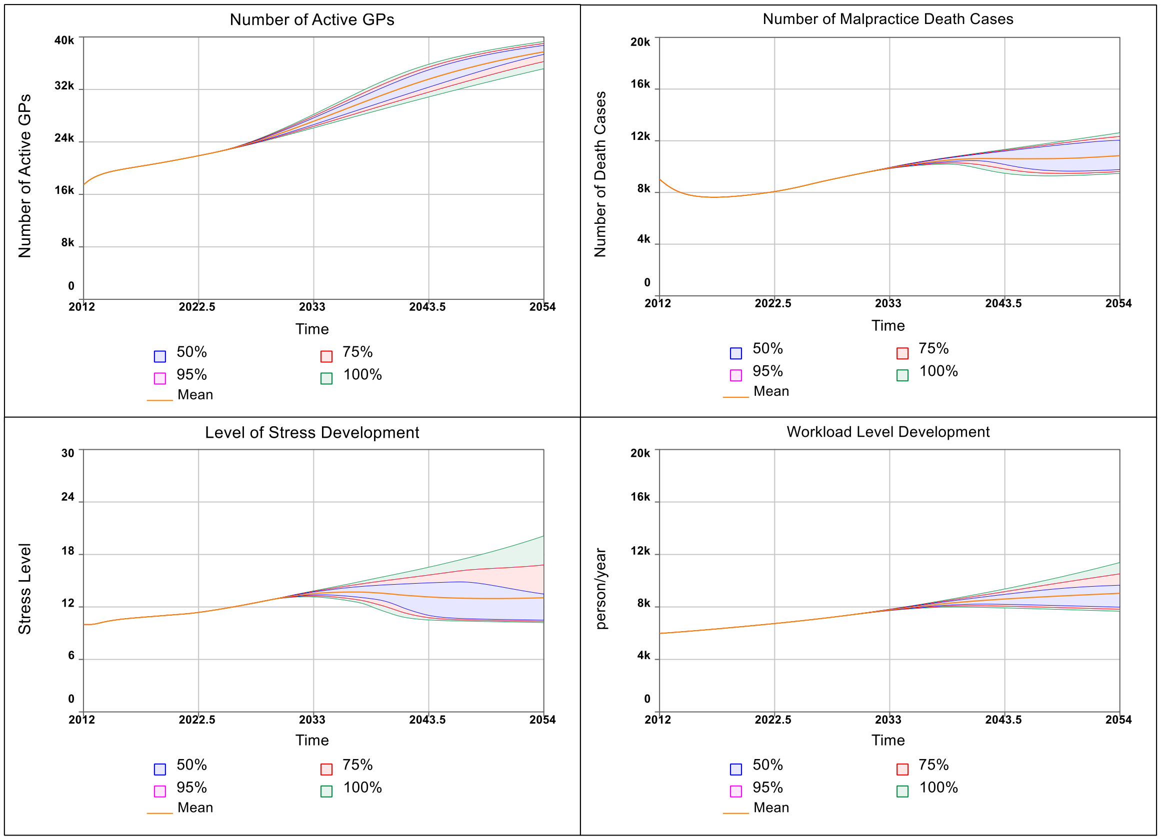

Figure (45): Montreal Uni. New Medical Students join yearly , Sensitivity Test.

Table (26): Montreal Uni. New Medical Students join yearly , Sensitivity Test Results.

	Montreal Uni doctor students capacity	Number of Active GPs	#Malpractice Death Cases
Run 1	145	35,167	12,627
Run 2	256.25	37,347	12,045
Run 3	367.5	38,148	10,335
Run 4	478.75	38,720	9,772
Run 5	590	39,304	9,475

Changing the number of new medical students who can enroll every year will change the number of MDC in the same direction. It is expected that when we increase the number of new medical students, MDC will decrease, and the opposite is true also. The same description applies to the change in the number of medical students in other universities in Quebec(see Figure (45), Table (26)).

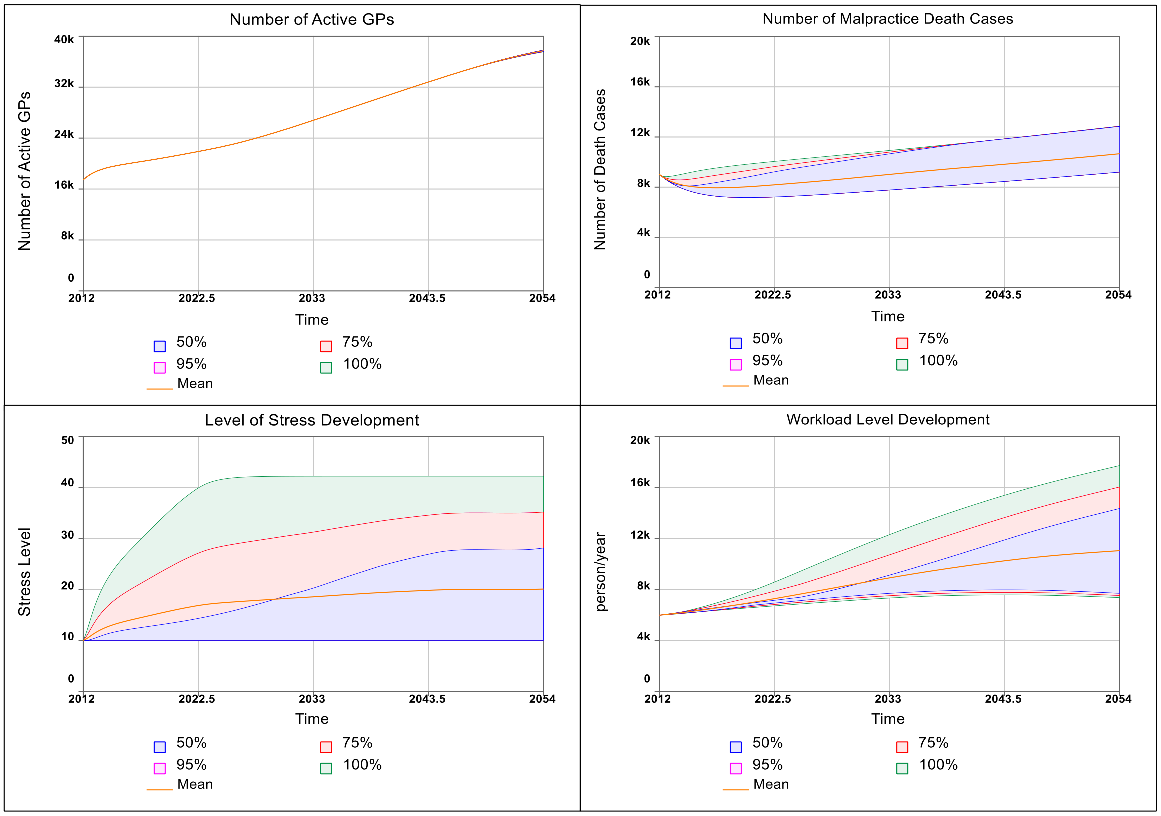

Figure (46): Normal Number of Patients A GP can handle, Sensitivity Test.

Table (27): Normal Number of Patients A GP can handle Sensitivity Test.

	Normal number of patients per GP	Number of Active GPs	#Malpractice Death Cases
Run 1	2,990	37,551	12,847
Run 2	5,233	37,605	12,871
Run 3	7,475	37,818	9,202
Run 4	9,718	37,824	9,203
Run 5	11,960	37,824	9,203

The “normal number of patients a GP can handle” controls the relative workload value, which also affects the stress value. When the value of this parameter increases, this means the dominator of the relative workload will be high, which can absorb more patients; these more patients will be the nominator. In other words, when the GP can deal with a high number of patients, the excessive number of patients will be less stressful, and the other way also applies. That is why we observe an increasing number of MDC when we decrease the normal number of patients a GP can handle. However, the value of the normal number of patients a GP can handle was determined depending on verified data from the literature, and it is a semi-standardized value, so it will not be easy to change it significantly (see Figure (46), Table (27)).

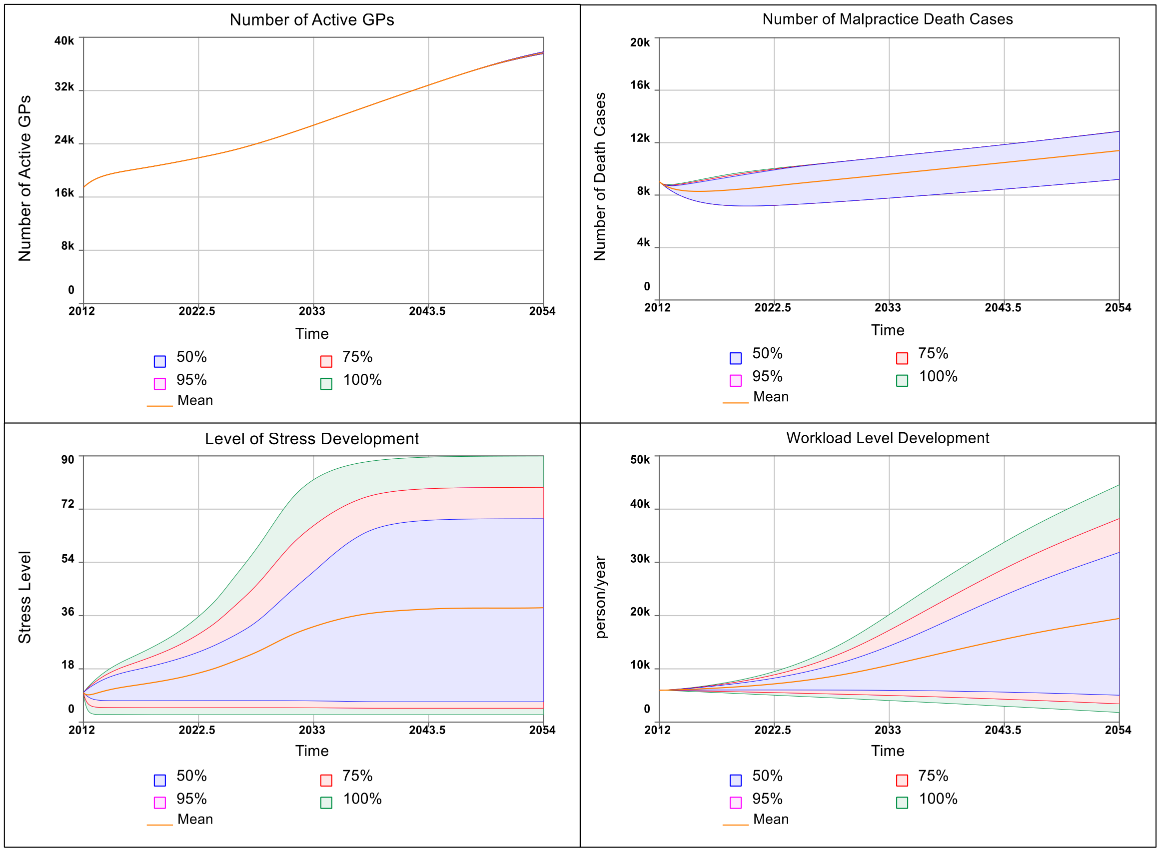

Figure (47): Time to Decompress Stress Sensitivity Test.

