Study Report

The "ease of use" of vaccines: a simulation study of the factors impacting the efficiency of the organizational models of vaccination centers.

(Italian translation: *“l'"ease of use" dei vaccini”: uno studio di simulazione dei fattori con impatto sull'efficienza dei modelli organizzativi dei centri vaccinali*)

Authors

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Abstract

Optimizing the efficiency of a vaccination point of dispensing (POD) is particularly relevant during epidemics or in low-resources settings. The decision of adopting proper organisational models and of taking into account the ease-of-use of vaccines could be of a paramount importance for resources-saving. Evidence is therefore urgently needed for healthcare decision-makers. To this aim, in this work we propose to use a simulation optimization approach. In particular, as specific case study, we show how it could be possible to obtain up to 17.5% time saving during a meningococcal vaccination session and relevant cost-saving (e.g., up to 45M euros in real vaccination scenarios).

Keywords

Vaccination, ease-of-use, point-of-dispensing, organisational model, simulation optimization

Introduction

World Health Organization (WHO) in a important documentation states, about ease of use in a vaccination context, that “In some situations the time required to prepare a vaccine is critical, such as during campaigns with long lines of waiting clients or during outreach activities. For these situations a vaccine product that is easier to use and takes less time to prepare can be extremely valuable and can help to increase coverage” and also that “... Immunization programmes may also decide to select products that are similar to those already in use to minimize the burden on health care workers” (1).

Efficiency and management of vaccination is particularly relevant in low resources settings. For example, regarding meningococcal vaccination, a vaccination point of dispensing (POD) could be called to reach a coverage target in a short span of time (e.g.., 2-3 weeks (2)). This target could be reached, for instance, in a organizational setting in which is offered only a single specific vaccine (such as during a epidemic vaccination campaign). Another example can be derived from Italian national immunization plans which could mandatorily require the raising of specific vaccine coverage over a given percentage within a period of two/three years, e.g., >95% within 2019 for the meningococcal vaccination in Italy (3), without allocating (and possibly cutting) more resources.

Given that the ease of use of a vaccine could be crucial for its impact on the immunization programme and resources-saving (1) the problem is how to quantify its benefits for a vaccination POD in different scenarios, i.e. target population and specific organisational setting.

Since this problem require in-deep specific analysis it is clear that is quite impossible to solve a thorny topic like this with simple tools currently available or with a common sense approach. Thus we choose to deal with it by resorting to a “simulation optimization approach” (4–7).

The case study

We focused on two kind of vaccination POD dispensing only meningococcal vaccination.
The first, i.e., the ideal vaccination POD, is organized according to recommendations of the WHO (2,8) with 1 “vaccination team” (i.e., 1 supervisor, 2 nurses, 3-4 record clerks, 2-3 local community representatives, 1 technician responsible for the cold chain, and 1 driver) supported by fundamental logistics, having a daily goal of 1000 vaccinations (about 300 per working shift).
The second, i.e., the real vaccination POD, is a limited version of the ideal one (but more adherent to a common vaccination center) in terms of available operators: 1 supervisor and 1 security officer are allocated, while nurses (2 or 3, to be investigated the exact number in the following simulation experiments) have to perform all activities reserved to record clerks, communicative representatives and technicians which are not available as in the ideal case. Such a real POD organizational model is based upon observations in a real vaccination setting.

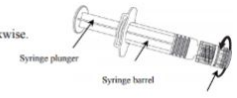
In particular, we are interested in measuring the efficiency impact of the ease-of-use of specific vaccines (1), namely Nimenrix (9) and Menveo (10), which are available on the market and that can be both used in real vaccination POD in Italy. This because such a vaccines are quite different in terms of reconstitution phase as stated in their technical labels (see next figure).

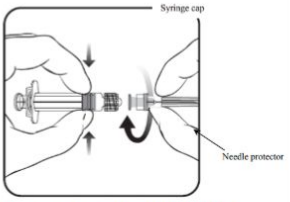
NIMENRIX

Instructions for reconstitution of the vaccine with the solvent presented in pre-filled syringe

Nimenrix must be reconstituted by adding the entire content of the pre-filled syringe of solvent to the vial containing the powder.
To attach the needle to the syringe, refer to the below picture. However, the syringe provided with Nimenrix might be slightly different (without screw thread) than the syringe described in the picture. In that case, the needle should be attached without screwing.

1. Holding the syringe **barrel** in one hand (avoid holding the syringe plunger), unscrew the syringe cap by twisting it anticlockwise.





2. To attach the needle to the syringe, twist the needle clockwise into the syringe until you feel it lock (See picture).
3. Remove the needle protector, which on occasion can be a little stiff.
4. Add the solvent to the powder. After the addition of the solvent to the powder, the mixture should be well shaken until the powder is completely dissolved in the solvent.

The reconstituted vaccine is a clear colourless solution.
The reconstituted vaccine should be inspected visually for any foreign particulate matter and/or variation of physical aspect prior to administration. In the event of either being observed, discard the vaccine.
After reconstitution, the vaccine should be used promptly.

A new needle should be used to administer the vaccine.

Any unused medicinal product or waste material should be disposed of in accordance with local requirements.

MENVEO

Reconstitution of the vaccine

Menveo must be prepared for administration by reconstituting the powder with the solution.

The contents in the two different vials (MenA powder and MenCWY solution) are to be mixed prior to vaccination providing 1 dose of 0.5 ml.

Using a syringe and suitable needle (21G, 40 mm length or 21 G, 1 ½ inch length), withdraw the entire contents of the vial of solution and inject into the vial of powder to reconstitute the MenA conjugate component.

Invert and shake the vial vigorously and then withdraw 0.5 ml of reconstituted product. Please note that it is normal for a small amount of liquid to remain in the vial following withdrawal of the dose. Prior to injection, change the needle with one suitable for the administration. Ensure that no air bubbles are present in the syringe before injecting the vaccine.

Following reconstitution, the vaccine is a clear, colourless to light yellow solution, free from visible foreign particles. In the event of any foreign particulate matter and/or variation of physical aspect being observed, discard the vaccine.

Menveo is given as an intramuscular injection, preferably into the deltoid muscle.

Any unused product or waste material should be disposed of in accordance with local requirements.

Figure. Nimenrix vs Menveo reconstitution. Details are extracted from the leaflets published by the European Medicine Agency website (11) (12).

The specific aim of the study is answering to the following questions:

- given the use of Nimenrix vaccine, the vaccination POD under study is able to provide up to 300 doses per shift (i.e., to reach the WHO goal) ?
- given the use of Menveo vaccine, the vaccination POD under study is able to provide up to 300 doses per shift (i.e., to reach the WHO goal) ?

