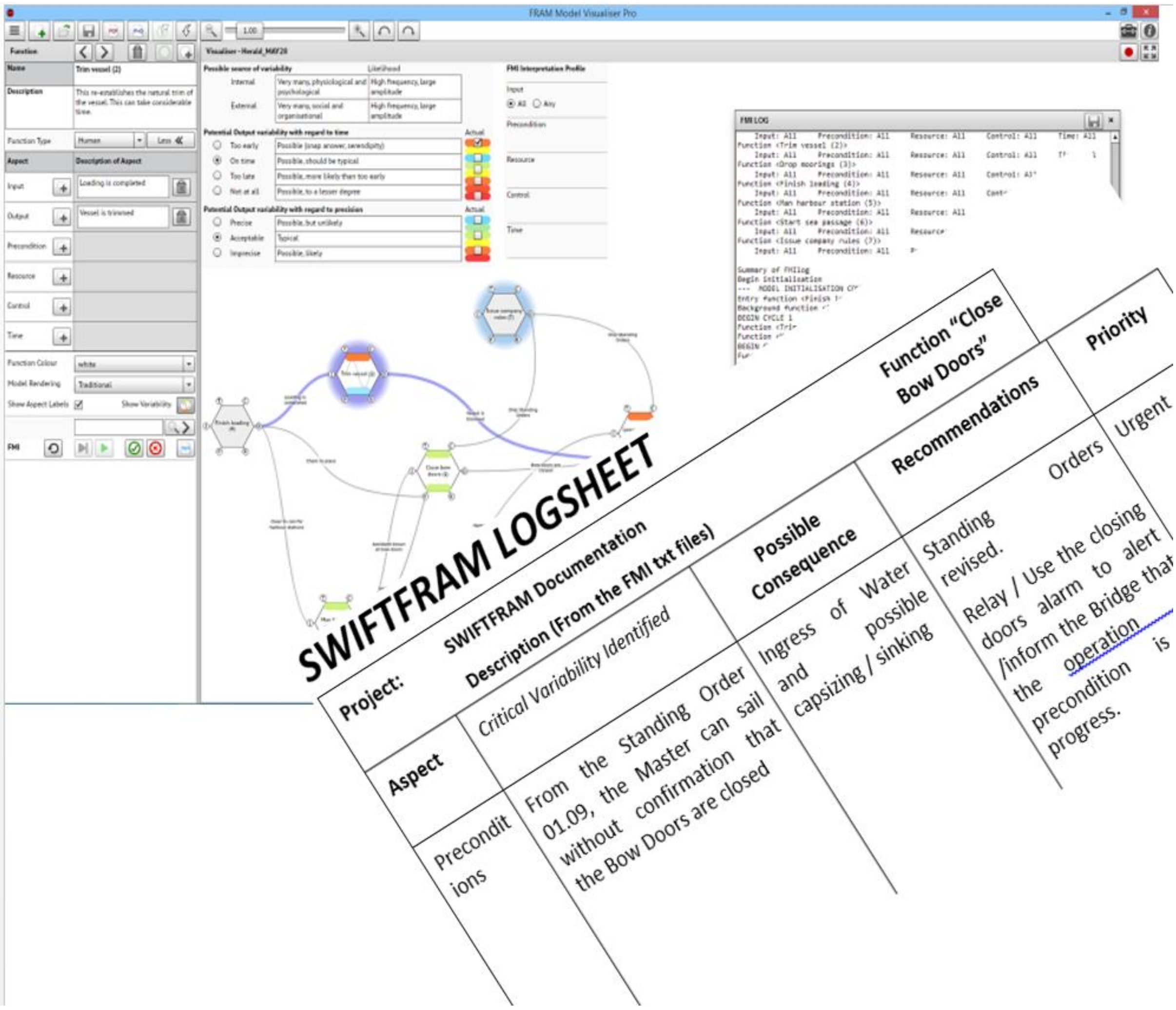


8/22/2020

FRAMSYNT

"SWIFTFRAM"

PREDICTIVE ANALYSIS OF COMPLEX SYSTEMS' BEHAVIOUR

PREDICTIVE ANALYSIS OF COMPLEX SYSTEMS' BEHAVIOUR

Rees Hill, Mark Boult, Mark Sujan, Erik Hollnagel and David Slater

"No one designs systems to fail, but they sometimes design systems that are difficult to understand"

> *"Although HAZOP is a valuable technique, no-one jumps out of bed on a Monday morning shouting, 'Hooray! I've got a HAZOP today!*
>
> *There is a net loss if, in our eagerness to document it and explain it to everybody, we discover less information worth documenting.*
>
> *If HAZOP and similar systems are not acceptable to creative minds, they will never succeed."* **T.Kletz HAZOP & HAZAN**