Table (28): Time to Decompress Stress Sensitivity Test Results.

	Normal time to decompress	Number of Active GPs	#Malpractice Death Cases
Run 1	0.25	37,824	9,203
Run 2	0.6875	37,824	9,203
Run 3	1.125	37,610	12,872
Run 4	1.5625	37,561	12,851
Run 5	2	37,554	12,848

The normal time to decompress stress is crucial as it can be used as an intervention point. If we find ways to increase the base of the stress decompression, decreasing the time to decompress stress, then a significant impact will be expected, as shown in Figure (47) and Table (28).

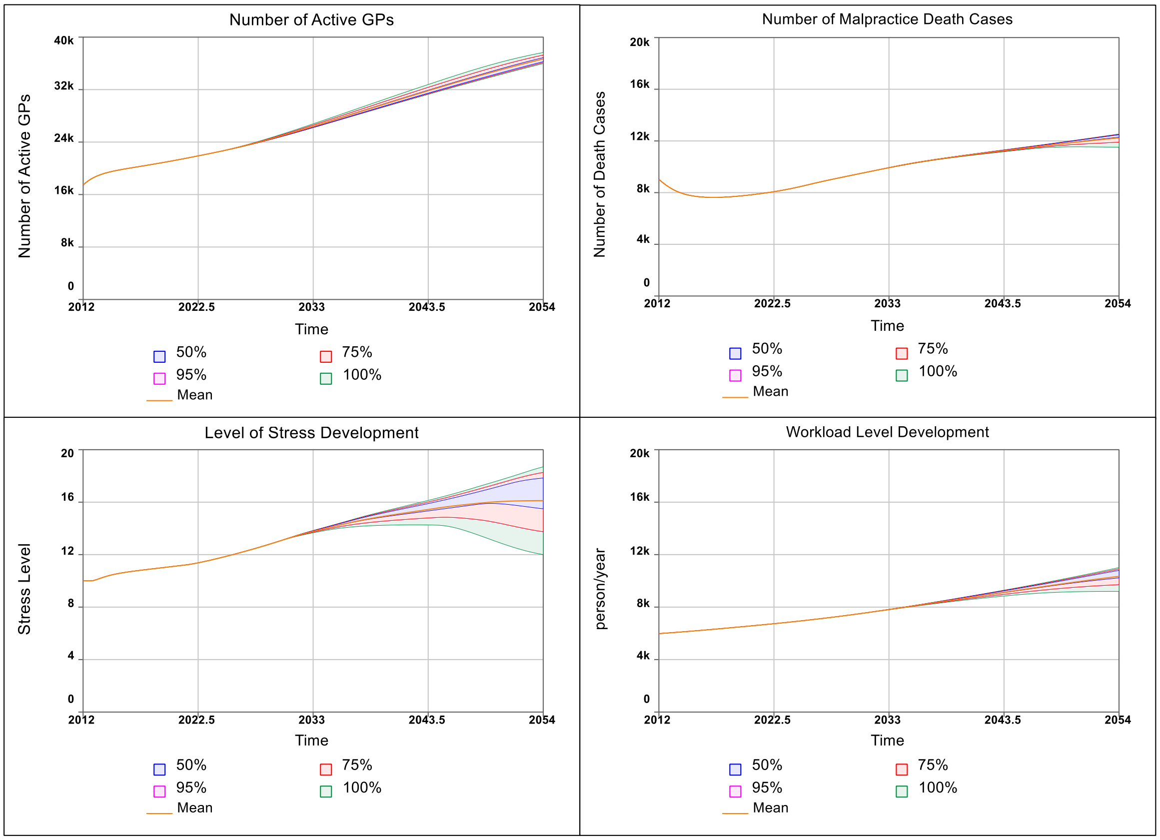

Figure (48): Normal time to recruit Sensitivity Test.

Table (29): Normal time to recruit Sensitivity Test Results.

	Normal Time to recruit	Number of Active GPs	#Malpractice Death Cases
Run 1	1.211307316	36,879	12,292
Run 2	1.401909149	36,619	12,381
Run 3	0.521316562	37,661	11,521
Run 4	1.853830537	35,971	12,536
Run 5	1.651908236	36,263	12,480

The time to recruit new medical students showed a low sensitivity impact when it is put for testing. The behavior of the model was as expected (see Figure (48), Table (29)).

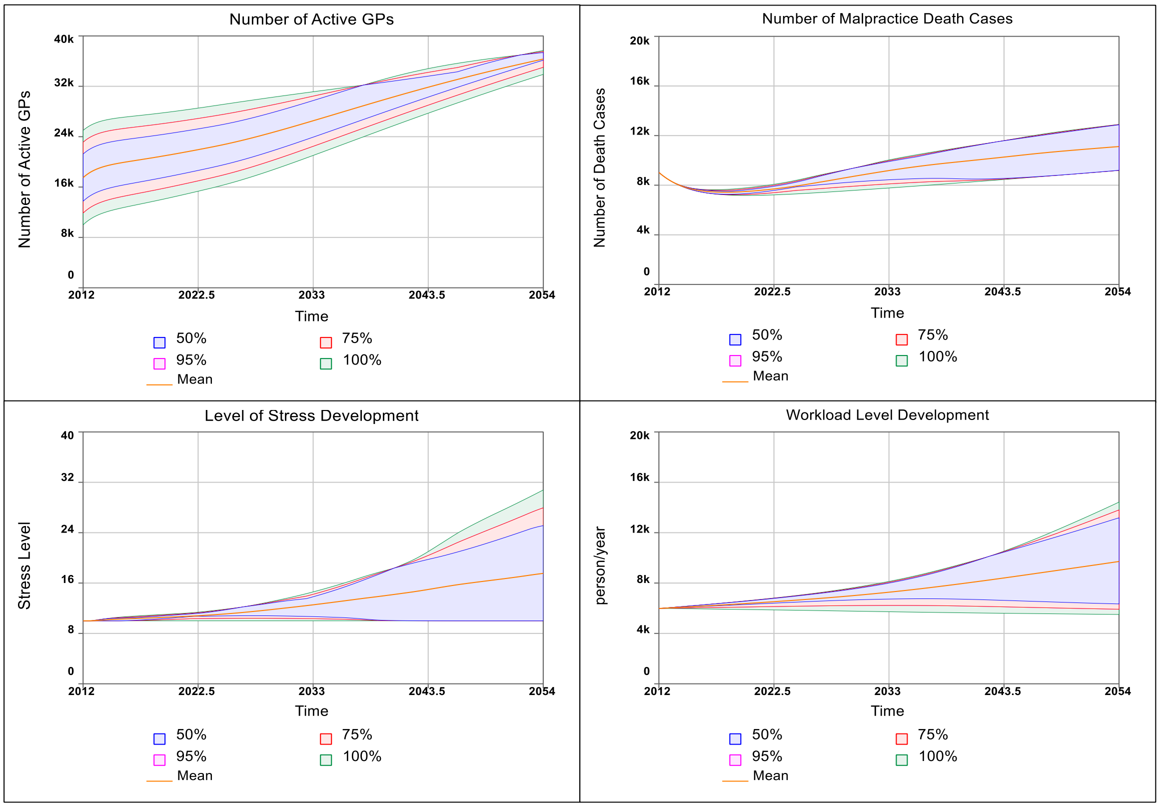

Figure (49): The Initial Value of Number_of_GPs Sensitivity Test.

Table (30): The Initial Value of Number_of_GPs Sensitivity Test.

	Number of GPs	Number of Active GPs	#Malpractice Death Cases
Run 1	10,000	33,895	12,905
Run 2	13,750	36,146	12,871
Run 3	17,500	37,687	11,406
Run 4	21,250	37,359	9,192
Run 5	25,000	36,560	9,203

The model showed high sensitivity to the change in the initial number of active GPs; this is because the value of this parameter will determine the gap between the required and the current number of active GPs. A higher initial number of active GPs means less stressed GPs with less workload leading to less MDC, and the opposite scenario also applies when the initial number of active GPs decreases; the number of MDC will increase due to the high workload and stress on active GPs (see Figure (49), Table (30)).

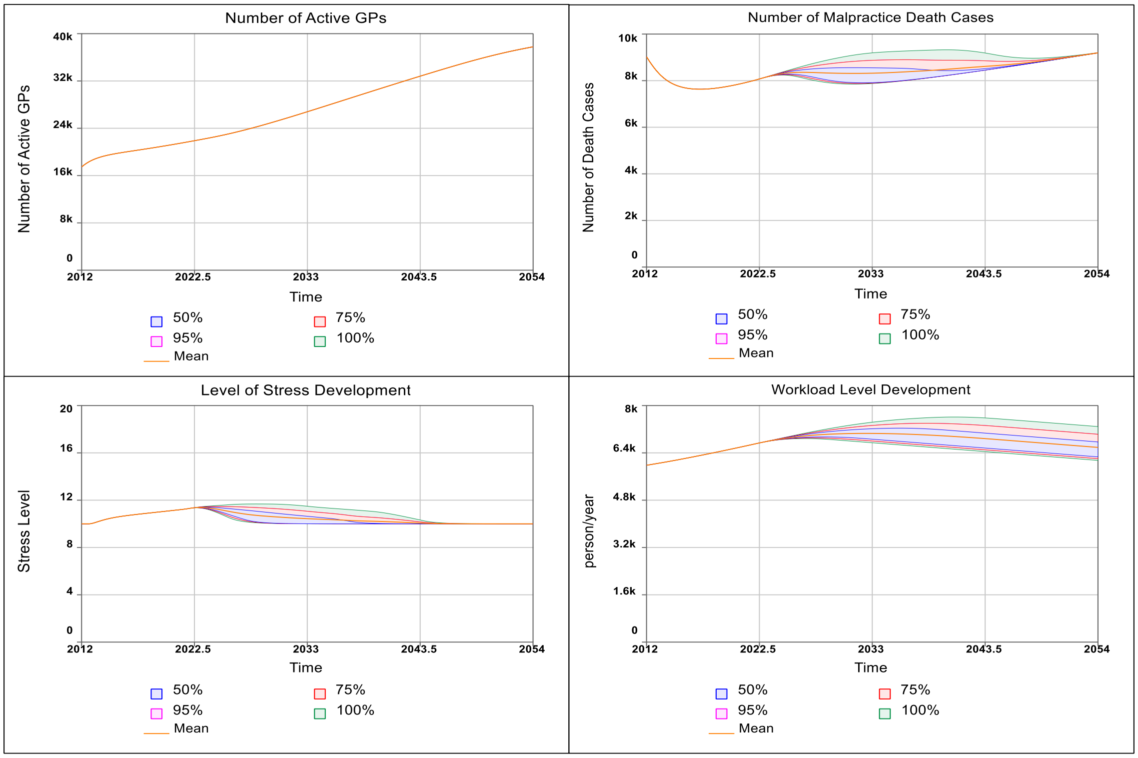

Figure (50): Number of saved hours by PP per Week Sensitivity Test.

