Options for optimizing Slovak national vaccination strategy

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Abstract: The national vaccination strategy has undergone several updates since its publication in December 2020. The original strategy assumes priority vaccination of health professionals and other critical occupations and continues with priority according to age. The strategy revised in January took more account of some chronic diagnoses, which were elaborated in more detail in the March revision. Considering limited supply of vaccine and high incidence of COVID-19 cases throughout witner and early spring 2021, it was vital to find most optimal vaccination strategy to minimize avoidable deaths. Despite the adjustments, there is (was), especially in March 2021, an opportunity to reduce the relative mortality index we develop by a few percentage points, using available data and resources.

Methods: We normalize the overall risk of the population to the pre-vaccination status. The result is a relative mortality index that considers the impact of vaccination on the individual risk of death from Covid-19. When determining risk groups, we consider the basic age groups, risks of some professional or social groups and diagnoses that are according to available studies linked to greater probability of hospitalization and / or death. Altogether, 17 groups of diagnoses were used in the analysis, out of which five were regarded as most at risk: acute cancer, dialysis patients, people with organ transplants, people with Down syndrome and COPD. Data on disease prevalence was taken from health insurance companies. This enabled a detailed analysis, including regional and local implications. Only registered vaccines were considered for modelling.

Results: January modification of the vaccination strategy will help reduce the risk of mortality on Covid-19 by about 1.5 %. March update brings only a slight improvement. However, there is additional 1 % for further optimization. These changes can (could be) implemented during March to April, especially given the still low vaccination coverage of older age groups.

Primary space for improvement is in the increase of priority for combinations of the oldest groups of the population with chronic diseases (groups among strong population years 60-80 years of age with combinations of chronic diagnoses). At the same time, it is possible to slightly delay younger age groups up to 60 years, even if they have a chronic diagnosis. According to the modified national vaccination strategy, these groups are expected to arrive at about halfway through the schedule, but their relative risk is average or lower despite the existence of a chronic diagnosis.

Conclusions: The recent modifications of the national vaccination strategy bring a significant improvement over the original strategy. However, we see opportunities for further optimization by considering the risks of more defined population groups, especially among groups of "younger seniors" with co-morbidities, who could be preferred. Furthermore, the algorithm can be used to set most optimal vaccination strategy not only at national, but also at regional level, up to the detail of individual GP practices. Similarly, developed model can be quickly and effectively used to select a risk group of the population and prioritize any type of medical preventive action.

Results of the paper were used by health insurance companies to fine-tune their vaccination priorities in spring 2021.

1 Objectives and introduction

Slovak COVID-19 vaccination strategy was published in December 2020 and has since undergone several adjustments. The original strategy prioritized health professionals and other critical occupations and continued with priority according to age. Revised strategy from January changes this approach and put greater priorities on chronic diseases, which were further expanded in March updates. Yet, considering a lack of supply of vaccines in spring 2021, further improvements could have been made to improve relative mortality index.

The aim of this paper is to present possible adjustments to Slovak national COVID-19 vaccination strategy.

Our primary goal was to adjust strategy to reduce avoidable mortality from COVID-19. The second objective was to protect the country's critical workforce to fight the pandemic. We consider a priority to vaccinate health professionals, although their relative risk of dying from Covid-19, although relatively high, is not always highest among at-risk groups.

2 Methodology

We created a relative mortality index that considers the impact of vaccination on the individual risk of death from Covid-19 and compared it to each of the vaccination updates to determine their efficiency.

Process of determining risk groups, relative risks, vaccination priority settings and vaccination schedules are described in following sections.

2.1 Risk groups

When determining risk groups, we took into account the basic age groups 16-44, 45-59, 60-64, 65-69, 70-74, 75-79, 80-84, and 85 and over. Furthermore, we considered the increased risk according to selected diagnoses and the risks of some professional or social groups.

The basic distribution of risk is based on the history of deaths in Slovakia as of March 2021 (IZA, 2021; ŠÚSR, 2021) In further calculations, we consider the distribution of deaths in 2021, when the British strain B117 was already widespread in Slovakia. Taking into account the size of each demographic group, the relative risks of mortality were calculated.

