A Systems Analysis of the COVID-19 Pandemic Response in the United Kingdom – Part 1- The overall Context.

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Abstract

The most common reaction to suggesting that we could learn valuable lessons from the way the current pandemic has been/ is being handled, is to discourage the attempt; as it is suggested that it can all be done more accurately and authoritatively after the inevitable Public Inquiry (Bennet)*. On the other hand, a more constructive approach, is to capture and understand the work that was done, normal activities, positive adaptations to challenges and failures that may have occurred. Such an approach aimed at improving what worked, rather than blaming people for what went wrong, has the potential to contribute more successfully to controlling the consequences of the current crisis. Such an approach should thus be aimed at detecting and feeding back lessons from emerging and probably unexpected behaviours and helping to design the system to adapt better to counter the effects.*

The science and discipline of Human Factors (HF) promotes system resilience defined as organisational ability to adjust their functioning before, during or after significant disturbances (such as a pandemic) enabling adaptation and operation under anticipated and unanticipated circumstances. A "functional" approach methodology enables dentification of where the system and its various interdependent functions (an activity or set of activities that are required to give a certain output), could be improved and strengthened; if not immediately, at least for the future. Along these lines, suggestions for adding key resilience functions are additionally identified and outlined. The application and insights gained from this functional approach to the 2015 MERS-Cov pandemic in South Korea has been attributed to the effective response to the current crisis in that country (Min, 2020).

In this paper, we present an overarching framework for a series of projects that are planned to carry out focussed systems-based analysis to generate learning from key aspects of the COVID-19 pandemic response in the United Kingdom

The Context

Responding to outbreaks of new forms of infectious diseases, is a major challenge in today's global societies: being networks of complex interconnected sociotechnical systems. Since the turn of the century, the World Health Organisation (WHO) has declared a series of pandemics each with difficult and diverse challenges, namely SARS (2002/3), Swine Flu (2009), Polio (2014), Ebola (2014), MERS-Cov (2015), Zika (2016), Kivu Ebola (2018) and now COVID-19 (2019). The problems are exacerbated by very rapid propagation (Seventy-two hours to global infections (American Assoc, 2014), and unforeseen and unexpected behaviours with unique characteristics, causing varying degrees of medical, social and economic catastrophes.

This behaviour and the speed of spread of these pandemics is the outcome of the myriad of complex interactions between vectors and societies, as well as the type, timing and effectiveness of society's responses. Sound epidemiological modelling based on experience in previous outbreaks is vital, but these complex multiple interactions inevitably result in unforeseen and unexpected developments, which predetermined models cannot always predict and their predirected responses cannot often cope with.

Learning at a systems level from the current response to the COVID-19 outbreak is critical to respond to secondary waves or future new viral outbreaks. Public enquiries have already been called for. The problem is the clear need to learn at this moment, not retrospectively with potential negative connotations of focusing upon failures. A more constructive approach, is to capture, reflect and understand the work that was just been done or is on-going. The aim is to explore the normal activities, positive adaptations to challenges and failures that may have occurred in managing the current COVID-19 outbreak. Such an approach is aimed at detecting and feeding back lessons from emerging and probably unexpected behaviours and helping to design the system to adapt better to counter the effects.

The Problem

At present during this initial COVID-19 outbreak there is a gap in knowledge at a systems level of what is actually happening or has happened. In response, multiple novel initiatives have been developed to understand the effect on systems performance and impact on health (physical and mental) and wellbeing. There will be many studies which will aim to highlight issues and problems to be identified as the "root causes" of any failures pinpointed as responsible for how the system reacted to, or failed to cope, with the current crisis. But fixing single point failures to address current behaviours is no guarantee that they will solve the problems thrown up by the one to come. There is a need to explore and model the interdependent relationships and functions that constitute the current response to COVID-19. It is particularly needed here, as there has rarely been in recent history, such a high volume of decisions made, affecting all sectors / aspects of society at once or so closely. From a public health perspective, never have so many macro and meso level players had to adjust / adapt at once / in urgency. Decision-making at nearly all levels informed by little to no evidence base.

