Model to Evaluate SARS-CoV-2 Transmission in Finnish Defence Forces' Leave Arrangements

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I. Introduction

As a safety procedure during the SARS-CoV-2 pandemic, the Finnish Defence Forces (FDF) significantly changed conscripts' leave arrangements and training implementations. New leave arrangements, combined with other precautions, have been successful at preventing the disease spreading widely within the organization so far. To evaluate the FDF intervention, we have implemented an agent-based SEIR model[1]. In particular, we simulate two leave arrangements to see if one is better at preventing infections among conscripts than the other.

II. Method

A. Related Work

Some prior military-related studies in modelling infectious diseases (such as different types of influenza) have also used SEIR-models or at least some variants of it [1,2]. Besides, there has been research into transmission risks in facilities [3]. We did not find any research of SARS-CoV-2 modelling in a military conscription context. Agent-based SEIR-models have been used extensively in modelling SARS-CoV-2 intervention measures [4-6]. However, we did not find disease prevention measures similar to those implemented by the FDF from any other large conscription-based militaries.

B. Leave arrangements

The simulation attempts to comply with the same principles the FDF is following currently [7]. The simulated population is divided into four subgroups: conscript groups *A*, *B*, *C*, and the rest of the population (i.e. *civilians*). Conscript groups are equal in size (i.e. 1/3rd of all conscripts). While in service, conscript groups should not interact with each other nor *civilians*. While on leave, a conscript group may interact with *civilians* (and other conscript groups on leave).

C. Simulation

The simulation logic is such that three conscript groups alternate their leaves according to their leave arrangements so that most of the time there are two conscript groups in service and one on leave. There is a short time window during group exchanges when two groups are on leave simultaneously. [2]Conscripts are assumed to move freely during their leave, just as the general population.

While in service, conscripts who show infection symptoms, along with nearby *exposed* individuals are quarantined. At the same time, some conscripts may experience and spread the disease without

[1] Each person is assigned one of the following states: Susceptible(S), Exposed(E), Infected(I) or Recovered(R), with every person being represented as an agent (A). Such that: $N = A_S+A_E+A_I+A_R$, where N is the total population.

[2] For example, if group *A* leaves on Thursday, group *B* arrives on Friday. This is done in order to facilitate cleaning work for disinfecting the areas used by the previous group.

appearance of symptoms. Such *asymptomatic* conscripts would not be automatically quarantined. On the other hand, if a conscript on leave develops infection symptoms, they are ordered in self-quarantine. The model does not take into account quarantines caused by other diseases than SARS-CoV-2.

For the simulation, we used available data from the European Centre for Disease Prevention and Control and the Finnish Institute for Health and Welfare at the time of writing [8-10]. The simulation parameters are summarised in Table I.

TABLE I. SIMULATION PARAMETERS

Parameter	***Value***
Reproduction number in the general population (R0)	1.8 [10]
Close contact range	⩽ 1.5 m [9]
Incubation period (uniform)	1-14 days [9] (avg. 7)
Symptomatic/Asymptomatic period (uniform)	7-14 days [9] (avg. 12)
Quarantine length	14 days
Asymptomatic cases	45% [11]
Amount of conscripts	3000
Simulation duration	165 days
Chance of infection per close contact	17.3% [9]

We assumed that infected individuals are spreading disease during the incubation period, while not being aware of their condition [12,13]. In 45% of cases [8] (worst-case scenario) agents do not develop symptoms i.e. undergo the disease asymptomatically. These carriers are equally infectious. The only way for asymptomatic carriers to get quarantined is for them to get quarantined with a symptomatic carrier. Then all neighbouring agents would be marked as *exposed* and quarantined en masse.