In Italy, such a focus on meningococcal vaccination is also motivated by the recent epidemics in the Toscana region (13) and by the current national immunization plan “Piano Nazionale Prevenzione Vaccinale” (14), recently approved by the Ministry of Health, which mandatorily extends the coverage of meningococcal vaccination to a cohort of 12-18 years old. Also the raising of vaccine coverage within 2019 to a percentage greater than 95% is an important goal for public health professionals and regulatory agencies in Italy (3).
More in general, worldwide, according to WHO “Meningitis remains a universal public health challenge in countries around the world - cases and outbreaks are highly dreaded. The global number of deaths due to meningitis was estimated at 380,000 annually. Meningitis is an epidemic-prone disease, and as such deserves special attention given the potentially major impact on health systems, the economy and society as a whole due to the disruptive nature of meningitis outbreaks which are costly and challenging to control (15).

Materials and Methods

The study adopts a quantitative research methodology supported by a simulation approach.

We identified three main steps for solving the simulation problem.

- **Step 1 (feasibility of the simulation)** consists of an agile iterative prototyping of the conceptual model and simulator of the vaccination POD. Proofs of concept (POC) of the simulator are implemented by using specialized simulation software in order to define, as fast as possible, the required time and costs for performing
- **step 2 (implementation)** and
- **step 3 (application)** of the simulation.

The modelling process requires the collaboration between subject matter experts (e.g., medical doctors) and modeling experts (e.g., mathematical engineers) in order to answer accurately to the specific questions under investigation by estimating relevant key performance indicators (KPI) of the vaccination POD (next figures).

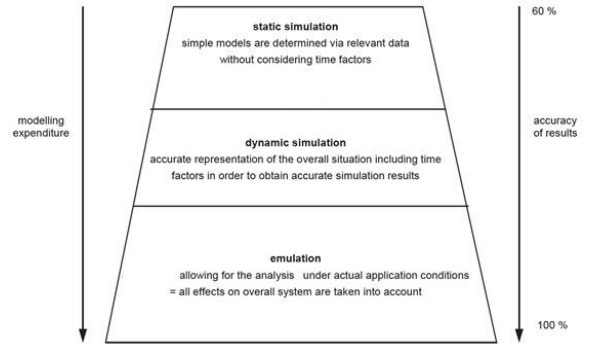


Figure. Accuracy of results (adaptation from (16)).

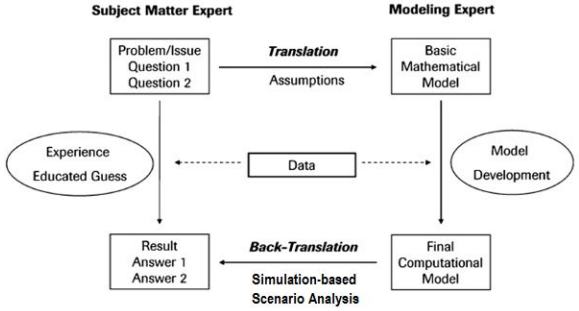


Figure. Modeling process (adaptation from (17)).

Conceptual model of the vaccination POD

A top-down method is used to build up the conceptual model of the vaccination POD. Areas and zones of the vaccination POD are identified from WHO guidelines (2,8).

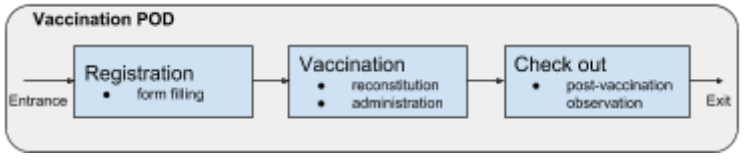


Figure. Conceptual model of the vaccination POD.

Then, parameters characterizing each area and zone both in terms of activities, materials and resources, including relevant parameters assessing the goal under study, are proposed, discussed, chosen and have been quantified by the modelers. These decisions come out

from various documents (including mandatory parameters like “daily session duration”) and from direct observations, not only from the simple choices of the modelers.
Some initial assumptions were necessary to better define the model's needs (see “notes” in next figure).

Area	Zone	Parameters				
		Name	Type	Values	Unit of measure	Range
		number of vaccination sessions	Input	positive integers		1;15
		session duration	Input	positive reals	minutes	330;340;350
		target population (ie, users) to be vaccinated	Input	positive integers		280:300;280x15;300x15
		user's waiting time	Output	positive reals	minutes	-
		user's time in system	Output	positive reals		-
		number of doses administered	Output	positive integers		-
		vaccination coverage	Output	[0,100] %		-
		number of doses used	Output	positive integers		-
		percentage of vaccine utilization	Output	[0,100] %		-
		number of health staff - supervisor	Input	positive integers		1
		number of health staff - nurses	Input	positive integers		1-4
		number of security officers				1
		number of voluenteers	Input	positive integers		0-4
		health staff utilization	Output	[0,100] %		-
Entry & Registration Area	Entrance	time between arrivals	Input	positive reals	minutes	(note 1)
		entrance capacity	Input	positive integers		1 (note 2)
		user's health status	Input/Output	{0=bad,1=good}		1 (note 3)
		entrance lenght of time	Input/Output	positive reals	minutes	not relevant
	Waiting	work-in-progress (WIP) at the waiting zone	Output	positive integers		- (note 4)
		waiting capacity	Input	positive integers		300 (note 5)
		waiting lenght of time	Output	positive reals	minutes	-
	Registration	WIP at the registration zone	Output	positive integers		- (note 4)
		registration capacity	Input	positive integers		1-4 (note 5bis)
		registration lenght of time	Output	positive reals	minutes	-
Clinical Area	Sorting	WIP at the sorting zone	Input/Output	positive integers		0 (note 4)
		sorting capacity	Input	positive integers		300 (note 5)
		sorting lenght of time	Output	positive reals	minutes	-
	Vaccination	WIP at the vaccination zone	Output	positive integers		- (note 4)
		vaccination capacity	Input	positive integers		1-4
		mix of vaccine products per session	Input	[0,100] %		Nimenrix 100%; Menveo 100% (note 6)
		vaccine reconstitution lenght of time	Input/Output	positive reals	minutes	Nimenrix 0,833+/- 17%; Menveo 1,15+/- 17% (note 7)
		number of reconstitution errors	Output	0 or positive integers		0
		vaccination administration lenght of time	Input/Output	positive reals	minutes	0,5 +/-0,166 (note 8)
First-aid & Discharge Area	Check out	WIP at the check-out zone	Output	positive integers		- (note 4)
		check-out capacity	Input	positive integers		300 (note 5)
		check-out lenght of time	Output	positive reals	minutes	-
	Exit	number of users	Output	positive integers		-
		number of vaccinated users = number of administered doses	Output	0 or positive integers		-