It is really important then, to model how the systems in place in the UK should have functioned and to observe how the effects of unusual variability in expected conditions affected them. There is also the need to reap the benefit of understanding the actual "Work as Done" (WAD) to meet the challenges of the COVID-19 outbreak. Professional insights into what went well and what went wrong, drawing upon WAD experiences are key to improve system performance and resilience for second waves or the next pandemic. Globally it is recognized that different countries have followed different pathways to respond to the COVID-19 outbreak. The potential to model functional interdependencies, their variabilities and emergent responses to the pandemic at a national level, utilizing the same analytical approach may reveal data to inform future decision-making.

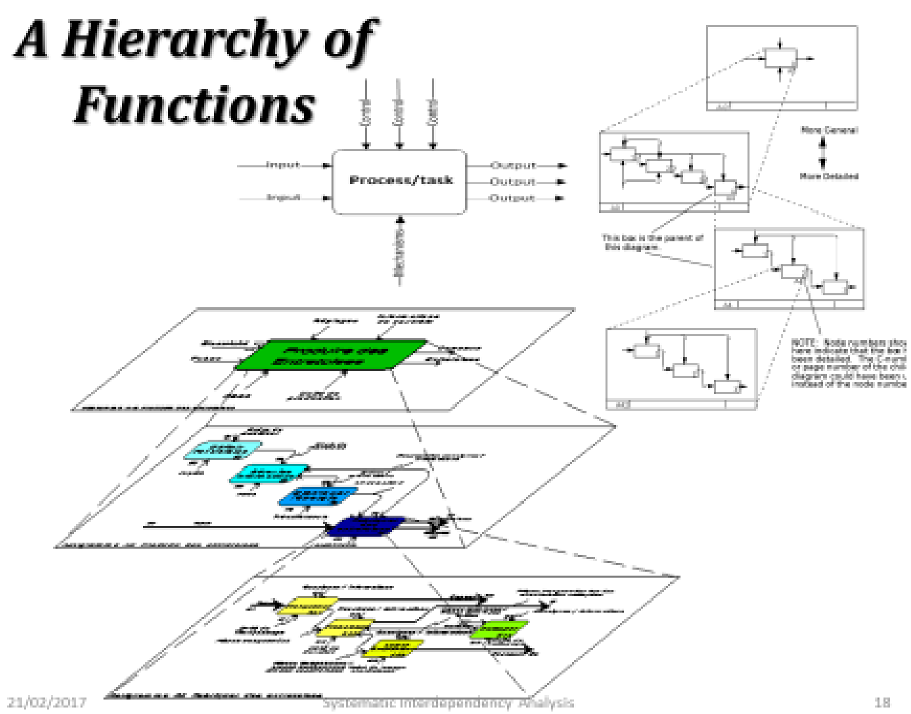
The Approach

The Functional Resonance Analytic Methodology approach (Hollnagel E.), seeks to describe and analyse the effects and outcomes of multifaceted interactions in real systems, to better to understand and predict the emergence of these surprises. It identifies and addresses a natural variability in the way "functions" interact in the real world, (as is), rather than assume they will always behave as imagined, in any predetermined "model" on which we are predicting "normal"

outcomes. Understanding how these functions actually interact then allows the scope for ensuring sufficient resilience in the system to cope with the actual ("normal"), variability to be expected.
The FRAM approach has been applied successfully to the way the South Korean Authorities responded to the 2015 MERS outbreak (Min, 2020). The aim of the study was to improve the system for the next pandemic. The approach and findings have been attributed as improving the current COVID-19 pandemic in South Korea. (Min 2020 reference) Min and colleagues (2020) are now exploring the current outbreak in South Korea using the same FRAM approach. A parallel study is planned in Sweden and Italy (Pers Comms Prof Hollnagel). In Australia, a suggested protocol for keeping "diaries" for significant observations on responses to emergent behaviours and "surprises" has been circulated (Braithwaite, 2020). In the UK the Safety Innovation Research Network (SIREN (Slater D. , 2020)) are committed to working on a number of projects using the FRAM approach to explore the UK response in more detail. The FRAM approach has been previously successfully applied in the UK to enhance sepsis management at the primary care level. (McNab 2018)
This paper aims to provide a macro system description and model as a common framework for UK contributions, to ensure all the details fit into a consistent picture, so that all the lessons learned can be upwardly compatible with this and other similar international studies. In order illustrate the FRAM method as a structured approach for generating learning about complex systems, this paper uses FRAM to describe the way in which the overall national pandemic response and management functions were deployed in the current UK COVID-19 response. The FRAM model provided forms the basis for spinning out and drilling down into a series of planned subprojects in the UK each aiming to build in resilience and learnings to better cope with this pandemic.