The risk of dying from Covid-19 for men is significantly higher than for women. However, we did not consider it realistic to set different criteria for individual sexes. Therefore, after aggregation, we use the following relative risks:

- Age group 45-59 is a reference group
- Group 16-44 is only 0,10 multiple of risk compared to the reference group (RR)
- Category 60-64 has 3,23-fold greater risk than RR
- Category 65-69 has 5,33-fold greater risk than RR
- Category 70-74 has a 9,00-fold greater risk than RR
- Category 75-79 has 12,88-fold greater risk than RR
- Category 80-84 has 20,81-fold greater risk than RR
- Category 85+ has a 25,43-fold greater risk than RR

We also considered the following chronic diagnoses, which according to available sources have a significantly higher risk (CDC, 2021; PHE, 2021; Semenzato et al. 2021).

- oncological - in active treatment (new cases per year, diagnosis C00-C99)
- dialyzed (Z49)
- transplantation (kidneys, heart, liver, pancreas, lungs - diagnosis Z94)
- Down syndrome (Q90)
- chronic obstructive pulmonary disease (severe forms: J44.00, J44.01, J44.10, J44.11, J44.80, J44.81, J44.90, J44.91)
- bronchial asthma (J45)
- sickle cell disease (D57)
- oncological, in monitoring (C00-C97)
- autoimmune diseases with the administration of immunosuppressants (ATC_L04)
- diabetes (divided into E10 and E11)
- cardiovascular diseases - heart attack in 2020 and later (I21 and I22)
- cardiovascular diseases - other (I05 to I52)
- chronic kidney disease (N18)
- osteoporosis (M80)
- Alzheimer's disease with dementia (F00)
- severe psychiatric disorders addressed in inpatient care
- TB and mycobacteriosis (A15-A19, A31)

We further aggregated these patients into larger groups. We tried to create groups of patients with similar risks, which for practical reasons can be specifically addressed in the vaccination strategy. We selected five critical diagnoses that are the riskiest and should be addressed as a matter of priority: acute oncological diseases, dialysis patients, people with organ transplants, people with Down syndrome and severe chronic obstructive pulmonary disease. These are relatively small groups of patients with a total of 75,000 people.

We aggregated other groups of diagnoses according to the number of diagnoses per patient with one diagnosis (without the five diagnoses and among cardiovascular diagnoses only with past infarction), two, three or more diagnoses (including all other cardiovascular diagnoses). We also aggregate age groups according to the division mentioned above. The resulting grouping is shown in Table 1. Cardiovascular diseases, apart from recent heart attacks, type 1 diabetes (E10) and bronchial asthma, are only considered in combination with other diagnoses.

The size of risk groups is based on data publicly available as of February 2020. The overall demographic data for Slovakia are as of 1 January 2020. The population structure may have changed slightly, as the pandemic resulted in higher mortality, especially among older groups, especially at the end of 2020.

2.2 Relative risk

The basic relative risks by age are based on current data on mortality from Covid-19 in Slovakia. We used the statistics of deaths on Covid-19 until 12.1.2021 (ŠÚSR, 2021). We also took into account the expected loss of life for each age group. The risk of death from Covid-19 increases with age significantly faster than the average life expectancy for each age group decreases. The order of risk as well as taking into account the potential loss of years of life remains the same - except for a group of 85+, which is due to the low life expectancy behind a group of seventy years old.

Number of patients in risk groups		Age cohort							
Diagnosis	**ICD-10**	**16-44**	**45-59**	**60-64**	**65-69**	**70-74**	**75-79**	**80-84**	**85+**
Oncological, new patients as of 2020	C00-C97	2 219	7 291	4 644	4 422	4 302	3 690	2 776	1 821
Dialysis	Z49	615	690	631	511	676	420	225	60
Transplantation of an organ	Z94	869	1 134	486	382	216	105	51	27
Down syndrome	Q90	493	55	3	4	0	0	0	0
COPD	J44	3 590	7 017	5 221	6 328	5 429	4 294	2 840	2 203
Other chronic diseases - one diagnosis		56 524	45 379	15 163	12 982	6 426	4 204	2 749	2 997
Other chronic diseases - two diagnoses		39 707	95 054	63 254	76 477	65 337	49 319	32 308	24 797
Other chronic diseases - three + diagnoses		9 243	28 379	22 451	30 121	30 373	26 474	18 506	12 933
Without a diagnosis		2 058 452	918 450	248 060	198 178	118 482	71 343	41 649	38 738

Table 1: Number of people in each of used risk groups; Source: NCZI (2021); OECD (2019); own calculation

