Exploring the Impacts of COVID-19 on Coastal Tourism to Inform Recovery Strategies in Nelson Mandela Bay, South Africa.

Supplementary Material

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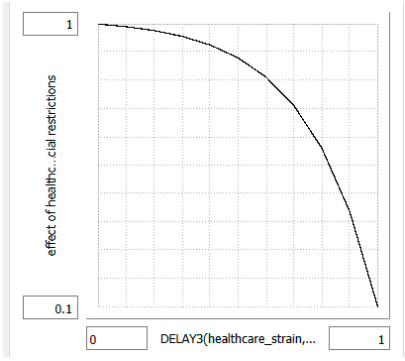
Table S1. Model Documentation

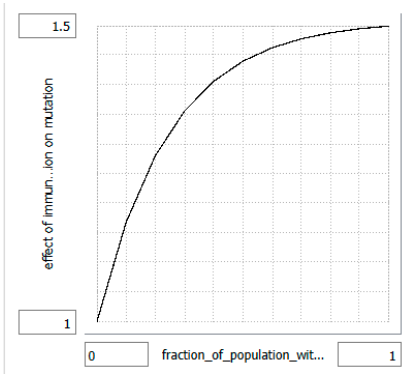
Variable and type	Parameter and Units	Reference(s) and assumptions
Covid-19 sub-model		
Susceptible Population (stock)	60 million persons	Initial value. South African Population reported in 2021.
Exposed Population (stock)	0 persons	Initial value.
Symptomatic Infections (stock)	0 persons	Initial value. Transmission of the virus is initiated through imported infections coming from foreign tourists in January 2020. These are the symptomatic infections that are reported.
Asymptomatic Infections (stock)	0 persons	Initial value.
Recovered Population (stock)	0 persons	Initial value.
Hospitalised Population (stock)	0 persons	Initial value. This is the initial value of persons hospitalised from COVID-19, not for other reasons.
Deceased Population (stock)	0 persons	Initial value.
Vaccinated Population (stock)	0 persons	Initial value.
Total population	60 million persons	South African Population reported in 2021.

Normal contacts per person	14 persons/person/day	This differs per country (Rahmandad et al., 2021); in South Africa the contact rate is assumed to be high due to the close living conditions and form of domestic travel. The influence of this value can be investigated during sensitivity analysis.
Contacts per symptomatic persons	2 person/person/day	This is very small, assuming they are in quarantine but do come into contact with family members, who perhaps do are not adherent to quarantine regulations.
Infectivity	0.0125 dmnl	Estimated to obtain a reproduction between 3-5 depending on a change in contacts, the infectivity of the variant and the duration of the infection (Khairulbahri, 2021).
Incubation time	5 days	Parameter obtained from other COVID-19 system dynamic studies including (Ibarra-Vega, 2020; Rahmandad et al., 2021).
Fraction symptomatic	0.1 dmnl	Based on seroprevalence estimates, only 10% of overall covid cases are officially reported. For every case we know that there are nine other cases that we don't know about, because they're asymptomatic. In other words, the infection rate is 10x higher than the case rate. This can be assumed to be due to the nature of symptoms showing as well as testing capacity (Grant et al., 2021).
Infection duration	14 days	Parameter obtained from other COVID-19 system dynamic studies including (Ibarra-Vega, 2020; Rahmandad et al., 2021) and is reported in (Karim, 2020).
Fraction requiring hospitalisation	0.15 dmnl	Parameter obtained from other COVID-19 system dynamic studies (Ibarra-Vega, 2020; Li et al., 2020).
ICU fraction	0.20 dmnl	This is the fraction of hospitalised persons requiring critical care. This value is said to range between 15-20% (Evans, 2020). Severe cases are defined in relation to ICU hospitalisation.

Hospitalisation delay	5 days	Assumed it takes on average 5 days before severe symptomatic persons require hospitalisation. According to Grant et al., 2021, "It takes 10-14 days for an infection rate to show up on a PCR test and then a few more days before the patient needs to be hospitalised".
Fatality fraction	0.05 dmnl	3-5% (Ibarra-Vega, 2021 & Evans, 2020).
Hospital capacity	3000 persons	Severe cases are defined in relation to ICU hospitalisation. This corresponds to the number of intensive care units (ICU) beds in South Africa. Estimates range from 7195 beds together with 2926 practically available nationwide across both public and private sectors (Evans, 2020; Schröder et al., 2021). Other estimates provided in Naidoo and Naidoo, 2021.
Time to perceive severity	30 days	Obtained through hand calibration to match the infection peaks from data. Similar length delay as in Khairulbahari, 2021.
Fraction of population accepting the vaccine (or vaccination hesitancy)	0.50 dmnl	"In SA, Covid vaccine acceptance ranged from 52% to 82%, while an outright non-willingness to take the vaccine stood at under 20%" (Ebrahim, 2021).
Vaccination rollout fraction	STEP(0.005*effect of perceived severity on vaccination demand, 420)	Fraction of daily vaccinations administered daily. Daily vaccination statistics obtained from https://www.statista.com/statistics/1231031/daily-number-of-covid-19-vaccination-doses-in-south-africa/ and https://www.covid19sa.org/southafricavaccination accessed on 21 February 2022. The daily vaccination is further dependent on the vaccination demand as perceived by the public through the level of health severity. The initial target was to vaccinate 67% of the population by the end of 2021 to achieve heard immunity (www.gov.za/covid-19/vaccine). To date, only 35% of the population have received one vaccination dose, whereas only 30% are fully vaccinated. Daily target was ~300 000 per day, SA begins covid 19 vaccination for adolescents – Africnews.com, accessed in February 2021.