ABSTRACT

Complex systems present a challenge to designers and users alike, in that it is difficult to be confident that the current, tried and tested methods of analysing and predicting systems' behaviour can cover all of the variabilities experienced in their practical operations in the real world. Progress has been made using approaches (such as Accimaps (Rasmussen)*, STAMP* (Leveson) *and FRAM* (Hollnagel E.)*), which have attempted to take a higher-level view of the various factors and influences which affect behaviour. One of these,* (Hollnagel E.) *has proved useful in improving the operation of intensive, high stress operations, such as in aviation and healthcare, which require an understanding of how different and unusual developments affect the successful outcomes of procedures and practice and suggest insights as to how they can be managed better. This Functional Resonance Analysis Method (FRAM), is utilised essentially as a way of representing systematically all the interactions and interdependencies that take place, or need to take place, to get the job done. These very important, but largely qualitative insights are then used to improve the system and/or its operation in an essentially informal way. Similarly, the FRAM "models" are not necessarily internally or intergroup consistent and tend to reflect particular interests and interpretations of the various users, now in some 14 countries. To systems analysts from a more formal background, this approach lacks the mathematical rigour and systematic application needed to reassure them, that such insights are a result of the methodology, not just the expected better understanding gained from a systematic common and concerted non-linear "mind mapping" of the system. This paper sets out to address this issue and develop the methodology to a more formal and hence a more traditionally acceptable approach to rigorous systems analysis. It explores the options available to help establish the approach more widely and utilise the full potential of the method in not just better understanding, but credibly predicting the behaviours of complex systems.*

Guidewords – FRAM, SAFETY II, Complex systems,

Context

Predicting the behaviour of systems is relatively straightforward if you have a reliably accurate "model" of how the system works. Even in the absence of this understanding, if there is sufficiently convincing historical data on how the system, as a "black box" responds to various inputs and environmental conditions, confident predictions can be made as to its future behaviour. The problem arises when the simple systems become complex". Defined as -

"Complex systems are systems whose behaviour is intrinsically difficult to model due to the dependencies, competitions, relationships, or other types of interactions between their parts or between a given system and its environment. Systems that are "complex" have distinct properties that arise from these relationships, such as nonlinearity, emergence, spontaneous order, adaptation, and feedback loops, among others." ((Wiki)

Here it is difficult to obtain a comprehensive and comprehensible picture of what is going on in the system in sufficient detail to apply (combinations of) simple mathematical rules to calculate the predicted behaviour. Even extensive operating data cannot be guaranteed to be a reliable guide to how a complex black box will behave in all circumstances encountered. As most practical systems in everyday usage are, by nature, complex, this presents a real challenge for system engineers, designers, implementers, operators and users.

Systematic probing of complex systems' behaviour in practice is not new. In the 1960's, ICI in the UK developed an approach, termed Hazard and Operability Studies(HAZOPS) (Kletz), which are now a standard methodology for checking the practicalities of implementing theoretical designs and facilitating thorough reviews of applications; such as commissioning of new plant and maintenance and changes to existing ones.

The emphasis in carrying out these studies was always, as much on practical insights and improvements, as anticipating potential problems. The technique relies on involving, as well as enabling, operational experience and insights; as well as establishing and ensuring the realisation of design intent through appropriate study team members and effective facilitation.

The technique works well with engineering and process plant systems; as these can be comprehensively described and understood from standard Process Flow Diagrams and Process and Instrumentation Diagrams (PFD's and P&ID's). Attempts to extend the approach to softer and more complex systems, such as software programming and healthcare, have proved more problematic. One of the main issues has been the difficulty of producing P&ID equivalents for the teams to focus on.

The crux of the approach is thus to formulate and formalise a common "picture" of the process involved and how it was designed to operate successfully. The vagaries of the real-world operational environments were then superimposed systematically, as variabilities in the prevailing conditions; and the resulting effects traced and probed. The insights achieved could result in significant, both operational and safety improvements in practice.

Now, a similar approach has been developed, for analysing the subtleties of the behaviour of complex systems, i.e. such as those involving humans, using a new technique which looks at the critical functions involved in the process and the effects of variabilities in their interactions. This methodology, the Functional Resonance Analysis Method (FRAM) (Hollnagel E.), is finding increasing application in high hazard, highly intensive operations in Healthcare and Aviation. But the essential objective is very similar. This can be expressed as the desire to ensure that the actual operational details (Work as Done), are recognised and to identify what makes a system work successfully in the light of the natural and inevitable variability in the conditions in which it happens in the real world. To risk analysts and safety professionals in the "harder" engineering areas, however, the technique has hitherto been viewed as more of a useful "mind map", with none of the formality and rigour in application they are used to.