Table (31): Number of saved hours by PP per Week Sensitivity Test.

	Total saved hours week	Number of Active GPs	#Malpractice Death Cases
Run 1	2	37743.8611379	9,194
Run 2	4	37780.5392085	9,188
Run 3	6	37790.5881976	9,191
Run 4	8	37793.5297397	9,192
Run 5	10	37793.7278712	9,192

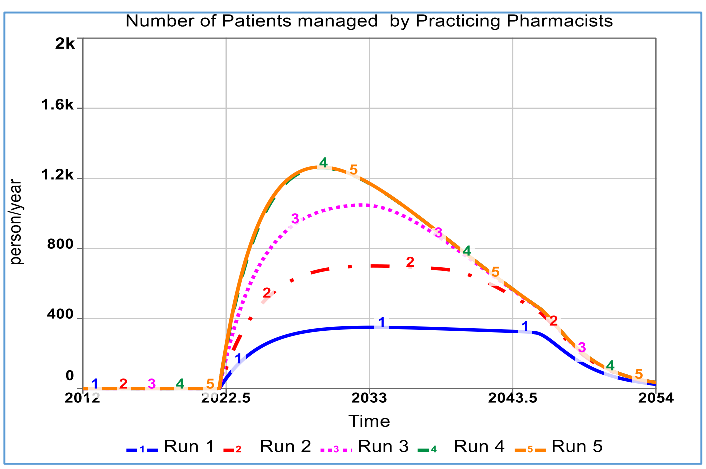

Figure (51): Number of Patients treated by PP.

The number of saved hours by PP per week is about 98% of 1 an hour per day. Changing this value will affect the total time the PP will keep helping the GP until new GPs are joining the service, so if the saved hours are high, the PP will keep working with GP for a shorter time, and the opposite applies. Figure (51) shows the effect of the tested parameter on the number of patients treated by a GP.

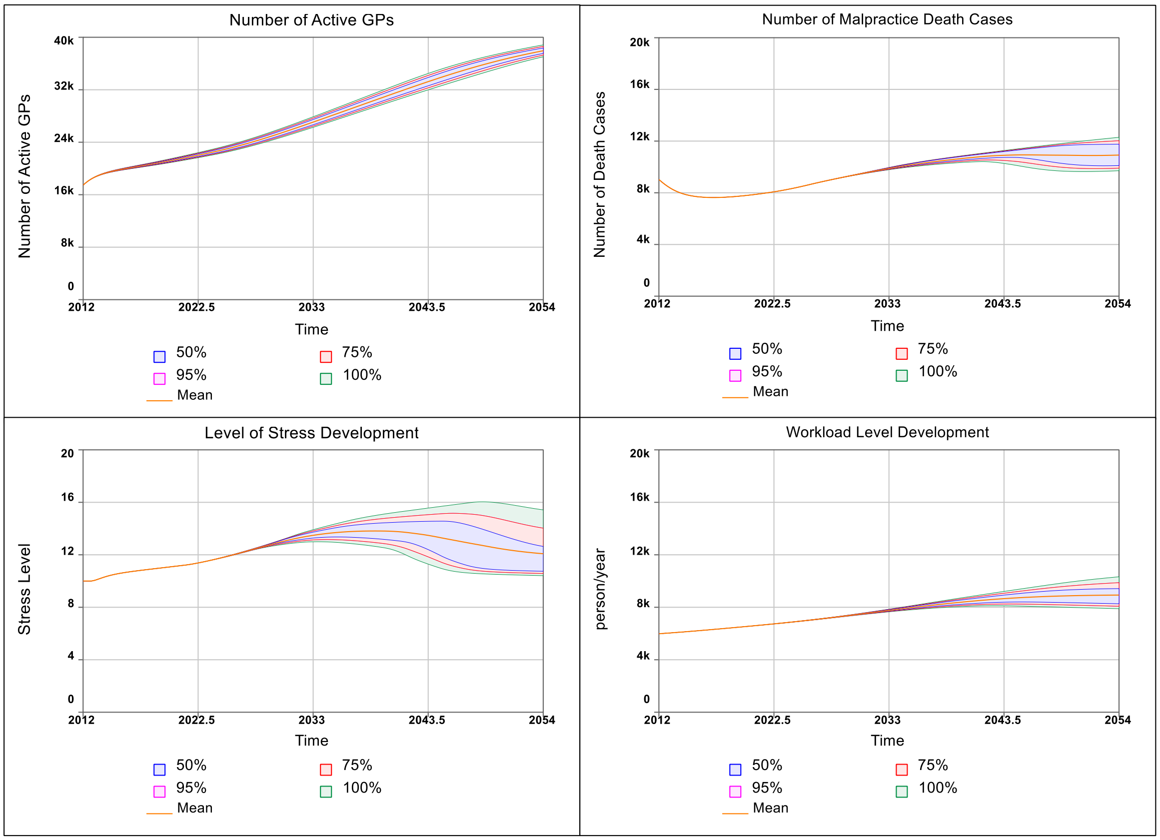

Figure (52): Percentage of Immigrant GPs Sensitivity Test.

Table (32): Percentage of Immigrant GPs Sensitivity Test.

	Percentage of immigrant GPs	Number of Active GPs	#Malpractice Death Cases
Run 1	0.04	37,028	12,294
Run 2	0.07	37,540	11,762
Run 3	0.10	37,951	10,724
Run 4	0.13	38,372	10,106
Run 5	0.16	38,842	9,708

Table (32) and Figure (52) show a moderate sensitivity level by changing the value of the percentage of immigrant GPs. The model behaved as expected in response to these changes. This parameter is a candidate leverage point that can help in covering the shortage of GPs in Quebec.

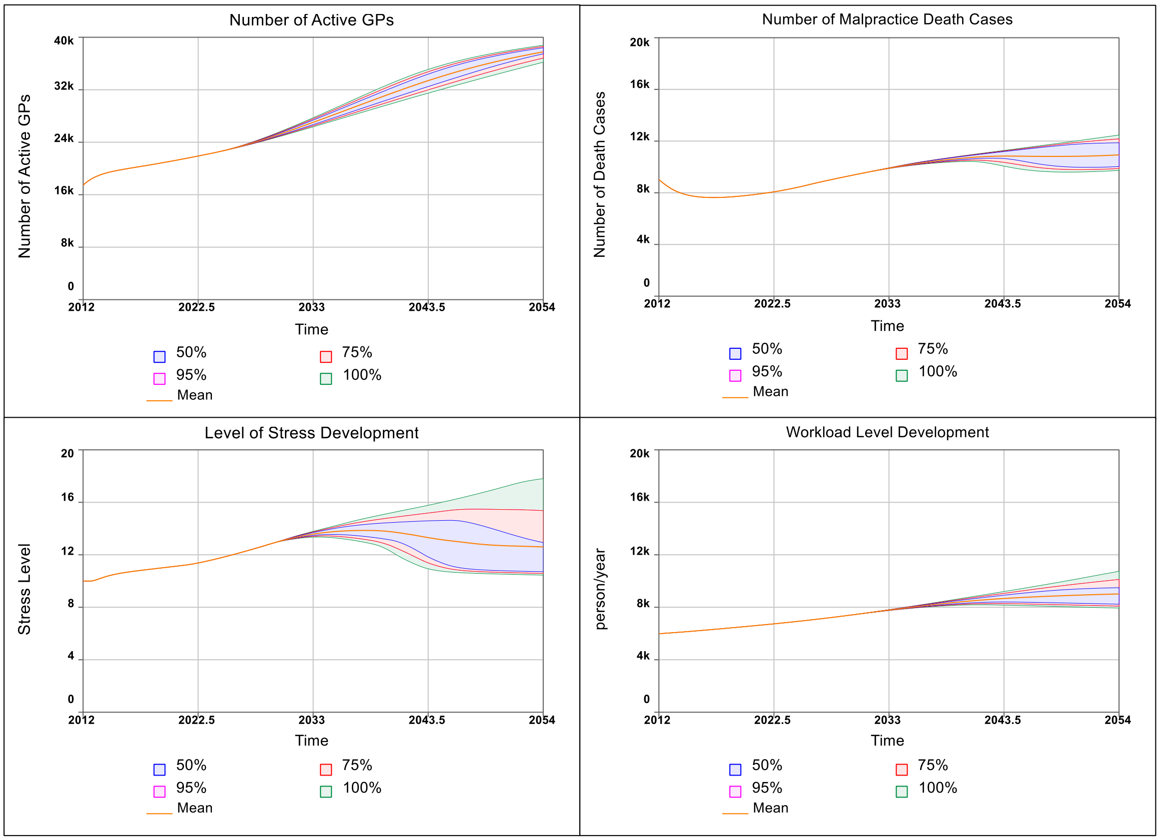

Figure (53): Sherbrooke Uni Medical Students join Yearly, Sensitivity Test Results

Table (33): Sherbrooke Uni Medical Students join Yearly, Sensitivity Test Results

	Sherbrooke Uni doctor students capacity	Number of Active GPs	#Malpractice Death Cases
Run 1	100	36,194	12,470
Run 2	175	37,468	11,872
Run 3	250	38,008	10,568
Run 4	325	38,406	10,028
Run 5	400	38,787	9,728

Changing the number of new medical students who can enroll every year will change the number of MDC in the same direction. It is expected that when we increase the number of new medical students, MDC will decrease, and the opposite is true also. The same description applies to the change in the number of medical students in other universities in Quebec (see Figure (53), Table (33)).