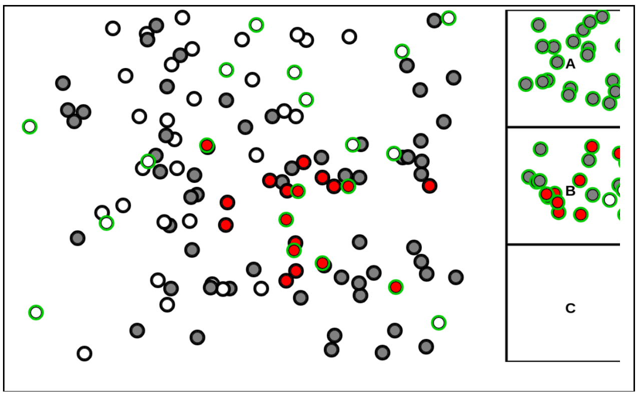

Fig. 1. A simplified graphical version of the simulation setup with reduced amount of agents. Agents move in random patterns in their assigned areas and thus having close contacts with other agents facilitating the transmission of the infection. White-susecptible, Red-infected, Gray-recovered. Green edge of an agent denotes conscripts from the rest of the population. (Quarantine not visible.)

In the simulation, all persons will make a full recovery and become immune to reinfection. This appears to be a reasonable assumption since:

1. Conscripts are younger than 28 years old (19.1 years old on average [14]) and have no severe pre-existing conditions [15].
2. SARS-CoV-2 biological immunity has been estimated to last 6-12 months [6], while the conscription military service lasts one year at maximum.

We simulated two different leave arrangement scenarios: the present leave arrangement (27 days of service, followed by 15 days of leave) and a shorter one (13+8 days) used briefly before the present arrangement.

The choice of service/leave proportion is constrained by the number of conscript groups. From three groups *A*, *B*, *C* one group is on leave and two in service. Both scenarios were tested with and without a 14-day quarantine procedure.

III. RESULTS

The simulation results are presented in Table II and III. The positive effect of shorter service- and leave period (13+8 vs. 27+15 days) is quite pronounced (p≃0.08) for decreasing the total number of infected conscripts, given that quarantine measures are implemented. Without quarantines, the difference effectively disappears (p-value of ~0.53) with a significantly higher amount of conscripts becoming infected than with quarantine.

TABLE II. SIMULATION RESULTS I

Leave Arrangement Used (Days in Service) + (Days on leave)	**Results (20 simulation runs per arrangement and quarantine variation)**				
	14 Day Quarantine Used	***Amount of Conscripts Infected***	***Difference***	***Worst Case Scenario: Able[a] Conscripts at Minimum***	***Difference***
13+8	Yes	0.36%	3.26%	53.2%	40.9%
13+8	No	3.62%		94.1%	
27+15	Yes	0.57%	4.82%	69.4%	27.5%
27+15	No	5.39%		96.9%	

[a] Conscripts not symptomatic or in quarantine,

The use of quarantines is statistically beneficial over both leave arrangements with p-values less than 0.05 using the non-parametric two-tailed

Mann-Whitney U Test. The principal explanation is the following: quarantines cut off diseases in service, thus leaving more conscripts healthy.

Figure 2 and 3 (see Appendix) present the difference of incubation periods using two rotations (13+8 and 27+15) with and without asymptomatic carriers. The incubation periods for the simulations for this figure had zero variance. With shorter incubation periods, such as the common influenza, the two rotations have no significant difference. With longer incubation periods the difference becomes significant as the asymptomatic carriers spread the disease for a longer time continuously with a longer in-service period. In Figure 3 there is no significant difference between the leave arrangements when asymptomatic cases do not occur.

TABLE III. SIMULATION RESULTS II

Leave Arrangement Used (Days in Service) + (Days on leave)	**Results (Quarantine Used, 50 simulation runs per leave arrangement)**				
	Amount of Infected Conscripts on average in total	***Amount of Infected Conscrips on average in service***	***Amount of Infected Conscripts on average on leave***	***Ratio of Infected Conscripts leave/service of all infected Conscripts***	***p-value for the difference between two ratios of Infected conscripts leave/service***
13+8	12.93	7.98	4.95	0.62	0.07
27+15	23.33	18.62	4.71	0.253	
Difference between leave arrangements	-10.4	-10.64	0.24	0.367	

The ratio of conscripts falling ill on leave and in service is higher with 13+8 arrangement with difference of 0.367 and p-value of 0.07.