Age group	**16-44**	**45-59**	**60-64**	**65-69**	**70-74**	**75-79**	**80-84**	**85+**
Adjusted relative risk according to age	0,18	1,00	2,26	3,04	4,02	4,30	4,92	3,54

Table 2: Adjusted relative risk according to age; Source: IZA (2021); ŠÚSR (2021); own calculations

Age group	**16-44**	**45-59**	**60-64**	**65-69**
healthcare workforce	32 000	35 000	9 000	3 000
social care employees	5 000	4 800	1 200	0
social care clients	15 000	12 000	3 000	0
soldiers, police, critical infrastructure	15 000	15 000	0	0
teachers	24 000	24 000	6 000	2 000

Table 3: Number of selected professionals and social groups according to age Source; IZA (2021); ŠÚSR (2021); own calculations

Additional relative risk to the reference age group without diagnoses	
one chronic disease	0,6
two chronic diseases	1,5
three and more chronic diseases	3
new oncological cases, dialysis, transplants, Down, COPD	5,15
healthcare workforce	7
social care employees	1,4
social care clients	1,05
soldiers, police, critical infrastructure	0,3
teachers	0,6

Table 4: Additional relative risk to the reference age group without diagnoses; own calculations; Source: Jarkovský et al (2021), Mutambudzi et al. (2021), Semenzato et al (2021).

We recognize that taking life expectancy into account can be morally questionable in the provision of health care - just as disregarding it can be morally questionable. The resulting risk weights are shown in Table 2.

We also included selected groups of professionals and social groups (social care services clients under 65) who have an increased risk of infection and death on Covid-19. Their numbers and age distribution are given in Table 3. Additional risk for groups of chronically ill and professions is further calibrated using studies by Jarkovský et al (2021), Semenzato et al. (2021) and Mutambudzi et al. (2021), shown in Table 4.

We assumed that paramedics, teachers, and social care services staff does not suffer from combination of three or more chronic diseases. We assumed that they have a similar health status as the rest of the population. We assumed good health without chronic diseases for members of the uniformed forces and employees of critical infrastructure. Soldiers and police officers were more involved in testing in Slovakia than in other countries, but at present the testing capacity has increased so that systematic assistance from the armed forces is no longer so necessary. Therefore, we considered it sufficiently realistic to take estimates of increased risk from the literature. The resulting relative risks to the 15-64 group are then as follows in Table 5.

Relative risk / diagnosis	extra risk	16-44	45-59	60-64	65-69	70-74	75-79	80-84	85+
Oncological, new patients as of 2020	4	0,76	3,27	6,39	8,31	10,08	9,94	10,93	8,43
Dialysis	4,2	0,79	3,40	6,65	8,64	10,48	10,34	11,37	8,76
Transplantation of organ	3,5	0,69	2,95	5,75	7,48	9,07	8,95	9,84	7,58
Down syndrome	16	2,59	11,13	21,73	28,24	34,27	33,80	37,16	28,65
COPD	3	0,61	2,62	5,11	6,64	8,06	7,95	8,74	6,74
Other chronic diseases - one diagnosis	0,6	0,24	1,05	2,05	2,66	3,23	3,18	3,50	2,70
Other chronic diseases - two diagnoses	1,5	0,38	1,64	3,20	4,15	5,04	4,97	5,47	4,21
Other chronic diseases - three + diagnoses	3	0,61	2,62	5,11	6,64	8,06	7,95	8,74	6,74
healthcare workforce	7	1,22	5,24	10,23	13,29	16,13	15,91	17,49	13,48
social care employees	1,4	0,37	1,57	3,07	3,99	4,84	4,77	5,25	4,04
social care clients	1,05	0,31	1,34	2,62	3,41	4,13	4,08	4,48	3,45
soldiers, police, critical infrastructure	0,3	0,20	0,85	1,66	2,16	2,62	2,58	2,84	2,19
teachers	0,6	0,24	1,05	2,05	2,66	3,23	3,18	3,50	2,70
others	0	0,15	0,65	1,28	1,66	2,02	1,99	2,19	1,69

Table 5: Final relative risk indices for age groups; Source: own calculations

Available data on patients contain relatively few people with obesity. Most diagnoses of E66 are recorded in children, adult patients are rarely treated directly for obesity. In the data from National center for healthcare information (herein as "NCZI) we see only 2 034 such persons. At the same time, the European Health Survey shows that more than 1% of the population has serious obesity with a BMI over 40, i.e. about 50,000 adults. However, as this is a visually obvious diagnosis, possibly verifiable in a few seconds, we consider it sufficient for patients to present this diagnosis when registering for vaccination, without the need for confirmation by the attending physician. Underweight (BMI below 18.5) can also be considered, especially in combination with type 1 diabetes.