Methodology

Modelling complex sociotechnical systems is a major challenge, particularly in healthcare. This is because of the many variable and moving structural elements such as the capacity and the capabilities of staff under uncertain and variable conditions. To deal with such a complex picture, approaches have been successfully demonstrated in areas such as software, and computer systems, where components are treated as abstract functions (boxes), where physical and internal details are not necessary to understand what's going on. One of the methods successfully employed for accomplishing this is one which has been developed for modelling complex electronic systems - the Structured Analysis and Design Technique (SADT) (Marca, 1987).



This approach allowed complex systems to be modelled as fractal-like sets of interacting hierarchies (Fig. 1)

Fig. 1 The SADT schematic of nested functional boxes.

This also illustrates well its facility for modelling functions which are really an aggregation of a number of individual sub functions. The modeller is then able to look at a system from a top down high-level overview, while at the same time having the facility to probe into the internal structures of contributing function at the more detailed levels.

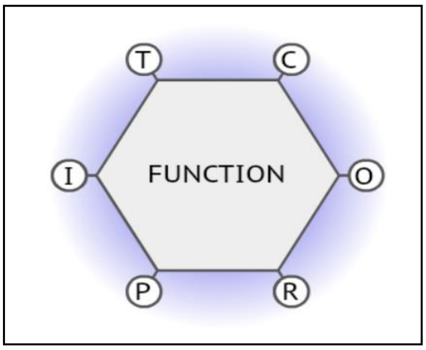
This allowed the building of functions into structures and to define and keep track of the myriad of interconnections involved. A classic example can be seen in the MARIA model of Portugal's Air Traffic Management System (Santos, 2016).

FRAM (Hollnagel E. , 2012), is an extension of this methodology and is now a well-established approach for modelling and analysing what goes on in highly intensive and hazardous operations of systems highly dependent on human performance to make them work successfully. Key examples of its application can be found in the Healthcare, Marine and Air Traffic control operations. A recent review has provided a useful reference list of the various different areas of application and the key centres of its ongoing development (Patriarca, 2020). It builds on the well-established SADT (Structured Analysis and Design Technique) with the crucial difference in that it can additionally cope with dynamic interactions between functions such as Timing and Emergence.

In principle, the methodology allows the analyst to build a "mind map" of the functions of the system and imposes a discipline of systematically and logically tracing exactly how the functions rely on their interactions with all the other functions; and what these interdependencies do to its ability to complete successfully, the task it was designed for. A fuller description is given in the manual (Hollnagel E. S., 2018). In most applications, the analyst constructs the system of functions from information researched on its purpose and designed operation, termed Work As Imagined. Issues identified are then followed up with the people actually doing the work and the practical insights can then be used to improve the system (and the FRAM visualisation – "as is").

It has usually been carried out as a qualitative probe, with the insights gained, triggered by the analyst systematically working through the mind map, or in discussion, where the FRAM visualisation forms a common picture as the basis for authentication with the operators. Recent developments (Slater) are working on enabling the automatic interrogation of the propagation of effects in FRAM models and the dynamic display of issues and “resonances” with specific links to aid the analyst in the systematic identification and communication of insights and issues. In this application, because of the complexity of the systems, the analyses had to be qualitative, using the FRAM models as mind maps. The key principles of these models can be seen in the following figures.