NOTES	
	note 1: we assume no delay between patient arrival (all target patient are ready to enter into vaccination POD)
	note 2: we assume that patient entered into vaccination POD one by one
	note 3: we assume that all patient are in good halth status
	note 4: the output value is a control variable: If it's value is different from 0 it means that some people are not scheduled for next vaccination session
	note 5: we assume that non-clinical activities are optimized at the highest level of efficiency
	note 6: in our experiments we assumed the single utilization of one type of vaccine per session
	note 7: range and statistic distribution come out from 2 videos observation
	note 8: this value and its distribution came out from interviews with medical doctor and direct observation in in a real vaccination setting

Figure. Relevant parameters defined by the modelers and their ranges.

Simulation model of the vaccination POD

The discrete-event simulation (DES) of the vaccination POD, i.e., the simulator (see next figure), is implemented in Simio version 10 (build 168.16501), an integrated development environment for realizing general-purpose simulations (18).

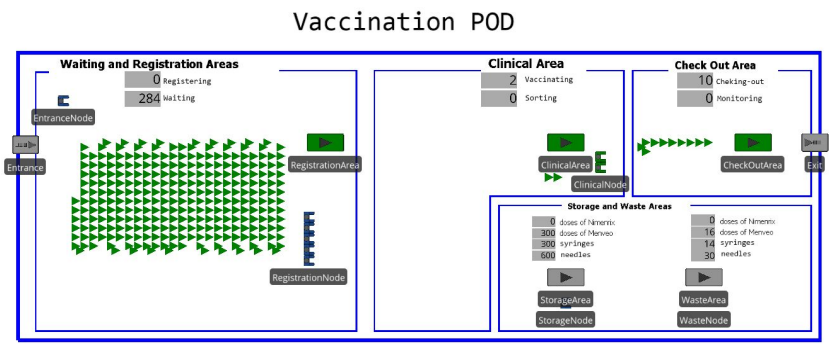


Figure. Simulator of the vaccination POD (at the beginning of simulation). Patients are represented by green triangles. Spatial dimension are neglected assuming rapid movements of people (both patients and operators).

Verification of the simulator (i.e., the process of confirming that the simulation is correctly implemented with respect to the conceptual model) and validation of the simulator (i.e., the checking of the accuracy of the computational model's representation of the real system) has been performed by comparing its results with the WHO indications, on field observation (next figure) and results obtained by another independent implementation in R (https://www.r-project.org/).

Next figure shows the results obtained from several observation in a real vaccination setting. These data (not published), derive from a recent degree thesis (which the authors co-tutored) (19), which has provided crucial measure (in terms of KPI) we used to compare data we adopted in simulation model (particularly in “real setting”).

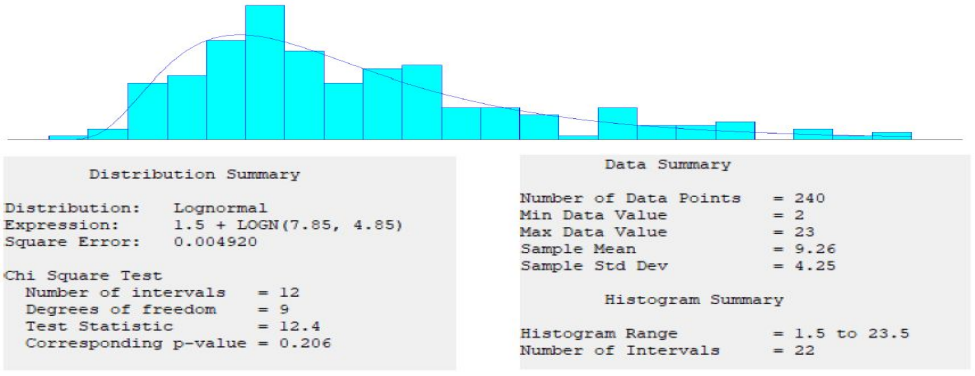


Figure. Overall registration and vaccination length of time (in minutes) observed during a study (19) in a vaccination POD of the National Health Service in Rome (1-week, February, 2018) during ordinary vaccination sessions (i.e., in a non-epidemic condition).

Simulation Experiments

Given a target population to cover, such a simulator is used to perform several scenario analysis (i.e., experiments for testing different settings and target), including Simulation Optimization of the vaccination session (particularly its duration) and Response Sensitivity Analysis based on linear regression to relate experiment responses (i.e., time to target) to specific input parameters of interest (i.e., vaccine administration time and vaccine reconstitution time).

Fixed parameters (which are the same for all vaccination POD scenarios under investigation in the following) are:

- shift duration (380 minutes),
- session duration (340 minutes, starting 10 minutes after the beginning of the shift),
- administration length of time (described by a uniform distribution in the range of 20 and 40 seconds), and
- reconstitution length of time (described by a triangular distribution in the range of 50 and 70 seconds with median 60, and a triangular distribution in the range of 69 and 97 seconds with median 83, for Nimenrix and Menveo, respectively).

“Control variables” (a.k.a. controls), i.e., parameters which change over different scenarios hereafter shown, are:

- the target population per session (300 or 280 people),
- the registration area capacity (3 or 4 for the ideal vaccination POD, and 2 or 3, i.e., equal to the clinical area capacity, for the real vaccination POD),
- the clinical area capacity (2 or 3) and
- the adopted meningococcal vaccine (Nimenrix or Menveo).

The simulated vaccination team, which differs from ideal and real POD, is composed by:

- 1 supervisor;
- 1 security officer;
- community representatives in number equal to the registration area capacity or zero for the ideal and real vaccination POD, respectively;
- record clerks in number equal to the registration area capacity or zero for the ideal and real vaccination POD, respectively;
- nurses in number equal to the clinical area capacity;
- technicians in number equal to 1 or zero for the ideal and real vaccination POD, respectively.

Results

By using two instances of the simulator, the ideal vaccination POD and the real vaccination POD defined in the introduction of the case-study have been tested together (next figure).

Figure. Ideal vaccination POD (left) and real vaccination POD (right) under investigation at the same time (i.e., per single scenario).