2.3 Priority setting

In our basic model, the priorities for vaccination are based on the Table 5, organized from the highest to the lowest risk. The only change is in moving all health professionals to the beginning of the schedule, in line with the objectives and in line with reality of vaccination in Slovakia. Given that the threat to the functioning of the economy is not that present in other professions due to sick leave and quarantine, we did not increase the priority for critical infrastructure.

In the alternative scenario, we simulated (i) the old national vaccination strategy (ii) its updated version by decree of the Ministry of Health from 19th January 2021 that placed higher prioritization on older people and the moved members of the critical infrastructure into replacement group and (iii) and currently valid version of the strategy, updated by decree of the Ministry of Health on 5th of March 2021 - with prioritization, in particular according to age and without priority for members of critical infrastructure.

The table below also provides assumptions as to what part of a population will eventually be vaccinated. For most groups, it is estimated as 70% (which will require strong communication campaign, as currently only about 55 % of the population wants to get a vaccine). For members of critical infrastructure, we assume eventually 100% vaccination, similarly to social care staff and clients, where vaccination may eventually be introduced as a condition of admission to the facility (similarly as vaccination against influenza is currently mandatory).

For health professionals and teachers - where there is a better awareness of SARS-COV-2, we assumed 85% participation in vaccination. Resulting prioritization of all 4 scenarios are shown in Table 6 below.

Category	Relative Risk	Number	Estimated vaccinatio n rate	Priority according to the model	Propority according to the first update	Priority according to the original strategy	Priority accoridng to the latest update
healthcare workforce; 65-69	13,29	3 000	85%	1	1	1	1
healthcare workforce; 60-64	10,23	9 000	85%	2	3	2	3
Other chronic diseases - three + diagnoses; 80-84	8,74	18 506	70%	3	2	2	2
Other chronic diseases - three + diagnoses; 70-74	8,06	30 373	70%	4	3	2	3
Other chronic diseases - three + diagnoses; 75-79	7,95	26 474	70%	5	4	2	3
Other chronic diseases - three + diagnoses; 85+	6,74	12 933	70%	6	1	1	1
Other chronic diseases - three + diagnoses; 65-69	6,64	30 121	70%	7	3	2	3
Onko + CHOCHP + Dialyz. + Transp. + Down S	6,15	75 740	85%	8	4	2	4
Other chronic diseases - two diagnoses; 80-84	5,47	32 308	70%	9	2	2	2
healthcare workforce; 45-59	5,24	35 000	85%	10	3	2	3
Other chronic diseases - three + diagnoses; 60-64	5,11	22 451	70%	11	1	2	1
Other chronic diseases - two diagnoses; 70-74	5,04	65 337	70%	12	4	2	3
Other chronic diseases - two diagnoses; 75-79	4,97	49 319	70%	13	1	1	1
Other chronic diseases - two diagnoses; 85+	4,21	24 797	70%	14	3	2	3
Other chronic diseases - two diagnoses; 65-69	4,15	75 148	70%	15	5	2	4
Other chronic diseases - one diagnosis; 80-84	3,50	2 749	70%	16	2	2	2
Other chronic diseases - one diagnosis; 70-74	3,23	6 426	70%	17	4	2	4
Other chronic diseases - two diagnoses; 60-64	3,20	59 534	70%	18	3	2	3
Other chronic diseases - one diagnosis; 75-79	3,18	4 204	70%	19	4	2	3
social care employees; 60-64	3,07	1 200	100%	20	3	2	3
Other chronic diseases - one diagnosis; 85+	2,70	2 997	70%	21	5	2	4
Other chronic diseases - one diagnosis; 65-69	2,66	12 756	70%	22	1	1	1
teachers; 65-69	2,66	2 000	85%	23	4	2	4
social care clients; 60-64	2,62	3 000	100%	24	4	3	4
Other chronic diseases - three + diagnoses; 45-59	2,62	28 379	70%	25	2	2	2
others; 80-84	2,19	41 649	70%	26	5	2	7
Other chronic diseases - one diagnosis; 60-64	2,05	14 271	70%	27	1	2	4
teachers; 60-64	2,05	6 000	85%	28	3	2	3
others; 70-74	2,02	118 482	70%	29	4	2	3
others; 75-79	1,99	71 343	70%	30	6	3	4
others; 85+	1,69	38 738	70%	31	7	3	4
others; 65-69	1,66	194 733	70%	32	4	2	4
Other chronic diseases - two diagnoses; 45-59	1,64	88 250	70%	33	5	2	7
social care employees; 45-59	1,57	4 800	100%	34	1	1	1
social care clients; 45-59	1,34	12 000	100%	35	1	2	7
others; 60-64	1,28	230 472	70%	36	8	4	4
healthcare workforce; 16-44	1,22	32 000	85%	37	6	4	7
Other chronic diseases - one diagnosis; 45-59	1,05	42 131	70%	38	9	3	7
teachers; 45-59	1,05	24 000	85%	39	1	1	1
soldiers, police, critical infrastructure; 45-59	0,85	15 000	100%	40	10	1	7
others; 45-59	0,65	840 703	70%	41	10	4	7
Other chronic diseases - three + diagnoses; 16-44	0,61	9 243	70%	42	5	2	11
Other chronic diseases - two diagnoses; 16-44	0,38	38 306	70%	43	5	2	11
social care employees; 16-44	0,37	5 000	100%	44	1	1	1
social care clients; 16-44	0,31	15 000	100%	45	1	2	11
Other chronic diseases - one diagnosis; 16-44	0,24	54 530	70%	46	6	3	11
teachers; 16-44	0,24	24 000	85%	47	9	3	11
soldiers, police, critical infrastructure; 16-44	0,20	15 000	100%	48	11	1	11
others; 16-44	0,15	1 970 846	70%	49	11	4	11