A FRAM function is normally represented as a hexagon with each of the 6 types of interlinking “Aspects”, having the ability to dynamically interact with other functions in its environment in the following categories



I – INPUTS – the interaction that starts the function
O – OUTPUTS – produced by the function
P – PRECONDITIONS – necessary before the function can operate
R – RESOURCES – drawn on by the function during operation.
T – TIME – any time constraints on its operation.

Fig. 2 – The FRAM hexagonal “Function” node

Then, activities in these complex systems are modelled solely as a set of hexagonal nodes of the required network of the necessary FRAM functions and not the physical agents, or components that implement the actions involved.

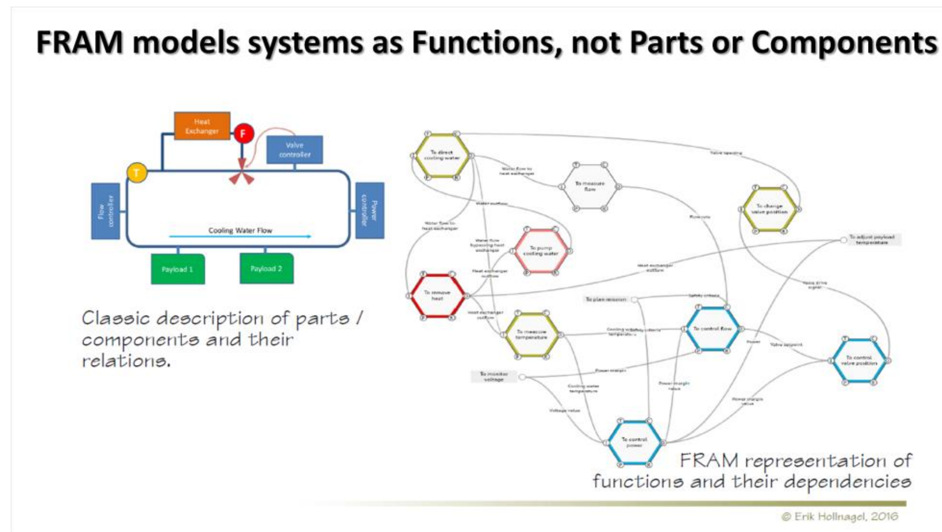


Figure 3 – Functional Modelling

This greatly simplifies the process being studied into a visualization of such activities as a series of interactions of these functions and their reliance for successful operation on critical (and naturally variable) interdependencies. These interdependencies, or Aspects of the function have been grouped into sets of six generic categories to help the analyst and these are set out below.