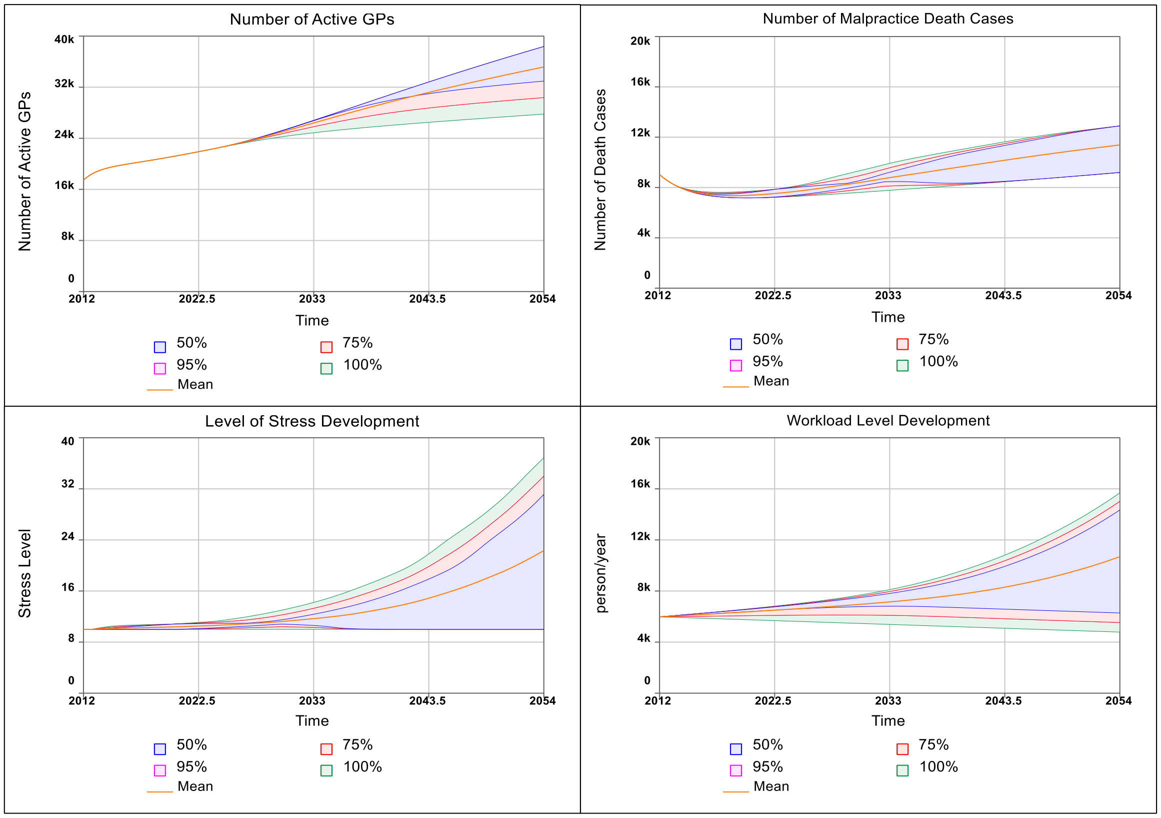

Figure (54): Desired Percentage of GPs Sensitivity Test.

Table (34): Desired Percentage of GPs Sensitivity Test Results.

	The desired percentage of GPs	Number of Active GPs	#Malpractice Death Cases
Run 1	0.00168	27,788	9,203
Run 2	0.00294	32,954	9,189
Run 3	0.00420	38,371	12,900
Run 4	0.00546	38,371	12,892
Run 5	0.00672	38,371	12,735

The model shows a high sensitivity to this parameter as it directly affects the required number of active GPs; OECD determined the value of this parameter, which means that we cannot further investigate this parameter as it is already fixed (see Figure (54), Table (34)).

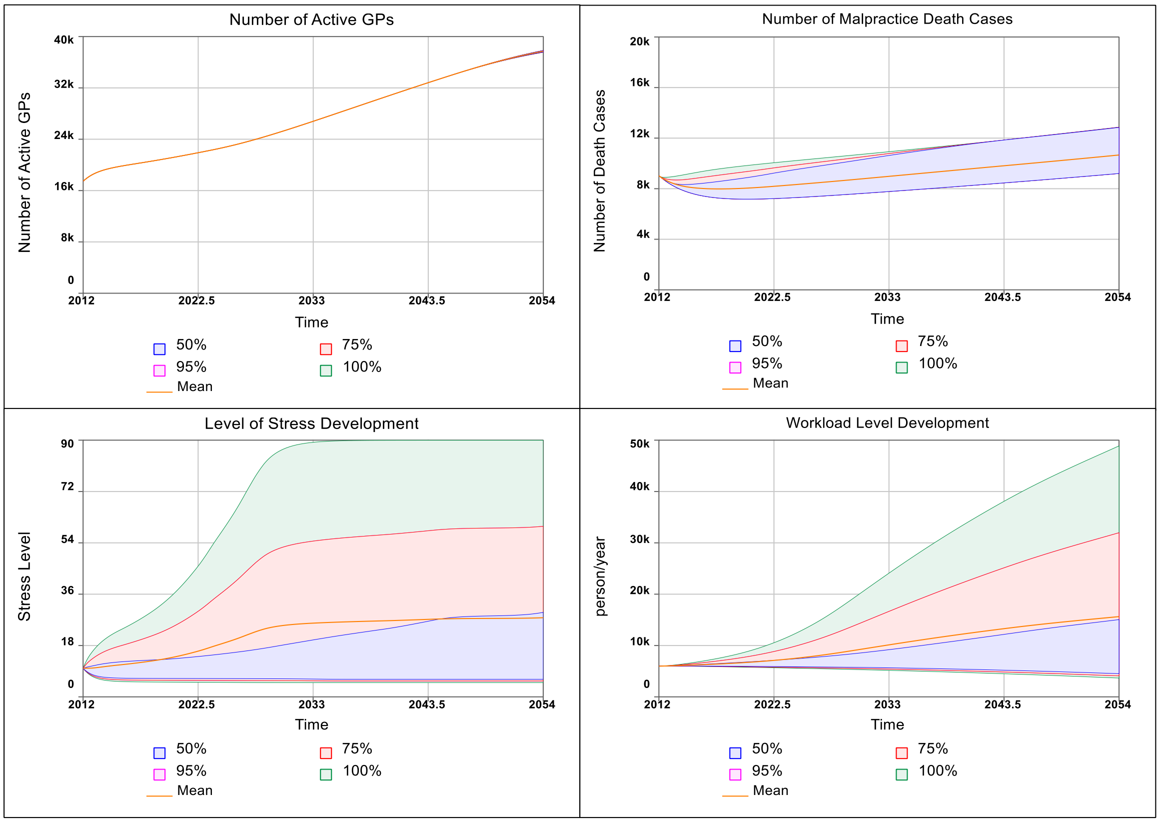

Figure (55): Time to Accumulate StressSensitivity Test.

Table (35): Time to Accumulate Stress Sensitivity Test Results.

	Time to Accumulate Stress	Number of Active GPs	#Malpractice Death Cases
Run 1	0.50	37,550	12,847
Run 2	0.88	37,602	12,870
Run 3	1.25	37,824	9,203
Run 4	1.63	37,824	9,203
Run 5	2.00	37,824	9,203

The “time to accumulate stress” parameter showed high sensitivity in the model behavior; this is expected as this parameter affects the duration of time a stress unit requires to be added to the stress stock. When the accumulation is slow, the stress level will increase slowly, and if the decompression time is fixed and lower than the accumulation time, then the decompression will be more effective than accumulation, releasing more stress units than accumulating them (see Figure (55), Table (35)).

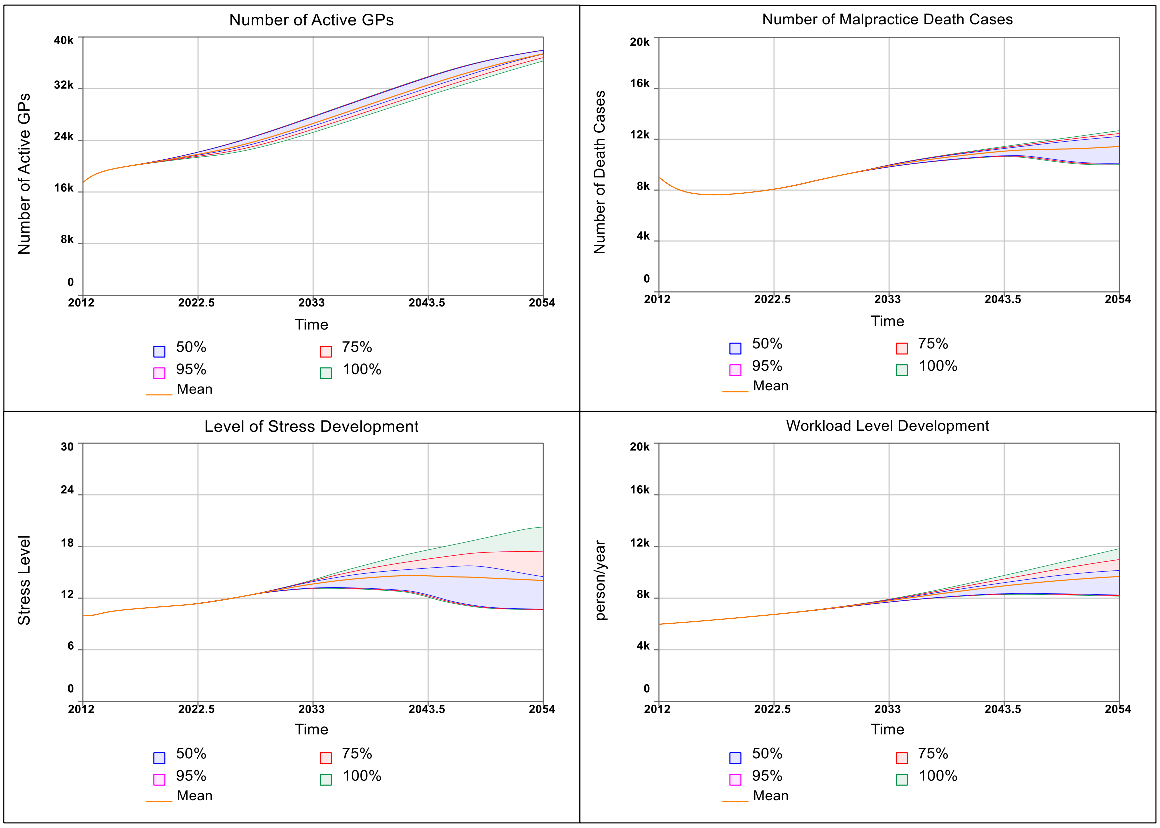

Figure (56): Recruitment- Turn Over Fraction Sensitivity Test.

