Disease Outbreak Under Deep Uncertainty

Identifying Adaptive Robust Strategies using Multi Objective Robust Decision Making and Dynamic Adaptive Policy Pathways

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Authors & Student numbers;

Rizky Januar – 4614267

Tian Xie - 4619420

Weiyu Zhu - 4627156

Gurvinder Arora - 4617479

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Executive Summary

This report contains the case of analysis of a disease outbreak under deep uncertainty. Deep uncertainty implies that the decision-making strategy needs to be formulated with very little information about the disease under analysis and little or no consensus on the available information and objectives. Under these conditions, an adaptive policy design process has been developed and executed. The Policy design process is developed under the framework of Dynamic Adaptive Policy Pathways. Using the process, a given disease outbreak model is analysed and different policy options are implemented. The policies are then adapted for robustness by analysing the vulnerabilities of the policies under multiple scenarios.

Through the process of iteration, the policies; vaccination, isolation and hygiene awareness program are chosen and levers are built into the model. From the analysis, it shows that a combination of all 3 policies is best suited to satisfy the objective; Deceased Population, Reported Cases & Cumulative project costs, requirements. Using this policy combination, scenario discovery is performed, which calculates Basic reproduction number as the most dominant uncertainty. Multi-objective Robust Decision Making (MORDM) is then applied to calculate the policy lever values that produce the most optimum and robust strategies. One of the candidate strategy is applied to the model and the results are discussed in the Analysis section.

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1 Introduction

1.1 Case Brief

Emergence of unknown infectious disease outbreaks pose a dire threat to the human health and social stability. Human mortality due to infection is estimated to be around 13-15 million deaths annually till at least 2030 (WHO, Mortality and global health estimates, 2013). With the population growth, fast urbanization process land change, increased travel frequency and livestock production, the probability for emergence and spread of unknown infectious disease is quite likely to increase (Heesterbeek, 2015). So, it is of considerable significance to devise strategies which enable us to prevent a disruptive outbreak of an unknown disease. The typical interventions of disease outbreak consist of vaccination, quarantine, isolation, hygienic awareness raising and so on. System dynamic (SD) facilitates the modelling and simulation of complex system with causal relations (Lane, 2000). In the given case, the basic SD model is expanded with susceptible-exposed-infectious-recovered (SEIR) structure through Vensim by incorporating policy interventions like vaccination and quarantine and then run the model through exploratory modelling and analysis (EMA) workbench.

Sensitivity Analysis, Patient Rule Induction Method (PRIM) for Scenario Discovery, and Dynamic Adaptive Policy Pathways (DAPP) in combination with Multi-Objective Robust Decision Making (MORDM) are applied to explore the robust strategies for controlling unknown infectious disease. Sensitivity analysis is used to investigate to what extent the change of different inputs influences the outputs. PRIM is applied to find sub regions in the input space for the optimization of the value of target variable. DAPP together with MORDM allow for dynamic adaption over time for achieving specific objectives (Hassnoot, 2013).

1.2 Research Question

Based on the open description of the case available with us, the following research question has been formulated for the case:

- How can the policymaker develop a robust policy for a mass disease outbreak, given the wide range of uncertainty?

The question will be used to develop an analysis sequence with Dynamic Adaptive Policy Pathway (DAPP) approach (Hassnoot, 2013) where modelling tools and available literature will be used to provide insights on the questions,

- How does the uncertainty grow as different policy options are explored?
- What are the robust policies available given the DAPP framework?

The subsequent section elaborates on the process sequence of analysis and motivates on the choice of tools. With DAPP framework as reference, the entire process sequence is mapped to every step.

2 Methodology

(Hamarat, Kwakkel, & Pruyt, 2013)introduce Adaptive policy-making framework for the decision making under deep uncertainty. It is motivated that predictive approaches are likely to fail under deep uncertainty as there is no consensus on the approach, knowledge and in some cases the even the objectives. To provide valuable insights in cases falling under this umbrella, policy making needs to be dynamic with sufficient provisions for adaptation. The framework, thus proposed (**Figure1**) provides a high-level outline of adaptive policy making. Keeping the framework as reference, for the given case and the high range of uncertainty involved, a process sequence was developed to tackle the unknown disease outbreak. The literature motivation of the model, update and the policy selection process has been discussed in the subsequent section.

Figure 2 shows the analysis sequence developed for the case. The entire process has been divided into 2 phases;

- Phase I – System Development, which covers the iterative process of insight generation and Policy options testing in the model

- Phase II – Policy Optimization and trade-off, where the best policy combination obtained from Phase I is optimized for Robustness across various lever options.

2.1 Conceptual Framework

Based on the figure, the sequence of operations is explained and mapped to the DAPP framework as presented earlier. Although the process sequence is case specific, it should be noted that this process sequence is applicable to any decision-making case under deep uncertainty. As the method of generating alternative is searched, this process has a Multi-Objective Robust Decision-Making (MORDM) approach to develop adaptive strategies.

2.1.1 Phase I – System Development

The process was initiated with the simplified population disease outbreak model made with Vensim. Based on the model, the first process selected is open exploration using ema workbench. The focus of this stage is to gather as many insights as possible on the model and the behaviour of different populations subsets as the uncertainties play out. initial a scan is performed on all possible indicators as there is no consensus on objective setting and the values.