The simulator of the ideal vaccination POD provides the following responses:

- O (i.e., output patients) is the number of vaccinated people;
- T2T (i.e., time to target) measures the time elapsed from the beginning of the vaccination session to the time when all the target population is covered (0 otherwise);
- FT (i.e., free time percentage) measures the ratio between the time remaining to the end of session after the T2T, and the session duration.

In the simulation of the real vaccination POD, the responses O_real, T2T_real and FT_real have the same meaning of O, T2T and FT for the ideal vaccination POD, respectively.

Having fixed exactly the same relevant parameters for both vaccination POD (as stated more in details in the previous section, e.g., the shift duration to 380 minutes) and by varying as control variables the target population per session, the number of vaccinators (i.e., the clinical area capacity) and the presence or absence of supporting personnel (i.e., the registration capacity which characterizes the ideal and real setting, respectively), the analyzed vaccination scenarios are six (next figure). Furthermore, due to the randomicity of the parameters vaccine reconstitution and administration length of times, 100 simulation replications per scenario simulation has been executed.

Scenario		Replications		Session - Controls	Registration Area - Controls	Clinical Area - Controls	Responses					
☑	Name	Required	Completed	targetPopulationPerSession	RegistrationAreaCapacity	ClinicalAreaCapacity	O	T2T (Minutes)	FT	O_real	T2T_real (Minutes)	FT_real
☑	Nimenrix-Scenario02-300	100	100 of 100	300	3	2	300	225.989	33.5328	300	300.356	11.6601
☑	Menveo-Scenario02-300	100	100 of 100	300	3	2	300	283.504	16.6164	280.46	0	0
☑	Nimenrix-Scenario02-280	100	100 of 100	280	3	2	280	210.987	37.945	280	280.348	17.5447
☑	Menveo-Scenario02-280	100	100 of 100	280	3	2	280	264.657	22.1596	280	334.101	1.73495
☑	Nimenrix-Scenario03-300	100	100 of 100	300	4	3	300	151.166	55.5393	300	200.551	41.0144
☑	Menveo-Scenario03-300	100	100 of 100	300	4	3	300	189.708	44.2036	300	238.887	29.7392

Figure. Definitive scenario analysis of the Ideal (first three responses columns) and Real (last three responses columns) vaccination POD.

The first two scenarios show us that with a clinical area capacity of 2 units, a target population per session of 300 people (i.e., the WHO goal) cannot be served by using the Menveo vaccine in real vaccination POD. Thus, the comparison of two vaccines can only be performed decreasing the target to 280 people. Having fixed this target, for the real vaccination POD the average free time percentage (i.e., FT_real) is about 17.54% and 1.73% for Nimenrix and Menveo, respectively (see previous figure at column FT_real, scenarios Nimenrix-Scenario02-280 vs Menveo-Scenario02-280). More in details, the next two figures show SMORE (Simio Measure of Risk & Error - i.e., box) plots including FT_real minimum, maximum, mean, median (with upper and lower percentile) and confidence intervals.

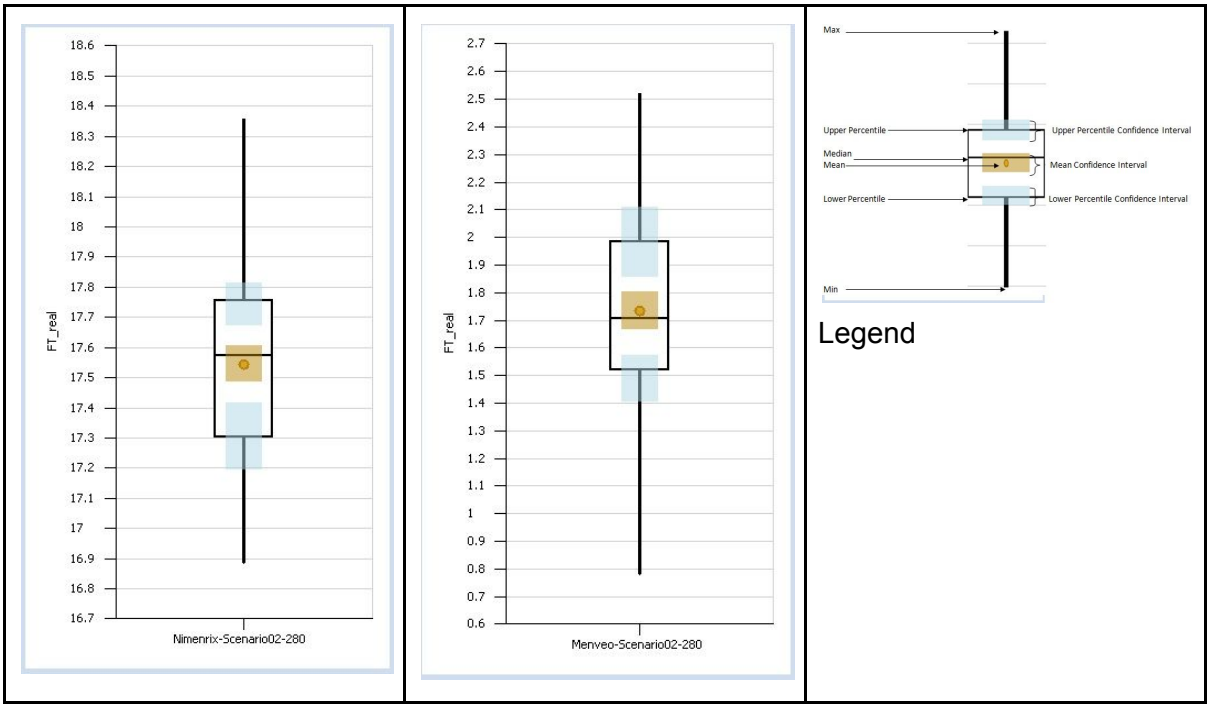


Figure. Free time (%) in the real vaccination POD when the target population is 280 people, the number of vaccinators is 2, and the used vaccine is Nimenrix and Menveo, respectively.

Such a free time percentages (shown in the previous figure) corresponds to an average time to target (i.e., T2T_real) of 280.3 and 334.1 minutes when the used vaccine is Nimenrix and Menveo, respectively (next figure). Thus, the time saving can be simply evaluated by difference with the session duration (i.e., 340 minutes).

