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EXECUTIVE SUMMARY

The social simulation component of the TELL ME project (WP4) started in February 2013. This second report details the intended design of the simulation model. The model architecture and validation criteria were presented in the previous report (D4.1 released in August 2013). To provide for an integrated and independent design document, that earlier material is also included in this report. Thus report D4.2 supersedes report D4.1.

The objective of the TELL ME simulation model is to provide guidance for health authorities about the effectiveness of different communication plans before, during and after an influenza epidemic. As the objective of such communication is to limit the impact of the epidemic, the model must connect proposed plans to epidemic progress.

This design document describes a two layer simulation. One layer consists of simulated individuals that receive communication messages, adjust their attitudes accordingly, perceive their situation and make decisions about whether to adopt (or cease) protective behaviour. This behaviour is founded on a hybrid psychological model that includes attitudes, subjective norms and perceived threat. The other layer is a spatial epidemic simulation. The layers interact with each other; epidemic progress is the major element of an individual's perceived threat, which affects their behaviour choices, and the adoption of protective behaviour affects the force of infection (through transmissibility) of the epidemic.

The simulation is to be developed in NetLogo, a specialist agent-based modelling application. This will enable model users to input communication plans and also to manipulate other parameters that are relevant for planning, such as the country to be considered and the recovery rate for the disease. The communication plan will be input to the model with a formalised language that captures key elements of message content, delivery channel, target group and timing (see section 3.1). The outputs of the model will report epidemic information (such as incidence and prevalence over time) and adoption rates of vaccination and other protective behaviour.

The connection and mutual influence of the communication, personal protective behaviour and epidemic progress is a substantial theoretical advance over existing models (see section 1.3). The key benefit of the TELL ME simulation is to assist health authorities to understand their complex decision making environment and stimulate a broad perspective.

However, data are not available to accurately parameterise the model (see section 5). That is, the model will not be sufficiently precise and accurate to directly compare potential communication plans. Nevertheless, it can also guide future data collection efforts, the structure is based on relevant psychological theories and the model parameters can be adjusted as more data becomes available.

The TELL ME model will be assessed against four broad types of tests (see section 6):

- Utility: Does the model meet the requirements of the project?
- Face or conceptual validity: Are the model design and results consistent with theory and plausible?
- Verification: Is the design appropriately translated into model code?
- Empirical or operational validity: Do the model results match available data?

Aspects of this validation are to be conducted by different groups, with multiple assessment where possible. The four groups are the modellers (principally for technical testing), TELL ME project partners, other subject matter experts and health professional focus groups. The other subject matter experts

include government and academic representatives with expertise in health communication, epidemiology management, risk behaviour and epidemic modelling.

At the time of writing (February 2014), model development is on track. Model construction has commenced, with a target completion date of 31 August 2014.

1 Introduction

The TELL ME project aims to develop an evidence-based communication package to respond to major epidemic outbreaks, notably flu pandemics. An agent-based model is to be developed as part of the project for use by agencies in assessing different communication plans.

This report sets out the model design, describing the major components of the model and the logical rules to be followed by the entities within the model. It incorporates the previously reported (D4.1) architecture and validation design elements. The specifications included in this report are not final. The design may change during model development. For example, the data needed to construct the model as envisaged may not be available. Therefore, this report should be interpreted as a statement of intent rather than a final description of the model.

The simulation software is expected to be available for testing by October 2014 (D4.4 and D4.5). The final prototype is due in January 2015 (D4.3 Prototype Software).

1.1 Role of the simulation model in TELL ME

In the event of an influenza outbreak, health agencies and other official bodies provide information about the progress of the epidemic and recommended actions to be undertaken by the public and particular groups who face greater risk. Recommended actions may include vaccination and protective behaviours such as washing hands and avoiding public places.

The TELL ME project is to assist health agencies to develop plans to communicate before, during and after any infectious disease outbreak in an effective way, so as to encourage appropriate population behaviour and minimise the impact of an epidemic. There are two major tools to be developed: a communication kit and an agent-based model to assist with plan design decisions.

The model is to provide decision support for health agencies (and other official information providers), assisting relevant officials to understand the complex problem of communicating effectively before, during and after an influenza epidemic. More specifically, it is to allow comparison of options for communication plans, with the user to enter a communication plan and explore some of the key effects on behaviour and consequently on the progress of the epidemic. To do this, the model must:

- allow input of key features of different communication plans;
- allow input of key features of the scenario or situation in which the communication plan is intended to be used;
- respond in moderately realistic ways to different communication plans; and
- provide output in a way that assists the user to understand the impact of the communication plan.

These four requirements shape the model design. The input and output comprise the interface and are discussed in section 3. The model uses rules to apply the input to a simulated population and thereby generate output concerning the effect of the communication given the context of the situation. These rules comprise the model logic and are discussed in section 4.

1.2 What question is the model to answer?

A single focus question is useful during a model design to guide selection of relevant characteristics and relationships to be included (or excluded) in the final model structure. This allows the model to represent the essential aspects of the real world without incorporating its full complexity. The relationships to be included in the TELL ME model are those relevant to the focus question:

- Given a specific communication plan, what proportion of the population is infected over the duration of the epidemic?

By specifying that the communication plan is an input, this question focusses the design requirements on the relationship between communication and total infected population, which provides for intermediate relationships with behaviour. The plan is not the only input, however, as the infected population will also rely on the specifics of the disease (such as infectious period) and population. It is implicit in the focus question that these other inputs are held constant for the comparison between plans.

This focus question supports a range of criteria and model outputs that facilitate comparison between competing communication plans. These criteria concern several associated questions that assist users to not only make decisions, but also to understand the model results:

- What proportion of general population and specific target groups adopt protective behaviour?
- Which features of communication are most important in achieving desirable population behaviour?
- What is the expected size of the epidemic and how is its impact distributed spatially and temporally?

1.3 Advancing modelling of behaviour during epidemics

The TELL ME project relies on the connection between protective behaviour and epidemic transmission. That is, personal voluntary decisions to be vaccinated or adopt hand hygiene and social distancing measures reduce the impact of an influenza outbreak. Without such a connection, there would be no value in communication encouraging such behaviour. However, these decisions are influenced by the person's situation, which includes proximity and other features of the epidemic. That is, there is interdependence and feedback between the personal behaviour and the epidemic. Further, the situation changes throughout an epidemic, so any model must be dynamic and allow behaviour to change over simulated time.

Since the focus of the model is the effect of communication, it must connect communication to behaviour. That connection should be consistent with both the relevant psychological theories and any empirical data. As people respond differently in the same situation, this condition also requires that the model includes substantial heterogeneity with respect to demographic characteristics but also individual responses within demographic groups. For example, the WP1 literature review found that men and women have different levels of vaccine acceptance, but also that only some people are willing to be vaccinated (TELL ME, 2012).

Together, these two broad conditions establish five minimum functional standards for the model design:

- Communication affects behaviour
- Behaviour is based on appropriate psychological models
- Heterogeneity of behaviour response and situational awareness
- Two-way dynamic influence of epidemic on behaviour and behaviour on epidemic
- Parameterisation with empirical data, where available

A recent review (Funk et al., 2010) identified 25 theoretical studies that considered the mutual influences of personal behaviour and epidemiology of infectious disease (the fourth standard above). Almost all the models reviewed were compartment models, which is the standard mathematical approach to modelling epidemics with differential equations. This approach creates nominal compartments for people of different epidemic status such as 'susceptible' or 'infected', and models the rates at which people move between compartments. Behaviour is added by increasing the number of compartments and adjusting rates (different approaches are classified in (Perra et al., 2011)). For example, the 'susceptible' may be split into 'susceptible, good hand hygiene' and 'susceptible, poor hand hygiene' and the rate of infection for the former would be lower than the latter.

However, these models are unable to deal with the heterogeneity requirements of TELL ME. Compartment divisions would be needed not just for behaviour choices, but also factors that contribute to behaviour such as different levels of perceived risk, geographic proximity to the outbreak, exposure to communication, and relevant demographic features. The most appropriate modelling methodology to allow all these factors to influence behaviour is agent based modelling (ABM - discussed at section 2.1).

The capacity to work with substantial heterogeneity has led to the use of ABMs in two areas of epidemic modelling in particular. The first of these is the simulation of epidemics over social networks (Keeling and Eames, 2005) that reflect specific patterns of contacts between people that allow infections to be transmitted. The second is the use of detailed population, transport and mobility datasets to model the geographic spread of infections and the potential effect of policy measures intended to reduce mobility, such as quarantines or school closure (Ajelli et al., 2010).

Other models deal with different subsets of the desired functionality for the TELL ME model. For example, informal communication is included in two models of the two-way dynamic influence of personal behaviour and epidemic transmission (Funk et al., 2009; Kiss et al., 2010) and there are several models that examine the impact of policy interventions using empirical data from the 2003 SARS outbreak (Bauch et al., 2005).

Of most relevance to the TELL ME project is a recent agent based model of facemask use during the 2003 SARS outbreak in Hong Kong (Durham and Casman, 2012). It at least partially meets three of the five functional standards. The authors present this model as the "first demonstration of a quantitative HBM [Health Belief Model] suitable for incorporation in agent-based epidemic simulation" (Durham and Casman, 2012), explicitly recognising its limitations but also the need to compromise realism to achieve model feasibility. Individual behaviour is modelled using the Health Belief Model (see section 4.2), calibrated with published data about facemask use during the outbreak (Lau et al., 2003). While there is heterogeneity of behaviour response, that arises from randomisation of the parameters for simulated individuals (around the calibrated average best fit parameters) rather than calibrating to different population groups. The modelled facemask adoption occurs in response to dynamic epidemic information about prevalence and deaths, but there is no influence of facemask use on the progress of the epidemic.