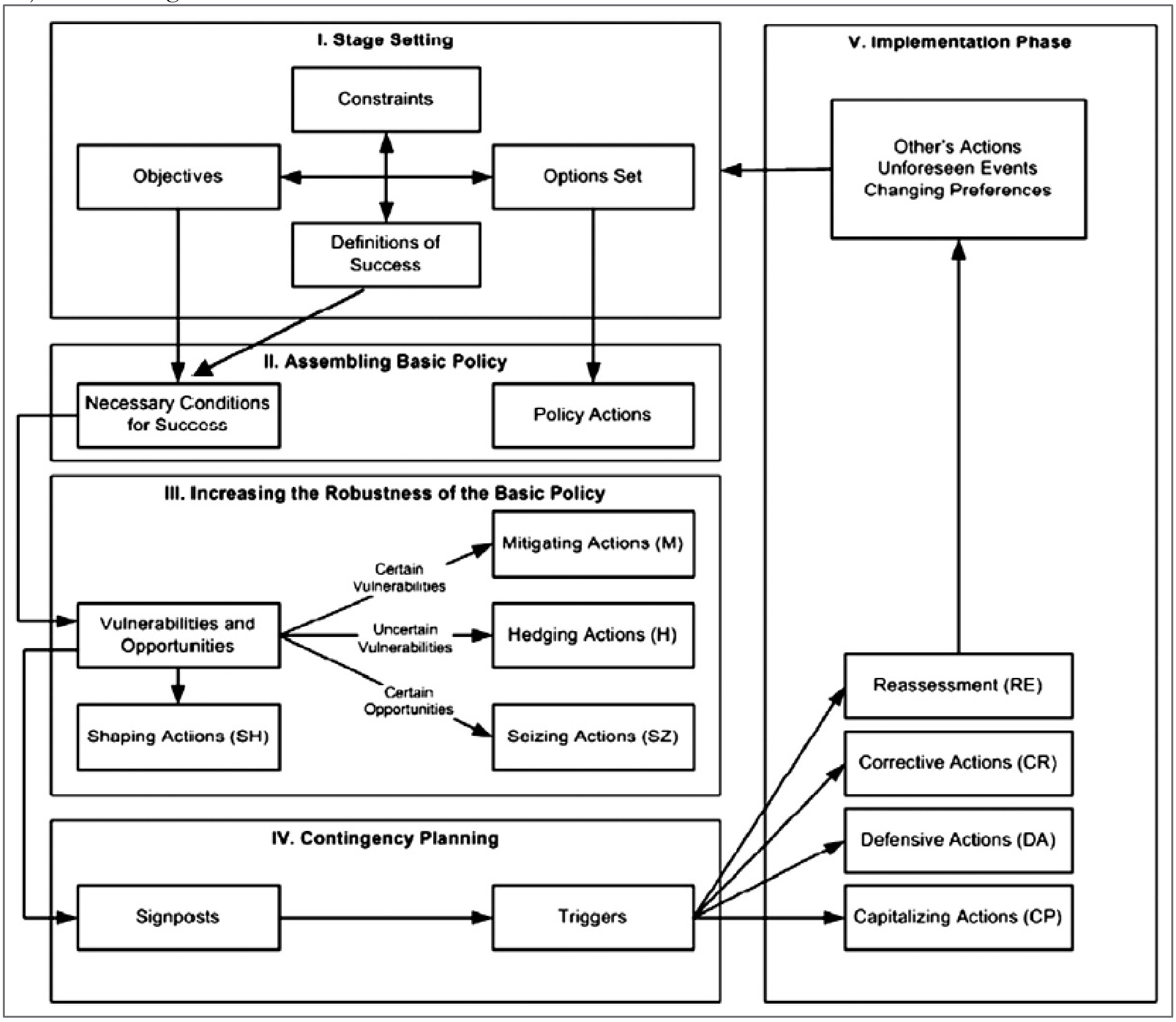

Figure 1 Dynamic Adaptive Policy Pathways

The insights gained from exploration, along with the model are used to understand the relation of output to input. The 2 techniques used to explore input output relations, i.e. Scenario Discovery and Sensitivity Analysis assist is identifying,

- Dominant uncertainties with respect to sensitivity to outputs and rank them
- The uncertainties that have the most dominant effect on the output by mapping the input space.

After comparison with literature, the model state is updated by adding structural policies to the model[1]. Each additional policy structure increases the model size and ultimately the model complexity. The whole process is iterative in nature and is repeated until a satisfactory model of the situation is reached with sufficient comprehensiveness about the known unknown of the case.

Comparing with the framework, this is linked to the Step I – Stage setting, where constraints and objectives are fine-tuned along with exploration of available options set, thereby translating them into concrete potential policy structures. This leads to Step II – Assembling basic policy, where different policy structures are switched 'On/Off' individually and in combination with each other to compare visually with each other about the effect on Selected indicators[2]. The central idea is to narrow down the policy combination initially using search methods (MORDM) and then optimize the policy for robustness in the Phase II of the process.

2.1.2 Phase II – Policy Optimization and Trade-off

Based on the iterative approach in Phase I, and by obtaining more insights into the complexity, uncertainties associated with the model, the next phase is initiated. Here the updated model with the selected policy is now run over different policy lever combinations to arrive at an objective value. The process highlights 2 approaches to accomplish this;

- Using Vulnerability analysis of the model with Scenario Discovery to assist in narrowing down the uncertainties by informed estimation of objectives.
- By using Robust optimization algorithm and specifying the objective functions for minimization/maximization for each outcomes of interest.

The objective value from here is used to run a vulnerability analysis of the policy, by applying scenario discovery to it, with optimized objective function values. In comparison with the DAPP framework, the process maps to step III where the vulnerabilities of the policies are identified. The range of uncertainty is reduced for the restricted parameters in scenario discovery and the model is updated, if necessary, for policies 0with the reduced uncertainty. The most restrictive parameters can be identified here as signposts (Step IV) as mentioned in the DAPP framework.

This model is now considered as final, for Multi-Objective Robust Optimization followed by Robustness measure of the policy levers. From the output of optimized lever combinations, for robustness, regret metrics are used to identify non-dominated policy outcomes. These outcomes are then represented as policy trade-off strategies for different combinations of objective values.

[1] It is important to note that as the model grows with regards to structural policies, so do the uncertainties associated with the model. This can be seen in the comprehensiveness of the Vensim Model attached. More about this will be covered in Section **XX**

[2] A not here is that the policy structures are tested without exploring over the levers.