The FDF employs about 12,000 employees and trains 22,000 conscripts annually [16]. This simulation only analyzes the movement of conscripts. The employees or reservists in refresher exercises are not modeled, which is a significant limitation of this simulation. It should be also noted that this study does not take into account aspects related to training arrangements in conscripts' service. In this study the reproduction number was constant, however in the future we intend to expand it by using a time-varying reproduction number.

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APPENDIX

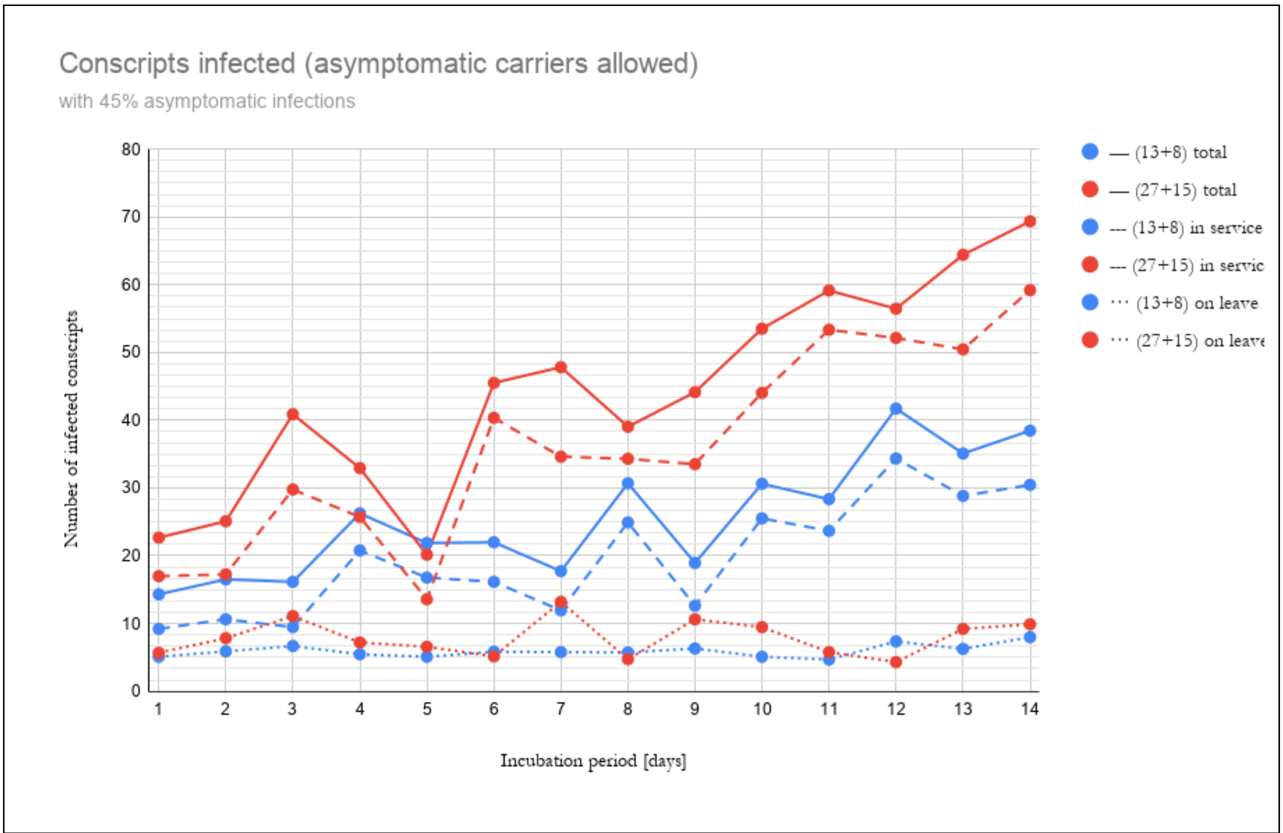

Fig. 2. Red lines belong to the longer 27+15 rotation arrangement, while blue – to the shorter 13+8. Solid lines represent the total number of infected conscripts and are combined from those infected on leave (dotted line) and in service (dashed line). The results are averaged over 20 simulation runs for every period. Longer incubation period of the disease (over 9 days) leads to more infected conscripts in the case of longer service periods ($p \simeq 0.08$)