Immunity time frame	180 days	Immunity may differ based on the vaccination type, however, the model assumes only one type of vaccine. A study by Goldberg et al., 2021on waning immunity suggested that vaccinated persons were found to be protected even after 6 months, compared to unvaccinated persons though the effectiveness of vaccination was considerably lower as time progresses from the vaccination date. A study by Brereton and Pedercini, 2021 report on the effectiveness of infected-recovered immunity versus vaccination immunity and states that recovered immunity and vaccination immunity can range between 5-12 months. In South Africa, most of the population have received the Pfizer vaccination and the duration before the booster could be requested was 180 days (de Wet, 2022).
Deimmunization fraction	1 dmnl	It is assumed that the whole vaccinated population and all recovered persons may become susceptible after the 180-day immunity period. The model does not differentiate between natural recovered versus vaccination immunity but assumes as 6-month immunity duration for both. In the model the deimmunization fraction is further also dependent on the fraction of the population with immunity, with the logic that the more persons have immunity the lower the chances of spreading the virus through the effects of herd immunity.
Reinfection fraction	1 dmnl	
Chance of a false negative test for tourists	0.25 dmnl	Modeler's estimate. Different kinds of tests have different levels of accuracy, but the outcome of you test result can also depend on your viral load and the number of days since initial infection. Rapid tests, which are required for travel purposes, have been shown to be less accurate than polymerase chain reaction (or PCR tests), and may therefore result in false negatives. https://www.healthline.com/health/how-accurate-are-rapid-covid-tests#how-accurate-is-it accessed 21 September 2021.
People per 100 thousand persons of the population	600 persons/person	This is the number of people per 100 thousand of the South African population of ~60 million people and is used to calculate the daily infections per 100 000 of the population.
Moving average timestep	7 days	This is the averaging time used to calculate the seven-day moving average.

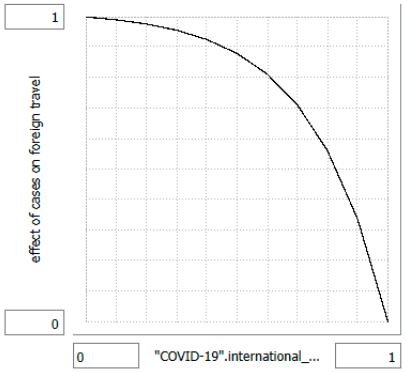
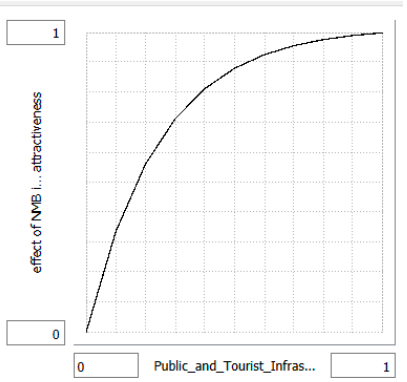
Risk perception delay	365 days	Assuming the recurring waves have made people for cautious and aware of the risk associated to being infected.
Travel Health Notice Level (stock)	0 persons	This is according to the CDC travel health notice thresholds (CDC, 2021). The travel health threshold level is calculated based on the cumulative new cases the past 28 days per 100 000 population. Level 4 (red list) more than 500: avoid/no travel to this destination Level 3 high 100-500 persons: make sure you are vaccinated: unvaccinated travellers should avoid unnecessary travel Level 2 moderate 50-99 persons: cautionary travel Level 1 low fewer than 50 persons: make sure you are fully vaccinated before travel All of the levels essentially require you to be vaccinated. Note these are only recommendations from the CDC, countries may choose to use their own travel criteria as well.
Travel health threshold prohibiting travel	500 persons	
Incidence time delay	28 days	
Graphical Functions		
Effect of hospital strain on social contacts (dmnl)		The dimensionless converter “effect of hospital strain on social contacts” invokes different levels of social restrictions on contacts depending on the level of health care strain. When hospitals are full, the level of intervention is limited to 10% of normal contacts. This effect on social restrictions becomes stronger only when hospitals reach around 75-80% of capacity. x limits: 0-1 dmnl y limits: 0.1-1 dmnl.