Table (36): Recruitment- Turn Over Fraction Sensitivity Test.

	Turnover Fraction	Number of Active GPs	#Malpractice Death Cases
Run 1	0.060	37,974	10,003
Run 2	0.126	37,394	12,178
Run 3	0.064	37,934	10,109
Run 4	0.130	37,343	12,217
Run 5	0.194	36,288	12,674

The turnover fraction affects the number of new medical students joining medical schools, so this parameter delays the achievement of the goal and decreases the number of new medical students who will enroll every year. A moderate sensitivity is observed in testing this parameter; this is an expected behavior of the model as it causes changes in the time the gaps in the system need to cover (see Figure (56), Table (36)).

C. Model Documentation

Top-Level Model:

"New_Med._Students"(t) = "New_Med._Students"(t - dt) + ("Recruiting_Qualified_Med._St." - Withdrawing_the_admission) * dt

INIT "New_Med._Students" = 928

UNITS: person/year

DOCUMENT: Number of new medical students who are ready to join the medical school.

Accumulated_Budget(t) = Accumulated_Budget(t - dt) + (Allocating_budget) * dt

INIT Accumulated_Budget = 5000000

UNITS: CAD/year

DOCUMENT: This stock is mainly used as a memory for the budget approved in all the years of the simulation.

Hospital_residency(t) = Hospital_residency(t - dt) + (Finishing_school - Finishing_residency - Joining_for_specialty - Unmatched_Students) * dt

INIT Hospital_residency = 3600

UNITS: person

DOCUMENT: The number of students who are in the residency period.

Level_of_Stress(t) = Level_of_Stress(t - dt) + (Accumulating_stress - Decompressing) * dt

INIT Level_of_Stress = Normal_Stress

UNITS: stress unit

DOCUMENT: Stress level, its value will be compared to the normal stress value to estimate the current stress level that the GP is suffering from.

Number_of_Active_GPs(t) = Number_of_Active_GPs(t - dt) + (New_Graduates_New_GPs + Immigrating_GPs - Retiring_GPs_rate) * dt

INIT Number_of_Active_GPs = INIT(Number_of_GPs)

UNITS: person

DOCUMENT: The accumulated number of doctors who are currently practicing medicine.

Quebec_Population(t) = Quebec_Population(t - dt) + (Birth_rate - Death_rate) * dt

INIT Quebec_Population = 8061101

UNITS: person

DOCUMENT: The population of Quebec in 2012

The estimated population of Quebec, Q3 (2021).

Reference:

(Institut de la Statistique du Québec, 2022)

https://statistique.quebec.ca/en/produit/tableau/population-of-quebec

Reference_Number_of_GP_in_Quebec(t) = Reference_Number_of_GP_in_Quebec(t - dt) + (GPs_Joining_Service) * dt

INIT Reference_Number_of_GP_in_Quebec = 17550

UNITS: GP

DOCUMENT: This is the number of GPs in Quebec (reference mode)

Reference: https://www.jstor.org/stable/pdf/resrep23989.7.pdf

Students_in_Specialty(t) = Students_in_Specialty(t - dt) + (Joining_for_specialty - Finishing_specialty - dropping_out_of_Specialty) * dt

INIT Students_in_Specialty = 130

UNITS: person

DOCUMENT: The number of doctors who are training to become specialists.

"Students_in_Universities_(Doctoral_Programs)"(t) = "Students_in_Universities_(Doctoral_Programs)"(t - dt) + (Joining_Med_Students - Finishing_school - Dropping_out) * dt

INIT "Students_in_Universities_(Doctoral_Programs)" = 928

UNITS: person

DOCUMENT: The number of students who are studying at the university in medical schools.

Workload_Level(t) = Workload_Level(t - dt) + (Workload_Addition - Workload_Removal) * dt

INIT Workload_Level = Initial_Workload

UNITS: person/year

DOCUMENT: The cumulative number of patients that the GP should handle. It is accumulated by the Workload Addition and decreased by the Workload Removal.

"Recruiting_Qualified_Med._St." = IF Switch_Graduates_Capacity = 1 AND policy_start_time<=TIME THEN Perceived_Med_Students_Gap/Average_Time_to_Hire ELSE 88.4

UNITS: person/year^2

DOCUMENT: Recruiting represents the entire process from applying til joining the medical school.

Accumulating_stress = Normal_Stress*Effect_of_RW_on_Stress/Time_to_Accumulate

UNITS: stress unit/year

DOCUMENT: This is the rate of stress that is added to the level of stress stock.

Allocating_budget = Allocated_Budget

UNITS: CAD/year^2

DOCUMENT: The process of planning the ways to expend the approved budget.

Birth_rate = Quebec_Population*Birth_fraction

UNITS: person/year

DOCUMENT: The flow represents the number of newborn children added to the population.

Death_rate = Quebec_Population*Death_fraction

UNITS: person/year

DOCUMENT: The flow that represents the number of dying persons every year.

Decompressing = Level_of_Stress/Actual_time_to_decompress

UNITS: stress unit/year

DOCUMENT: This flow represents the rate of stress elimination.

Dropping_out = Dropout_fraction*"Students_in_Universities_(Doctoral_Programs)"

UNITS: person/year

DOCUMENT: The estimated number of medical school students who drop out from their universities after joining medical schools yearly. (Glauser, 2019).

dropping_out_of_Specialty = Students_in_Specialty*Fraction_of_dropping_doctors

UNITS: person/year

DOCUMENT: The rate of students who are dropping from the specialty training.

Finishing_residency = Hospital_residency/Duration_of_residency

UNITS: person/year

DOCUMENT: The number of students who complete the medical training and become GPs and are ready to join the service.

Finishing_school = "Students_in_Universities_(Doctoral_Programs)"/Time_studying_at_school

UNITS: person/year

DOCUMENT: The number of students who finish the medical school program every year, to be transferred to residency.

Finishing_specialty = Students_in_Specialty/Duration_of_specialization

UNITS: person/year

DOCUMENT: The outflow that represents the graduating specialists.

GPs_Joining_Service = "Growth_Rate_in._GPs_in_Quebec"*Reference_Number_of_GP_in_Quebec

UNITS: GP/year

DOCUMENT: Number of GPs who are joining the healthcare system serving the people of Quebec.

Reference: https://www.jstor.org/stable/pdf/resrep23989.7.pdf

Immigrating_GPs = Immigrant_GPs

UNITS: person/year

DOCUMENT: The inflow of doctors who are coming from abroad working in Quebec as immigrants.

Joining_for_specialty = Hospital_residency*Fraction_of_Students_Specialization

UNITS: person/year

DOCUMENT: This is a representation of the doctors who complete residency and join the specialty training.

Joining_Med_Students = IF (Switch_Graduates_Capacity) =0 THEN Number_of_Recruited_New_Med_Students ELSE Number_of_funded_students

UNITS: person/year

DOCUMENT: Number of new medical students who are joining the medical schools.

New_Graduates_New_GPs = Expected_GPs_graduates_fraction*Total_Enrollment_in_universities

UNITS: person/year

DOCUMENT: The inflow of the new GPs who graduate from universities and are now joining the active GPs who serve the local community in Quebec.

Retiring_GPs_rate = Number_of_Active_GPs//"Drs._retirement_age"

UNITS: person/year

DOCUMENT: The outflow in which senior doctors are retiring every year.

Unmatched_Students = "Fraction_of_Unmatched_._Students"*Hospital_residency

UNITS: person/year

DOCUMENT: This is the unmatched number of college graduates that they couldn't secure a slot for residency training.

https://www.carms.ca/news/2021-r-1-main-residency-match-results-released/

Withdrawing_the_admission = "New_Med._Students"*Turnover_Fraction

UNITS: person/year/year

DOCUMENT: Overall turnover of new medical students.

Workload_Addition = adding_excess_patients*Normal_number_of_patients_per_GP*Effect_of_stress_on_Workload/Simulation_duration

UNITS: person/year/year

DOCUMENT: This inflow is the rate at which the worker receives additional work each month.

The Workload Addition is the inflow of the number of patients a GP handles per year; it is controlled by “adding_excess_patients” .

Workload_Removal = Productive_Output/Simulation_duration

UNITS: person/year/year

DOCUMENT: This outflow is the rate at which the worker clears their workload and is simply given by the worker's productive output.

"Drs._retirement_age" = 68

UNITS: year

DOCUMENT: The estimated age of retirement for doctors in Quebec.

"Unlike most people who generally retire at age 60 or 65, aging physicians tend to retire later because they can. For example, data from the Collège des médecins du Québec indicate that general practitioners retire around age 68 whereas specialists wait until age 72."

Reference:

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3264000/#:~:text=Unlike%20most%20people%20who%20generally,specialists%20wait%20until%20age%2072.

"Fraction_of_Unmatched_._Students" = 1.2/100

UNITS: dmnl/year

DOCUMENT: This is the fraction of graduate students who couldn't secure a slot for residency training.

(2021 R-1 Main Residency Match Results Released - CaRMS, 2021)

https://www.carms.ca/news/2021-r-1-main-residency-match-results-released/

"Fund_per_Med._student_year" = (Tuition_fees+Stipend)

UNITS: CAD/person/year

DOCUMENT: The total fund is required to support each medical student joining the medical colleges in Quebec.

"Growth_Rate_in._GPs_in_Quebec" = 1.6/100

UNITS: dmnl/year

DOCUMENT: This is the growth rate of GPs every year in Quebec.

https://www.jstor.org/stable/pdf/resrep23989.7.pdf

"Med._Students_Recruitment_Goal" = Allocated_seats_for_Med_students

UNITS: person/year

DOCUMENT: New medical students' number which represents the goal set by the university board for the program based on the administration of the medical school's estimated demand for the program, budget, etc.