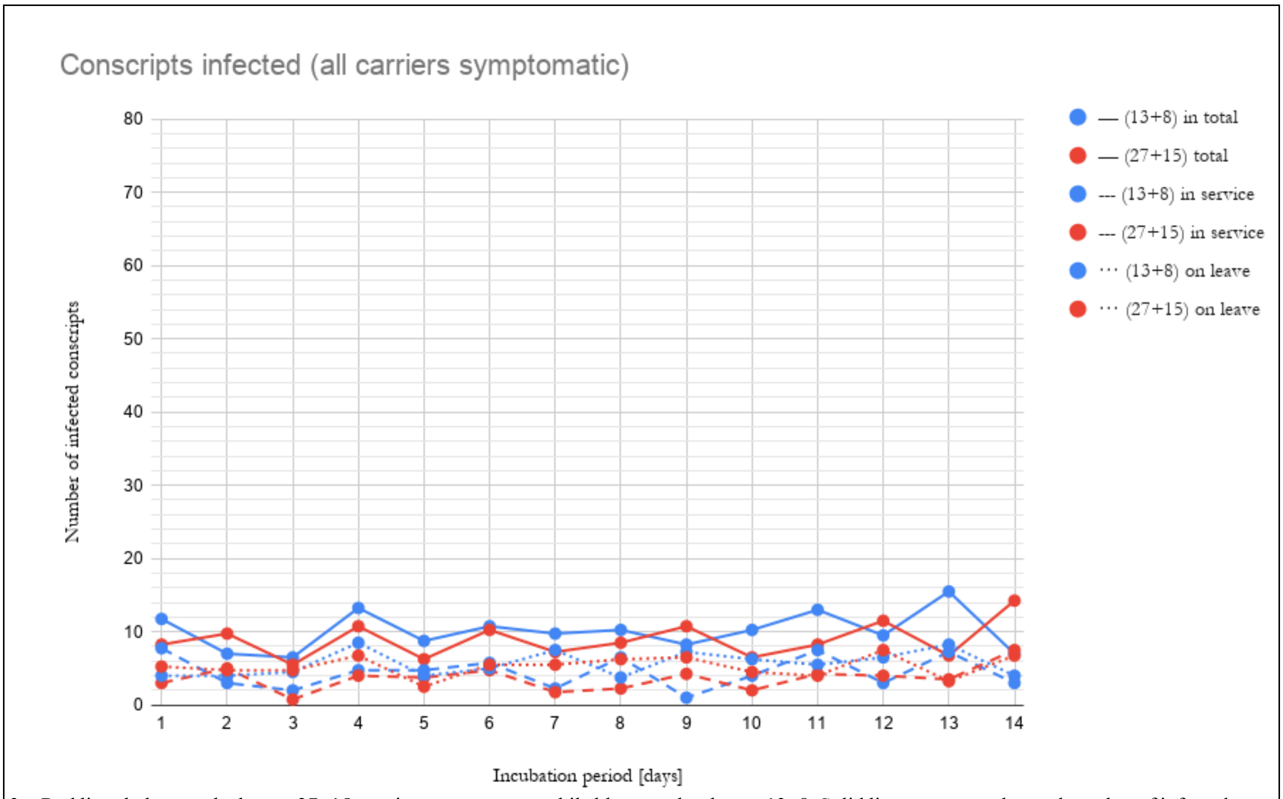

Fig. 3. Red lines belong to the longer 27+15 rotation arrangement, while blue – to the shorter 13+8. Solid lines represent the total number of infected conscripts and are combined from those infected on leave (dotted line) and in service (dashed line). The results are averaged over 20 simulation runs for every period. There is no significant difference between rotations.