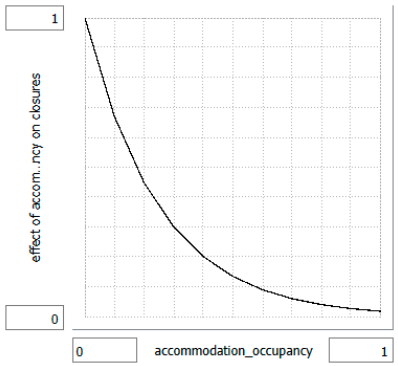
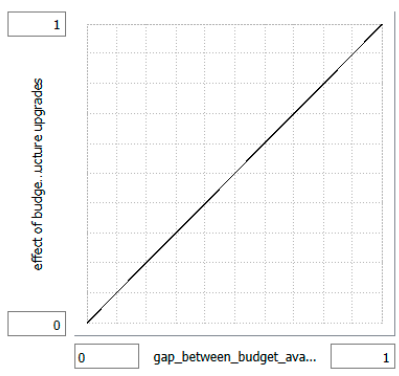
Effect of immunity fraction on mutation (variant infectivity)		The dimensionless converter "effect of immunity on mutation" assumes that as the fraction of the population with heard immunity increases, the level of mutation and hence variant infectivity starts to level of at around ~70%. The infectivity of the variant increases with a faster rate as the fraction of population with immunity is below 50%. x limits: 0-1 dmnl y limits: 1-1.5 dmnl.
NMB Tourism and Accommodation sub-model		
Variable and type	**Parameter and Units**	**Reference(s) and assumptions**
NMB Domestic Overnight Tourists (stock)	30 000 persons	Approximations based on annual tourism figures in 2019. Take note that the model time units are in days, so the initial tourism value will be the number of tourists in the bay on a given day. In 2019, there were 2 368 220 domestic tourists (overnight, but not all paid) that visited NMB. Domestic tourists stay on average 3.3 days. In 2019, a total of 307 733 foreign tourists visited NMB. Each foreign stays on average 2.4 days. Source: Nelson Mandela Bay Municipality – Department of Economic Development, Tourism & Agriculture (NMBM EDTA).
NMB Foreign Overnight Tourists (stock)	1300 persons	
Fraction of provincial domestic overnight tourism received by NMB	0.11 dmnl/year	EC received 14.3 % of provincial overnight trips in 2019 (mean of two quarters) (Stats SA, 2020). NMB receives 75% of EC domestic tourism (Myles and Louw, 2014), therefore 78% of 14.3% = ~ 11%.
Fraction of provincial domestic day trips	0.06 dmnl/year	EC received 7.8% of provincial domestic day trips in 2019 (mean of two quarters) (StatsSA, 2020).

Fraction of domestic visitors that overnight	0.70 dmnl	Domestic (overnight and day trip)= 2 368 000 + 1 200 000 = 3 657 000 (day trip is 33% of domestic tourism, i.e. ~=70% of domestic tourists overnight some VFR some in paid accommodation) – Data from Nelson Mandela Bay Municipality – Department of Economic Development, Tourism & Agriculture.
Fraction of foreign tourism received by NMB	0.024 dmnl/year	EC receives ~3% of national tourism (Myles and Low, 2014). NMB receives 2.4 % of SA national tourism (i.e. foreign tourists).
Normal foreign tourists visiting SA per year	10.2e6 persons/year	A total of 2.8 million tourists came to SA in 2020, showing a decrease of 73% from 10.2 million tourists recorded in 2019 (Stats SA, 2020). The national goal is to receive a total of 21 million tourists by 2030 (SAT, 2021).
Day to year converter	365 days/year	-
Time spent in the bay domestic	3 days	Average bed nights spend by domestic tourists in 2019 - NMBM EDTA.
Time spent in the bay foreign	2 days	Average bed nights spend by foreign tourists in 2019 – NMBM EDTA.
Fraction of domestic tourists willing to pay for accommodation	0.36 dmnl	In 2019 there were 7 865 057 domestic bed nights (or visitor days) of which 2 815 711 were paid and 5 049 346 were staying with relatives (VFR) – NMBM EDTA.
Fraction of foreign tourists willing to pay for accommodation	0.50 dmnl	In 2019 foreign bed nights were 728 998 of which 372 470 were paid and 356 470 were staying with relatives – NMBM EDTA.
Accommodation Facilities (Stock)	400 facilities	400 total registered facilities in NMB in 2019 consisting of 36 hotels, 96 self-catering, 95 B&Bs, 156 guesthouses and 17 budget facilities – NMBM EDTA. Note that information and tourism data are not collected from unregistered AirBnB facilities.
Bed capacity per facility	50 persons/facility	There are a total of 15 787 beds available on NMB across the 400 facilities to obtain roughly 40-50 persons/facility. Note this is an assumption and that capacity per facility differs greatly depending on the size of the facility. Assuming one bed takes one person – NMBM EDTA.
Normal price per bed night	567 Rand/person/day	2019 value - NMBM EDTA.