The proposed TELL ME model is ambitious, advancing modelling about health behaviour during influenza epidemics in several ways simultaneously. From the literature, it appears that there are no existing influenza models that attempt to comply with more than three of the functional standards and many comply with only one. By including communication and mutual influence, however abstractly, the TELL ME model will be a substantial second step to extend and generalise modelling of protective behaviour and epidemic progress.

2 Architecture

2.1 Agent-Based Modelling

The modelling technique to be used for the TELL ME project is agent-based modelling (ABM). ABM "is a computational method that enables a researcher to create, analyse, and experiment with models composed of agents that interact within an environment" (Abdou et al., 2012). There are several important elements in this description.

Firstly, the model is composed of autonomous and heterogeneous agents. That is, there are many simulated individuals with different properties and decision making rules. In TELL ME for example, properties include geographic location and access to media, and rules include epidemic prevalence at which the individual will seek vaccination.

Secondly, these agents interact within an environment. That is, the individuals are able to perceive the situation in which they find themselves, take that situation into account in their decisions and take actions that affect the environment. Continuing the example, the individuals are able to perceive the epidemic prevalence in their location and receive media reports, which allows them to check their 'seek vaccination' rule and assess whether the epidemic threshold has been met.

Finally, ABM is a computational method that simulates interactions over time. Simulations allow 'what if' questions to be tested quickly, cheaply and without the ethical problems of setting up experiments. Provided the key interactions are properly represented in the model, the simulation can explore the consequences of different actions. For TELL ME, different communication plans can be implemented as separate runs of the model and the responses of individuals and consequent impact on epidemic size and duration compared.

It is important to recognise, however, that the results of a simulation run will not be suitable for forecasting. For example, it would not be appropriate to claim that a particular communication plan would lead to 20% fewer infections. The model is a simplified representation of the key relationships that exist in the real world. That simplification is what makes the model useful – knowledge about the real world can be captured and its consequences can be understood - but the model will not be detailed enough to support specific claims. The model is a mediator "used primarily to establish the capability of the conceptual model to represent the system and to then gain some insight into the system's characteristics and behaviours" (Heath et al., 2009), so as to understand potential implications of different scenarios.

2.2 Model entities

There are three main types of TELL ME model objects for which interaction and behaviour rules are required:

- Messages, packaged as communication plans;
- Individuals, who receive the messages and exhibit behaviour that may include epidemic protective actions such as seeking vaccination or avoiding public places; and
- Regions, which hold information about the local progression of the epidemic.

As the communication plan will involve triggering messages in specific situations (see section 3.1), the Messages will need to recognise whether the trigger has occurred; such as checking whether prevalence levels exceed a given threshold. They will also need to communicate specific information to appropriate Individual agents.

Regions manage the epidemic modelling. Their properties include population density, including the proportion of the population in specific epidemic states such as 'infected'. They use the protective behaviour status of Individuals at their location to adjust the underlying infectivity rate. This rate is used to update the population proportions in each epidemic state in accordance with mathematical equations.

The model will include a few thousand Individuals, with randomly assigned demographic and psychological characteristics that reflect the heterogeneity of a country's population and consequent attitude ranges (where known). These characteristics will include the most important relevant to attitudes that were identified earlier in the TELL ME project , such as gender and 'high risk' health status perception (TELL ME, 2012).

There are four defining characteristics of agents in an ABM (Abdou et al., 2012):

- Perception: Agents can perceive their environment, including other agents in their vicinity.
- Performance: They have a set of behaviours that they are capable of performing such as moving, communicating with other agents, and interacting with the environment.
- Memory: Agents have a memory in which they record their previous states and actions.
- Policy: They have a set of rules, heuristics or strategies that determine, given their present situation and their history, what they should do next.

Individuals perceive the epidemic state of Regions for risk assessment, the content of Messages directed to them, and the attitude of other Individuals so as to monitor norms. They perform various behaviours in response to these perceptions and in accordance with their policy, most notably adopting or abandoning protective behaviour such as seeking vaccination. This also requires memory of their own state, including attitude values and whether they are performing particular behaviours.

2.3 Model software

The simulation is to be developed in NetLogo (Wilensky, 1999), a specialist ABM application with its own programming language. This will enable model users to input communication plans and also to manipulate other parameters that are relevant for planning such as the country to be considered and the infectivity of the disease.

A NetLogo model has three components. The 'Interface' component provides tools to allow the user to manipulate key model parameters and run the model, and reports of results including charts and other information to monitor the simulation during the run. The elements to be included in the interface are described at section 3. The 'Info' component is to allow accessible documentation to be packaged with the model. The 'Code' component sets out agent properties, interaction rules and data. That is, this provides the programming to implement the model logic as described in section 4.

As well as providing the structure and tools for building an agent-based model, NetLogo also provides tools for analysing the results of model simulations. For example, the BehaviorSpace tool provides scenario management capabilities, so that results from multiple simulation runs can be exported for analysis. These tools are not part of the model design, but will be described in the documentation provided with the prototype software.

3 Interface

As noted in section 1.1, the intended use of the model imposes three requirement on the interface. There are two broad types of input, the communication plan to be assessed and the situation in which that plan is intended to be used. Separately, the model output must provide information necessary to assess and compare communication plans, particularly the impact of the plan being assessed.

There are many elements that could be included in the input interface. These include:

- description of the messages that make up the proposed communication plan;
- coefficients for equations that represent the way in which communication influences behaviour change;
- epidemic characteristics such as infectivity and duration; and
- population characteristics such as distribution of attitudes about epidemic response behaviours, density, demographic structure.

If the model is to be accessible, only a small number of these can be available from the model interface. In order to meet these challenges, the interface will be divided into sections. The main interface will enable control of only the most important parameters and scenario settings. Other sections will provide for further detail but only be available by accessing separate interface screens.

The main assessment criteria for the competing communication plans is to be 'what proportion of the population is infected over the duration of the epidemic?'. Thus, epidemic impact is a key feature of the model output, including charts of prevalence over time and spatial maps. However, decision makers also require information that assists them to understand the key influences on that impact, so as to potentially design more focussed and effective options. Hence, the output will also include charts and summary data concerning protective behaviour, the direct effect of the communication.

3.1 Input: Communication plan

To allow the model to interpret a communication plan, or package of messages, a language is required to describe the messages. This section develops such a language and provides examples of potential communication plans using that language.

There are several ways in which communication can be understood and hence plans can be described. In his seminal paper, Lasswell (1948) asserts that communication can be described as the answers to five questions: who; says what; in which channel; to whom; and with what effect? A formal version of this transmission focussed framework comprises five elements: Sender, Message, Channel, Receiver, and Effect (Shannon and Weaver, 1949). While their concern was noise, or the ways in which the transmission could be disrupted, this model provides the basic elements necessary in describing the key elements in accessing an audience.

Modern understanding of communication is more nuanced, focussing on the meaning(s) and function of a message (Jakobson, 1960) or the role of communication in developing our social reality (Newcomb, 1953). These understandings recognise that the effect of messages will be subject to influencing factors such as tone, choice of spokespersons, terminology and timing; and that the context is important in how the recipient interprets any communication. Crafters of messages must select appropriate languages, ensure messages are consistent and culturally sensitive, and take account of many other details. This understanding recognises that the impact of communication depends on many contextual factors that influence how a message is encoded by the sender and decoded by the receiver (Hall, 1980).

Modern approaches have also moved away from the linear transmission model in other ways. For example, the Convergence Model of Communication (Rogers and Kincaid, 1981) recognised the importance of feedback cycles in effective communication processes. This approach suggests that the sender is able to add or modify the information according to the needs and responses of the audience. That is, the communications designer is able to receive direct input from the audience and translate it into an effective communication plan, in a back and forth iteration, slowly converging to a common ground.

For the purposes of the simulation, this nuanced understanding is neither feasible nor desirable. The simulation must describe the most basic elements of the messages constructed by health agencies and intended to encourage protective behaviour by individuals. While it is important to understand how individuals interpret messages, it is more fundamental to model whether they receive the message at all. The design of messages to most effectively communicate, and hence issues of meaning and interpretation, are to be addressed in the Communication Framework Model and Communication Kit developed elsewhere in the TELL ME project (WP3).

As well as the formal health agency communication, there is also communication over which health agencies has only limited control. For example, people may discuss the epidemic situation and attitudes about protective behaviour, sharing information (or misinformation) and influencing each other's attitudes. Social media also allows more distant private individuals to interact directly, providing individuals with access to information and attitudes outside of their specific location. In addition, concerned individuals may discuss protective behaviour with healthcare professionals. This communication forms part of the rules within the model, rather than the interface, and is described in the model logic (section 4.3).

3.1.1 Message language

A communications plan (or campaign) will involve one or more tactics. For example, a simple campaign may involve just a print advertisement. A more complex campaign may involve television advertising, celebrity endorsement at several public events and a print advertisement, each with complementary content. For the purposes of the model, the print advertisement, television advertising, and programme of events are each considered an individual message.