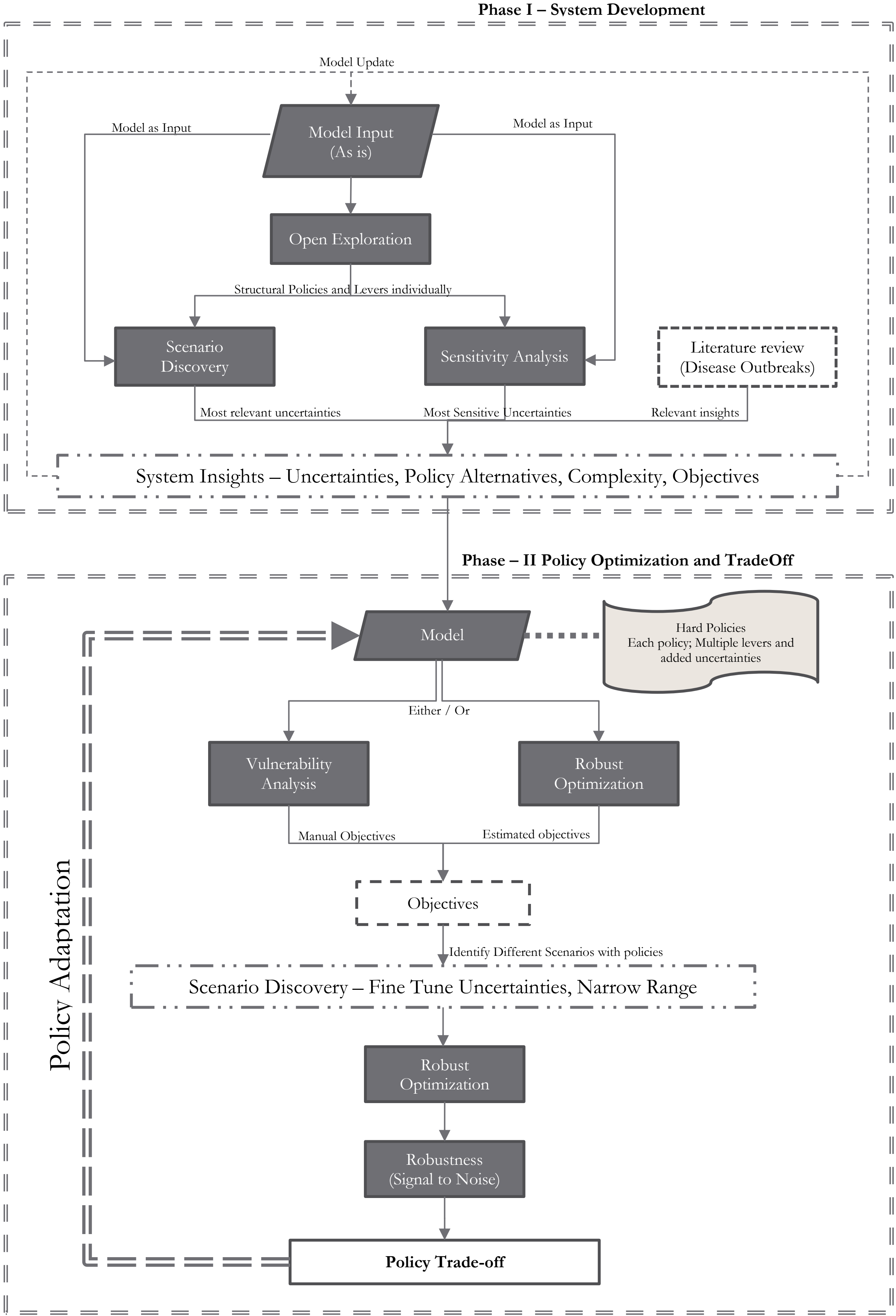

Figure 2 Analysis Process - Disease Outbreak

With the final set of information and the trigger signposts available, the levers can be endogenized in the model and the process (Phase II) can be repeated to calculate the adaptation tipping points. However, for the scope of this report, only qualitative adaptation strategy has been motivated. This leads to various trigger generated actions as described in Step V of the framework which can be endogenized in the model for signposts and tipping points. The implementation phase as discussed in the framework has been left out of scope. **Table 1** below shows the mapping of different steps in the DAPP framework to the proposed Phase process.

Table 1 Mapping DAPP to the Analysis Framework

Analysis process Developed		**DAPP Framework (Hamarat e.al)**	**Tools/Techniques Applied**
Phase I Iterative	Model Input	Step I – Stage Setting	Vensim Model
	Open Exploration	Step I – Stage Setting	EMA Workbench
	Sensitivity Analysis	Step I – Constraints	SOBOL, MORRIS
	Scenario Discovery	Step I – Options Set	PRIM
	System Insights	Step II – Necessary conditions for success	Vensim, Literature
Phase II DAPP Cycle	Model Updated	Step II – Policy Actions	Vensim/PySD
	Vulnerability/ Robust Optimizations	Step III – Vulnerabilities and opportunities	EMA/ Platypus
	Objective Fine Tune	Step III – Identifying Actions	Platypus/PRIM
	Scenario Discovery – Fine Tune	Step III – Shaping Actions	PRIM
MORDM	Robust Optimization	Step – III – Shaping actions	Platypus
	Robustness Metric	Step – IV – Signposts/Triggers	Signal to noise Ratio
	Policy Trade-Off	Step – V – Adaptive policy	Vensim update

The approach of Policy architecture is **transformative** with respect to the adaptation tipping points and hence even with a multi-policy structure, the need to roll-out a policy, the scale of the role out and the implementation time can be adapted based on tipping points. Being an unknown disease outbreak with essentially limited information, makes having a protective adaptivity approach extremely difficult.

3 Case Operationalization

Based on the framework mentioned in the previous section, the operationalization on the given case is presented. The Analysis Process was applied to the case using Python notebooks, which are presented as an attachment along with this policy brief. For details on motivations of the techniques used, refer the notebook where the entire process sequence has been followed. Through an iterative process, the gathered insights were implemented on the model in the form of structural policies and levers. This section will motivate the model development and the policy choices identified in Phase I, that were used to dive into Phase II.

3.1 Model Development

As mentioned the Vensim model provided in the case covered the population aspect of the with the SI(E)R framework with a switch for Exposed population case to be on or off as an uncertainty. The initial range of uncertainties and constants was provided in model description of the assignment. In Phase I, after gathering the insights through different applied techniques mentioned in **Table 1** there was significant addition of information to the model. All the model developments have been recorded in the attachments. The model was updated in 4 stages,

- Base model, as provided in the case (Phase I)
- Updated Model, after policy and uncertainty exploration and implementation (Phase II – Initial)
- Updated Model, after fine tuning for objectives (MORDM Input)

- Adaptive model, with a sample robust strategy from MORDM outcome

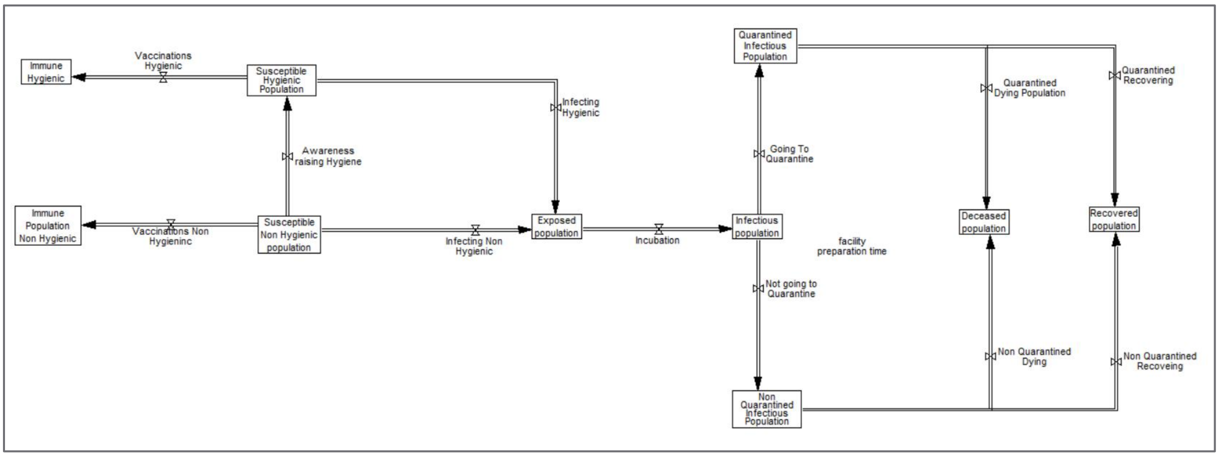

Figure 3 Updated Model Structure

Figure 3 shows the model structure after updating the model from SI(E)R to a more comprehensive stock flow structure. The facilities requirement, along with the effect of policies on the model has been endogenized into the structure. The combination of different policies activates the stock flow structure relevant to it, thereby changing the proportion of population between stocks.