"New_Med.Mal._Death_Rate" = Change_in_MDC*Initial_malpractice_death_rate//Malpractice_Death_cases

UNITS: 1/year

DOCUMENT: This is the new medical malpractice death rate which is calculated depending on the performance of the proposed model.

"Num._of_MDC_Saved_by_Quality" = SMTH1(("Percentage_of_Patients_.Safety_&_Quality_of_Service")*Malpractice_Death_cases, 3,Malpractice_Death_cases-Malpractice_Death_cases)

UNITS: person/year

DOCUMENT: The number of potentially saved lives as a result of the change in the service quality and the patient safety level.

"Percentage_of_Patients_.Safety_&_Quality_of_Service" = GRAPH(Normalized_Effect_of_Stress_on_Workload*Switch_Grad_PP/Switch_Grad_PP)

Points: (10.00, 0.3000), (12.00, 0.1316), (14.00, 0.0645), (16.00, 0.0461), (18.00, 0.0289), (20.00, 0.0158), (22.00, 0.0066), (24.00, 0.0000), (26.00, 0.0000), (28.00, 0.0000), (30.00, 0.0000)

UNITS: Dimensionless

DOCUMENT: This is the change in service quality and patient safety in response to the current level of stress a GP is suffering from; it is estimated that the improvement that could be achieved in the proposed model does not exceed 30% as per the mentioned reference.

When Normalized Effect of Stress on Workload near 10 units, then "Percentage of Patients Safety & Quality of Service" (PSQS) will be near 0.3, when the stress increases the Normalized Effect of Stress on Workload will increase, this will cause a drop in the PSQS.

(Anderson and Abrahamson, 2017)

Actual_time_to_decompress = Effect_of_stress_on_decompression*Normal_time_to_decompress

UNITS: year

DOCUMENT: The value of this converter demonstrates the relationship between the normal time to get rid of stress and the effect of stress on decompression.

Actually_Number_of_Patients_handled_by_PP = DELAY1 (Number_of_Patients_treated_by_PP, 3)

UNITS: person/year

DOCUMENT: The number of patients handled by PP with consideration to 3 years delay.

adding_excess_patients = GRAPH(Relative_excess_in_patients)

Points: (1.0000, 0.8000), (1.0500, 0.9850), (1.1000, 1.0919), (1.1500, 1.2053), (1.2000, 1.3016), (1.2500, 1.3583), (1.3000, 1.4065), (1.3500, 1.4433), (1.4000, 1.4660), (1.4500, 1.4887), (1.5000, 1.5000)

UNITS: Dimensionless

DOCUMENT: This ratio represents the amount of workload transferred to the workload level and the stress structure. It is assumed that when the relative excess in patients is equal to 1 or less, the transferred effect through this converter is equal to 0.8 of the pressure; this is because the transferred pressure will be under control and will need no extra efforts to release it, the available dynamics are able to manage this pressure. However, when the relative excess in patients is higher than 1, the pressure will start increasing the same way the relative excess in patients is increasing.

Allocated_Budget = DELAY3(Approved_Budget, 1)

UNITS: CAD/year^2

DOCUMENT: The budget will be allocated after a delay time, a year after approval.

Allocated_seats_for_Med_students = MIN(Desired_graduated_GPs, Possible_capacity_wt_Policy_Switch_Status)

UNITS: person/year

DOCUMENT: The number of seats that are allocated for new medical students.

Approved_Budget = IF Switch_Approved_Budget_Percentage = 1 THEN (desired_budget*Optimistic) ELSE IF Switch_Approved_Budget_Percentage = 2 THEN (desired_budget*Realistic) ELSE (desired_budget*Pessimistic)

UNITS: CAD/year^2

DOCUMENT: The amount of funds approved by authorities to provide funds for the new medical students.

Average_Time_to_Hire = Normal_Time_to_recruit*Effect_of_Recruitment_Gap_on_Time_to_Hire

UNITS: year

DOCUMENT: The average time to hire is the average time it takes to recruit, select, and deploy new medical students. This is a function of the normal time to hire, which is based on the organizational average, and the effect of recruitment gaps on time to hire.

Hovmand, P. (2020). Staffing Model. System Dynamics Summer School- Bignners Track- Modeling Policies Chapter.

Birth_fraction = .0158

UNITS: 1/year

DOCUMENT: This is the fraction of births that are added to the population every year -Quebec.

Reference:

https://montrealgazette.com/news/local-news/bouncing-babies-quebecs-birth-rate-has-returned-to-pre-pandemic-levels#:~:text=There%20were%20an%20estimated%2084%2C900,2019%2C%20the%20number%20was%2084%2C309.

Capacity_multiplier = SMTHN (1.5, Time_required_to_increase_capacity,5, 1)

UNITS: Dimensionless

DOCUMENT: The highest value of universities' capacity to admit new medical students. This capacity can not be exceeded in any circumstances within this project.

Source for delay time:

montrealgazette.com

Quebec expands admission to medical schools by more than 100...

nearly 140 in the coming 3 year

Change_in_MDC = Malpractice_Death_cases-"Num._of_MDC_Saved_by_Quality"

UNITS: person/year

DOCUMENT: The current number of death cases related to medical malpractice errors.

https://canadiandimension.com/articles/view/do-no-harm

Current_Capacity_Multiplier = 1

UNITS: dmnl

DOCUMENT: The current multiplier is meant to increase or decrease the available number of slots for new medical students in Quebec. Its value is 1 when no intervention is required or no policy is activated.

Current_Num_of_patients_visiting_GP = (Normal_number_of_patients_per_GP+More_patients)

UNITS: person/year

DOCUMENT: Actual number of patients who visit GPs every year.

Death_fraction = Initial_death_rate-(Initial_malpractice_death_rate-"New_Med.Mal._Death_Rate")

UNITS: 1/year

DOCUMENT: The calculated death fraction of the Quebec population.

Desired_active_drs_adjustment = MAX(Gap_btwn_Active_&_required_GPs/Policy_Adjustment_Time, Possible_capacity/10)

UNITS: person/year

DOCUMENT: The desired number of doctors needed to be added yearly to implement the recommended policy.

desired_budget = IF Switch_Graduates_Capacity =0 THEN 0 ELSE (Desired_cost_of_Medical_Student)

UNITS: CAD/year^2

DOCUMENT: This is the amount of funds that is required to increase the number of funded new students.

Desired_cost_of_Medical_Student = Recruited_students*"Fund_per_Med._student_year"

UNITS: CAD/year^2

DOCUMENT: The cost of financing the whole required number of new medical students.

Desired_drs_graduates_fraction = (Desired_New_Graduates_New_GPs//Total_Enrollment_in_universities)

UNITS: Dimensionless

DOCUMENT: The desired fraction of graduated doctors that should facilitate the implementation of the recommended policy.

Desired_graduated_GPs = Total_Enrollment_in_universities*Desired_drs_graduates_fraction

UNITS: person/year

DOCUMENT: Desired number of doctors that will solve the problem under study.

Desired_New_Graduates_New_GPs = IF Desired_active_drs_adjustment <= 0 THEN 0 ELSE Desired_active_drs_adjustment+ Perceived_substitute_number_for_retired_doctors+Total_of_dropping_out_students

UNITS: person/year

DOCUMENT: The desired number of new medical school graduates, which means particularly the number of newly graduated doctors.

Doctors_graduating_yearly = (Finishing_specialty+Finishing_residency)

UNITS: person/year

DOCUMENT: The number of new GPs graduating from medical school.

Dropout_fraction = 0.05

UNITS: 1/year

DOCUMENT: This is the percentage of students that are dropping out from the medical study program during the first 5 years.

Reference:

(Glauser, 2019)

https://studyabroadaide.com/study-medicine-canada/

Duration_of_residency = 2

UNITS: year

DOCUMENT: Number of years a medical student should be trained after completing 5 years in University to become a licensed GP.

Reference:

(Lagarda-Leyva and Ruiz, 2019)

Duration_of_specialization = 7

UNITS: year

DOCUMENT: The average time to from sepciality training.

(Lagarda-Leyva and Ruiz, 2019)

Effect_of_Recruitment_Gap_on_Time_to_Hire = GRAPH(Recruitment_Gap//"Med._Students_Recruitment_Goal")

Points: (0.000, 0.993307149076), (0.100, 0.982013790038), (0.200, 0.952574126822), (0.300, 0.880797077978), (0.400, 0.73105857863), (0.500, 0.500), (0.600, 0.26894142137), (0.700, 0.119202922022), (0.800, 0.0474258731776), (0.900, 0.0179862099621), (1.000, 0.00669285092428)

UNITS: Dimensionless

DOCUMENT: As the recruitment gap gets larger relative to the goal, the urgency to recruit new medical students increases in order to meet university's expectations that the program is fully staffed. The increased urgency is reflected in a shorter average time to hire.

Hovmand, P. (2020). Staffing Model. System Dynamics Summer School- Bignners Track- Modeling Policies Chapter.

Effect_of_RW_on_Stress = GRAPH(Relative_workload)

Points: (1.000, 1.000), (1.200, 1.114), (1.400, 1.342), (1.600, 1.588), (1.800, 1.807), (2.000, 2.114), (2.200, 2.307), (2.400, 2.526), (2.600, 2.763), (2.800, 2.921), (3.000, 3.000)

UNITS: Dimensionless

DOCUMENT: This converter represents the effect of workload on stress. when the workload increases, the stress will accumulate and increase as well, leading the stressed GP to suffer from burnout symptoms. It is estimated by the author from (isee ExchangeTM, 2022) “Battle Burnout, Take a vacation”

Effect_of_stress_on_decompression = GRAPH(Relative_Stress)

Points: (1.00, 1.000), (3.90, 1.401), (6.80, 1.466), (9.70, 1.510), (12.60, 1.563), (15.50, 1.615), (18.40, 1.652), (21.30, 1.704), (24.20, 1.773), (27.10, 1.834), (30.00, 1.883)

UNITS: Dimensionless

DOCUMENT: This converter represents the effect of stress on the process of decompressing stress; if the stress level is high, the decompression will require more time to be completed, and the opposite applies.

Effect_of_stress_on_Workload = Level_of_Stress/Normal_Stress

UNITS: dmnl

DOCUMENT: This converter represents the effect of stress on workload; when the stress increases, the workload will increase because productivity will also decrease.