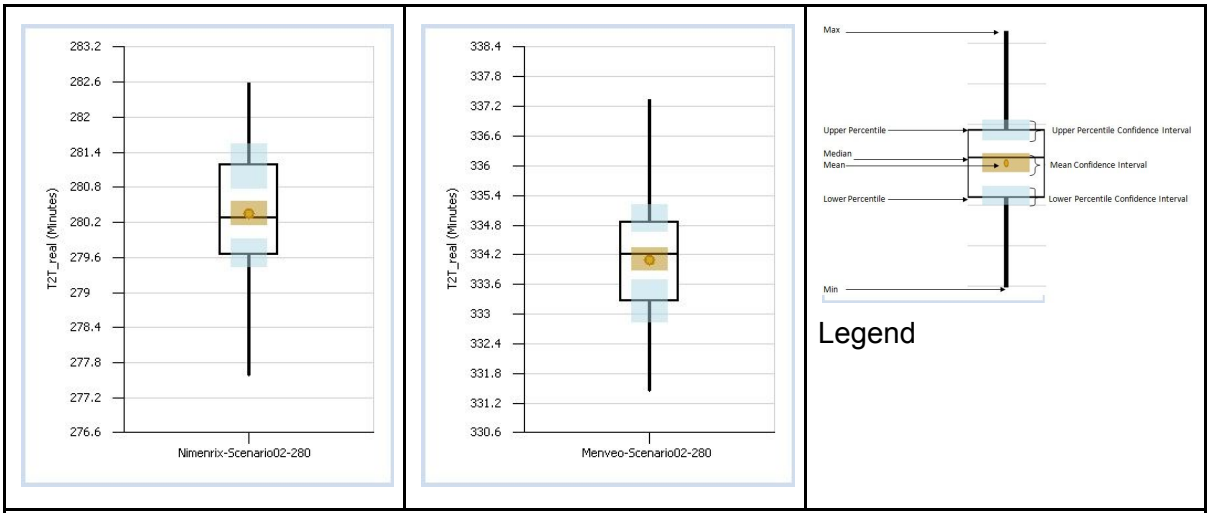
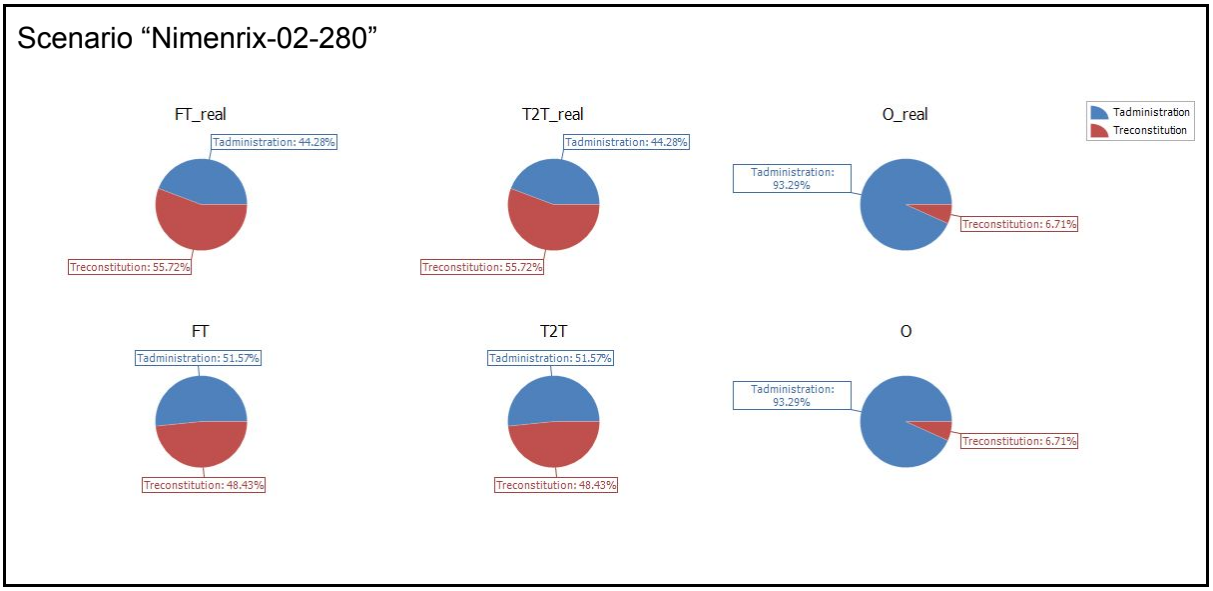


Figure. Time to target (minutes) in the real vaccination POD when the target population is 280 people, the number of vaccinators is 2, and the used vaccine is Nimenrix and Menveo, respectively.

By continuing the focus on the scenarios characterized by a target population of 280 people, the sensitivity analysis shows that the relevance of reconstitution phase for having free time, i.e., the impact of the ease of use of the vaccine, is 55.72% and 47.76% when the adopted vaccine is Nimenrix and Menveo, respectively. The number of vaccinated users (i.e., O_real = 280 people in both cases) is less influenced by the reconstitution of Nimenrix (6.71%) and more sensible to the reconstitution of Menveo (36.98%), while the other impact on the covering of the target population derives from the time spent by the vaccinators doing the administration of the vaccine.



Scenario “Menveo-02-280”

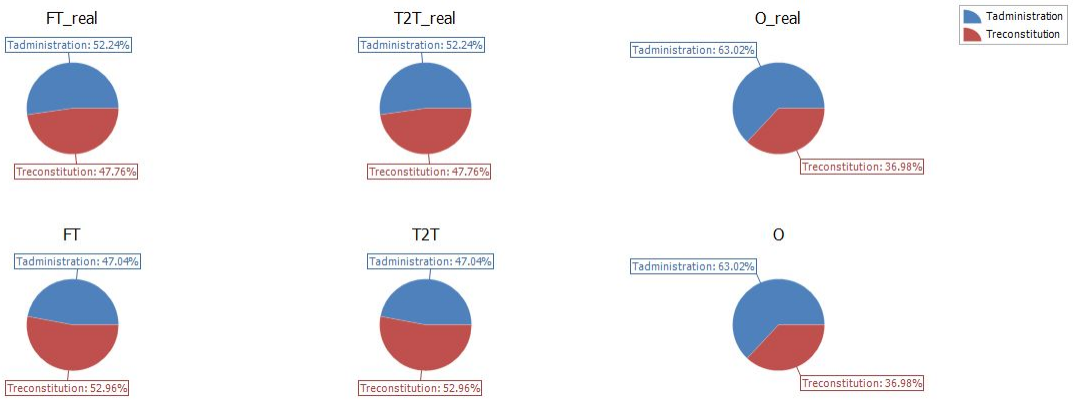


Figure. Sensitivity analysis. Weights (%) of the vaccine administration time (i.e., Tadministration) and the vaccine reconstitution time (i.e., Treconstitution) on the defined responses (i.e., FT, T2T, O for the ideal vaccination POD, and FT_real, T2T_real, O_real for the real vaccination POD) when the target population is 280 people, the number of vaccinators is 2, and the adopted vaccine is Nimenrix (up) and Menveo (down), respectively.