3.1.1 Objectives Development

During the phase 1 open exploration of the model, all the stocks from the Vensim model were being monitored. With the available information on the structure, the only clear objectives that could be determined were;

- Deceased population
- Infected population

Given the information provided in the model, literature review was performed on available models on disease outbreaks (Auping, Pruyt, & Kwakkel, 2016). The model structure was deemed incomplete and additional effects were endogenized in the model scope. The scope was cost was developed into the model structure as a large operation to handle disease outbreak could require significant funds (Doctors, 2015). This resulted in adding Cumulative Project Cost was added into the model. Not only does this add a relevant information to the model, it also introduces a trade-off from Cost-Benefit perspective, as the operation needs to be comprehensive, while cost effective[3].

Furthermore, to handle and control the outbreak (Refer section 3.2), structure was expanded to include infrastructure and handling of the disease. This meant that, due to geographical and dispersed nature of disease spread, as assumption, detection of the cases was equally important when compared to number of people infecting. Therefore, Number of reported cases through tracing personnel was added as the third objective. Post Phase I, the following 3 Objectives were developed into the model;

- **Deceased Population**; To minimize
- **Reported Cases**; To minimize[4]
- **Cumulative Project Cost**; To minimize

3.1.2 Uncertainty Development

During the development of model, it was observed that as the information structures were being explored, the uncertainty range of the policy grew as well. Based on the additional Objectives and Policies implemented in the model, the addition of uncertainty was unavoidable. The additional uncertainties

[3] Although it could be argued from consequentialist perspective itself (MSF, facts and Figures), limited spending initially by the government could lead to higher causalities and result in more cost for safe disposal of the deceased. This will be discussed in Policy selection Section 3.2

[4] Although it can be argued that isolation policy, as discussed later, will mean more reported cases, which is not necessarily a negative indicator

associated with the model development can be found in the **Table 2**. For instance, if the addition of cost module is discussed, there are multiple known unknowns associated with it; Personnel cost, Facilities cost, logistics, etc. The only way to account for their effects into the model, for a comprehensive analysis, they are introduced in the model.

Table 2 Parameter Uncertainty list

Parameter name	Range of uncertainty values
Awareness Effect time	3, 15
Awareness Effectiveness	0.01, 0.2
Vaccination Effectiveness	0.1, 0.8
Contact Factor Reduction	0.01, 0.4
Basic reproduction number	0.5, 5 -> 1.5, 5[5]
Average critical condition and recovery period	5, 15
Average infectious period	7, 21
Vaccination Speed improvement	1, 2
Vaccination Speed Non-Hygienic	20, 100
Average incubation time	0.5, 14
Switch SEIR or SIR	0, 2
Vaccine Preparation and availability time	30, 120
Case fatality rate reduction	0.001, 0.01
Case fatality rate	0.015, 0.55
Recovery Improved	0, 3
Personnel per case to handle	2, 4
New Personnel Training Time	10, 20
Isolation capacity preparation time	5, 10
Fraction of Tracing personnel	0.25, 0.5
fraction of staff getting infected	0.01, 0.1
fraction of recovered population volunteering for personnel	0.05, 0.15
fraction of susceptible population volunteering for personnel	0.00001, 0.0001
Disease Detection rate	0.1, 0.6
Staff costs	500, 900
Vaccines cost per case	50, 200
Cost for Isolation facilities	75, 300
Cost for Advertising	100, 350
Cost for handling deceased	900, 2000
Development cost for vaccines	200, 700
Vaccines Dosage	1, 6

It is worth noting that the scoping of the model was selected on the combination of insights gained in Phase I, from quantitative and qualitative data. The additional structure of the model, makes it completely different model compared to the initial model provided making the comparison between Phase I and Phase II model

[5] Fined tuned by scenario discovery. Refer section 4.

invalid. Similarly, the selection of objective was made on similar grounds and need not be motivated as the best possible combination of objectives, as no one combination is most ideal; Arrow's paradox (Kasprzyk, 2016).

3.2 Policy Implementation

As per the Analysis process highlighted in Section 2.1, after an extensive literature survey, the following list of policies has been prepared. The list consists of proven and policies which have been used in the past to manage disease outbreaks. It is important to note that the identified policies, from the list of the potential candidates, have been added to the model as structural changes. Once the structural policies were built, levers were created per policy to vary the policy parameters and test them across multiple scenarios.

3.2.1 Potential Policies

Table 3 shows the various policies identified and their nature as mapped to the actions specified in the Step IV of the DAPP framework[6]. Out of the available policies options in the table, based on the analysis results of Open exploration and Vulnerability analysis candidate policies are identified. The policies are then sampled in Phase II, where scenarios are identified to perform a vulnerability analysis. In case of unsatisfactory results, the structural policies are not modified, but additional levers are searched until the policy is robust. Details will be covered in Analysis section.

Table 3 Potential Policies

Potential Policy Option	Action Type (DAPP)	References
Awareness Programs	Hedging Action	(Frieden, 2011)
Vaccination program	Hedging Action	(Frieden, 2011)
Encourage research on the Super Infectious diseases	Preventive Action	(Frieden, 2011)
Investing in critical infrastructure – manpower, hard infrastructure	Preventing/Hedging Action	(WHO, Global Task Force on Cholera Control, 2017)
Isolate the infected population	Mitigating Action	(Frieden, 2011)
Distribute Safety Mask	Preventive/Mitigating action	(CDC, 1998)
Closure of Public Facilities – Schools/Parks	Mitigation/Hedging	(Frieden, 2011)
Surveillance programs for detection	Mitigation/Hedging Action	(CDC, 1998)

4 Analysis

In this section, only the key insights and findings are presented for relevant steps. For the detailed iterative process, the step by step analysis can be found in the Jupyter notebook.

4.1 Base Case

As explained earlier, the base case provided limited information for a comprehensive analysis, therefore, open exploration was performed, where scenario discovery and sensitivity analysis were used to gain insight.

4.1.1 Open Exploration

Based on the open exploration, the relationship between outcomes and uncertainties was explored. The findings of Sensitivity and Scenario Discovery on Deceased Population are presented in **Table 4.**

[6] Refer section 2

Table 4 Open Exploration Base case

Open Exploration Method (Base Case)	Critical Uncertainties
Sensitivity Analysis	Basic Reproduction Number
Scenario Discovery	Basic Reproduction Number

4.2 Phase I

Based on the Model development, the comprehensive model obtained was run for Open exploration. Since the model now obtained is significantly different from the base model, Open exploration is performed again to generate insights into the models. The critical uncertainties thus obtained (**Table 5**) are the one which need to be controlled by policies.