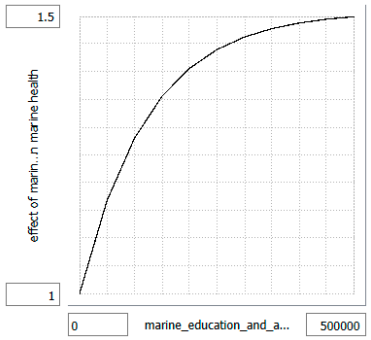
accommodation closure delays	30 days	Assuming it takes about 1 month for the facility for close it's doors after low (below 15%) occupancy levels. See graphical function "effect of accommodation occupancy on closures".
Tourism employee multiplier	0.025 persons/person	In 2019 there were a total of 3.9 million tourists (including day visitors) and a total (direct and induced) labour force of 98 538. This translates in ~ 40 tourists per employee or 0.025 employees per tourist. In 2019, there were 44 790 direct jobs in tourism and a total of 98 538 direct and indirect jobs. The ratio among direct and indirect is 98 538/44790 = 2.2 indirect jobs for each direct job. Data from NMBM EDTA.
Average daily spend per domestic visitor	791 Rand/person/day	Based on day visitor value, because the cost of accommodation is already accounted for in bed night costs – NMBM EDTA
Average daily spend per foreign visitor	723 Rand/person/day	2019 value – NMBM EDTA
Tourism budget (Stock)	30 million Rand	The total estimated budget for Nelson Mandela Bay Tourism (NMBT) agency according NMBT, 2018 is R25 million. Let's assume the municipality budget the same or more, thus equating to a minimum annual budget of R30 million.
Fraction of tourism revenues to NMB tourism budget	0.20 dmnl	This is the revenues obtained from tourism operators and hotels etc. from taxes and fees because one can't assume all the revenues go to the municipality. A lot of the revenue go straight back into the business to cover their costs and invest in their businesses.
Operational costs fraction	0.30 dmnl/day	Assuming the municipality uses 0.30 of the budgets to cover operational costs for governance and tourism related operations.
Fraction of funding dedicated to covid-relief.	1 dmnl/day	After engagements with the municipality it was stated that during lockdown, funding was diverted from the tourism marketing budget to fund tourism relief incentives. As lockdown levels and social restrictions are relaxed the budget is periodically being restored for tourism functions. The level that the budget is restored by can be adapted during scenario analysis.

Tourism recovery funding	10e6 Rands	These are cash injections from the national tourism council, assuming they give a cash injection annually (i.e. every 365 days) to different provinces. This effect is formulated through a pulse function.
Public and Tourist Infrastructure (stock)	0.70 dmnl	This is a dimensionless metric to represent the 'intactness' of public and tourism infrastructure. Initially it is assumed that infrastructure was 70% intact, though this may be an overestimate, as the trends of infrastructure deterioration are prominent in the metro for the past decade.
Upgrade delays	365 days	Assuming it takes a minimum time of 1 year for large upgrades including the time to plan and finance the upgrade.
Infrastructure deterioration time	365 days	Assuming it takes 1 year for the infrastructure to deteriorate depending on the intactness of the infrastructure level.
Desired infrastructure condition	1 dmnl	This is assumed to be the highest infrastructure level, where buildings and tourism infrastructure is assumed to be fully intact and functional.
Costs per general upgrades and maintenance	1e6 Rand	Assuming the general costs of maintenance and upgrades is a minimum of 3 million per upgrade. The model does not differentiate between different magnitudes of upgrades however the value can be adapted during scenario planning.
Seasonal effect	1+SINEWAVE(0.10, 360)	The seasonal multiplier increases and decreases the attractiveness of tourism by 10% over the summer and winter holiday period.
Graphical Functions		

Effect of covid cases on foreign travel (dmnl)		This converter captures the non-linear relationship between the travel ban, defined according to the international CDC travel threshold, on the effect of arrivals of foreign tourists. If the number of infections exceeds the travel ban limit threshold (i.e. 500 persons), foreign travel is strictly prohibited. If the number of infections is below the travel limit, then travel regulations are slowly eased thus allowing a higher percentage of travel. x limits: 0-1 dmnl y limits: 0-1 dmnl.
Effect of NMB infrastructure on tourism attractiveness		The dimensionless converter, "the effect of NMB infrastructure on tourism attractiveness" is dependent on the condition of public and tourism infrastructure and effects the level of tourism attractiveness. As tourism infrastructure condition decreases below 50% the effect of tourism attractiveness becomes more apparent. x limits: 0-1 dmnl y limits: 0-1 dmnl

Effect of accommodation occupancy on facility closures		The lower the accommodation occupancy the higher the rate of accommodation closures. Closures become more evident as occupancy levels fall below 20%. x limits: 0-1 dmnl y limits: 0-1 dmnl
Effect of budget on infrastructure upgrades		The dimensionless converter, "effect of budget on infrastructure upgrades" explains that upgrades will progress as normal as long as there is enough budget towards infrastructure, i.e. infrastructure upgrades will occur depending on the availably of budget and the costs of upgrades. Upgrades to the value of R3million can occur if the budget is greater or equivalent to the project cost. x limits: 0-1 dmnl y limits: 0-1 dmnl
Coastal and Marine Tourism sub model		
Variable and type	**Parameter and Units**	**Reference(s) and assumptions**
Marine Health (stock)	0.8 dmnl	Assuming that the natural state of the marine system was functioning at 80% of its natural state in 2019. Value substantiated through stakeholder opinion from Vermeulen et al., 2022 (in review). Marine health affects the coastal and marine attractiveness through aesthetic effect, that together is impacted on through beach closures as a result of the lockdowns.