Messages that make up a communications plan each have several properties and each property has a specific value. In the example, each message was described by specifying the channel or delivery mechanism such as 'television' or 'endorsement'. 'Channel' is an example of a property or type of characteristic, providing categories of descriptors. In contrast, 'television' is a possible value for the property of 'channel'.

In describing a communications plan to the model, each message will need to be fully specified, with a particular value selected for each property. The objective for the set of properties is therefore to have the smallest possible number of properties (to limit the amount of description required) while including the detail required to apply the message to modelled entities. For each property, the set of values should be as small as possible (to minimise the number of rules) but include all the values that lead to different effects.

The key properties in the transmission oriented communication framework (Shannon and Weaver, 1949) are: Sender, Message, Channel, Receiver, and Effect. For the communications plans input to the model, the Sender is the health authority, or equivalent official source. As it does not change, the Sender does not need to be part of the language. The Effect is not within the control of the health agency and is included in the model rules rather than the language describing the communication.

The remaining three properties are included in the communication language, supplemented with properties necessary to coordinate the package of messages. These properties and the values they may take are presented at Table 1. They were initially developed based on discussions at a session of the TELL ME October 2013 WP3/WP4 communication workshop, and refined in accordance with comments on the draft language from TELL ME partners in November 2013. The table also describes the way in which the model rules interpret the value.

Table 1: Properties to describe messages in a communication plan and their possible values

Property	Value	Interpretation and logic impact
Content: Which aspects of the attitude and behaviour model are affected by message		
	Epidemic status	Provides information: affects trust and perceptions of prevalence
	Benefits	Explains why adopt behaviour in terms of benefit to self: affects attitude
	Norms	Emphasises that other people expect the person to adopt behaviour: affects perceived subjective norms
	Recommend	Those with high attitude and norms but low threat reassess behaviour as if threat is high
Behaviour: Which behaviour type is the subject of the message		
	Vaccination	The content affects only attitudes or perceived norms about vaccination
	Non-vaccination	The content affects only attitudes or perceived norms about non-vaccination measures such as appropriate hand hygiene or social distancing
	Both	The content affects attitudes or perceived norms about vaccination and other behaviour
Channel: Which simulated individuals receive the message		
	Mass media	Each person has specified probability of receiving message
	Social media	Each person who is assigned as accessing social media has specified probability of receiving message
	Events	Probability of receiving message depends on threat
	Health media	Healthcare professionals have high probability of receiving message
	Health profession	Probability of receiving message depends on attitude of local healthcare professionals, as they are providing communication
Target: Which simulated individuals consider the message to be relevant to them		
	All	All exposed to communication respond
	High risk	Affected only if have 'high risk' property randomly assigned
	Healthcare	Affected only if 'healthcare professional' property
	Infected	Affected only if currently infected
	Anti-vaccination	Affected only if negative attitude about vaccination
Trigger: When the message occurs during a simulation		
	Before	Message in place before the start of the simulation
	Infections: National	Message to all when cumulative infection reaches some specified proportion of the national population
	Infections: Local	Message when and where cumulative infection reaches some specified proportion of the local population
	First death	Message occurs immediately after first death
	Regular	Message at specified intervals (number of days)
	After	Message occurs when prevalence falls to some proportion of peak

The Message aspect of the formal communication framework has two component properties: Content and Behaviour. Together, these describe the message that is intended to be communicated. 'Content' refers to what the message is intended to communicate, such as persuasive information to encourage particular behaviour. 'Behaviour' identifies which type of behaviour is the subject of the message, vaccination or protective measures such as appropriate hand hygiene (or both). It is important to distinguish between these because a vaccine may not be available and, even if it is available, people who have safety concerns about vaccines can still be encouraged to adopt other behaviour. The model uses this information to determine the effect of the message on those who receive it and consider it relevant to them.

Channel in the communication framework is directly transferred as Channel in the simulation model. This is the delivery mechanism for the message, such as mass media (television, newspapers) or social media (Facebook, Twitter). The model uses this information to identify which simulated individuals are exposed to the message and the credibility of that message.

Receiver in the framework is translated as Target in the model. The health authority is not able to control who actually receives the message, but who they intend the message to reach. The model uses this information to identify whether a simulated person who is exposed to the message (via Channel) then responds to it. For example, a messaged targeted to high risk persons will have no effect on any person not flagged as high risk, even if they receive it.

The final component of the language concerns coordination of messages that occur at different phases of an epidemic to make up a communication plan. For example, a campaign may focus on facts and figures during the preparatory stage, emphasise hand hygiene and other protective behaviours when the infection is detected in the local population, and then recommend vaccination for high risk groups once a vaccine is available. The model steps through simulated time and must therefore be aware of when the individual messages are communicated. This timing is described by the Trigger property, which defines the type of event that initiates a message. In addition, some triggers allow additional parameters (not shown in the table) that further specify the timing. For example, one trigger is that a certain proportion of the population has been infect and the additional parameter for this situation is the particular proportion to be applied.

In a real world communications plan, it is not sufficient to describe a message simply as, for example, 'mass media campaign to recommend vaccination to at risk groups to be run once cumulative incidence reaches 2% of the population…'. Other details include the duration and frequency of the advertisements, choice of spokespersons, the need to be clear about who is at risk, content of the advertisement to be respectful and contextually sensitive, selection of appropriate languages, and many other details. The communication language for the simulation model will not include these implementation features. Instead, the logic rules assume that the message designer is sufficiently skilled and knowledgeable to develop appropriate messages with the assistance of the TELL ME communication kit as required.

3.1.2 Example plans

A communication plan is a set of messages. One way to think about different possible communication plans is to imagine different scenarios and develop a plan that is suitable for that particular situation. However, once generated, a plan will be able to be simulated in the model, regardless of the situation being modelled.

Two example plans are presented, specifying its component messages using the properties described at Table 1. For example, the first plan (Table 2) contains 12 messages that would be delivered to different target audiences during the epidemic. The numbering is for convenience only, and has no meaning.

Message 1 occurs 5 days before the epidemic reaches the country being modelled, and uses mass media to recommend that high risk individuals adopt protective behaviour such as hand hygiene or social distancing. Message 10 puts in place social media messages every 3 days that provide information about the epidemic.

Table 2: Example high activity plan

Message	Target	Channel	Content	Behaviour	Trigger and parameter	
1	High risk	Mass media	Recommend	Other	Before	-5 days
2	High risk	Social media	Recommend	Other	Before	-5 days
3	Healthcare	Health media	Benefits	Other	Before	-5 days
4	All	Mass media	Epidemic Status	Other	First Death	-
5	All	Mass media	Benefits	Other	First Death	-
6	All	Mass media	Benefits	Other	Infections	National 1%
7	All	Events	Benefits	Other	Infections	Local 5%
8	All	Social media	Norms	Other	Infections	Local 2%
9	All	Mass media	Epidemic Status	Other	Regular	3 days
10	All	Social media	Epidemic Status	Other	Regular	3 days
11	All	Mass media	Benefits	Other	After	50%
12	High Risk	Health prof	Recommend	Other	After	50%

The first example plan (Table 2) is potentially appropriate for a worst case situation, where symptoms are severe and there is no vaccine. It involves extensive communications activity, focussing on non-vaccination behaviours. The second example plan (Table 3) is more suitable for an outbreak with milder symptoms, where the main concern is the impact on those people with existing poor health.

Table 3: Example low activity plan

Message	Target	Channel	Content	Behaviour	Trigger and parameter	
1	High risk	Mass media	Recommend	Both	Before	-5 days
2	High risk	Social media	Recommend	Both	Before	-5 days
3	Healthcare	Health media	Benefits	Both	Before	-5 days
4	All	Mass media	Epidemic Status	Both	Regular	3 days
5	Infected	Health prof	Benefits	Other	Before	0 days
6	High Risk	Health prof	Recommend	Other	After	50%

3.1.3 Responses to emerging problems

There are many problems that may occur during an epidemic that influence people's attitudes about protective behaviours. Communication plans may also include elements to respond to such problems if they emerge.

Separately, the model will also allow the input of some unplanned events as part of the scenario to which the communication plan is intended to respond. The model user will be able to indicate whether or not the health agency responds to the event (to allow comparison) but not the form of that response. These events and their implications for the model include:

- Rumour: lowers trust in health messages for those exposed to the rumour. Exposure is higher for those with access to social media. Health agency response restores trust, shortens the duration of the effect.
- Vaccine problems such as access difficulties or side effects: decrease in attitude scores for vaccination and lowers trust. Health agency response restores trust (for example, by explaining how the problem arose and has been corrected), shortening the duration of the effect and the size of trust impact.

- False alarm: prior expected epidemics did not occur. Initial attitudes are decreased and severity is discounted in the threat perception. Health agency response corrects the threat perception.
- Initial alarm or complacency: information not available at the beginning of the epidemic. Fixed severity and prevalence information are initially used for the threat perception component of the behaviour model. After the initial period, if the actual values are not similar, trust in messages is decreased and overcorrection in attitude (after alarm) or threat perception (after complacency). Health agency response reduces the size of the effect at the end of the initial period.

3.2 Input: Epidemic situation

As well as the communication plan to be assessed, the model inputs will include details of the situation in which the plan is to be delivered. This includes key characteristics of the population potentially affected by the hypothetical epidemic and details about the infection itself.