Table 5 Open Exploration Phase I model

Open Exploration Method (Base Case)	Critical Uncertainties
Sensitivity Analysis	Basic Reproduction Number, Average number of infections
Scenario Discovery	Basic Reproduction Number

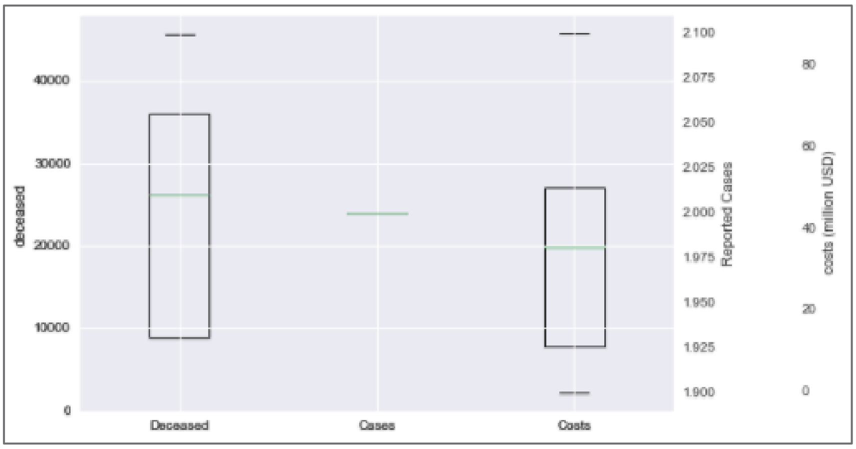

Figure 4 Boxplot Objectives No Policy

The above Table highlights that from both the techniques, Basic Reproduction number is the most critical uncertainty. Therefore, it is important to build robust policy levers around factor to have a robust solution.

4.2.1 Phase I Policies

The choice of the policy from all the available option was made considering the effect on Objectives, with the additional insights gained from open exploration. The policies chosen initially for the scope of the analysis, are the following;

- Hygiene Awareness Policy
- Vaccination Policy
- Isolation Policy

The choice of the policies has been made to have a combination of prevention, mitigation and hedging actions. As can be seen from **Table 6**, the 3 policies chosen, map the 3 action types as mentioned in Step IV of DAPP framework. Another factor motivating the selection of the policies is the real-life applicability to Ebola case (Auping, Pruyt, & Kwakkel, 2016), which has been used a key inspiration to develop the model. Linking it to the literature of the case (Doctors, 2015), the major chunk of the spending during the Ebola went into the facilities, vaccination and awareness campaigns. A detailed qualitative reflection on the implications of these policies is covered in Section 5.

Table 6 below shows different implemented policies along with their lever ranges. The range for levers has been motivated in the Vensim model equation comments, and the rest have been assumed for simplicity.

Table 6 Policies with levers Phase I

Policy	Policy Levers	Lever Range (Unit)
Switch Vaccine or No Vaccine (0,1) Integer	Vaccination Program Start time	10 – 365 (Days)
Switch Isolation/Quarantine Program (0,1) Integer	Isolation Scale up Start Time	10 – 365 (Days)
	Fraction of additional personnel as proactiveness	0.2 – 1.0 (Dmnl)
	Fraction of Additional capacity as proactiveness	0.2 – 1.0 (Dmnl)
	Average Staff commissioning time	30 – 365 (days)
	Facility commissioning time	30 – 365 (days)
Switch Awareness Program (0,1) Integer	Hygiene program start time	10 – 365 (Days)

From the above table, the 'switch' policies are structural policies, while the levers are iterative variables which will be optimized in Phase II. The structural policies are compared in iterations and the following 4 combinations of structural polices are tested over uncertainties.

- No Policy
- Vaccination policy On
- Isolation Policy On
- Hygiene Awareness Policy On
- All Policies On

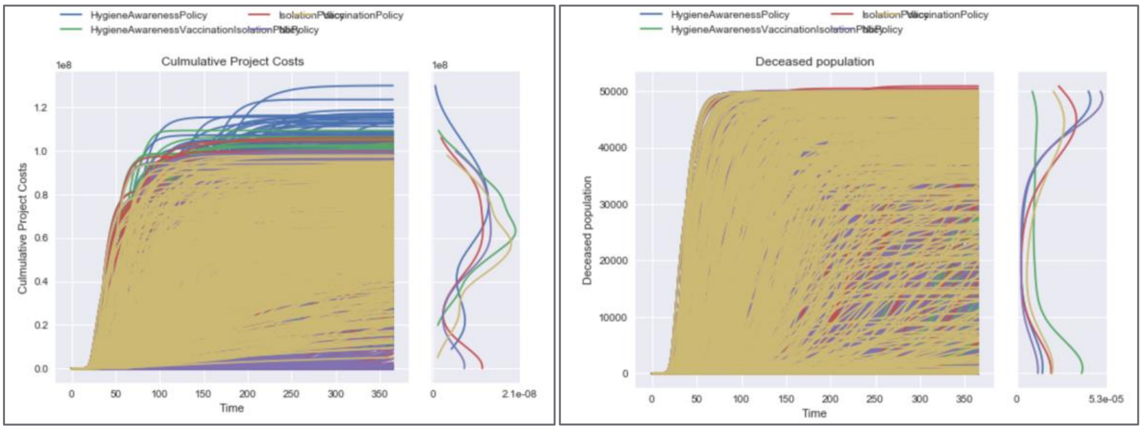

Figure 5 Structural Policies effect on objectives

The results are represented in **Figure 5** which shows that within this set of models, 'All Policies On' performs the best over the objectives. Based on the findings, the model 'All policies on' is chosen as the updated model for Phase II.

4.3 Phase II

For the updated model with policy structure, the model is run for Vulnerability analysis using scenario discovery with difference policy levers across the 'All policy on' model. The uncertainties now identified represent the candidate parameters which can be **signposts** for the DAPP approach. The critical uncertainties thus obtained are shown in **Table7**. An alternate approach is to run the model for robust optimisation using platypus directly and obtained optimized objectives. This is the either/Or sequence in the process methodology.

Table 7 Vulnerability Analysis Phase II model

Vulnerability Analysis	Critical Uncertainties
Sensitivity Analysis	Basic Reproduction Number, Average infectious, Case fatality ratio
Scenario Discovery	Basic Reproduction Number (**1.1 – 5**[7]), Case fatality Ratio

From the results, it is observed that even after implementing the policy, the rank of basic Reproduction number has not changed. The updated range of the critical uncertainty obtained from vulnerability is used for MORDM analysis.