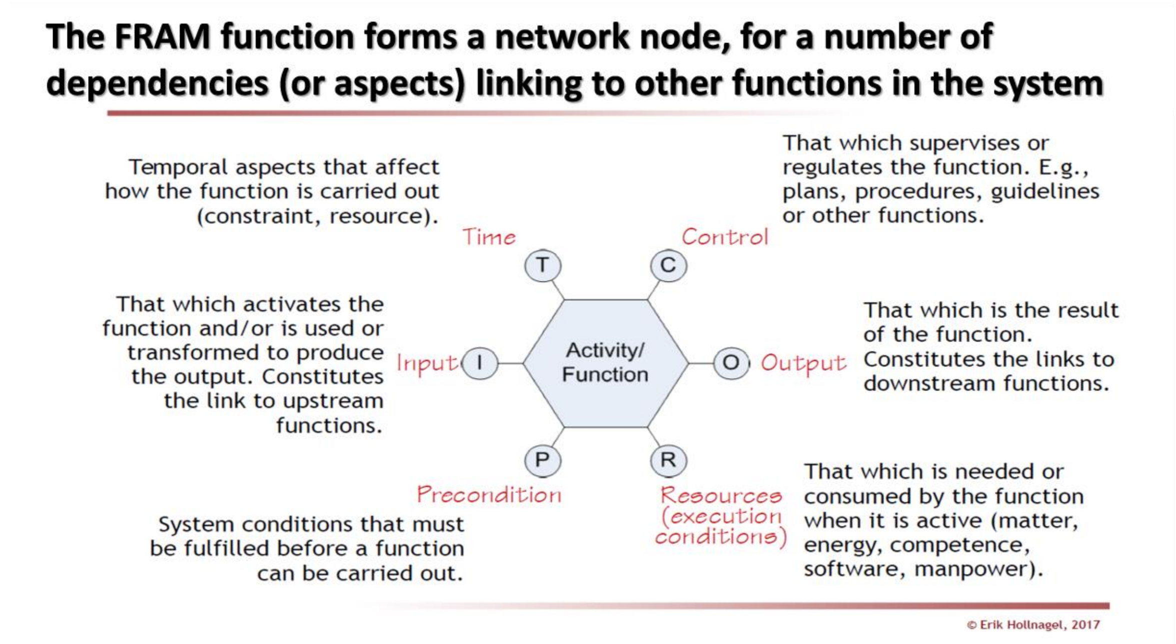


Fig. 4 – The categorisation of the "Aspects"

A High-Level FRAM

The response system for emergencies in government, involves a myriad of interacting people, ministries, agencies, committees and front-line responders. To deal with such a complex picture, the FRAM approach can then, as SADT, be employed to look at different aspects and various levels of detail. Recognising this, this paper sets out the high level, National Overview Model, in order to provide the framework needed to tease out the contributions of identified critical aspects which the teams will investigate. But both the framework and the individually developed sub-modules, will have all been developed using a consistent application of the FRAM methodology. This will involve a number of steps: -

Step 1 – Acquire Real time Records and Experiences

The first step will be to assemble a record of the experiences of the teams actually working in the healthcare responses (WAD). A useful blueprint and suggested pro-forma "diary" pages are outlined in Braithwaite et al – "Learning from COVID-19 in real time: Expressions of Resilient Performance during the Pandemic" (ref). Adopting this common, globally initiated template approach, will give us the possibility of using a wide range of data from different countries as a resource.

Step 2 – Model the System

The second step is to build and analyse the FRAM model: -

1. Identify the essential functions active in the process.
2. From the Timeline observed, identify the critical points in the process where there was a distinct change in how the system behaved – the instantiations
3. Determine and assign the observed variabilities in function interactions and how these propagated to affect other functions
4. Trace out and evaluate how these variabilities affect and propagate through the various critical instantiations involved.

5. Identify, analyse and test how the system and critical function performance reliability can be improved; and how resilience can be added as additional and organisational resilience functions.

Step 3 – Development and Assessment of Improvement Options

This step will draw on the experience of the team, the insights from this and other approaches to develop and assess options for ensuring a better and more resilient systems. This will be discussed and tested against experiences and learnings from other countries approaches

Results

Model Completeness and Correctness.

A number of sources (UK, 2020) were used to identify the key functions. The following model (Figure 5) was then produced as the first step in the overall project. It is planned to produce a more detailed analysis, fleshing out steps 2. And 3, when the results of some of the more detailed studies become available. The focus of this paper though, is to build and validate the overarching model, which will set the framework and provide the background functions for all the detailed studies proposed as follow up. For a model this complex, it is not possible to trace reliably and check systematically, every interaction between the functions identified and specified. As these non-linear interdependencies are critical to the way in which the model will predict how the "as imagined" system will operate and respond, a formal and systematic check of the model's viability has been undertaken. The FMI (FRAM Model Interpreter) method employed has been developed by Hollnagel (Hollnagel E.), as a way of analysing the implications from the model presented. The methodology sets out to explore how changes to upstream functions affect the downstream functions. This can show how the dependencies defined by the aspects, determine the order of activation. the FMI is thus basically a set of production rules. Production rule systems, an approach widely used in artificial intelligence in the 1980s, are defined as follows:

"A production system (or production rule system) is a computer program typically used to provide some form of artificial intelligence, which consists primarily of a set of rules about behaviour but it also includes the mechanism necessary to follow those rules as the system responds to states of the world."