Results obtained by independent implementation in R showed a good reproducibility of our simulation model, particularly in T2T results (next figure).

POD Simulations in R (100 replications)			
POD	**Scenario**	**O**	**T2T (minutes)**
Ideal POD	Nimerix-scenario02-300	300	**226**
	Menveo-scenario02-300	300	**283**
Real POD	Nimerix-scenario02-300	300	**300**
	Menveo-scenario02-300	284	**340**
Ideal POD	Nimerix-scenario02-284	284	**214**
	Menveo-scenario02-284	284	**268**
Real POD	Nimerix-scenario02-284	284	**285**
	Menveo-scenario02-284	284	**340**
Ideal POD	Nimerix-scenario03-300	300	**151**
	Menveo-scenario03-300	300	**189**
Real POD	Nimerix-scenario03-300	300	**201**
	Menveo-scenario03-300	300	**239**

Figure. Results given by the R simulator of the vaccination POD.

In sum, according to the above results, it is possible to answer positively to the initial questions of the case study with some recommendations:

- vaccination POD should allocate operators as in the ideal setting (according to WHO), or
- real vaccination POD with fewer operators than in the ideal case should use the most ease-of-use vaccine, i.e., Nimenrix, which has lowest reconstitution time.

Discussion

In this study, as we are interested in measuring the impact of the ease-of-use of two different meningococcal vaccines available on the market in Italy, namely Nimenrix and Menveo, we compare simulated performance of ideal POD (with a complete vaccination team according to WHO) and real POD (with a reduced vaccination team) providing only one type of vaccination (i.e., mono-type vaccination) to a predefined target patients (assumed to be present at the beginning of the vaccination and in good health status). By adopting this ease-to-organize vaccination session, also non-clinical activities of the POD can be optimized at the highest level of efficiency. This could be considered as a limit of the study. However, if this first impression is exceeded, such a organisational model gives to the vaccination POD the ability to operate efficiently both in emergency situations as well as in normal conditions, even with relevant time and cost saving by leveraging the ease-of-use of the adopted vaccine. Even the quality of the service (18) can be improved more easily by engaging patients and health workers in the study of relevant aspects of the single specific vaccination. Due to lack of usable evidences from literature or observable vaccination POD which operate “in the same condition” hypothesized, the results of the study do not care about vaccine reconstitution errors or possible vaccination side effects.

We in particular evaluated the effects of the advantage given by the reduction of the reconstitution time provided by Nimenrix during a mono vaccination session in a real vaccination POD. Having a target of 280 people per session (340 minutes), the ability of the clinical area (i.e., vaccinators) to achieve it is less sensible to the reconstitution of Nimenrix (6.71%) and more sensible to the reconstitution of Menveo (36.98%), while for the rest it depends from the time spent in doing the administration of the vaccine. The resulting average free time percentage is about 17.5% (60 minutes) and 1.7% (6 minutes) for Nimenrix and Menveo, respectively. The above percentages are critical to understand and suggest how to reach the right number of vaccinated patient in a short span of time. The differences emerged from the sensitivity analysis could be hold in consideration and better investigated in order to offer a more efficient service.

Such a result can be easily applied for obtaining further insights and evaluations (see next figure for some examples of possible economic implications in a real scenario). For example, the application to the case of meningitis epidemics in Tuscany region of Italy could reveal an overall cost saving of about 45 millions of euros by using the Nimenrix vaccine for implementing an hypothetical vaccination campaign according to the WHO recommendations.

	WHO Example - Real settings		Tuscany Example (>17 y.o.) - Real settings	
	Scenario "Nimenrix-02-280"	Scenario "Menveo-02-280"	Scenario "Nimenrix-02-280"	Scenario "Menveo-02-280"
estimated population	50.000	50.000	3.173.234	3.173.234
target population (%)	0,70	0,70	0,70	0,70
target population	35.000	35.000	2.221.264	2.221.264
goal coverage (%)	100,00%	100,00%	100,00%	100,00%
goal coverage	35.000	35.000	2.221.264	2.221.264
number of doses per person	1	1	1	1
number of doses to administer	35.000	35.000	2.221.264	2.221.264
number of doses needed, assuming wastage (~17%)	40.950	40.950	2.598.879	2.598.879
number of doses needed assuming need for a reserve (~25%)	51.597	51.597	3.274.587	3.274.587
campain duration	15	15	15	15
target population per session	**280**	**280**	**280**	**280**
number of PODs needed	8,33	8,33	528,87	528,87
time to start the vaccination session (minutes)	10,00	10,00	10,00	10,00
time to target population per session (minutes)	284,24	334,10	284,24	334,10
time after the end of the session, before shift end (minutes)	30,00	30,00	30,00	30,00
number of supervisors	1,00	1,00	1,00	1,00
cost of supervisor (euros/hour)	48,00	48,00	48,00	48,00
cost of supervisor (euros)	233.454,96	269.352,72	233.454,96	269.352,72
number of security officer	1,00	1,00	1,00	1,00
cost of security officer (euros/hour)	13,71	13,71	13,71	13,71
cost of security officer (euros)	66.680,57	76.933,87	66.680,57	76.933,87
nurses	**2**	**2**	**2**	**2**
cost of nurse (euros/hour)	26,47	26,47	26,47	26,47
cost of nurse (euros)	257.481,37	297.073,60	257.481,37	297.073,60
total costs of resources per POD (euros)	557.616,90	643.360,19	557.616,90	643.360,19
total costs of resources (euros)	4.646.807,49	5.361.334,96	294.908.150,61	340.255.407,37

Figure. Examples of economic implications. In case of meningitis epidemic and according to recommendations by the WHO, operators of each involved vaccination POD can be temporary hired to cover the target population within 2 weeks from the start of the vaccination campaign. The free time (if any) could be use to close the POD itself in advance for having a cost saving (assuming operator unitary costs per hour).

Although a mono-type vaccination POD is not so frequent to observe in reality, we underline that this can be a valid organization to be taken into consideration when there is a specific request to reach a vaccination goal especially in a low setting resources and in a few days/weeks of vaccine sessions.

Our simulation results are confirmed by independent implementation of the simulator.

Future work could regard the simulation of specific vaccination centres in Italy and the prototyping of simulation-based decision-support software for decision-makers of vaccination POD.