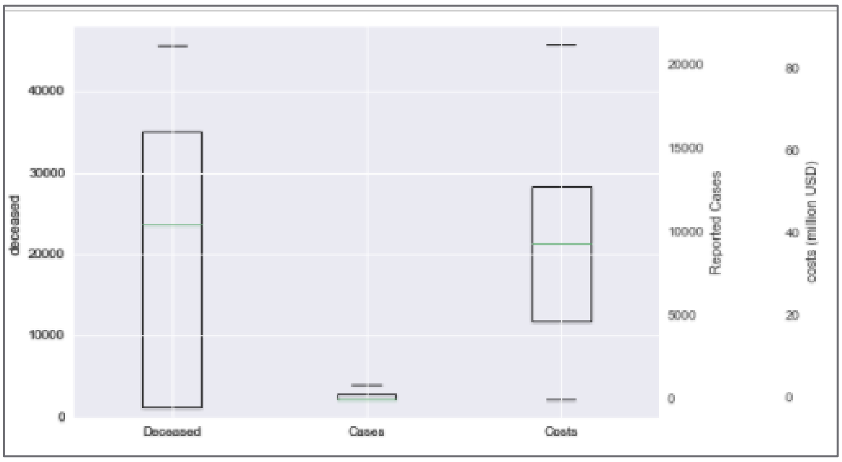

Figure 6 Boxplot objectives All Policy case

4.3.1 Phase II Policies

Based on the identified vulnerability against Basic reproduction number, 2 additional policy levers are built into the model;

- **Media outreach Rollout; 1 – 2 (Dmnl)**
- **Vaccination rollout Rate; 1-2 (Dmnl)**

These 2 levers map the rollout of the policy by phasing it into a continuous range rather than a switch on or Off. The added levers, in the model structure, influence the Basic reproduction number.

4.4 MORDM

4.4.1 Trade-Off

To obtain insights from MORDM step, the results are visualized and shown in this section, with parallel coordinate plotting; given that there are multiple dimensions captured. **Figure** 7 shows the non-dominated trade-off plot generated from Multi-Objective Robust Decision-Making script. Based on the non-dominated trade-offs plot above, there seems to be a trade-off between deceased population and cumulative project costs. To observe more insight on this, normalized robustness matrix (between zero and one) is shown in **Figure** 7.

[7] New Range of uncertainty

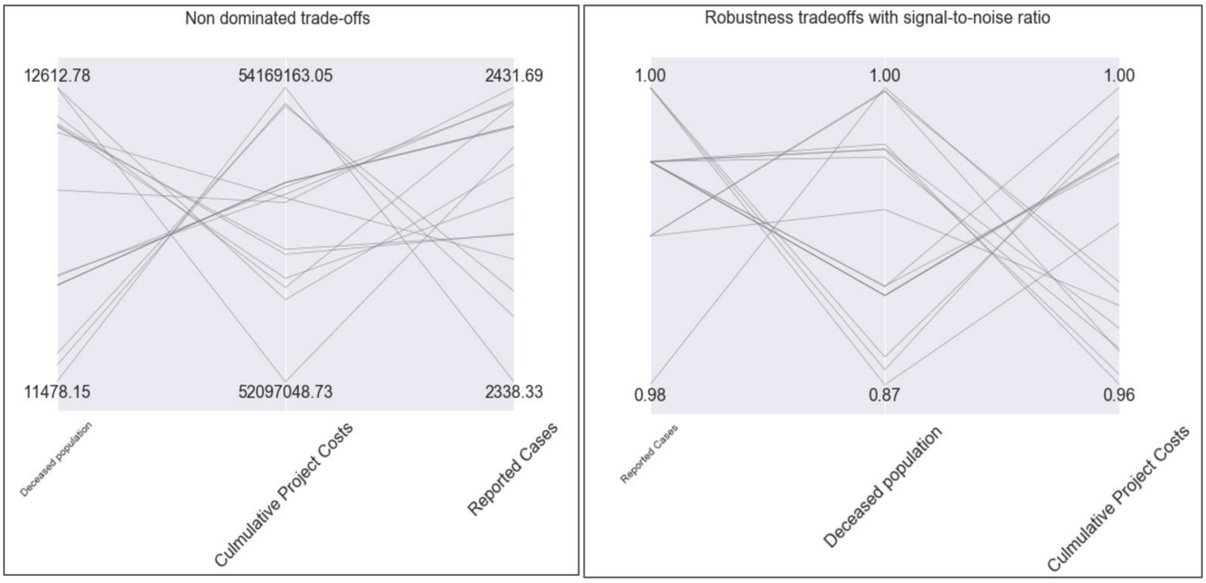

Figure 7 parallel coordinate plot: Non-dominated trade-off Objectives & Robustness

Robustness plot shows that Cumulative Project Costs objective values are more distributed in two separate clusters, while the deceased population is more evenly distributed. This shows that there is an apparent trade-offs among these two objectives across the scenarios. Regarding reported cases objective, however, the plot shows that there seems to be a more non-linear correlation with other two objectives.

4.4.2 Model result with candidate strategy

The **Figure 8** shows the updated objective values with one of the generated candidate strategies in MORDM.

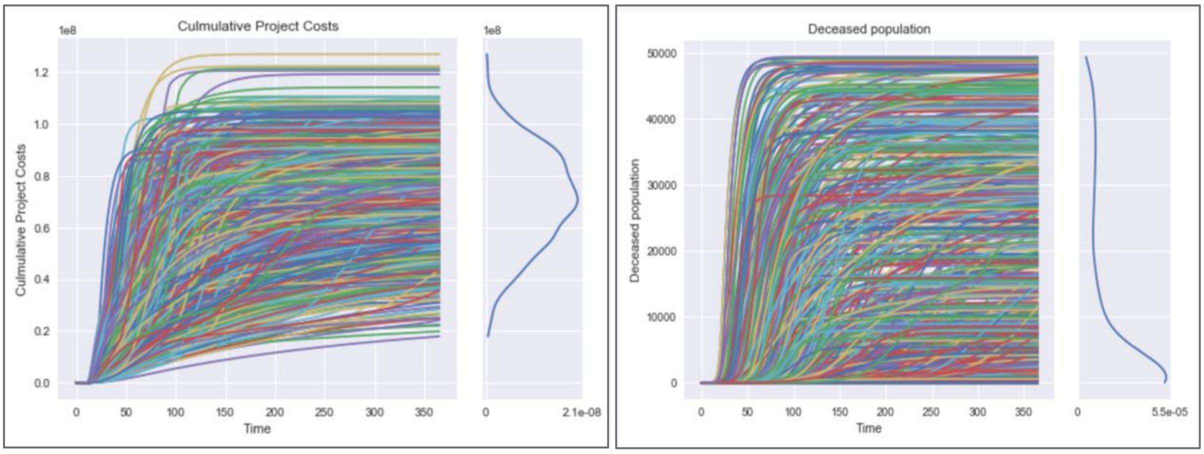

Figure 8 Candidate Strategy over Objectives

The mean objective values are given below in the **Table 8.**

Table 8 Objective Outcomes for a given MORDM candidate strategy

Objective	Optimisation requirement	Mean Value optimised
Deceased Population	Minimize	**11478**
Reported Cases	Minimize	**2339**
Cumulative Project Costs	Minimize	**54.17 Mill USD**

4.5 DAPP

In the analysis process, there is scope for DAPP by iterating over Phase II. However, due to time restrictions, that has not been explored.