Marine use development	0.2 dmnl	This value is assumed to change over time, depending on the rate of maritime developments in the bay. We can assume it is the percentage of natural marine area being converted or used.
Desired marine health	1 dmnl	Desired marine health essentially represents the maximum normal state of the marine environment.
Health deterioration time	600 days	Modeler's estimate. It is assumed health deterioration occurs over 2 years. It is assumed that the health of the marine environment has not deteriorated with a large rate over the two years of the pandemic as many developments were on hold during this time.
Health restoration time	365 days	Modeler's estimate. Health restoration is a measure of the resilience of the marine environment. Note this may differ for different species and habitats but has been generalised for the whole marine system. Note that interventions such as an MPA can increase the health recovery time, through increased resilience.
Fraction of tourists interested in marine tours	0.05 dmnl	Estimates using assumptions obtained from Hara et al., 2003. Assuming marine wildlife tours are intended for the foreign market and a small fraction of the domestic market due to the cost of tours. Many foreign tourists also do marine wildlife tours in Plettenberg Bay, therefore there is competition between tour operators. Also see Findlay, 1997; Hoyt, 2001. Let's assume this is for all marine tours including scuba-divining, BBWW, shark cage diving etc.
Tour costs per person	2000 Rand/person/day	Stakeholder conversation with tour operators in the bay. Values can range from R1500-2100.

Tourist spend per beach trip	15 Rand/person/day	Modelers estimate based on the following logic: It is free to go to the beach. However, going to the beach is often a fun trip, so it may involve buying and ice cream, cooldrink or coffee from one of the nearby shops. Perhaps having a lunch or some fish and chips from the restaurant near the beach. Or it may involve the transport costs to get to the beach. Port Elizabeth is known as the 10-minute city. It takes 10 minutes to get to most places, and therefore if residents had to drive or take the bus it may cost ~ R25. i,e the cost per visit. Alternative method: see Ballance et al., 2000 - apply the travel cost method: According to current fuel prices: R14.830 Average fuel consumption per car: 9 L/100km - therefore one can travel on average 11km on 1 liter of fuel. It costs minimum of R15 to get to a beach within 11km of your home. Average distance to travel to Summerstrand beaches - ~12 km from residential areas in PE. Therefore, R15 is the minimum spend assuming you either drove, bought an ice cream, a coffee etc.
Fraction of funds dedicated to marine conservation	0.20 dmnl	Modeler's estimate. This goes towards awareness programs, MPA management etc.
Graphical functions		
Effect of marine awareness of marine health		The higher the amount of funding dedicated to marine conservation and awareness the higher the effects of marine health restoration through conservation efforts. x limits: 0-500 000 dmnl y limits: 1-1.5 dmnl

File S1. Model Equations

COVID-19 sub-model

Asymptomatic_Infections(t) = Asymptomatic_Infections(t - dt) + (infecting_asymptomatic - asymptomatic_recoveries) * dt

INIT Asymptomatic_Infections = 0

Deceased_Population(t) = Deceased_Population(t - dt) + (fatalities) * dt

INIT Deceased_Population = 0

Exposed_Population(t) = Exposed_Population(t - dt) + (advancing - infecting_symptomatic - infecting_asymptomatic) * dt

INIT Exposed_Population = 0

Hospitilised_Population(t) = Hospitilised_Population(t - dt) + (hospitalisation_rate - hospital_recoveries - fatalities) * dt

INIT Hospitilised_Population = 0

Recovered_Population(t) = Recovered_Population(t - dt) + (symptomatic_recoveries + asymptomatic_recoveries + hospital_recoveries - reinfection_rate) * dt

INIT Recovered_Population = 0

Susceptible_Population(t) = Susceptible_Population(t - dt) + (loss_of_vaccination_effectiveness + reinfection_rate - advancing - vaccinations) * dt

INIT Susceptible_Population = 60e6

Symptomatic_Infections(t) = Symptomatic_Infections(t - dt) + (infecting_symptomatic - symptomatic_recoveries - hospitalisation_rate) * dt

INIT Symptomatic_Infections = 0

Travel_Health_Notice_Level(t) = Travel_Health_Notice_Level(t - dt) + (infection_rate_per_100_000_population - incidence_outflow) * dt

INIT Travel_Health_Notice_Level = 0

Vaccinated_Population(t) = Vaccinated_Population(t - dt) + (vaccinations - loss_of_vaccination_effectiveness) * dt

INIT Vaccinated_Population = 0

advancing = risky_contacts*variant_infectivity

asymptomatic_recoveries = Asymptomatic_Infections/infection_duration

fatalities = (Hospitilised_Population*adjusted_fatality_fr)/infection_duration

hospital_recoveries = (Hospitilised_Population*(1-adjusted_fatality_fr))/infection_duration

hospitalisation_rate = (Symptomatic_Infections*hospitilisation_fraction)/hospitalisation_delay

incidence_outflow = Travel_Health_Notice_Level/incidence_time_duration

infecting_asymptomatic = (Exposed_Population*(1-fraction_symptomatic))/incubation_time

infecting_symptomatic = (Exposed_Population*fraction_symptomatic)/incubation_time

infection_rate_per_100_000_population = "seven-day_moving_ave._per_100_000_population" {daily_cases_per_100_000_population

loss_of_vaccination_effectiveness = IF TIME >730 THEN (Vaccinated_Population*deimmunization_fraction)/vaccination_immunity_scenario ELSE (Vaccinated_Population*deimmunization_fraction)/immunity_duration

reinfection_rate = (reinfection_fraction*Recovered_Population/immunity_duration)

symptomatic_recoveries = (Symptomatic_Infections*(1-hospitilisation_fraction))/infection_duration

vaccinations = IF TIME > 730 THEN (Susceptible_Population*vaccination_acceptance_scenario*"vaccination_roll-out") ELSE (Susceptible_Population*vaccination_hesitancy*"vaccination_roll-out") { IF TIME >= 400 THEN (Susceptible_Population*fraction_of_population_accepting_the_vaccine*initial_vaccination_goal)*effect_of_perceived_severity_on_situational_awareness ELSE 0