Table 1 – Overview Model Validation

FMI log
Begin initialisation
Entry function <To cause a significant infectious disease outbreak>
Exit function <To control the Pandemic>
--- MODEL INITIALISATION COMPLETED.
BEGIN CYCLE 1
Function <To provide expert Advice> has been activated.
Function <To Provide Policy Advice> has been activated.
Function <To initiate an infection custer> has been activated.
BEGIN CYCLE 2
Function <To Decide Response> has been activated.
BEGIN CYCLE 3
Function <To Decide the National Interest> has been activated.
BEGIN CYCLE 4
Function <To Authorise National Response> has been activated.
BEGIN CYCLE 5
Function <To Manage Response> has been activated.
BEGIN CYCLE 6
Function <To communicate Policy> has been activated.
Function <To provide medical needs> has been activated.
Function <To prevent UK outbreak> has been activated.
Function <To Provide Testing Facilities> has been activated.
Function <Description:Drug Companies> has been activated.
BEGIN CYCLE 7
Function <To respond to Events> has been activated.
Function <To supply PPE> has been activated.
Function <To supply Ventilators> has been activated.
Function <To supply Oxygen> has been activated.
BEGIN CYCLE 8
Function <To produce an effective treatment> has been activated.
BEGIN CYCLE 9
Function <To manage healthcare> has been activated.
BEGIN CYCLE 10
Function <To Provide Social Care> has been activated.
Function <To provide community Care> has been activated.
BEGIN CYCLE 11
Function <To provide Clinical response> has been activated.
Function <To administer Intensive care> has been activated.
Function <To Test for Virus> has been activated.
BEGIN CYCLE 12
Function <To Trace and isolate Contacts> has been activated.
Function <To Prevent Importing Cases> has been activated.
BEGIN CYCLE 13
Function <To Quarantine Cases> has been activated.
Function <To ensure compliance> has been activated.
BEGIN CYCLE 14
Function <To monitor the effects> has been activated.

The basic principle is that each function “looks” for the conditions that may activate or “trigger” it. If those conditions exist, the functions are activated, and the output is generated.
This output will then be detected by other (downstream) functions, which then will become activated, and so on. In this way the activity is propagated through the model according to how the relations between functions have been specified, i.e., according to the potential couplings defined by the aspects.

The Table shows the FMI analysis results for the overview system FRAM produced here, consisting of 33 functions, (Appendix 1) and shown below in Figure 5.

An initial “walk-through” of the way the analysis describes the way the system has actually behaved, gives us confidence that it is sufficient to employ as a first pass. This model will be further developed to act as a linking narrative for all the Future Work planned.