5 Reflection on Findings

5.1 Motivation Through Literature

In this section, a reflection regarding policy advices is presented. The reflection discusses how policy decision and implementation interact with the institutional & multi-actor processes and ethical values/dilemmas.

5.1.1 Critical Junctures and Crises

In this section, the introduction to crisis following from outbreak will be introduced. It is comprehensible that an unknown disease outbreak can lead to multi-dimensional crises. Initially, the social instability which emerges in the form of social stress and panic after the declaration of an outbreak. In countries like China, where social stability is crucial public value for nurturing economic development (Huang, 2004), the effect of the outbreak can influence the economic stream. Hence, the involvement of decision makers in formulating a response strategy is paramount, as mitigation strategies alone cannot provide a comprehensive adaptive strategy.

Furthermore, the political implications entailing a mishandled outbreak needs to be considered for decision makers as well. The aftermaths of the crises may lead to political blaming from public and adversaries on the grounds of the inability to foresee and prevent the outbreak, ultimately questioning their political legitimacy. In summary, policymakers will need to undergo important junctures (Chan, 2014):

- **Outbreak declaration to the public** – Although currently left out of the scope in the model, it is recommended to commit the declaration as soon as the outbreak is detected. This is necessary to prevent setting back mitigation responses. Being a delicate issue, it needs to be framed to avoid inciting fear and tensions within the public.
- **Coordination with other strategic actors**. Comprehensive mitigation/defensive process will require multi-institutional governance and coordination among actors at various governance levels (Prescott, 2007) (Lipsitch, 2011). This is necessary to account for the uncertainties surrounding the infrastructure and logistics capabilities (e.g. vaccines preparation and delivery). Secondly, this ensures prevention of conflict of objectives between actors with different mandates. For example, quarantining population can have a disruptive impact on business leading to an economic slowdown of economic activities.
- **Incorporating public participation to improve decision making process**. Social support can be helpful in confidence building as sharing the information regarding disease outbreak, and involving local leaders for legitimacy of the decisions, can facilitate smooth implementation (Chan, 2014).

5.2 Implemented Policy Risk Reflection

5.2.1 Vaccination Program

In this section, the social and ethical aspects that may influence the implementation of vaccination program from a decision-making perspective will be discussed. The economic aspect regarding its cost has been endogenized in the System Dynamics model[8].

5.2.1.1 Social Aspect

For a long time. there have been growing adversities for the idea of vaccination. In the US, for instance, during an outbreak of measles in Minnesota, self-declared anti-vaccine groups were held under scrutiny by the authorities, who mentioned it to be an "unnecessary outbreak". This vaccine scepticism has originated from various sources of information in the past; most prominent of which is a medical article published in late 90s, that cited that vaccination as a cause for autism in children. Although disproved and heavily criticized in the scientific community, the vaccination-autism causation argument has been one of the prime basis for anti-vaccine political and social groups to defend their stance (Iannelli, 2016). Emerging conspiracy

[8] Refer Phase II Vensim Model

theories regarding influence of big pharmaceutical companies, policymakers, and medical actors on vaccination have caused more severe disagreement of information (Blaskiewicz, 2013).

This information uncertainty is in line with argument of (Sarewitz, 2004) that multiplicity of scientific information cannot ignore the accompanying political controversies; rather, they can also be used to "claim scientific justification of their position". Facing this uncertainty, the scientific community acknowledging the missing causation between vaccination and autism (and other related side effects) is always careful in presenting their conclusion to avoid further heated debates. It has been argued that "when a scientist says, 'we have no evidence that there is a link between vaccines and autism', what they are really saying is 'we are as positive as someone who can humanely be that there is no such link." (Mnookin, 2011).

During cases of infectious disease outbreak, it is recommended as well that the decision-makers should take the pivotal role in framing the appropriate information to be communicated to public. 'Appropriateness' here can be defined as to what extent the amount and type of information are needed to encourage willingness of people to receive vaccinations. One way of communicating the information accordingly is with concept of value-based framing, which means the content of communication should be in line with relevant, deeply held public values (Institute, n.d.).

Furthermore, with mass media rising to be an essential transmitter of public information during such an outbreak, adapting the communication framing strategies based on environment and agenda of mass media should be considered by the decision makers. Accordingly, (Kott, 2016) studying the frame of news media regarding information provided by public health officials can provide insights on the communication process.

5.2.1.2 Ethical Aspect

From the ethical aspect, at least three things to be considered by policymakers regarding vaccination policy (Moodley, 2013).

- **Safety, i.e. non-maleficence**. Deploying vaccines in large scale should comply to the prevailing global rules which regulate effectiveness and safety of vaccinations. Massive deployment of vaccination during outbreak of infectious diseases might induce side effects of mal-handling. Accordingly, the noticed side effects can be taken as opportunity to improve effectiveness of the vaccinations.
- **Consent**. Related to vaccination, it is important to acknowledge the individual autonomy values as best as possible. However, since policymakers are dealing with infectious disease outbreak, time is limited to deal with individuals on case by case basis. Additionally, there can be an ethical dilemma (utilitarian vs deontological perspective), given opposition to vaccinations by some groups of population. In this circumstance, should the government enforce vaccination policy to these groups so the larger fraction of the public will be less possibly infected? Therefore, it is recommended to commit further research on how to modify the process of acquiring public/individual compliance in this case.
- **Vaccination to all**. This aspect is highly related to nurturing distributive value of vaccination policy. Since policymakers are dealing with the entire population, it is important to ensure that the vaccination must be made available at a mass-scale deployment level. Given the limited number of vaccines available in any case, it is argued that larger fraction of them should be targeted to population of major transmitters, instead of the vulnerable ones (Boven, 2017). This implies that identifying best target group for mitigation could be necessary.

Figure 1 shows ethical-related guidance for policymakers regarding vaccine implementation.