"seven-day_moving_ave._per_100_000_population" = "seven-day_moving_average"/people_per_100_thousand_persons_of_the_population

adjusted_contacts_owing_to_risk = normal_contacts_per_person*effect_of_healthcare_strain_on_social_restrictions

adjusted_fatality_fr = fatality_fraction*healthcare_strain*(1-fraction_of_population_vaccinated)

cases_to_envoke_interventions = 5000

chance_of_a_false_negative_for_tourists = 0.25

confirmed_cases = Recovered_Population*fraction_symptomatic

confirmed_cases_per_100_000_population = (confirmed_cases/people_per_100_thousand_persons_of_the_population)

contacts_per_symptomatic_persons = 2

covid_data = GRAPH(TIME)

deimmunization_fraction = 1-fraction_of_population_with_immunity

effect_of_perceived_severity_on_travel_attractiveness = MIN(DELAY3(healthcare_strain, travel_risk_perception_delay), 1)

effect_of_perceived_severity_on_vaccination_demand = DELAY3(healthcare_strain, 365)

fatality_fraction = 0.05

fraction_of_population_vaccinated = Vaccinated_Population/total_population

fraction_of_population_with_immunity = herd_immunity/total_population

fraction_susceptible = Susceptible_Population/total_population

fraction_symptomatic = 0.1

future_varaint_infectivity = 0.15

future_variant_introduction_time = 580

future_variant_switch = 1

healthcare_strain = IF TIME > 730 THEN ICU_demand/ICU_capacity_scenario ELSE ICU_demand/ICU_hospital_capacity

herd_immunity = Recovered_Population+Vaccinated_Population

hospitalisation_delay = 5

hospitilisation_fraction = 0.15*(1-fraction_of_population_vaccinated)

ICU_capacity_scenario = 3000

ICU_demand = Hospitilised_Population*ICU_fraction

ICU_fraction = 0.20

ICU_hospital_capacity = 3000 {7000 {9000

immunity_duration = 180

incidence_time_duration = 28

incubation_time = 5

infection_duration = 14

international_travel_bans = IF TIME > 730 THEN ((Travel_Health_Notice_Level/travel_threshold_scenario)) ELSE ((Travel_Health_Notice_Level/travel_health_threshold_prohibiting_travel))

intervention_% = 0.25

intervention_switch = 1

locked_down_delay = 7

"locked-down_contacts" = IF intervention_switch=0 OR TIME <=time_actual_ends THEN lockdown_%_planned_and_historical ELSE IF HISTORY("seven-day_moving_average",TIME-locked_down_delay) < cases_to_envoke_interventions THEN lockdown_%_planned_and_historical ELSE MIN(83.6, lockdown_%_planned_and_historical+intervention_%)

moving_average_timestep = 7

normal_contacts_per_person = 14 {25

normal_infectivity = 0.0125

people_per_100_thousand_persons_of_the_population = 600

R0 = normal_infectivity*infection_duration*normal_contacts_per_person

reinfection_fraction = 1

risk_response_time = 30

risky_contacts = (total_contacts*fraction_susceptible)+tourists_importing_infections

Rt = variant_infectivity*infection_duration*adjusted_contacts_owing_to_risk

"seven-day_moving_average" = Symptomatic_Infections/moving_average_timestep

time_actual_ends = 600

time_to_perceive_risk = IF TIME > 730 THEN risk_response_time ELSE 30

total_contacts = (Asymptomatic_Infections*adjusted_contacts_owing_to_risk)+total_contacts_from_symptomatic_persons

total_contacts_from_symptomatic_persons = Symptomatic_Infections*contacts_per_symptomatic_persons

total_population = 60e6

tourists_importing_infections = IF TIME >= 1 THEN NMB_Tourism_&_Accomodation.foreign_tourists_arriving_in_SA*chance_of_a_false_negative_for_tourists*fraction_symptomatic ELSE 0

travel_health_threshold_prohibiting_travel = 500

travel_risk_perception_delay = 365

travel_threshold_scenario = 500

vaccination_acceptance_scenario = 0.5

vaccination_hesitancy = 0.5 {0.7

vaccination_immunity_scenario = 180

"vaccination_roll-out" = STEP(0.005*effect_of_perceived_severity_on_vaccination_demand, 400)

variant_infectivity = (normal_infectivity*effect_of_immunity_fraction_on_mutation)+(normal_infectivity*STEP(future_varaint_infectivity, future_variant_introduction_time)*future_variant_switch) {MAX(normal_infectivity*(STEP(effect_of_immunity_fraction_on_mutation, DELTA_variant_introduction_time)), normal_infectivity)+(normal_infectivity*STEP(effect_of_immunity_fraction_on_mutation, OMICRON_variant_introduction_time)*OMICRON_switch)+(normal_infectivity*STEP(effect_of_immunity_fraction_on_mutation, future_variant_introduction_time)*future_variant_switch)