Table 6: Prioritisation of vaccination, in 4 calculated scenarios; Source: own calculations

2.4 Vaccination schedule

For vaccination, we assumed deliveries according to publicly available information published in daily press. We only took into account already approved BionNTech / Pfizer, Moderna and AstraZeneca vaccines. For the first two vaccines, we expect a period between two doses of 4 weeks. For AstraZeneca, we modelled a 10-week period between the two doses. This vaccine is only for people under 70 years of age. If the model allows multiple vaccines to be administered at the same time, BioNTech / Pfizer or Moderna will be used first, followed by AstraZeneca. At the same time, we assumed that from the supplied vaccines, a reserve for the second dose is always left for those who have already received the first dose. We also assume that all available vaccines will be used without loss.

The amounts of published doses are used in the model so that the delivered vaccine is consumed evenly before the next delivery (postponing half of the vaccines to the 2nd dose). The model did not include the Johnson & Johnson vaccine, but it is relatively easy to expand it with this option. We have not yet included it due to uncertainty about the delivery schedule.

Uncertainty about vaccine supply assumptions is, of course, great. Accelerating delivery would improve the results of our model in all scenarios, as well as the approval of the Astra Zeneca vaccine in all age groups, or possibly others. The delay acts in the opposite direction. However, the qualitative results of the model remain unchanged.

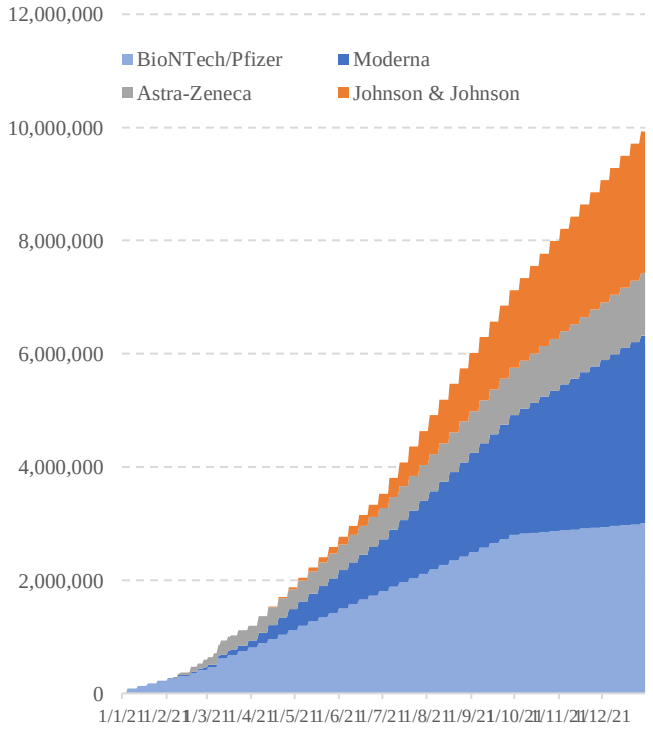

Figure 1: Estimation of vaccine deliveries (doses); Source: own calculations March 2021