At the region level, the model will run a standard fixed population spatial mathematical model, with compartments for susceptible, infected and recovered subpopulations (Bailey, 1975; May and Anderson, 1984). The required parameters are: population, force of infection (or similar combination of contact rate and probability of transmission given contact), recovery rate, and movement rates between spatially distinct subpopulations. The interface will allow selection of a country, which will then retrieve GIS population density data to create the population by region. The other parameters will be directly controlled by the interface and will be identical for all regions. That is, the model will not allow the epidemic parameters to be different for different regions within the country.

There are several other parameters to be available in the input interface that concern the context in which the communication plan is to be assessed. The severity of the epidemic will be operationalised as the case fatality rate. As one of the potential behaviours to be adopted is vaccination, key vaccine features will also be included in the inputs including when it is available and for which populations groups – such as healthcare workers or everyone. For both vaccination and non-pharmaceutical protective behaviours, the efficacy of the behaviour will also be accessible with the input interface.

Default values will be provided for these inputs so that the user only needs to change particular parameters of interest. These default values will be chosen based on best evidence, for specific countries where available and appropriate.

3.3 Output: Simulation results

There are two types of results to be provided by the model output: adoption of protective behaviour and epidemic progress. Further, the output is to be provided in several ways: a map to display spatial information, plots of time series, and reporting of specific numbers.

The map output will be updated during the simulation and, at any point of simulated time, will provide broad information about the epidemic status of regions and protective behaviour adopted by simulated people within each region. The map in initial versions of the model will look similar to Figure 1 but may be revised following user testing of the model. In this initial version, coloured squares are used to indicate epidemic progress (red for 'active', blue for 'not yet reached' and green for 'post epidemic') with a circle to indicate whether the majority of simulated people in the region have (purple) or have not (white) adopted protective behaviour.

Plots will provide key information over the entire period of the simulation. Plotted information about behaviour will include the proportion of the population who have adopted each protective behaviour:

vaccination and non-pharmaceutical measures, and also the range of values for this proportion across regions. Epidemic plots will provide the proportion of the simulated population who are susceptible, infected, immune or dead.

Figure 1: Example map (of United Kingdom), displaying regional information about epidemic status and adoption of protective behaviour.

Specific numbers will also be reported on the interface. Behaviour results will include vaccination rates and maximum adoption of non-pharmaceutical protective measures. Epidemic results will include peak incidence and prevalence, and when these peaks occur, as well as the total proportion of the population ever infected.

4 Model logic

The model logic connects the inputs to the outputs, establishing moderately realistic rules that describe the way that the model is to respond to different communication plans and epidemic situations. The relationships that are to be included are those relevant to the focus question of 'Given a specific communication plan, what proportion of the population is infected over the duration of the epidemic?'. The relationships that must therefore be captured in the model logic are the effect of packages of communications on people's behaviour in the presence of an epidemic, and the consequent effect on the spread of a disease. The structure of these relationships are included in the model as rules and are calibrated using data where possible.

These rules are formulated with equations or logical if-then statements, connecting situations to agent actions, and encoding the influences between properties and decisions of different types of agents. For the TELL ME model, rules are required for many aspects of message reception, attitude change, behaviour and disease transmission. For example, these rules describe the way that communication messages are interpreted by individuals and change their behaviour, which in turn impacts on infectivity and disease spread in the region where those people 'live'. Developing and describing these rules is the primary objective for the model design.

The rules have been developed from information contained in the reports of WP1 and WP2, specific additional literature analyses, and a stakeholder communication process involving experienced epidemic response managers and other key personnel. They are not intended to fully capture the complexity and subtlety of the ways in which people respond to communication and make decisions. Instead, the rules rely on available model variables to operationalise abstractions of key effects.

4.1 Broad model logic

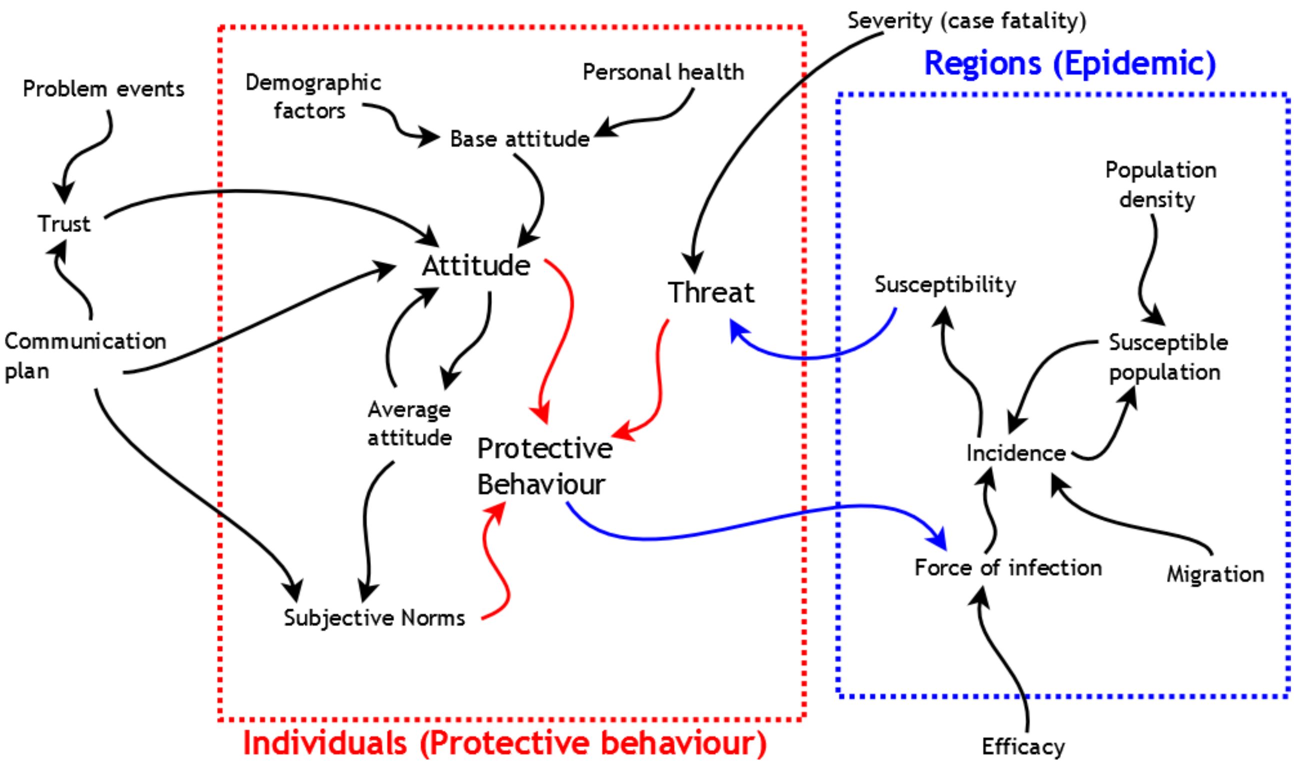
The broad model logic is at Figure 2. The key entities within the model are communication plans, individuals and regions. The text describes major properties of these entities and are grouped by entity. The arrows identify the pattern of influences between properties of entities. For example, the protective behaviour adopted by individuals affects the regions' infectivity rates used in the epidemic model. The arrows in this logic diagram therefore indicate the main interactions for which rules will be required.

The major flow of influence is the effect that communication has on attitude and hence behaviour, which affects epidemic transmission and hence prevalence. Prevalence contributes to perceived risk, which also influences behaviour, establishing a feedback relationship. In addition, there are several secondary relationships that are not on this major flow, but add complexity to the system behaviour. For example, widespread adoption of visible individual behaviour (such as wearing facemasks) increases the social pressure to adopt such behaviour. Another example is changes in attitudes arising from informal communication between friends.

The operation of these relationships will depend on specific characteristics of the simulated individual and their situation. For example, an individual's perceived risk is influenced by the epidemic prevalence in their location, rather than simply the national prevalence, as well as their own demographic characteristics. Individuals will also have access to different information affected by, for example, whether they use social media. Those information differences also contribute to different behaviour.

Agent-based modelling allows for differences in individual characteristics and recognises situations within the modelling software. The model logic rules therefore focus on translating such information into actions and behaviours by the model entities.

Figure 2: Broad model logic.



4.2 Simulating the protective behaviour of individuals

There are several well established models from psychology that predict (or explain) behaviour and change in behaviour on the basis of other variables such as attitude or perceived risk. Three of these are particularly important. The Theory of Planned Behaviour is the dominant general purpose behaviour model in psychology. The Health Belief Model and Protection Motivation Theory are also popular in the health behaviour literature.

There is no agreement on which of these psychological models is most suitable for any specific type of behaviour, and there is insufficient detail about parameters that may be appropriate for epidemic influenza. Thus, they cannot be directly adapted to determine protective behaviour for simulated individuals in the TELL ME model.

Nevertheless, they provide guidance on the factors that should be included in the simulation model. Some of the explanatory factors are shared, and there have been attempts to develop a theory that combines the strengths of each. While the combined theory has not been generally adopted in psychology, it provides the most suitable framework for individual behaviour in the TELL ME model because it incorporates the explanatory factors that change during an epidemic.

4.2.1 Theory of Planned Behaviour

The Theory of Planned Behaviour is the dominant psychological model about the influences on behaviour. It is an extension of the earlier Theory of Reasoned Action, which asserts that intention is the best predictor of behaviour, and that intention is predicted by three factors (Fishbein, 1995). According to this theory, intention is increased in the presence of:

- attitude: favourable evaluation about the specific behaviour;

- subjective norms: perceived social pressure to perform the behaviour, or approval from other people; and
- behavioural control: perceived ease of undertaking the behaviour.