NMB_Tourism_&_Accommodation sub-model:

Accommodation_Facilities(t) = Accommodation_Facilities(t - dt) + (- accommodation_closures) * dt

INIT Accommodation_Facilities = 400

NMB_Domestic_Overnight_Tourists(t) = NMB_Domestic_Overnight_Tourists(t - dt) + (domestic_arrivals - domestic_departures) * dt

INIT NMB_Domestic_Overnight_Tourists = 30000

NMB_Foreign_Overnight_Tourists(t) = NMB_Foreign_Overnight_Tourists(t - dt) + (foreign_arrivals - foreign_departures) * dt

INIT NMB_Foreign_Overnight_Tourists = 1300

Public_and_Tourist_Infrastructure(t) = Public_and_Tourist_Infrastructure(t - dt) + (infrastructure_investment - infrastructure_decay) * dt

INIT Public_and_Tourist_Infrastructure = 0.7

Tourism_Budget(t) = Tourism_Budget(t - dt) + (tourism_funding - tourism_costs) * dt

INIT Tourism_Budget = 30e6

accommodation_closures = effect_of_accommodation_occupancy_on_closures/closure_delays

domestic_arrivals = NMB_overnight_domestic_tourists*NMB_tourism_attractiveness_multiplier

domestic_departures = NMB_Domestic_Overnight_Tourists/"time_spent_in_the_bay_-_domestic"

foreign_arrivals = (foreign_tourists_arriving_in_SA*normal_fraction_of_foreign_tourism_received_by_NMB*NMB_tourism_attractiveness_multiplier)

foreign_departures = NMB_Foreign_Overnight_Tourists/"time_spent_in_the_bay_-_foreign"

infrastructure_decay = Public_and_Tourist_Infrastructure/infrastructure_deterioration_time

infrastructure_investment = effect_of_budget_on_infrastructure_upgrades/upgrade_delays

tourism_costs = (covid_relief_spending*Tourism_Budget)+(tourism_infrastructure_budget_need/upgrade_delays)+(Tourism_Budget*operational_costs_fraction)

tourism_funding = tourism_budget_from_tourism_revenues+recovery_funding

accommodation_capacity = Accommodation_Facilities*bed_capacity_per_facility

accommodation_occupancy = (foreign_tourist_accommodation_demand+domestic_tourist_accomodation_demand)/accommodation_capacity

accommodation_revenue = total_bednights_sold*normal_rate_per_bednight

annual_bednights_sold = total_bednights_sold*day_to_year

annual_tourism_revenue = daily_tourism_revenue*day_to_year

average_daily_spend_per_domestic = 700 {1500

average_daily_spend_per_foreigner = 723

bed_capacity_per_facility = 50

closure_delays = 30

costs_for_general_upgrades_and_maintenance = 3e6

covid_relief_spending = IF TIME >365 THEN ("COVID-19".effect_of_perceived_severity_on_travel_attractiveness)*"fraction_tourism_funds_to_covid_relief_(scenario)" ELSE ("COVID-19".effect_of_perceived_severity_on_travel_attractiveness)*fraction_of_funding_dedicated_to_covid_relief

daily_tourism_revenue = accommodation_revenue+daily_tourist_spendings+Coastal_&_Marine_Tourism.coastal_and_marine_tourism_revenue+(NMB_domestic_day_visitors*day_visitor_spend/day_to_year)

daily_tourist_spendings = (NMB_Foreign_Overnight_Tourists*average_daily_spend_per_foreigner)+(NMB_Domestic_Overnight_Tourists*average_daily_spend_per_domestic)

day_to_year = 365

day_to_year_1 = 365

day_visitor_spend = 700

desired_infrastructure_condition = 1

domestic_tourist_accomodation_demand = NMB_Domestic_Overnight_Tourists*fraction_domestic_tourists_needing_paid_accommodation

domestic_tourist_pool = "COVID-19".herd_immunity+susceptible_domestic_population_travelling

foreign_tourist_accommodation_demand = (NMB_Foreign_Overnight_Tourists*fraction_foreign_tourists_needing_paid_accommodation)

foreign_tourist_pool = normal_foreign_tourists_visiting_SA_per_year*effect_of_cases_on_foreign_travel

foreign_tourists_arriving_in_SA = foreign_tourist_pool/day_to_year_1

fraction_domestic_tourists_needing_paid_accommodation = 0.36

fraction_foreign_tourists_needing_paid_accommodation = 0.50

fraction_of_domestic_visitors_that_overnight = 0.70

fraction_of_funding_dedicated_to_covid_relief = 1

fraction_of_provincial_domestic_overnight_tourism_received_by_NMB = 0.11

fraction_of_provinical_domestic_day_trips = 0.06

fraction_of_tourism_revenues_to_NMB_tourism_budget = 0.20

"fraction_tourism_funds_to_covid_relief_(scenario)" = 0.5

gap_between_budget_available_and_infrastructure_need = MAX(Tourism_Budget-tourism_infrastructure_budget_need, 0)

gap_between_desired_and_current_infrastructure_state = MAX(desired_infrastructure_condition-Public_and_Tourist_Infrastructure, 0)

infrastructure_deterioration_time = 365

marketing_intensity = 1

NMB_domestic_day_visitors = ((1-fraction_of_domestic_visitors_that_overnight)*domestic_tourist_pool*fraction_of_provinical_domestic_day_trips)