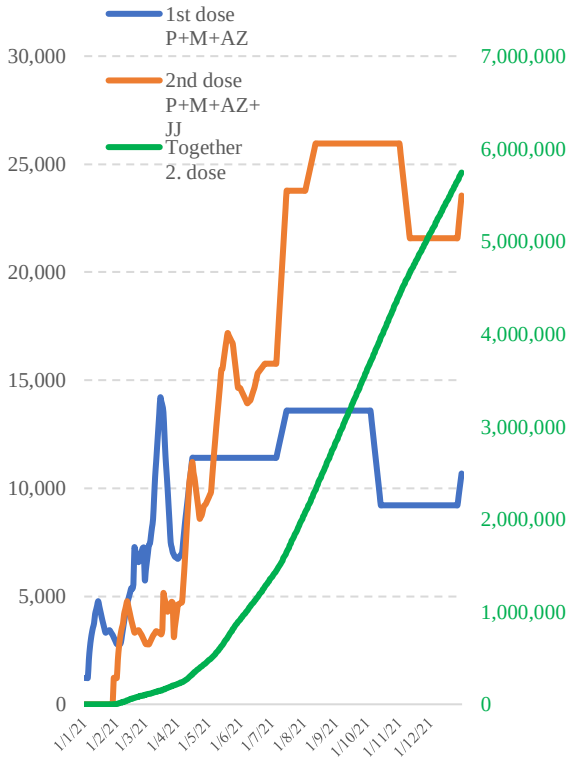

Figure 2: Estimated daily vaccination rate; Source: own calculations March 2021

2.5 Simulation

For each of the scenarios, we simulated the results as follows:

- Available vaccines were divided to groups according to priority, until the group for each charged with the expected coverage rate (as shown in Table 6). When a quota was filled for a priority group, we moved the vaccination to the next group in sequence.
- We only used AstraZeneca to people under 70 years of age.
- The second dose was expected 28 days after the first dose with mRNA vaccines or after 70 days with AstraZeneca
- For persons vaccinated with the first dose we expected a reduction in their level of risk and by 72 %. After a second dose of the protections 99 % (Dagan et al. , 2021) .
- This is how we adjusted the relative risk of people who have already been vaccinated. We could then calculate the total risk as a weighted sum according to the number of people in each group and their original (Table 5) or by vaccination reduced relative risk.

- We assumed that vaccination with one dose reduces the risk of transmitting the infection by 50% and increases to 80% after the second dose.
- We normalized the overall risk of the population to the pre-vaccination status. The result was a relative mortality index. This index considered in particular the impact of vaccination on the individual risk of death of individuals in Covid-19. We also considered reducing the number of susceptible individuals after vaccination. On the other hand, it is also likely that society will respond by releasing the severity of measures and discipline of the population. We did not dare to estimate the resulting effect of these opposing epidemiological factors. However, it is highly likely that even by the end of 2021, collective immunity will not be achieved, and the spread of the pandemic will not stop.

4 Results

The result of the simulation is shown in Figure 3. We see that the modified national vaccination strategy is a significant step forward from the original strategy. The current version of the strategy is only a slight improvement compared to January update. Vaccination will reach high-risk groups 85+, 80-84 and other senior groups of the population faster. However, this strategy can be further optimized based on our results. Specifically, it is recommended to increase priorities for combinations of the oldest groups of the population with chronic diseases (groups aged 60-80 with combinations of chronic diagnoses) . At the same time, it is possible to postpone slightly younger age groups up to 60 years, even if they have a chronic diagnosis, or a combination of diagnoses in the younger age groups.

According to the modified national vaccination strategy, these groups are expected to arrive at about halfway through the schedule, but their relative risk is average or lower despite the existence of a chronic diagnosis.

Our results should be taken as a threshold result, if it would be possible to mobilize all sensitive groups in the right order completely effectively. As in practice the vaccination of some groups will be extended and members of critical infrastructure or members of less sensitive groups will be vaccinated as substitutes, the decline of the curves will be slightly slower than shown in Figure 3. However, qualitative differences will be maintained.