Effect_of_Work_Overload_on_Productivity = GRAPH(Relative_workload)

Points: (1.000, 1.0000), (1.100, 0.9937), (1.200, 0.9783), (1.300, 0.9417), (1.400, 0.8662), (1.500, 0.7500), (1.600, 0.6338), (1.700, 0.5583), (1.800, 0.5217), (1.900, 0.5063), (2.000, 0.5000)

UNITS: Dimensionless

DOCUMENT: This variable is the stressor on the normal productivity of the GP given the perceived work overload.

When relative workload <=1, productivity is assumed to be 1, which means it is not affected by the workload. However, when the relative workload > 1, this means that the GP will handle more patients than the safe number of patients, which will cause extra workload and the productivity will decrease up to half of normal levels when the workload is doubled.

Expected_GPs_graduates_fraction = Fraction_graduated_GPs

UNITS: Dimensionless

DOCUMENT: The new calculated fraction of new doctors who graduate yearly from universities after applying the recommended policy.

Expected_Population = FORCST (Quebec_Population, Policy_time_period, Birth_fraction)

UNITS: person

DOCUMENT: It is a converter that forecast the population for the proceeding years (using FORCST).

Fraction_graduated_GPs = Doctors_graduating_yearly//Total_Enrollment_in_universities

UNITS: Dimensionless

DOCUMENT: The fraction of medical graduates from the total graduates from universities.

Fraction_of_dropping_doctors = 0.05

UNITS: dmnl/year

DOCUMENT: The rate of students who are dropping from specialty training.

Estimated by the author.

Fraction_of_recruited_students = "New_Med._Students"//Allocated_seats_for_Med_students

UNITS: dmnl

DOCUMENT: The achieved fraction of new recruits who will join the medical schools.

Fraction_of_Students_Specialization = 0.2

UNITS: 1/year

DOCUMENT: The fraction of medical students who pursue their studies to become specialists.

(Lagarda-Leyva and Ruiz, 2019)

Gap_btwn_Active_&_required_GPs = MAX (Goal_of_Active_GPs-Number_of_Active_GPs, 0)

UNITS: person

DOCUMENT: The Gap between the current active doctors in the community and the number of the required doctors to cover the estimated shortage.

Goal_of_Active_GPs = The_desired_percentage_of_GPs*Expected_Population

UNITS: person

DOCUMENT: The is the number of active doctors that the proposed policy aims to achieve.

Immigrant_GPs = Number_of_Immigrant_GPs/Policy_time_period

UNITS: person/year

DOCUMENT: The number of immigrant GPs that are coming every year to Quebec for practicing medicine.

{8.2% of total doctors in Quebec}

reference:

https://www.iedm.org/a-prescription-for-quebecs-doctor-shortage/

Initial_death_rate = 8.1/1000

UNITS: 1/year

DOCUMENT: The death rate of Quebec population as mentioned in the literature.

reference:

https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1310071001

Initial_malpractice_death_rate = 0.00115301

UNITS: 1/year

DOCUMENT: This rate is calculated as follows:

The population of Canada is about 34,690,000 persons in 2012.

The number of deaths caused by medical malpractice in 2012 was about 40,000 deaths.

By dividing the number of deaths mention above with the population of Canada, both numbers were reported in 2012. the result will be the death fraction of deaths caused by medical malpractices in Canada.

I assumed that the same rate applies in Quebec,

40,000/34,691,806 in (2012)

https://canadiandimension.com/articles/view/do-no-harm

Initial_Workload = 5980

UNITS: person/year

DOCUMENT: The initial number of patients a GP should see.

Laval_Uni_doctor_students_capacity = 223

UNITS: person/year

DOCUMENT: The total number of new medicine students this university can admit every year.

https://medapplications.com/laval-university-medical-school-admission-requirements/#:~:text=The%20Universit%C3%A9%20Laval%20Medical%20School,program%20admits%20223%20students%20yearly.

Malpractice_Death_cases = Quebec_Population*Initial_malpractice_death_rate

UNITS: person/year

DOCUMENT: The number of deaths that happen as a result of medical malpractice errors.

maximum_patients_PP_can_handle_yearly = Work_percentage_saved_by_PP*Current_Num_of_patients_visiting_GP

UNITS: person/year

DOCUMENT: The maximum nuber of patients PP can serve every year.

Reference:

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6146005/

McGill_Uni_doctor_students_capacity = 215

UNITS: person/year

DOCUMENT: The total number of new medicine students this university can admit every year.

https://masterstudent.ca/mcgill-medical-school-requirements-and-acceptance-rate/

Montreal_Uni_doctor_students_capacity = 291

UNITS: person/year

DOCUMENT: The total number of new medicine students this university can admit every year.

https://www.univcan.ca/universities/facts-and-stats/enrolment-by-university/

More_patients = IF Percentage_of_current_active_GPs <=0 THEN 0 ELSE IF ((1-Percentage_of_current_active_GPs)*Normal_number_of_patients_per_GP)<0 THEN 0 ELSE (1-Percentage_of_current_active_GPs)*Normal_number_of_patients_per_GP

UNITS: person/year

DOCUMENT: The number of patients that represents the excess number of patients as a result of shortage in doctors.

Normal_number_of_patients_per_GP = 23*5*52

UNITS: person/year

DOCUMENT: The number of patients a doctor can check in one year, 23 patients every day (5 days a week), for 52 weeks every year in 5 days a week.

(statista.com, 2022)

Normal_Stress = 10

UNITS: stress unit

DOCUMENT: This is an assumed value of stress that represents the normal level of stress.

(Gambardella and Lounsbury, 2017)

Normal_time_to_decompress = 1

UNITS: year

DOCUMENT: This is the time required to decompress stress.

Gambardella, P. J., & Lounsbury, D. W. (2017). Modeling Psychological and Sociological Dynamics Methods and Applications. 37.

Normal_Time_to_recruit = 0.5

UNITS: year

DOCUMENT: The average time to recruit new qualified medical students.

Adapted from:

Hovmand, P. (2020). Staffing Model. System Dynamics Summer School- Bignners Track- Modeling Policies Chapter.

Normalization_Factor = 10

UNITS: dmnl

DOCUMENT: This is a factor to normalized the affect of stress to be used in the "Percentage of Patients

.Safety & Quality of Service" graphical function.

Normalized_Effect_of_Stress_on_Workload = Normalization_Factor*Effect_of_stress_on_Workload

UNITS: dmnl

DOCUMENT: This the result of normalization for the effect of stress on workload converter.

Number_of_funded_students = Allocating_budget//"Fund_per_Med._student_year"*Universities'_capacity/Universities'_capacity

UNITS: person/year

DOCUMENT: This is the number of new medical student who are joining the medical schools every year

Number_of_GPs = 17454

UNITS: person

DOCUMENT: The number of doctors related to the population, this converter represents the initial value of the (Number of

Active Doctors in 2012) stock.

(Globerman et al., 2018)

(Canadian Medical Association, 2012)

URL: https://www.cma.ca/sites/default/files/2019-03/2012-01-spec-prov.pdf

Number_of_Immigrant_GPs = Number_of_Active_GPs*Percentage_of_immigrant_GPs

UNITS: person

DOCUMENT: The total number of immigrant GPs that practice medicine in Quebec.

Number_of_Patients_treated_by_PP = IF TIME >= policy_start_time THEN(IF Switch_Using_Practicing_Pharmacists = 1 THEN (DELAY1(MIN(IF (More_patients<250) THEN 0 ELSE More_patients, maximum_patients_PP_can_handle_yearly), 1, MIN(IF (More_patients<250) THEN 0 ELSE More_patients, maximum_patients_PP_can_handle_yearly))) ELSE 0)ELSE 0

UNITS: person/year

DOCUMENT: This is the actual number of patients a PP is serving. It decreases over time as new GPs join the working GPs community every year. So while the number of GPs is increasing, the number of PP will decrease since the need for PP will also decrease. PP will keep helping the GPs until the number of excessive patients becomes less than 250 patients yearly; in this case, the PP's mission will end in one year. That is the reason for using the smoothing function in this formula.

Number_of_Recruited_New_Med_Students = DELAY1 (MIN ("New_Med._Students", Allocated_seats_for_Med_students), 1)

UNITS: person/year

DOCUMENT: This is the number of the new medical students who are qualified and ready to join the medical school.

Number_of_weeks_per_year = 52

UNITS: week/year

DOCUMENT: Number of weeks every year.

Optimistic = 1

UNITS: Dimensionless

DOCUMENT: This option is the optimal option, that will provide fund to all the recruited students.

Perceived_Med_Students_Gap = MAX(SMTH3(Recruitment_Gap, Recruitment_Gap_Adj_Time), 0)

UNITS: People/year

DOCUMENT: It is the time when the admission department is estimating the required number of new qualified medical students to recruit.

Perceived_Stress = SMTH1(Level_of_Stress, Time_to_Perceive_Stress, Level_of_Stress)

UNITS: stress unit

DOCUMENT: This is the expected level of stress delayed as the recognition of the level of stress will take some time to be realized. It is estimated by the author.

Perceived_substitute_number_for_retired_doctors = SMTH1(Retiring_GPs_rate, Time_to_Perceive_the_#_of_retired_GPs)

UNITS: person/year

DOCUMENT: The number of new doctors who are required to compensate the number of retiring doctors.

Perceived_Workload = SMTH1(Workload_Level*adding_excess_patients, Time_to_perceive_Workload, Workload_Level)

UNITS: person/year

DOCUMENT: The number of tasks or workload the worker perceives they have to clear. It is assumed that the worker takes stock of the backlog every week in order to plan his weekly schedule for clearing the workload.

Percentage_of_current_active_GPs = Number_of_Active_GPs//Goal_of_Active_GPs

UNITS: Dimensionless

DOCUMENT: This is the number of current working GPs in Quebec.

Percentage_of_immigrant_GPs = 0.082

UNITS: Dimensionless

DOCUMENT: The percentage of immigrant GPs that are coming to work in Quebec, {8.2% of total doctors in Quebec}

reference:

https://www.iedm.org/a-prescription-for-quebecs-doctor-shortage/

Pessimistic = .75

UNITS: Dimensionless

DOCUMENT: This option represents the failure to approve an adequate budget to fund the new medical students.