NMB_overnight_domestic_tourists = (domestic_tourist_pool*fraction_of_domestic_visitors_that_overnight*fraction_of_provincial_domestic_overnight_tourism_received_by_NMB)/day_to_year

NMB_tourism_attractiveness_multiplier = IF TIME >730 THEN effect_of_NMB_infrastructure_on_tourism_attractiveness*seasonal_effect*marketing_intensity*Coastal_&_Marine_Tourism.adjusted_coastal_and_marine_attractiveness ELSE effect_of_NMB_infrastructure_on_tourism_attractiveness*seasonal_effect*Coastal_&_Marine_Tourism.adjusted_coastal_and_marine_attractiveness

normal_foreign_tourists_visiting_SA_per_year = 10.2e6

normal_fraction_of_foreign_tourism_received_by_NMB = 0.024

normal_rate_per_bednight = 567

operational_costs_fraction = 0.30

paid_domestic_bednights = domestic_tourist_accomodation_demand*day_to_year

paid_foreign_bednights = foreign_tourist_accommodation_demand*day_to_year

recovery_funding = tourism_recovery_funding_scenario*RAMP(1-
MAX("fraction_tourism_funds_to_covid_relief_(scenario)", 0), 365)

seasonal_effect = 1+SINWAVE(0.10, 360)

susceptible_domestic_population_travelling = IF TIME >= 60 THEN "COVID-
19".Susceptible_Population*("COVID-19".effect_of_perceived_severity_on_travel_attractiveness)
ELSE "COVID-19".Susceptible_Population

"time_spent_in_the_bay_-_domestic" = 3

"time_spent_in_the_bay_-_foreign" = 2

total_annual_tourists = (domestic_arrivals+foreign_arrivals)*day_to_year

total_bednights_sold =
domestic_tourist_accomodation_demand+foreign_tourist_accommodation_demand
{MAX((domestic_tourist_accomodation_demand*"time_spent_in_the_bay_-
_domestic")+(foreign_tourist_accommodation_demand*"time_spent_in_the_bay_-_foreign"), 0)

total_NMB_overnight_tourists =
NMB_Domestic_Overnight_Tourists+NMB_Foreign_Overnight_Tourists

tourism_budget_from_tourism_revenues =
daily_tourism_revenue*fraction_of_tourism_revenues_to_NMB_tourism_budget

tourism_employee_multiplier = 0.025

tourism_infrastructure_budget_need =
(costs_for_general_upgrades_and_maintenance*(1+gap_between_desired_and_current_infrastructure
_state))

tourism_labour = (total_annual_tourists+NMB_domestic_day_visitors)*tourism_employee_multiplier

tourism_recovery_funding_scenario = 10000

upgrade_delays = 365

Coastal_&_Marine_Tourism sub-model:

Marine_Health(t) = Marine_Health(t - dt) + (health_restoration - health_deterioration) * dt

INIT Marine_Health = 0.8

health_deterioration = pressures_from_other_marine_uses/health_deterioration_time

health_restoration = MAX((desired_marine_health-
Marine_Health)*effect_of_marine_awareness_on_marine_health, 0)/health_restoration_time

adjusted_coastal_and_marine_attractiveness = IF TIME <=480 THEN (Marine_Health)*"COVID-19".effect_of_healthcare_strain_on_social_restrictions ELSE Marine_Health

coastal_and_marine_tourism_revenue = marine_tour_revenues+revenue_from_beach_recreation

desired_marine_health = 1

fraction_of_funds_dedicated_to_marine_conservation = 0.20

fraction_of_tourists_interested_in_marine_tours = 0.05

health_deterioration_time = 600

health_restoration_time = 365

marine_education_and_awareness_funding = coastal_and_marine_tourism_revenue*fraction_of_funds_dedicated_to_marine_conservation

marine_tour_revenues = tourist_tour_demand*normal_cost_per_tour

marine_use_development = 0.2

normal_cost_per_tour = 2000

pressures_from_other_marine_uses = IF TIME < 720 THEN MAX(Marine_Health+MIN(0, desired_marine_health), 0) ELSE MAX(Marine_Health+MIN(marine_use_development, desired_marine_health), 0)

revenue_from_beach_recreation = tourists_partaking_in_coastal_and_marine_activities*tourist_spend_per_beach_trip

tourist_spend_per_beach_trip = 15

tourist_tour_demand = tourists_partaking_in_coastal_and_marine_activities*fraction_of_tourists_interested_in_marine_tours

tourists_partaking_in_coastal_and_marine_activities = adjusted_coastal_and_marine_attractiveness*NMB_Tourism_&_Accomodation.total_NMB_overnight_tourists

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