For a better numerical comparison, we calculated the area under the curve from Figure 3. Since the curves are levelling at about 1/3 of the original risk at the end of 2021 (which is understandable, as we assume that almost 30% of the population cannot be vaccinated and vaccination efficiency is not fully 100%), we calculate the content under the curve by 30.6.2021. Figure 4 shows that a modification of the vaccination strategy of 19.1.2021 will help reduce the risk of mortality on Covid-19 by about 1.5 % . However, we see further room for optimization by about 1 %. These changes could have been implemented during March to April, especially given the still low vaccination coverage of older age groups.

The use of these opportunities would require consideration of several criteria in determining order of vaccination and effective use of large data sources of our health information systems, cooperation with the attending doctors and flexible ordering system.

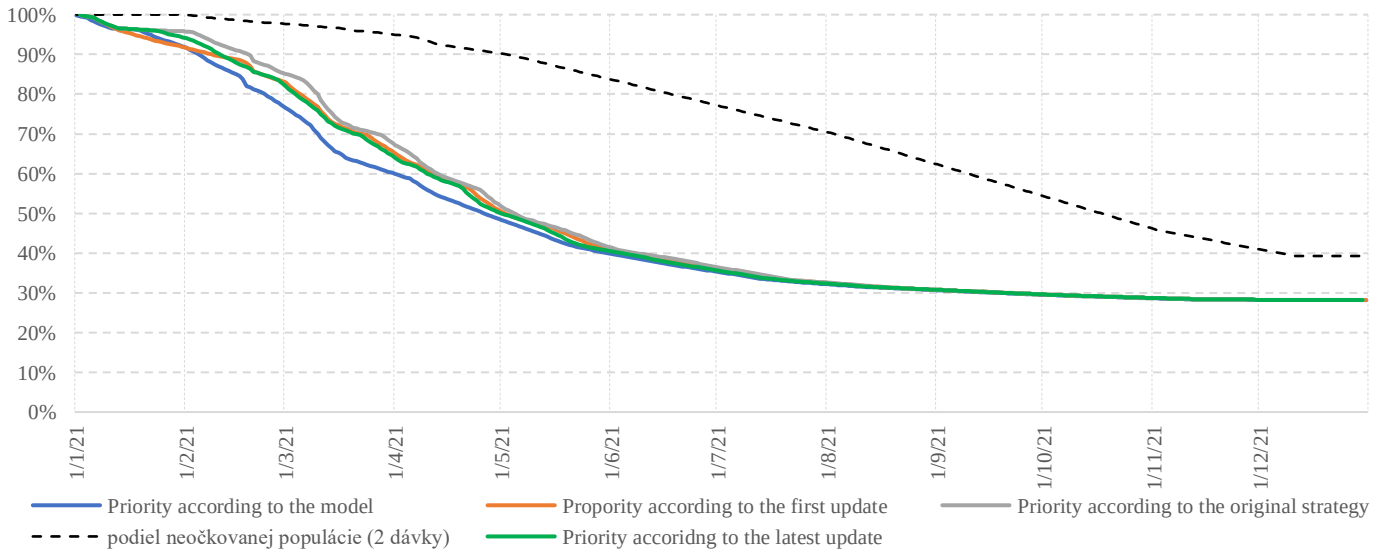

Figure 3: Relative mortality according to modelled scenarios; Source: own calculations

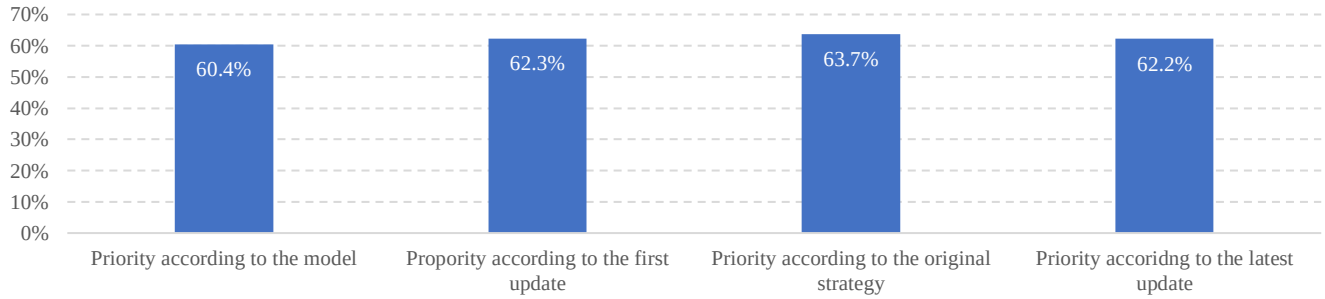

Figure 4: Reduction in relative mortality in all scenarios; Source: own calculations