The Theory of Planned Behaviour extends this understanding of behaviour by including perceived behavioural with intention as the predictors of behaviour, in addition to its role in predicting intention (Ajzen, 1991). This extension was introduced to recognise that many factors can interfere with intended behaviour, and that perceived control is one way to estimate the likely impact of these factors.

The model does not simply identify the important contributing factors but also proscribes the way they are combined. In particular, intention is a linear combination (weighted sum) of attitude, norms and control. If behaviour can be measured numerically (for example, amount of weight lost) rather than simply as whether the behaviour occurred, it should also be conceptualised as a linear combination of its inputs, intention and control.

However, the parameters associated with each explanatory variable depend on both the behaviour to be predicted and the situation (Ajzen, 1991). Also, predictive power varies considerably, with a major review of 185 empirical studies finding that, on average, 27% of the variation in behaviour is explained by the proposed explanatory variables (Armitage and Conner, 2001). Thus, only the structure can be adapted for the TELL ME model, and there is limited guidance on the actual numbers to use to use in potential rules to control behaviour.

4.2.2 Health Belief Model

For preventative health behaviour, an important alternative is the Health Belief Model (Rosenstock, 1974). This asserts that behaviour arises from two dimensions that motivate action - susceptibility and severity - and two that determine the action to be taken - benefits and barriers. There is also some underlying ‘cue to action’ or trigger (such as symptoms or exposure to media) to stimulate the need for a decision at all.

There is some evidence that the model has only limited predictive power (Janz and Becker, 1984). This is at least partly because the model is primarily descriptive; there are no standards about how to measure each of the four input factors, how to combine them into a prediction of behaviour, and only limited research about the triggers. Two reviews focussed specifically on this issue (Harrison et al., 1992; Carpenter, 2010) found that published studies do not support the use of HBM as a predictive model.

4.2.3 Protection Motivation Theory

Protection Motivation Theory (Maddux and Rogers, 1983) and related theories such as the Extended Parallel Process Model (Witte, 1992) focus on the role of threat in explaining preventative health behaviour. They argue that fear motivates intent, but behaviour only occurs if there is an effective remedy available. If threat is high but capacity to cope low, Protection Motivation Theory suggests that denial or other maladaptive behaviour will occur instead.

There are six explanatory variables constructed as two groups of three variables, appraising threat and coping strategy respectively. The likelihood of behaviour is a linear combination of these variables and increases in the presence of:

- vulnerability: perceived likelihood that the threat personally applies;
- severity: perceived seriousness of consequences of the threat;
- fear arousal: level of worry about the threat; and
- response efficacy: belief that the recommended behaviour will effectively deal with the threat;

- self-efficacy: perceived ease of undertaking the behaviour; and
- absence of costs or barriers that interfere with undertaking the behaviour.

There is empirical support that the framework is useful in explaining existing ongoing behaviour, but less support for its use in predicting future behaviour (Milne et al., 2000). In particular, the threat appraisal elements are only weakly predictive, but this could be partly due to difficulties in varying perceived severity.

4.2.4 Combining psychological theories

The different emphases of these theories reflects the variety of human behaviours. As a general purpose framework, the Theory of Planned Behaviour is expected to apply to leisure activities such as playing video games, effort and capacity driven behaviour such as getting a high grade in a university subject, as well as health related behaviour such as weight loss (Ajzen, 1991). In contrast, the other two theories focus on health specific factors such as severity. In an environment of several competing theories about behaviour, it is difficult for policy makers to identify how best to encourage desirable health behaviours.

In a 1992 workshop sponsored by the (US) National Institute of Mental Health, leading supporters of different theories discussed the overlap and reached consensus on eight important factors that explain variations in behaviour (Fishbein, 1995). Of these, one is the intention to perform the behaviour, two concern capacity to act on the intention, and the remaining five concern the strength and direction of the intention.

This consensus provides a framework within which to understand behaviour rather than a replacement model. For the purpose of operationalising behaviour in a simulation model, the consensus recognition that some of the explanatory factors included in separate models are essentially the same factor is particularly relevant. For example, the attitude measure from the Theory of Planned Behaviour is very similar to the combination of benefits and barriers from the Health Belief Model. While Protection Motivation Theory was not included in this reconciliation, it overlaps substantially with the Health Belief Model with, for example, threat appraisal adding only the emotional aspect of worry to the motivation factors of severity and susceptibility.

Instead of combining the strengths of each theory, another approach is to select a single theory based on its superior performance for the specific behaviour of interest. At least three studies (Oliver and Berger, 1979; Zijtregtop et al., 2009; Myers and Goodwin, 2011) have tested influences from both the Theory of Planned Behaviour and the Health Belief Model for predicting vaccination against an influenza epidemic, although they used different questions to measure those variables. These three studies consistently found that elements of more than one framework are important in vaccination intentions. All found that attitude and subjective norms from Theory of Planned Behaviour variables are important predictors and that predictive power increased with the addition of variables from the Health Belief Model. However, the particular additional variables differed between studies, with severity, susceptibility, and perceived vaccine efficacy each found important in two of the studies. This provides further support that a hybrid model is most appropriate for the TELL ME simulation.

Systematic reviews of psychological factors associated with vaccination against epidemic influenza using the framework of Protection Motivation Theory (Bish et al., 2011; TELL ME, 2012) found similar results. They identified the threat appraisal variables of susceptibility, severity and, to a lesser extent, worry, to be supported by evidence as associated with vaccination. For coping appraisal, the variables of efficacy, vaccine safety (including religious prohibition implications), trust in government or healthcare professional advice, and social norms were all found to significant factors.

There are fewer studies about the psychological factors that are associated with non-vaccination behaviour to protect against epidemic influenza, such as hand hygiene or wearing facemasks. However, systematic reviews (Bish and Michie, 2010; TELL ME, 2012) reported similar sets of relevant factors as for vaccination, also within the framework of Protection Motivation Theory.

4.2.5 Operationalising individual behaviour

The variables that must be included in the TELL ME model to simulate individual behaviour are not simply those that contribute to the behaviour, they must also change over time. Those that are important in predicting behaviour at any specific point in time but are fixed have a constant effect on the predicted behaviour and can be excluded. There are three processes that create change, communication and the progress of the epidemic.

There are three explanatory variables from the hybrid psychological theory that are to be included in the TELL ME model rules about individuals adopting protective behaviour:

- attitude: susceptible to change from communication (with messages such as 'vaccination protects your family'), the attitude variable is intended to cover the expected benefits of the behaviour and barriers to its adoption;
- subjective norms: susceptible to change from communication (with messages such as 'your family expects you to vaccinate') and visible changes in behaviour as the epidemic progresses, the norms variable is intended to cover the expectations of others to adopt the behaviour;
- threat perception: susceptible to change as the epidemic progresses, threat is intended to cover both susceptibility and severity.

In addition, trust will be included in as one of the inputs to attitude rather than directly to behaviour. This is susceptible to change from failures in communication or unexpected events, and is intended to cover willingness to be persuaded by health authority communication.

The same model structure will be used for vaccination and non-vaccination protective behaviour. However, there will be separate model processes for each, with the parameters calibrated for the specific type of behaviour. Separating the behaviours further or specifying detailed subpopulations would make the model more complicated, harder to understand, and require substantial information about differences between these behaviours within the same population and between subpopulations.

The choice of how to combine the explanatory variables and make the behaviour decisions (for example, weighted sum or logistic) will be made during calibration based on the available data. Regardless of this choice, three additional parameters will be required for the thresholds at which a simulated person seeks vaccination (B^V), adopts (B^+) or ceases (B^-) non-vaccination protective behaviour.

4.3 Simulating the inputs to individual behaviour

Individuals adopt behaviour based on their own situation, personal experience, and beliefs. The individual is more likely to adopt the behaviour if their attitude value is high, perception of norms is high and threat is high. Threat is a combination of disease severity and local prevalence. Each of these influences responds to changes in the simulated individual's situation, such as receiving communication or progress of the epidemic. Further, the impact of communication is moderated by the level of trust in the course of that communication. Rules are required to model the impact of those situational changes.

The communication aspects of the model will operate on simulated individuals. These individuals will be differentiated with respect to health status ('high risk' yes or no) and whether they are a healthcare professional. These simplifications capture the key aspects of demographic and health characteristics that are associated with different influenza related behaviours in the population.

4.3.1 Operationalising attitude

An individual's attitude is affected by many factors, including health status, culture, their understanding of the real or perceived risks and the degree of trust they have in the authors of relevant messages. Much of the literature about attitude change examines how the communicated message is processed and consequent implications for how messages should be designed to maximise attitude change (Bohner and Dickel, 2011). However, this does not provide the necessary theoretical background to simulate the amount of changed induced by any specific message. In the absence of specific theoretical guidance about effect size, the model logic rules are based on the Social Judgement / Involvement Theory.

Social Judgement / Involvement Theory (Sherif et al., 1965) asserts that the impact of communication depends on two key factors, the position of the communication and the latitude of acceptance for the receiver. Conceptually, attitudinal positions have a value over some range. Both the person receiving the message and the message itself have positions. The attitude of the person receiving the message changes toward the position of the message, but only if the message has a sufficiently similar position to not simply be rejected. The latitude of acceptance refers to the range of positions that are considered and integrated into the receiver's updated attitude.