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Annex

Object Name	Data Source	Statistic	Menveo-Scenario02-280	Menveo-Scenario02-300	Menveo-Scenario03-300	Nimenrix-Scenario02-280	Nimenrix-Scenario02-300	Nimenrix-Scenario03-300
IdealPOD	checkOutCapacity	FinalValue	300.0000	300.0000	300.0000	300.0000	300.0000	300.0000
	checkOutLengthOfTime	FinalValue (Hours)	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500
	checkOutWIP	FinalValue	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	dosesOfMenveoUsed	FinalValue	280.0000	300.0000	300.0000	0.0000	0.0000	0.0000
	dosesOfNimenrixUsed	FinalValue	0.0000	0.0000	0.0000	280.0000	300.0000	300.0000
	entranceCapacity	FinalValue	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	entranceLengthOfTime	FinalValue (Hours)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	freeTimePercentageAtClinicalArea	FinalValue	22.1596	16.6164	44.2036	37.9398	33.5364	55.5203
	numberOfDoctors	FinalValue	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	numberOfDosesAdministered	FinalValue	280.0000	300.0000	300.0000	280.0000	300.0000	300.0000
	numberOfDosesUsed	FinalValue	280.0000	300.0000	300.0000	280.0000	300.0000	300.0000
	numberOfNurses	FinalValue	2.0000	2.0000	3.0000	2.0000	2.0000	3.0000
	numberOfUsers	FinalValue	280.0000	300.0000	300.0000	280.0000	300.0000	300.0000
	numberOfVaccinatedUsers	FinalValue	280.0000	300.0000	300.0000	280.0000	300.0000	300.0000
	numberOfVaccinationSessions	FinalValue	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	PatientsWIP	FinalValue	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	percentageOfVaccineUtilization	FinalValue	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000
	registrationCapacity	FinalValue	3.0000	3.0000	4.0000	3.0000	3.0000	4.0000
	registrationLengthOfTime	FinalValue (Hours)	0.0083	0.0083	0.0083	0.0083	0.0083	0.0083
	registrationLengthOfTimeMax	FinalValue (Hours)	0.0083	0.0083	0.0083	0.0083	0.0083	0.0083
	registrationLengthOfTimeMin	FinalValue (Hours)	0.0083	0.0083	0.0083	0.0083	0.0083	0.0083
	registrationWIP	FinalValue	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	sessionDuration	FinalValue (Hours)	5.6667	5.6667	5.6667	5.6667	5.6667	5.6667
	shiftDuration	FinalValue (Hours)	6.3333	6.3333	6.3333	6.3333	6.3333	6.3333
	sortingCapacity	FinalValue	280.0000	300.0000	300.0000	280.0000	300.0000	300.0000
	sortingLengthOfTime	FinalValue (Hours)	1.1724	1.2585	0.8823	0.8602	0.9175	0.6495
	sortingLengthOfTimeMax	FinalValue (Hours)	2.3745	2.5541	1.8079	1.7337	1.8481	1.3312
	sortingLengthOfTimeMin	FinalValue (Hours)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	sortingWIP	FinalValue	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	targetPopulation	FinalValue	280.0000	300.0000	300.0000	280.0000	300.0000	300.0000
	timeToTarget	FinalValue (Hours)	4.4110	4.7251	3.1618	3.5167	3.7558	2.5205
	userHealthStatus	FinalValue	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	userTimeInSystem	FinalValue (Hours)	2.6397	2.7966	2.0141	2.1897	2.3098	1.6909
	userTimeInSystemMax	FinalValue (Hours)	4.8273	5.1415	3.5782	3.9331	4.1722	2.9369
	userTimeInSystemMin	FinalValue (Hours)	0.4546	0.4546	0.4540	0.4482	0.4482	0.4476
	userWaitingTime	FinalValue (Hours)	2.3500	2.5068	1.7244	1.9063	2.0265	1.4075
	userWaitingTimeMax	FinalValue (Hours)	4.5470	4.8520	3.2884	3.6573	3.8889	2.6534
	userWaitingTimeMin	FinalValue (Hours)	0.1664	0.1664	0.1664	0.1664	0.1664	0.1664
	vaccinationCapacity	FinalValue	2.0000	2.0000	3.0000	2.0000	2.0000	3.0000
	vaccinationCoverage	FinalValue	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000
	vaccinationLengthOfTime	FinalValue (Hours)	0.0314	0.0314	0.0314	0.0250	0.0249	0.0250
	vaccinationLengthOfTimeMax	FinalValue (Hours)	0.0370	0.0370	0.0370	0.0302	0.0300	0.0301
	vaccinationLengthOfTimeMin	FinalValue (Hours)	0.0258	0.0258	0.0258	0.0199	0.0198	0.0198
	vaccinationWIP	FinalValue	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	vaccineReconsitutionErrors	FinalValue	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	vaccineReconstitutionLengthOfTime	FinalValue (Hours)	0.0139	0.0138	0.0105	0.0114	0.0114	0.0090
	vaccineReconstitutionLengthOfTimeTotal	FinalValue						
		FinalValue (Hours)	2.8541	3.0416	1.9165	2.1263	2.2647	1.4904
	vaccineStorageCapacity	FinalValue	Infinity	Infinity	Infinity	Infinity	Infinity	Infinity
	waitingCapacity	FinalValue	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	waitingLengthOfTime	FinalValue (Hours)	1.1776	1.2483	0.8420	1.0462	1.1090	0.7580
	waitingLengthOfTimeMax	FinalValue (Hours)	2.1725	2.2979	1.4805	1.9236	2.0408	1.3221
	waitingLengthOfTimeMin	FinalValue (Hours)	0.1664	0.1664	0.1664	0.1664	0.1664	0.1664
	waitingWIP	FinalValue	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Figure. Ideal vaccination POD parameters and their figures.