Policy_Adjustment_Time = Policy_time_period*0 + (Policy_time_period/8)*1+policy_deadline*0

UNITS: year

DOCUMENT: This converter demonstrate the time interval in which the policy will be adjusted.

policy_deadline = STOPTIME

UNITS: years

DOCUMENT: The ending date of the policy.

policy_start_time = STARTTIME+10

UNITS: years

DOCUMENT: The start time of the policy.

policy_status = IF(Switch_Graduates_Capacity=1) AND(policy_start_time<TIME)THEN(1)ELSE(0)

UNITS: unitless

DOCUMENT: The status of the implementation of the policy, it checks whether the time and switch are within the designated boundary of the model in order to proceed with the policy implementation.

Policy_time_period = policy_deadline-policy_start_time

UNITS: years

DOCUMENT: The duration of the recommended policy's implementation.

Possible_capacity = Universities'_capacity*Current_Capacity_Multiplier

UNITS: person/year

DOCUMENT: Maximum available number of medical students that the universities in Quebec can admit for the medical school.

(Lagarda-Leyva and Ruiz, 2019)

Possible_capacity_wt_Policy_Switch_Status = IF Switch_Graduates_Capacity = 0 OR "Fund_per_Med._student_year" <=0 THEN Possible_capacity ELSE Possible_capacity*Required_Capacity

UNITS: person/year

DOCUMENT: This converter will be activated when the switch of policy is turned on, it represents the current available capacity that is available for the recruited new students. also it requires that the fund is available, otherwise the normal number of new medical students will be added every year without any changes, which is 928 new medical students yearly.

Productive_Output = Effect_of_Work_Overload_on_Productivity*Normal_number_of_patients_per_GP

UNITS: person/year

DOCUMENT: Productive Output is the number of tasks per year that is actually produced by the worker. It is given by the actual number of hours worked multiplied by the normal productivity as well as external stressors that affect the normal productivity.

Realistic = 0.85

UNITS: Dimensionless

DOCUMENT: This option represents the percentage of approved budget to fund the new medical students, however this option will provide partial fund that will improve the current situation, but this fund will not solve the problem.

Recruited_students = IF Switch_Graduates_Capacity =0 THEN Possible_capacity*Fraction_of_recruited_students//Fraction_of_recruited_students ELSE Fraction_of_recruited_students*Allocated_seats_for_Med_students

UNITS: person/year

DOCUMENT: Number of recruited new medical students.

Recruitment_Gap = "Med._Students_Recruitment_Goal"-"New_Med._Students"

UNITS: People/year

DOCUMENT: Actual gap between the number of new medical students needed to be considered and the number current medical students.

Hovmand, P. (2020). Staffing Model. System Dynamics Summer School- Bignners Track- Modeling Policies Chapter.

Recruitment_Gap_Adj_Time = 0.5

UNITS: year

DOCUMENT: The periods in which the goal is adjusted.

Reference_Mode = Quebec_Population*1.13/1000

UNITS: person

DOCUMENT: This is the reference mode for the medical malpractice deaths, multiplied by the fraction calculated by the author in chapter (1)

It has the same value of "Initial malpractice death rate" converter

source :https://www.oliveviewim.org/wp-content/uploads/2018/10/Makary-2016-3rd-leading-cause-of-death.pdf

Relative_excess_in_patients = (Current_Num_of_patients_visiting_GP-Actually_Number_of_Patients_handled_by_PP)//Normal_number_of_patients_per_GP

REPORT IN TABLE AS STOCK

UNITS: Dimensionless

DOCUMENT: The relation between the current number of patients a GP will handle to the normal number of patients which is determined by literature.

Relative_Stress = Perceived_Stress/Normal_Stress

UNITS: Dimensionless

DOCUMENT: This is the relative value that describes the difference between the current level of stress and the perceived stress.

Relative_workload = Perceived_Workload//Current_Num_of_patients_visiting_GP

UNITS: Dimensionless

DOCUMENT: The ratio between the perceived workload, which is measured by the number of patients, and the current number of patients a GP should handle.

Required_Capacity = IF Desired_graduated_GPs/Possible_capacity <=Capacity_multiplier THEN Desired_graduated_GPs/Possible_capacity ELSE Capacity_multiplier

UNITS: Dimensionless

DOCUMENT: The required number of slots for new medical students that should prepared for new students, however, its value depends on the current capacity not the required.

Sherbrooke_Uni_doctor_students_capacity = 199

UNITS: person/year

DOCUMENT: The total number of new medicine students this university can admit every year.

https://medapplications.com/university-of-sherbrooke-medical-school-admission-requirements/#:~:text=The%20four%2Dyear%20MD%20program,province's%20medical%20and%20educational%20needs.

Simulation_duration = (STOPTIME-STARTTIME)

REPORT IN TABLE AS FLOW

UNITS: year

DOCUMENT: The time of simulation, it is used here to normalize the flows to be yearly basis.

Stipend = 12000

UNITS: CAD/person/year

DOCUMENT: average stipend allowance that will be paid monthly for the medicine students.

estimated by the author.

Switch_Approved_Budget_Percentage = 1

UNITS: dmnl

DOCUMENT: Approved Budget Percentage Switch instructions:

Switch = 1 Optimistic, Budget = 1

Switch = 2 Realistic, Budget = 0.8

Switch = 3 Pessimistic, No Budget at All Or less than 0.75 of the Required Budget.

Switch_Grad_PP = IF Switch_Using_Practicing_Pharmacists =0 AND Switch_Graduates_Capacity = 0 THEN 20 ELSE 1

UNITS: dmnl

DOCUMENT: This switch will have the value of 20 when one of the other switches is zero, but if all the switches are having the value of 1 then it will have also the value of 1.

This switch will activate the influence of the scenarios on the service quality and patient safety.

Switch_Graduates_Capacity = 1

UNITS: dmnl

DOCUMENT: This is a policy switch, if its value is 1 then the policy is activated, if 0 then the policy is not activated.

Switch_Using_Practicing_Pharmacists = 1

UNITS: dmnl

DOCUMENT: Using Practicing Pharmacists Intervention:

Switch = 0, Intervention is not activated.

Switch = 1, Intervention is activated

The_desired_percentage_of_GPs = 336/100000

UNITS: Dimensionless

DOCUMENT: The percentage of doctors determined by OECD represents the ideal percentage of doctors a community should have to provide a decent medical service for the community.

https://www.oecd-ilibrary.org/docserver/ae3016b9-en.pdf?expires=1659275817&id=id&accname=guest&checksum=EC14954B47E2F31BCAFC08352C8E1A96

Time_required_to_increase_capacity = 6

UNITS: year

DOCUMENT: The time to expand the capacity in the medical schools in Quebec, it is reported by the literature, that it will take around 3 years to add 139 new medical students.

The estimated expansion is expected to be 139*2, which double of the number mentioned in the report, this is why the value of this converter is set to 6 years.

montrealgazette.com

"Quebec expands admission to medical schools by more than 100... "

Time_studying_at_school = 5

UNITS: year

DOCUMENT: This is the average time to be spent studying at the medical schools.

https://bemoacademicconsulting.com/blog/medical-schools-in-quebec

(Lagarda-Leyva and Ruiz, 2019)

Time_to_Accumulate = 1

UNITS: year

DOCUMENT: The time that the accumulation of stress need in order to effect the stock of the stress. (isee ExchangeTM, 2022) burnout model.

Time_to_Perceive_Stress = 1

UNITS: year

DOCUMENT: this the time to realize the current level of stress, it is estimated by the author.

Time_to_Perceive_the_#_of_retired_GPs = 0.5

UNITS: year

DOCUMENT: The time required to estimate the number of retiring doctors.

(Estimated by the Author)

Time_to_perceive_Workload = 0.5

UNITS: year

DOCUMENT: It is the time that is required to perceive the current workload.

Total_enrollment_fraction = 0.018126572

UNITS: 1/year

DOCUMENT: calculated by dividing the number of admitted students by the total number of applicants. 155970/population

Total_Enrollment_in_universities = Total_enrollment_fraction*Quebec_Population

UNITS: person/year

DOCUMENT: 2021 full-time and part-time fall enrolment at Canadian universities

Source:

Association of Atlantic Universities

Council of Ontario Universities

Individual institutions

Bureau de cooperation interuniversitaire

https://www.univcan.ca/universities/facts-and-stats/enrolment-by-university/

Total_number_of_saved_hours_per_year = Total_saved_hours_per_week_by_PP*Number_of_weeks_per_year

UNITS: hrs/year

DOCUMENT: Total number of hours saved by PP yearly basis.

(Maskrey et al., 2018)

Total_of_dropping_out_students = Dropping_out + Unmatched_Students + dropping_out_of_Specialty

UNITS: person/year

DOCUMENT: This the total number of students who are dropping from the medical schools and training.

Total_saved_hours_per_week_by_PP = 4.9

UNITS: hrs/Weeks

DOCUMENT: Number of hours actually saved by PP. (Maskrey et al., 2018)

Total_working_hours_for_a_GP_per_week = 40

UNITS: hrs/Weeks

DOCUMENT: Total number of hours a GP works weekly.

Total_working_hours_for_a_GP_per_year = Number_of_weeks_per_year*Total_working_hours_for_a_GP_per_week

UNITS: hrs/year

DOCUMENT: Total number of hours a GP works every year.

Tuition_fees = 5000

UNITS: CAD/person/year

DOCUMENT: Average Tuition fees that should be paid every year by every medical student.

https://bemoacademicconsulting.com/blog/medical-schools-in-quebec

Turnover_Fraction = .1

UNITS: 1/year

DOCUMENT: The fraction of prospective medical students who change their mind and drop their application to the medical schools in Quebec.

Adapted from:

Hovmand, P. (2020). Staffing Model. System Dynamics Summer School- Bignners Track- Modeling Policies Chapter.

Universities'_capacity = (Sherbrooke_Uni_doctor_students_capacity+Laval_Uni_doctor_students_capacity+McGill_Uni_doctor_students_capacity+Montreal_Uni_doctor_students_capacity)

UNITS: person/year

DOCUMENT: Universities' capacity, is the current available number of medical students that the universities in Quebec can admit for the medical school.

(Lagarda-Leyva and Ruiz, 2019)

Work_percentage_saved_by_PP = Total_number_of_saved_hours_per_year/Total_working_hours_for_a_GP_per_year

UNITS: dmnl

DOCUMENT: "GP time spent on key prescribing activities significantly reduced by 51% (79 hours, P<0.001) per week, equating to 4.9 hours (95% confidence interval = 3.4 to 6.4) per week per practice."(https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6146005/)