For example, consider a situation where the person has an original attitude position of 0.5 (within the range 0 to 1) and latitude of acceptance of 0.3. This indicates that they are completely undecided but an extreme message (with position <0.2 or >0.8) will have no effect. A message with a position of 0.7 will result in the person's attitude shifting to a more positive value somewhere between 0.5 and 0.7. However, a message with a position of 0.9 will not induce attitude change. In the vaccination context, a 0.7 message might be similar to 'vaccination is an effective way to protect you and your family, but we recognise that some people have concerns so you should talk to your doctor if you are unsure' and a 0.9 message might be similar to 'people opposing vaccination are ignorant and irresponsible, get vaccinated'.

For messages within the latitude of acceptance, the amount of change induced is proportional to the discrepancy between the person's existing attitude position and the position of the message. Thus, a greater difference in position will result in more change. In addition to the evidence directly supporting Social Judgement / Involvement Theory, there is empirical support for change in attitude proportional to discrepancy (Anderson, 1971; Danes et al., 1978).

Without some method for excluding highly discrepant messages, the proportional change in attitude would lead to all individuals adopting the same position if it was repeated enough, with those initially strongly different adjusting their attitude fairly quickly. This is clearly inconsistent with the experience in vaccination, where people have a range of attitudes (TELL ME, 2012). However, there is no agreement on how to exclude or discount these messages, despite specific comparison studies (Laroche, 1977; Fink et al., 1983; Kaplowitz et al., 1991). Hence, the relatively simple latitude of acceptance will be used in the simulation model.

Simulated individuals within the model will be assigned two initial attitudes as values between 0 and 1, representing attitude toward vaccination and toward non-vaccination protective measures, which includes hand hygiene or social distancing. The initial attitudes will be based on survey information about willingness to adopt protective behaviour within relevant subpopulations.

Attitude scores will change in response to messages included in the input communication plan with a Content value of 'Benefits' (see Table 1), particularly if the individual trusts the source of the message. If attitude prior to communication is sufficiently close to full acceptance (that is, the message is treated as having an attitudinal position of 1), then attitude score will increase. The amount of change is affected by trust.

In addition to the attitude change induced by the formal communication plan of the relevant health authority, the model will also include attitude change arising from informal communication, such as discussion with friends or exposure to media. The same mathematical approach will be used, with different parameter values for position of message, trust and constant of proportionality.

The change in attitude is given by:

$$A = \begin{cases} A_0 + \tau\alpha\left(A_m - A_0\right) & A_0 \geq 1-\theta \\ A_0 & A_0 < 1-\theta \end{cases} \tag{1}$$

with: A_0 for prior attitude
A_m for attitude position of message
A for post communication attitude
τ for trust in message source, including message quality effects
α for constant of proportionality, depends on message source
θ for latitude of acceptance
τ, α and θ are adjustable

For formal communication plan messages encouraging protective behaviour (Content value of 'Benefits'), attitude position will be set to 1. For informal communication, attitude position will be randomly drawn from the attitude distribution for the entire simulated population.

Communication plan messages will have no impact for those individuals already strongly opposed to the behaviour, unless specifically targeted (message has Target value of 'Anti-vaccination' from see Table 1). These messages will be modelled as if they have a moderate attitude position.

4.3.2 Operationalising trust

Each individual will have trust values for the various channels in the communication plan, and also for informal channels (such as friends, or social media). For formal communication, messages that provide information (Content value of 'Epidemic status') will increase trust. However, trust can be damaged by events included as part of the scenario (see section 3.1.3).

4.3.3 Operationalising subjective norms

Subjective norms describe how a person believes family, friends and other personally important people expect them to behave and the extent to which they feel compelled to conform. The norm will be operationalised as the average attitude of individuals in the same geographic location, together with some contribution from average attitude in other locations. If there is a message in the communication plan that emphasises norms (Content value of 'Norms'), then perceived norms will be higher than the weighted average of actual attitudes.

Perceived subjective norms is given by:

$$N = \begin{cases} \omega A_k + (1-\omega) A_{i \neq k} + \sigma & \text{if norms message} \\ \omega A_k + (1-\omega) A_{i \neq k} & \text{if not norms message} \end{cases} \quad (2)$$

with: N for perceived norm
A_k for average attitude in region k (where individual located)
$A_{i \neq k}$ for average attitude in other regions
ω for weight given to own region
σ for message impact
ω and σ are adjustable

4.3.4 Operationalising threat

Perceived threat will reflect both susceptibility and severity, with an adjustment intended to capture relative anxiety (that is, some people naturally worry more than others). Severity will be modelled from the case fatality rate and will therefore change as the epidemic progresses. However, early deaths and deaths that are geographically close will be given additional weight.

Following the method of (Durham and Casman, 2012), susceptibility will be modelled with a discounted cumulative incidence time series. That is, perceived susceptibility will increase as the epidemic spreads but recent new cases will impact more strongly than older cases. This approach also allows perceived susceptibility to increase but then gradually fade away after the peak has passed. Explicit modelling of the epidemic in the TELL ME model will allow geographical information to modify perceived susceptibility rather than rely entirely on national cumulative incidence. That is, susceptibility will be higher for the simulated individuals that are close to the new cases than for those further away.

Perceived risk is given by:

$$\begin{aligned} s_t &= \delta s_{t-1} + c_{t-1} \\ T_t &= r\sqrt{m\left(g s_{tk} + (1-g) s_t\right)} \end{aligned} \quad (3)$$

with: T_t for perceived threat at time t
s_t for susceptibility at time t
c_t for cases (incidence) at time t
δ for discount that applies to prior incidence
m for mortality rate over all prior cases
g for weight given to own location
r for relative worry (normal, centred on 1)
m, δ and g are adjustable

4.4 Simulating epidemic progress

In contrast to protective behaviour, which is simulated for individuals, the epidemic is modelled at the level of regions. A spatially explicit version of a standard epidemiological model will be used that mathematically estimates the number of people transitioning between different epidemic states. The epidemic progress influences behaviour (through risk perception as described in section 4.3.4). Individual behaviour influences epidemic progress through the parameter for force of infection. Thus, there is mutual interaction between the decisions taken by individuals and the epidemic.

4.4.1 Regional SEIR model

In the simplest mathematical models, people start in the susceptible (S) state, become infected and simultaneously infectious (I) and are eventually removed from calculations (R) because they either recover and become immune or they die. As influenza can involve a significant incubation period during which a person is exposed (E) but not yet infectious, the SEIR compartment model is more appropriate.

Assuming those who have recovered from the infection are fully immune, the SEIR model (ignoring the relatively slow processes of births and deaths from non-epidemic causes) is given by the following set of differential equations (Diekmann and Heesterbeek, 2000):

$$\begin{aligned} \frac{dS}{dt} &= -\beta SI \\ \frac{dE}{dt} &= \beta SI - \lambda E \\ \frac{dI}{dt} &= \lambda E - \gamma R \\ \frac{dI}{dt} &= \gamma R \end{aligned} \tag{4}$$

with: S, E, I and R for the proportion of the population in each epidemic state
β for force of infection (transmission probability and number of contacts)
λ for transition rate from E to I (so average duration of exposure period is $1/\lambda$)
γ for transition rate from I to R (so average duration of infectious period is $1/\gamma$)
β, λ and γ are adjustable

The difference equations form of these equations will be applied within each geographic region of the TELL ME simulation to calculate the number of people in each epidemic state over time. Inter-region migration (or proportion of contacts in other regions) influences the location of new infections. In the absence of such migration, the epidemic is unable to spread between spatial regions.

Simulated individuals will be 'infected' with probability equal to the exposure rate in their specific region. While the epidemic status has no effect on simulated behaviour for individuals, applying the epidemic equations allows the simulation to report behaviour by epidemic status.

4.4.2 Influence of protective behaviour

The effect on the epidemic of the simulated individuals adopting protective behaviour is applied by reducing the force of infection (β in equation (4)) to take the protective behaviour into account. The proportion of the individuals in the relevant region who had adopted protective behaviour and the efficacy of that behaviour are applied with:

$$\beta_k = \beta B_k (1 - e) \tag{5}$$

with: β_k for force of infection operating in region k
β for underlying force of infection for epidemic
B_k for proportion of individuals in region k who have adopted behaviour B
e for efficacy of behaviour B
e is adjustable

There will also be provision in the interface to allow general protective policies to be implemented such as school closures. These will be modelled by adjusting the underlying force of infection in accordance with the (input) stated efficacy of the policy.

5 Data Sources and Calibration

The model must be calibrated by adjusting model parameters so that the simulated behaviour is realistic. For many parameters, data is available about that specific parameter. Where the parameter is adjustable by the model user, the value based on data will be used as the default setting. However, there are also many parameters for which data is not directly available for calibration. In such a situation, the parameter will be calibrated by running the model with different values and selecting the value that generates the most reasonable behaviour.

In order to calibrate the model, data is required in three broad categories:

- Population density and demographic structure, particularly the proportion of the population in high risk or other target groups;
- Attitudes toward vaccination and specific protective actions in response to influenza risk; and
- Historical data concerning protective behaviour during past epidemics.

The calibration process will also include sensitivity testing. This testing will identify the model parameters that have the most influence on the simulation results and hence require the greatest accuracy in setting their values.

5.1 Calibration

The model design includes a substantial number of parameters that must be set to values to reflect the real world relationships that the model rules are intended to simulate. This includes all the values in the equations in section 4 that are referred to as 'adjustable'. In addition, appropriate values must be set for population structure and some of the parameters concerning communication effect. The parameters for which values must be assigned are listed at Table 4, together with information about how the default values are expected to be derived (source) and whether the value will be accessible through the user interface.