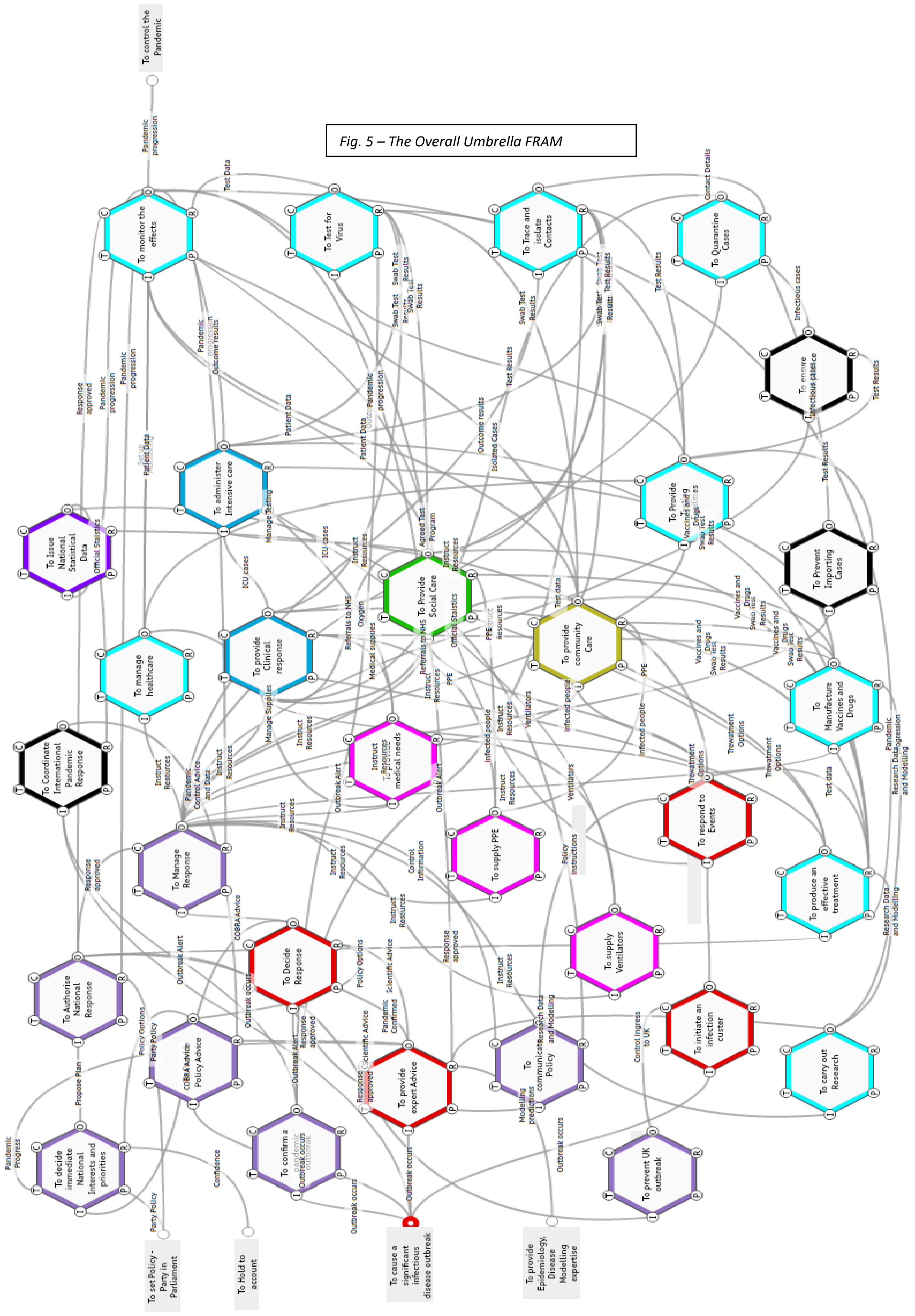


Fig. 5 – The Overall Umbrella FRAM

Future Work Planned

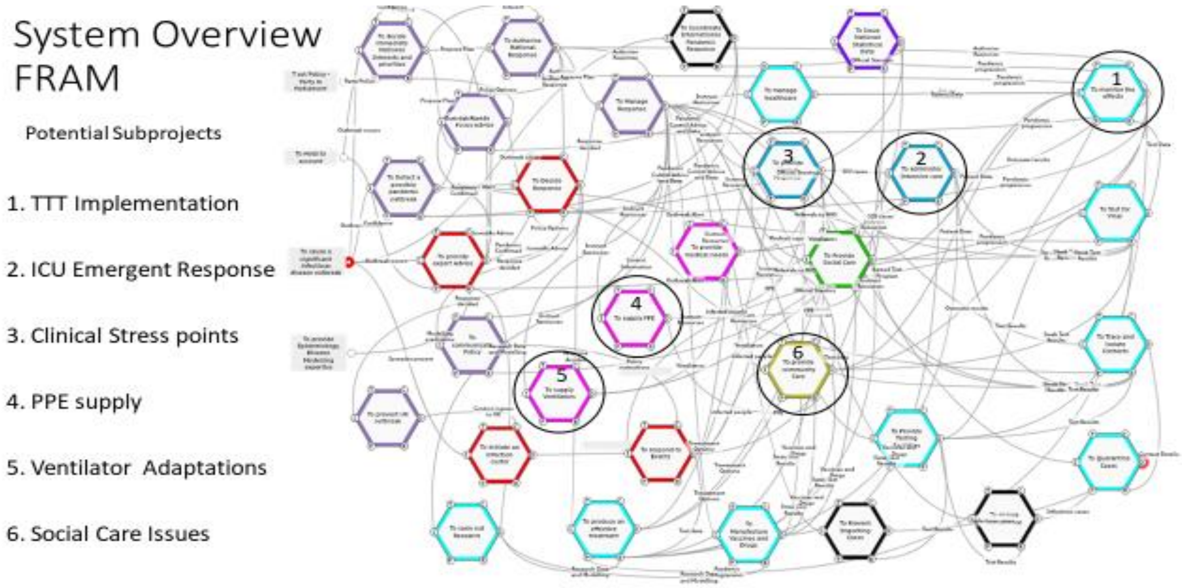
There are many important issues at many levels of operation, such that some overall structure needs to be established to try and see the overall picture. As this approach can let us drill down into the inner workings and details of the response, it is proposed that this overview FRAM will form the overall "umbrella" schematic for a learning project along the lines of the MERS 2015 South Korean study and report. This will establish the framework and background boundary functions for a number of follow up projects developing the details of specific aspects.