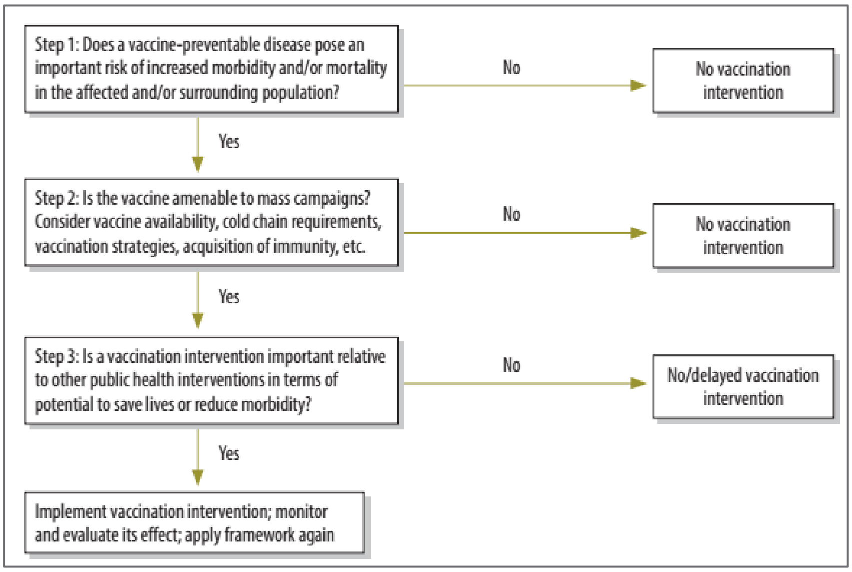

Figure 9 Flowchart on vaccine implementation related to ethical perspective (Moodley, et al., 2013)

5.2.2 Isolation and Quarantine Program

5.2.2.1 Socio-political Aspect

When isolation policy is implemented, the legitimacy and how public accepts the policy implementation can be an issue; since it can lead to socio-economic and political issues, to name a few.

- Reflecting, whether is it possible for policymakers to reduce social unrest within isolation policy implementation, by establishing mutual support among society at large and isolated people, can provide insights. Within context of isolation, this support can be nurtured by, for example, government facilitating sharing of food, logistics, and shelters among unaffected and the isolated population in crisis. In modelling context, accordingly, this social factor can be a scope for further research.
- Politically, isolation policy would be controversial, since it is plausible that government can face fierce political blaming due to perceived inability to prevent the outbreak in the earlier phase. This can lead eventually to political game. It is advisable, in this case, to come back to the art of framing, as to frame the emergency at outbreak crisis into the common values that are shared with larger fraction of the public, i.e. public health, long-term economic sustainability, national reputation, etc., onto the discussion table.
- Legally, implementing isolation policy to large scale population during outbreak should abide by the current implemented regulation of the region. This policy implementation may interfere to relevant public values such as autonomy, privacy, and independence, as well as financial interest. Therefore, working towards appropriate regulatory framework of isolation and quarantine is necessary. This step has been started, for example, in August 2016 by US Centre for Disease Control and Prevention (CDC) (Roth, 2016). Public hearing and participation towards improving such framework is necessary for obtaining formal consent and better public legitimacy.

5.2.2.2 Ethical Aspect

Regarding ethics of implementing isolation as policy to mitigate outbreak, a few points to be considered by decision makers:

- As discussed previously, isolating people has potentially negative consequences on multiple public values. Accordingly, policymakers should also consider the extent of infectiousness and fatality of the disease (Chan, 2014). This holds importance of monitoring the development of the outbreak over time and adapt the isolation implementation process, if necessary, accordingly. In this way, then, the difference of committing routine practices of disease mitigation and crisis response can be distinguished. (Chan, 2014)
- **The level of restriction regarding isolation**. This is related to two things: the extent of space restriction of the isolated population, and the procedural value regarding isolation enforcement. Policymakers should then consider raising awareness for people in committing voluntary isolation

(Upshur, 2003). Despite anything, the isolation policy implementation process should be carefully monitored, as smooth execution can reduce public opposition hence potentially improve its legitimacy.
- There are multiple layers of uncertainties regarding putting isolation into practice. Firstly, there are scientific and epidemiological uncertainties, especially related to how the policy can be considered effective (Bensimon, 2007). Additionally, as policies are implemented, there are accompanying uncertainties relevant to the policies themselves that cannot be ignored[9].
- From a consequentialist aspect, some reports suggest that in case of an outbreak, cost benefit should be thoroughly considered ((Chan, 2014); (Rubel, 2012)). Within disease outbreak context, this means when core belief / value of individual persons is against the mitigation policy, it will only be justifiable if it does not harm the basic value/interest of other population at large.

5.2.3 Hygiene Awareness
- Final part of policy advice discussion is related to effort of improving awareness to the population to commit vaccinations and improve their hygiene. While vaccinations can improve immunity of population, improving hygiene will on the other hand be able to reduce contact factor regarding contagion of the disease. Awareness improvement can be deemed more of an advocacy-oriented policy type compared to more action-oriented type approach of two previous policies.
- Given the softer orientation, there are hardly strong literature arguments to which we can consult the side effects regarding political side, ethical side, etc. However, we assume that there is a trade-off among effectiveness of the policies and the socio-political side effects. 'Hard policies' such as vaccination and isolation can lead to better model objective values with various side effects associated with them, that are not very much applicable to 'softer' policy such as hygiene awareness. More researches on this trade-off issues can be committed in the future.
- What also worth to mention here is that the differences of cultural norms can influence hygienic habits, so cultural norms and public values are supposed to be taken into consideration for developing effective interventions (Thompson, 2001)

5.3 Reflection – Credibility of Analysis
Given all the reflection associated with the policy operationalization, this section will briefly elaborate how the qualitative reflection can be inferred from the analysis. Elaborations are given in points below:
- Given the economic effect, ethical problem, and socio-political uncertainty regarding disease outbreak and the associated policies, it is argued that decision makers would prefer having robust policy levers. This requirement is specified given all the future uncertainties, that can be applied in the appropriate time frame. Previous discussion related to the implementation timing and appropriateness of isolation policy justifies our approach that adaptive design can be utilized to accommodate these concerns. In terms of isolation, overkilling the outbreak with too extensive magnitude of policy levers can lead to drastic economic downturn and other side effects.
- Despite the importance of adaptivity approach, there are some aspects which are equally important for insights and policy recommendation. There are two approaches for this: the ones regarding the scope of analysis, i.e. social unrest factor can be an opportunity for future research. On the other hand, the other ones related to communication, improving public debate, and consent issues should be considered as well during policy formulation and implementation. Accordingly, as previously discussed, the need of framing the content information and related strategies to the mass media and whole public is necessary.
- From the insights generated in the analysis, it is identified that only one uncertainty; Basic Reproduction Number is the only parameter that has relatively larger impact on the objective values. This raises a dilemma in terms of model structure; either the policies are robust and the uncertainty effects are mitigated, or the model is not dynamic and the feedback effects are ill defined in the model. This can be presented as a major critique of the analysis, or a successful achievement. The choice of framing and the credibility of the analyst/scientist are what legitimize the model. In the light of these findings, testing the model for comprehensiveness and having an adaptive approach with multiple scenarios becomes paramount.

[9] Refer section 3.1

6 Future Scope

Given the restricted time and scope of the project, the following aspects of the analysis are presented as future scope;

- Model Scoping
    - Adding social stresses in the model
    - Economic effects due to disruption
- Endogenizing policy levers to compute adaptation pathways using the model.
- Testing the process developed under methodology for multiple problems under the umbrella of deep uncertainty
- Comparing with Robust Decision making framework using Pareto optimal outcomes.

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