Population information is available from official datasets published by governments, accessible from GIS data stores such as SEDAC (at http://sedac.ciesin.columbia.edu/). Attitude and trust information (including attitude for key subpopulations) has been summarised in the literature review conducted as part of WP1 (TELL ME, 2012). Some parameters are set to specific variables because of the way the model rules are designed and no setting is required.

The parameters for the epidemic progress elements of the model are part of the input scenario that provide the context within which communication plans are to be assessed. Thus, their values reflect the particular scenario (such as high mortality but low probability of transmission). Nevertheless, default values will be provided for the model that provide some guidance on appropriate input values. These default values will be based on published literature estimating the values for past influenza epidemics such as SARS (Riley, 2003).

The parameters for the effect of communication and factors contributing to protective behaviour are more difficult. Some studies that provide impact of communication campaigns (Rubin et al., 2010), and data may also be available from health authorities who have conducted (and evaluated) influenza campaigns. Ultimately, however, the required data does not exist in the detail required as there are few studies, they measure different attitudes and behaviours, and only summary data are available for some. The most appropriate approach is therefore to vary the parameters over reasonable ranges and compare the model output to the limited data that report epidemic progress, attitudes and behaviour over time. These data sources are summarised at Table 5.

Table 4: Model parameters and sources for setting values

Parameter	Symbol	Source	Number	Interface
Population density		Official	Subnational	No
Subpopulation proportions		Official	National	No
Initial attitude	A_0	WP1	2 (behaviour)	No
Initial trust	τ	WP1 + Literature	7 (channel)	Advanced
Message attitude position	A_m	Model	0	No
Attitude impact proportionality	α	Calibration	7 (channel)	Advanced
Attitude latitude of acceptance	θ	Expert	2 (behaviour)	Basic
Trust increase with information		Expert	1	Advanced
Impact of problems		Expert	9	Advanced
Norms weighting for own region	ω	Expert	2 (behaviour)	Advanced
Norms impact of specific message	σ	Expert	2 (behaviour)	Basic
Susceptibility, incidence	C_{t-1}	Model	1	No
Susceptibility discount	δ	Calibration	1	Advanced
Expected mortality (case fatality)	m	Literature	1	Basic
Susceptibility weighting location	g	Expert	1	Advanced
Relative worry	r	WP1	1	No
Individual behaviour input weights		Calibration	3	Advanced
Individual behaviour thresholds	B^V B^+ B^-	Calibration	3	Advanced
Epidemic: force of infection	β	Literature	1	Basic
Epidemic: transition rate E to I	λ	Literature	1	Basic
Epidemic: transition rate I to R	γ	Literature	1	Basic
Behaviour efficacy	e	Literature	2 (behaviour)	Basic
Policy efficacy		Arbitrary	1	Basic

Table 5: Time series with epidemic and protective behaviour information

Reference	Country	Infection	Attitude / Behaviour
(Blendon et al., 2004)	Canada, USA	SARS	Hygiene, distancing, facemask
(Cowling et al., 2010)	Hong Kong	H1N1	Hygiene, distancing, facemask
(Ferrante et al., 2011)	Italy	H1N1	Vaccination, distancing
(Lau et al., 2003)	Hong Kong	SARS	Hygiene, distancing, facemask
(Lau et al., 2010)	Hong Kong	H5N1	Hygiene, distancing, quarantine
(Rubin et al., 2010)	United Kingdom	H1N1	Vaccination
(Weerd et al., 2011)	The Netherlands	H1N1	Vaccination, non-vaccination

The values for the parameters that influence individual protective behaviour are likely to differ between behaviours and cultures (or countries) and infections. Thus, the available data are clearly inadequate to parameterise the simulation. However, the facility to adjust parameter values will enable model users to use their judgement to correct parameters as required to, for example, assume the population in their country is more (or less) influenced by social norms than indicated by the model. An additional confounding issue is that the datasets that are available include the effects of communication and the epidemic data include the effects of adopted protective behaviour. Thus, the underlying parameters will be difficult to extract.

Finally, there are several less important parameters for which no information is available and varying them would lead to too many parameters in the calibration against the small number of time series datasets. Default values for these will be set based on discussion with expert stakeholders.

5.2 Sensitivity analysis

Sensitivity analysis will be conducted during calibration to understand the implications of the data scarcity. Sensitivity analysis varies the value of parameters over their plausible ranges and examines the effect on model results.

There are too many parameters in the TELL ME model to assess all the combinations of plausible values. Thus, the sensitivity analysis will have two broad sets of experiments. The first set will vary only one value at a time, holding all other parameters at their defaults. This will be run for all parameters separately. The second set will vary several of the key parameters (particularly those associated with attitude and behaviour change) to assess the interaction effect of these parameters.

The results of the sensitivity analysis will be included in the technical documentation released with the model. This will provide guidance on which parameters are the highest priority for further research (such as specific data collection during future epidemics). In addition, the sensitive parameters will be highlighted in the user guide.

6 Participation and Validation

There is no general approach that can be applied for model validation because what is appropriate depends fundamentally on the purpose of the model (Hodges and Dewar, 1992; Moss, 2007). The TELL ME model will be assessed against four broad types of tests:

- Utility: Does the model meet the requirements of the project?
- Face (Klügl, 2008) or conceptual (Heath et al., 2009; Sargent, 2010) validity: Are the model design and results consistent with theory and are they plausible?
- Verification (Gilbert, 2008): Is the design appropriately translated into model code?
- Empirical (Klügl, 2008) or operational (Heath et al., 2009; Sargent, 2010) validity: Do the model results match available data?

Aspects of this validation are to be conducted by different groups, with multiple assessment where possible (summarised at Table 6). The four groups are the modellers (principally for technical testing), TELL ME project partners, other subject matter experts and health professional focus groups.

6.1 Subject matter expertise

Effective model design and development relies on appropriate inclusion of expertise from several relevant subject matter areas such as communication, psychology, public health and epidemiology. Such expertise is to be accessed through workshops and on-going communication with two groups: stakeholders in epidemiology management in the United Kingdom and TELL ME project partners. A scenario planning workshop was included in the original TELL ME project plan (task T4.2). This is to be supplemented with two workshops with potential users of the model, selected TELL ME project partners and a project partner from the related E-COM@EU project.

The first workshop was held on 31 July 2013 to discuss the broad model logic (Figure 2) and preliminary interaction rules for four of the most important relationships. This workshop identified several additional factors to consider in the logic. The design will be refined through individual discussions with relevant workshop participants and draft design documents for comment by TELL ME project partners.

The workshop with TELL ME project partners (task T4.2) was conducted with validation of the WP3 communication framework in October 2013. This workshop shaped the initial draft of the communication language and other aspects of scenario inputs. This draft was circulated to project partners and the stakeholder group in December 2013 and has been revised accordingly for section 3.1.

Following construction of the prototype model, a further workshop will be held with the stakeholder group (approximately August 2014) to obtain final comment before formal user testing.

As well as these formal workshops, draft models will be made available to subject matter expert participants and TELL ME project partners for comment. In addition, meetings will be held with selected public health communication professionals to discuss the model logic, demonstrate prototypes, and obtain suggestions for revisions.

6.2 Health professional focus group testing

Once the prototype model has been completed, it will be assessed by two separate groups of public health and health communication professionals who have not previously been exposed to the TELL ME model. These assessments are included in the description of work as tasks T4.4 (European Union) and T4.5 (United States of America). Planning for these focus groups is not complete.

At this stage, all focus groups are to be structured as 2.5 hours demonstration and discussion with approximately 10 participants in each panel. The first hour is to include demonstration of the model and a question session. The demonstration would include scenarios to assist panel members to assess whether the model demonstrates empirically reasonable behaviour. The remaining time is for discussion about ease of use and reasonableness of results (see Table 6, professionals group).

The current plan for the United States is 3-5 panels from:

- 1-2 panels with representatives from the Center for Disease Control;
- 1 panel with State government health directors;
- 1 panel with practitioners; and
- 1 panel with officials from the Federal Department of Health and Human Services.

For Europe, current plans for Europe are to have at least one panel with a mix of health agency officials and medical professionals in each panel in association with a large European medical conference. Options for additional panels are being explored.

All sessions are to be videotaped for analysis. Any recommendations for revising the model are to be summarised and provided by end November 2014 to allow the model to be revised accordingly before delivery in January 2015.

6.3 Utility

The first group of criteria concern utility of the model. These assess whether the model meets the requirements of the project. As noted at section 1.1, the purpose of the model is to assist decision makers to compare different communication plans. To achieve this purpose, the model must meet certain functional requirements:

- Input - Potential communication plans can be entered into the model for testing;

- Output - Model to report the expected outcomes of the communication plan with respect to properties of interest; and
- Accessibility - Model able to be used and interpreted by officials developing communication plans.

There are two types of communication plans to be considered. The first are the predefined scenarios established by the TELL ME project partners. As these are designed by the project partners, their suitability is determined by those partners. The modellers are responsible for confirming whether each is able to be input in the prototype model and how. In addition, it would be desirable that there be some flexibility to try out new scenarios based on standardised descriptions of such elements as message content and trigger conditions. The subject matter experts (at the acceptance workshop) and the health professionals focus groups will assess the ease with which predefined and new scenarios can be input to the model.