Within this framework we therefore, we propose to highlight a number of key areas as sub projects.

These will include:-

1. Infection control in the University Hospital for Wales Emergency Department during the pandemic and its recovery
2. Responding to the intensive care challenges of COVID-19 in Manchester
3. The management of team performance - the prolonged effects of crisis on the responders – Epsom and St. Hillier
4. The specification, adaptation and supply of personal protective equipment – Business School - Cardiff
5. The Development of guidance for rapidly manufactured ventilators - CIEHF
6. The primary care outcomes - Glasgow

These points of interest are identified in this Umbrella Framework – National Response to COVID-19 - illustrated below.



To ensure consistency of approach of the individual sub projects' models, both within the framework of this project and the future compatibility and comparison with the other international FRAM Projects, it is proposed to have a central coordinating group and peer review process.
This group will offer an independent review of the process and findings from the individual studies to ensure academic rigour and optimal learning for NHS organisations. The project is the result of initial discussions and contributions from the UK's Safety Innovation and Research Network (SIREN),

whose members will form the participants in the project teams. These projects will run separately and concurrently with individual teams and team leaders.

Conclusions

The paper describes the application of a system modelling approach to provide an understanding of how to improve responses to pandemic emergencies based on the current experience. An informative model of the current UK response is presented is a framework for proposed future national and collaborative international studies. It is hoped that such a series of objective systems analyses can provide insights on how to successful adapt to provide the resilience needed in practice. Such insights are greatly aided by a clear visualisation of the complex interactions and interdependencies involved. It is envisaged that this FRAM approach will significantly assist designers of improved systems for this and future pandemics.

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Appendix 1 – Function List

Function Number	Description	Comment
0	To cause a significant infectious disease outbreak	Entry Function
1	To Decide Response	
2	To provide expert Advice	
3	To Provide Policy Advice	
4	To Manage Response	
5	To manage healthcare	
6	To communicate Policy	
7	To provide Clinical response	
8	To provide medical needs	
9	To Provide Social Care	
10	To provide community Care	
11	To Authorise National Response	
12	To monitor the effects	
13	To respond to Events	
14	To initiate an infection cluster	
15	To prevent UK outbreak	
16	To supply PPE	
17	To supply Ventilators	
18	To produce an effective treatment	
19	To administer Intensive care	
20	To Test for Virus	
21	To Trace and isolate Contacts	
22	To Provide Testing Facilities	
23	To Quarantine Cases	
24	To ensure compliance	
25	To Prevent Importing Cases	
26	To carry out Research	
27	To supply Drugs, Vaccines	
28	To set Policy - Party in Parliament	
29	To Hold to account	
30	To provide Epidemiology, Disease Modelling expertise	
31	To control the Pandemic	Exit Function
32	To Decide the National Interest	
33	To supply Oxygen	