Object Name	Data Source	Category	Statistic	Menveo-Scenario02-280	Menveo-Scenario02-300	Menveo-Scenario03-300	Nimenrix-Scenario02-280	Nimenrix-Scenario02-300	Nimenrix-Scenario03-300
RealPOD	checkOutCapacity	Check Out Area KPI	FinalValue	300.0000	300.0000	300.0000	300.0000	300.0000	300.0000
	checkOutLengthOfTime	Check Out Area KPI	FinalValue (Hours)	0.2593	0.2644	0.2500	0.2500	0.2500	0.2500
	checkOutWIP	Check Out Area KPI	FinalValue	0.0000	19.5500	0.0000	0.0000	0.0000	0.0000
	dosesOfMenveoUsed	Other Area KPI	FinalValue	280.0000	282.4600	300.0000	0.0000	0.0000	0.0000
	dosesOfNimenrixUsed	Other Area KPI	FinalValue	0.0000	0.0000	0.0000	280.0000	300.0000	300.0000
	entranceCapacity	Registration Area KPI	FinalValue	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	entranceLengthOfTime	Registration Area KPI	FinalValue (Hours)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	freeTimePercentageAtClinicalArea	Clinical Area KPI	FinalValue	1.7350	0.0000	29.7392	17.5755	11.6868	41.0305
	numberOfDoctors	POD KPI	FinalValue	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	numberOfDosesAdministered	POD KPI	FinalValue	280.0000	280.4600	300.0000	280.0000	300.0000	300.0000
	numberOfDosesUsed	POD KPI	FinalValue	280.0000	282.4600	300.0000	280.0000	300.0000	300.0000
	numberOfNurses	POD KPI	FinalValue	2.0000	2.0000	3.0000	2.0000	2.0000	3.0000
	numberOfUsers	Check Out Area KPI	FinalValue	280.0000	280.4500	300.0000	280.0000	300.0000	300.0000
	numberOfVaccinatedUsers	Check Out Area KPI	FinalValue	280.0000	280.4600	300.0000	280.0000	300.0000	300.0000
	numberOfVaccinationSessions	POD KPI	FinalValue	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	PatientsWIP	Check Out Area KPI	FinalValue	0.0000	19.5500	0.0000	0.0000	0.0000	0.0000
	percentageOfVaccineUtilization	POD KPI	FinalValue	100.0000	99.2919	100.0000	100.0000	100.0000	100.0000
	registrationCapacity	Registration Area KPI	FinalValue	3.0000	3.0000	4.0000	3.0000	3.0000	4.0000
	registrationLengthOfTime	Registration Area KPI	FinalValue (Hours)	0.0313	0.0313	0.0276	0.0279	0.0279	0.0250
	registrationLengthOfTimeMax	Registration Area KPI	FinalValue (Hours)	0.0493	0.0493	0.0460	0.0431	0.0430	0.0401
	registrationLengthOfTimeMin	Registration Area KPI	FinalValue (Hours)	0.0083	0.0083	0.0083	0.0083	0.0083	0.0083
	registrationWIP	Registration Area KPI	FinalValue	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	sessionDuration	POD KPI	FinalValue (Hours)	5.6667	5.6667	5.6667	5.6667	5.6667	5.6667
	shiftDuration	POD KPI	FinalValue (Hours)	6.3333	6.3333	6.3333	6.3333	6.3333	6.3333
	sortingCapacity	Registration Area KPI	FinalValue	280.0000	300.0000	300.0000	280.0000	300.0000	300.0000
	sortingLengthOfTime	Registration Area KPI	FinalValue (Hours)	0.5647	0.5978	0.5301	0.4015	0.4330	0.4020
	sortingLengthOfTimeMax	Registration Area KPI	FinalValue (Hours)	0.9707	1.0379	0.8986	0.7136	0.7658	0.6794
	sortingLengthOfTimeMin	Registration Area KPI	FinalValue (Hours)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	sortingWIP	Registration Area KPI	FinalValue	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	targetPopulation	POD KPI	FinalValue	280.0000	300.0000	300.0000	280.0000	300.0000	300.0000
	timeToTarget	POD KPI	FinalValue (Hours)	5.5684	0.0000	3.9814	4.6707	4.9933	3.3416
	userHealthStatus	POD KPI	FinalValue	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	userTimeInSystem	POD KPI	FinalValue (Hours)	3.3471	3.3716	2.5348	2.8690	3.0381	2.2023
	userTimeInSystemMax	POD KPI	FinalValue (Hours)	6.2393	6.3271	4.3978	5.0871	5.4097	3.7580
	userTimeInSystemMin	POD KPI	FinalValue (Hours)	0.4556	0.4556	0.4544	0.4492	0.4491	0.4481
	userWaitingTime	POD KPI	FinalValue (Hours)	3.0169	3.2161	2.2176	2.5579	2.7270	1.8941
	userWaitingTimeMax	POD KPI	FinalValue (Hours)	5.7405	6.1401	4.1131	4.8847	5.2122	3.5126
	userWaitingTimeMin	POD KPI	FinalValue (Hours)	0.1664	0.1664	0.1664	0.1664	0.1664	0.1664
	vaccinationCapacity	Clinical Area KPI	FinalValue	2.0000	2.0000	3.0000	2.0000	2.0000	3.0000
	vaccinationCoverage	POD KPI	FinalValue	100.0000	93.4867	100.0000	100.0000	100.0000	100.0000
	vaccinationLengthOfTime	Clinical Area KPI	FinalValue (Hours)	0.0396	0.0377	0.0396	0.0332	0.0332	0.0332
	vaccinationLengthOfTimeMax	Clinical Area KPI	FinalValue (Hours)	0.0598	0.0599	0.0598	0.0522	0.0520	0.0515
	vaccinationLengthOfTimeMin	Clinical Area KPI	FinalValue (Hours)	0.0261	0.0000	0.0262	0.0202	0.0202	0.0201
	vaccinationWIP	Clinical Area KPI	FinalValue	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	vaccineReconsitutionErrors	Clinical Area KPI	FinalValue	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	vaccineReconstitutionLengthOfTime	Clinical Area KPI	FinalValue (Hours)	0.0150	0.0150	0.0106	0.0123	0.0122	0.0086
	vaccineReconstitutionLengthOfTimeTotal	Clinical Area KPI	FinalValue						
			FinalValue (Hours)	2.8671	2.8918	1.9780	2.2966	2.4412	1.5866
	vaccineStorageCapacity	Other Area KPI	FinalValue	Infinity	Infinity	Infinity	Infinity	Infinity	Infinity
	waitingCapacity	Registration Area KPI	FinalValue	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	waitingLengthOfTime	Registration Area KPI	FinalValue (Hours)	2.4521	2.6183	1.6875	2.1563	2.2940	1.4920
	waitingLengthOfTimeMax	Registration Area KPI	FinalValue (Hours)	4.7698	5.1023	3.2145	4.1710	4.4463	2.8333
	waitingLengthOfTimeMin	Registration Area KPI	FinalValue (Hours)	0.1664	0.1664	0.1664	0.1664	0.1664	0.1664
	waitingWIP	Registration Area KPI	FinalValue	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Figure. Real vaccination POD parameters and their figures for different scenarios.