The output to be delivered by the model will be specified initially by the formal subject matter experts, who will identify the information required to assist with decision making. As for the predetermined communication plans, the modellers are responsible for confirming that these outputs are included in the model interface and further assessed by the subject matter experts and health professional focus groups. TELL ME project partners will consider these outputs in their reviews of draft models during the development process.

Accessibility, or the way in which the model is presented and used, will be assessed as part of the model testing. Formal testing is to be conducted by the subject matter experts' workshop before passing the model for further testing by the health professionals group. In addition, TELL ME project partners will have the opportunity for on-going comment about the ease of use and comprehensibility of the outputs as draft models are made available.

There are also several features of the model that are desirable but not necessary to provide the functionality. The modellers will be responsible for meeting these to the extent possible and reporting whether the criteria have been satisfied. These are:

- The model is to use GIS data to provide for model realism, promote acceptance and assist with interpretation;
- The model is to be platform independent so that it can be used by all decision makers regardless of their information technology infrastructure;
- The software to run the model is to be as cheap as possible (and preferably free); and
- The software to run the model should not require any extra software that may not be available to all users.

6.4 Face or conceptual validity

Conceptual validation is focussed on whether the model is reasonable from a theoretical perspective. That is, does the model design appropriately include relevant features of the real world target system and the relationships between them? The participatory process is intended to obtain direct comment and feedback about the design from experts from a broad range of disciplines. Face validity then relies on the effectiveness of this participation process (Moss, 2007). This will be assessed in several ways:

- Endorsement of each major draft of the design by the subject matter experts and TELL ME project partners;
- Analysis of the comments received in response to each major draft; and

- Survey and/or interview with some participants focussing on the effectiveness of the participation and the quality of the final design.

In addition, the experts will run several simple scenarios with the model to assess the reasonableness of the model's logic by examining the animation of epidemic spread and the results (Moss, 2007; Klügl, 2008).

6.5 Verification

Once the model design has been agreed, there is a technical issue of how to implement that design, or translate it into model code. Verification is the process of checking for accuracy and functionality of the translation and is the responsibility of the modeller.

The first set of verification criteria concern preventing and eliminating code errors or bugs. The following practices will be observed (Gilbert, 2008):

- Elegant modular code;
- Comments throughout that describe the purpose of sections of code and the meaning of variables and equations;
- Reporting of intermediate values in calculations and relationships during code development to ensure the intended relationship is implemented and diagnose errors where they arise;
- Iterative code development, where components of the model are tested before adding new components.

In addition, test cases will be used to verify larger sections of code. Verification will include (Gilbert, 2008; Sargent, 2010):

- Assertions or test messages in the code, to ensure only feasible parameter values can be run with the model;
- Corner and extreme condition tests, where parameter values are set to 0 or extreme values to ensure the model is able to deal with these parameter values and report reasonable results;
- Degeneracy tests, where only a single value is changed and the output is checked for consistency with that change;
- Observation or tracing of the simulation, monitoring the properties of specific agents each simulation step to ensure they change in the way expected.

6.6 Empirical or operational validity

The test for empirical validity is whether the model results match available data. A key difficulty is that available data is used to calibrate the model; that is, the parameters describing relationships within the model are derived from the data. Thus, care must be taken to test in a way that does not simply report back the data used. Furthermore, models typically suffer from under-determination, where there are many different models that are consistent with the data, with the consequence that good calibration is no guarantee of accuracy (Moss, 2007).

For the TELL ME project, these problems are particularly severe as there are few epidemics to provide data and even fewer where the communication is reported in sufficient detail to support empirical testing (see section 5). Thus, validation will rely on qualitative matching of macro behaviour using micro data calibration. That is, parameters for specific relationships within the model will be derived from data and the qualitative behaviour of the model as a whole will be compared to past epidemics. The capacity to reproduce behaviour will be assessed by the subject matter experts at the second workshop and in the health professional focus groups, and made available to project partners for comment.

Sensitivity analysis will also be performed to assess the robustness of results and provide indications of uncertainty (Sargent, 2010). This analysis systematically varies parameter values through plausible ranges and analyses the change in model output. The analysis will be performed by the modellers and reported to the subject matter experts for assessment.

6.7 Validation summary: Allocation of responsibility

The various validation tests are summarised in Table 6, together with the group responsible for assessing whether they have been satisfied. A 'Yes' in the table indicates that the group is required to undertake the specific validation as part of the model development process. An 'Optional' indicates that the relevant information will be made available to the group and comments sought.

Table 6: Mapping of validation criteria with assessor group

Criterion	Modellers	Experts	Partners	Professionals
Utility: communication plans	Yes	Yes	Yes	Yes
Utility: output content	Yes	Yes	Optional	Yes
Utility: output comprehensibility		Yes	Optional	Yes
Utility: convenience features	Yes			
Conceptual: participation process		Yes	Optional	
Conceptual: result reasonableness		Yes	Optional	
Verification: bug elimination	Yes			
Verification: simple test cases	Yes			
Empirical: qualitative behaviour		Yes	Optional	Yes
Operational: sensitivity analysis	Yes	Yes	Optional	

7 Development and Application

As this report is part of the on-going development of the TELL ME simulation model, this section provides an outline of current plans for the development process and eventual use of the model. It is a statement of intent, and will be revised as required and expanded in future reports.

7.1 Development plan

The broad model logic (Figure 2) was developed through several drafts initially based on the outputs of WP1 and WP2, then discussed with projects partners and subject matter experts. The detailed relationships included in the design were developed through a combination of discussions about the model logic and published literature.

The communication language (section 3.1) was initially developed based on discussions at a session of the TELL ME October 2013 WP3/WP4 communication workshop, and refined in accordance with comments on the draft language from TELL ME partners in November 2013.

A demonstration model has already been released. The next prototype will include more realistic (but uncalibrated) equations for the attitude and behaviour logic. Later development tasks include:

- constructing input interface for communication plans;
- supporting multiple protective behaviours, including varied adoption and efficacy;
- calibrating attitude and behaviour elements;
- consequences of different media access;
- adding detail to epidemic transmission (including migration, latency); and
- designing useful output charts and results reporting.

Verification and conceptual validation will be undertaken in parallel with model construction. The final prototype is planned to be completed by 31 August 2014 to permit sufficient time for utility assessment and empirical validation prior to release of the prototype to health professional focus group testing (tasks T4.4 and T4.5) from October 2014.

7.2 Promulgation and analysis plan

The final version of the model is to be released at the completion of the TELL ME project at 31 January 2015. This software will be accompanied by documentation that is expected to include:

- User guide: a guide to using the model;
- Technical reference: model design as implemented, data sources, validation results and other material that describes the way in which the model works and allows independent evaluation; and
- Scenario analysis: discussion of the model results from selected communication scenarios, including the uncertainty associated with the results.

The user guide will include information about how to enter communication plans and situational scenarios into the model, and how to interpret results. It will emphasise that the model is intended to promote understanding of the complex system within which epidemic communication is located and some of the broader interactions, rather than forecasting particular outcomes. This will be reinforced with examples such as those used for the validation process. These examples will be reported as multiple simulations over the same inputs, to provide guidance on the variability of model output.

The model is to be accessible from the website to download and possibly also to run from the website. In addition, the model and documentation will be provided to those organisations that have been involved in design discussions.

There are several tasks within WP5 (Dissemination and Policy Dialogue) to which the simulation model is explicitly expected to contribute some content:

- With regard to the press centre and newsletters (ST5.1.2), the final model will be available from the website and articles about major steps will be provided to the WP5 leader for inclusion on the website or in newsletters as appropriate.
- Final publishable summary report (ST5.1.5) will include appropriate material from the model documentation.
- The final stakeholder conference (ST5.2.2) will include at least one session presenting the model.
- Model development is expected to provide the basis for at least two journal articles, which supplement those originally planned in ST5.1.4.
- The model will be presented at relevant public health and simulation conferences (such as the European Social Simulation Association annual conference).
- The report on expected socio-economic influence and factors influencing use (ST5.3.1) will include an analysis of the simulation model.

CONCLUSIONS AND RECOMMENDATIONS

The objective of the TELL ME simulation model is to provide guidance for health authorities about the effectiveness of different communication plans before, during and after an influenza epidemic. As the objective of such communication is to limit the impact of the epidemic, the model must connect proposed plans to epidemic progress.

This design document describes a two layer model. One layer consists of simulated individuals that receive communication messages, adjust their attitudes accordingly, perceive their situation and make decisions about whether to adopt (or cease) protective behaviour. This behaviour is founded on a hybrid psychological model that includes attitudes, subjective norms and perceived threat. The other layer is a spatial epidemic simulation. The layers interact with each other; epidemic progress is the major element of an individual's perceived threat, which affects their behaviour choices, and the adoption of protective behaviour affects the force of infection (through transmissibility) of the epidemic.

The connection and mutual influence of the communication, personal protective behaviour and epidemic progress is a substantial theoretical advance over existing models. The key benefit of the TELL ME simulation is to assist health authorities to understand their complex decision making environment and stimulate a broad perspective.

However, data are not available to accurately parameterise the model. That is, the model will not be sufficiently precise and accurate to directly compare potential communication plans. Nevertheless, it can also guide future data collection efforts, the structure is based on relevant psychological theories and the model parameters can be adjusted as more data becomes available.

At the time of writing (February 2014), model development is on track. Model construction has commenced, with a target completion date of 31 August 2014.

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