5 Conclusion

Proposed modification of the national vaccination strategy brings a significant improvement over the original strategy. However, we see opportunities for further optimization by taking into account the risks of more defined population groups, especially among groups of "younger seniors" with co- morbidities who could be preferred. Taking advantage of these opportunities requires better handling of data on the health status of the population, which is already available to the public sector, as well as greater flexibility of the ordering system and cooperation with attending physicians resp. patients' health insurance companies.

Our approach also allows for flexible division into multiple groups by age, occupation, or diagnosis - which proves to be practical when opening vaccination options to other groups, where we have observed the exhaustion of available dates within minutes. We also demonstrate that grouping by diagnosis is possible using existing data in NCZI databases. Therefore, it would not be necessary to request confirmation from physicians from the vast majority of patients with chronic diagnoses, automatic verification of the registration system in the NCZI database is sufficient.

Furthermore, the algorithm can be used to set most optimal vaccination strategy not only at national, but also at regional level, up to the detail of individual GP practices. Similarly, developed model can be quickly and effectively used to select a risk group of the population and prioritize any type of medical preventive action. Results of the model were used by health insurance companies to fine-tune their vaccination priorities in spring 2021 (i.e., creation of lists of patients with chronic diseases which were sent to the National Health Information Center).

References

CDC (2021) Centers for disease control and prevention. People with Certain Medical Conditions. https://www.cdc.gov/coronavirus/2019-ncov/need-extra-precautions/people-with-medical-conditions.html

Dagan, N., Barda, N., Kepten, E., et al. (2021) BNT162b2 mRNA Covid-19 Vaccine in a Nationwide Mass Vaccination Setting. *The New England Journal of Medicine*, 384:1412-1423

Jarkovský, J., Benešová, K., Cerny, V. et al. (2021) Covidogram as a simple tool for predicting severe course of COVID-19: population-based study. *BMJ Open*. London: BMJ Publishing Group, 2021, vol. 11, No 2, p. 1-7. ISSN 2044-6055.

IZA (2021) Inštitút zdravotných analýz: github COVID-19 data. https://github.com/Institut-Zdravotnych-Analyz/covid19-data

Mutambudzi M, Niedzwiedz C, Macdonald EB, et al (2021) Occupation and risk of severe COVID-19: prospective cohort study of 120 075 UK Biobank participants. *Occupational and Environmental Medicine* 2021;78:307-314.

NCZI (2021) Národné centrum zdravotníckych informácií: dávky zdravotných poisťovní. http://www.nczisk.sk/Statisticke_vystupy/Tematicke_statisticke_vystupy/Pages/default.aspx

OECD (2019). OECD/European Observatory on Health Systems and Policies. *Slovak Republic: Country Health Profile 2019, State of Health in the EU*, OECD Publishing, Paris/European Observatory on Health Systems and Policies, Brussels, https://doi.org/10.1787/c1ae6f4b-en.

PHE (2021) Public Health England: Guidance on shielding and protecting people who are clinically extremely vulnerable from COVID-19. https://www.gov.uk/government/publications/guidance-on-shielding-and-protecting-extremely-vulnerable-persons-from-covid-19/guidance-on-shielding-and-protecting-extremely-vulnerable-persons-from-covid-19#cev

Semenzato, L., Botton, J., Drouin, J., Cuenot, F., et al. /2021) Maladies chroniques, états de santé et risque d'hospitalisation et de décès hospitalier pour COVID-19 lors de la première vague de l'épidémie en France: Étude de cohorte de 66 millions de personnes. EPI-PHARE. https://splf.fr/wp-content/uploads/2021/02/Epiphare-Maladies-chroniques-Etat-de-sante-et-risque-hospitalisation-et-de-deces-hospitalier-pour-COVID-19-66-millions-de-personnes-en-France-Mis-en-ligne-le-09-02-21.pdf

ŠÚSR (2021) Štatistický úrad Slovenskej Republiky. DEMOGRAFIA – PRÍČINY ÚMRTÍ V SLOVENSKEJ REPUBLIKE V ROKU 2020. https://bit.ly/365cnn5