But the potential additional contribution of this approach, is to provide a useful way of "picturing" the process, or procedure, under consideration; in a way that formal written descriptions, or instructions find difficult. Although the formal tomes of the ubiquitous Safety Management Systems look impressive, they often bear little resemblance to what actually happens "out there"!

So this paper suggests that a development, or combination of these two approaches could result in a useful, formally structured technique for the analysis of processes and procedures "as performed"(WAD),and systematic interrogation of the effects of variability in the interactions of critical functions as the process progresses.

This is thus a natural extension of the technique to provide a full SAFETY II (as well as the traditional identification of failures SAFETY I), approach. One could then term it a STRUCTURED WHAT IF TECHNIQUE using FRAM – **"SWIFTFRAM"**

FURTHER DEVELOPMENT OF THE METHODOLOGY

The challenges to taking the development further can be set out in three phases.

1. To build up confidence in the credibility of the "model"
2. To show how it can be used to facilitate a more structured and systematic analysis of complex systems, and
3. How the analysis can be used to predict reliably, the expected behaviours of such systems in unexpected, but not inconceivable, conditions.

1. MODEL CHECKING AND INTERPRETATION

There have been a number of attempts at employing a formal methodology to check the FRAM models for completeness and correctness. ((Hideki?) FRAMily, etc.)

Many have not been successful in that they have tended to treat the FRAM model as a fixed, predetermined logic diagram, which can be tested with approaches such as - (Eric?)refs---------. These studies do, however, demonstrate a real need and legitimate interest in having a more formal and transparent checking of their completeness and "sense".

Recent work by Hollnagel, has put forward a technique, FRAM Model Interpretation, (FMI) (Hollnagel, n.d.)which now sets out to provide this assurance step. Essentially the approach consists of initially "parsing" the model, to check that the "structure" is sound and legitimate. All interactions obey the "rules". All interactions make sense and there are no inappropriate "loops", or links involved or implied.

The method involves first checking whether the model is syntactically correct. An important part of that is the identification of orphans that the FMV provides. Other problems are potential auto-loops where the Output from a function is used directly by the function itself, or functions where the specification is incomplete because there is no Output.

A second aim of the FMI is to identify the differences between potential and actual couplings among functions. A FRAM model describes the potential couplings among functions, i.e., all the possible ways functions are related as specified by their aspects. In contrast to that, the actual couplings are the upstream-downstream relations that occur when an activity is carried out, which means when the FRAM model is realised for a set of specified conditions.
A third aim is to determine whether the activity described by the model in fact will develop as intended. In a FRAM model each foreground function defines a set of upstream-downstream relations through its aspects. The question is whether these relations are mutually consistent and whether they in fact will allow an event to develop as intended.
It is all too easy in a complicated model to have functions that mutually depend on each other, which in practice may lead to conditions where functions wait forever for an aspect to become fulfilled. The FMI can identify these cases by interpreting the model step-by-step while keeping track of the status of all the aspects and activation conditions.

PRINCIPLES OF INTERPRETATION

From a programming perspective, the FMI has been developed as a production system (sometimes called a production rule system). Production systems were widely used in artificial intelligence in the 1980s and 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.

So, the FMI is essentially a collection of production rules. The basic principle is that each function "looks" for the conditions that may activate or "trigger" it. These conditions include the Inputs, of course, but also the status of the aspects that have been defined for a function. If those conditions exist, the functions is 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. Technically speaking, the FMI relies on asynchronous parallel execution of the functions. (It is, of course, a pseudo parallelism rather than a true parallelism.) The interpretation is asynchronous because there currently is no practical way to define a reference "clock time" – let alone real time – in FRAM models. This means that the Time aspects only can be used to describe temporal relations between functions, such as "before", "after", or "while".

2. ANALYSING AND PREDICTING FROM THE FRAM MODEL

Establishing confidence in the model is just a start. The main reason for building it is to derive a more holistic understanding of what's happening in the system and how all the functions interact to produce the behaviours expected in the steps (instantiations) of the process being undertaken. What is now crucial is, not just whether the links are made in the right order, but whether they are effective. This is where the analyst needs to acknowledge the sort and extent of natural (and unnatural) variability in the timing or precision of these interactions and interdependencies. And it is not just the implications of this variability for that particular function's output, or completing that instantiation successfully, there is also the question of how that propagates through the system and sets the scene for subsequent steps and instantiations.

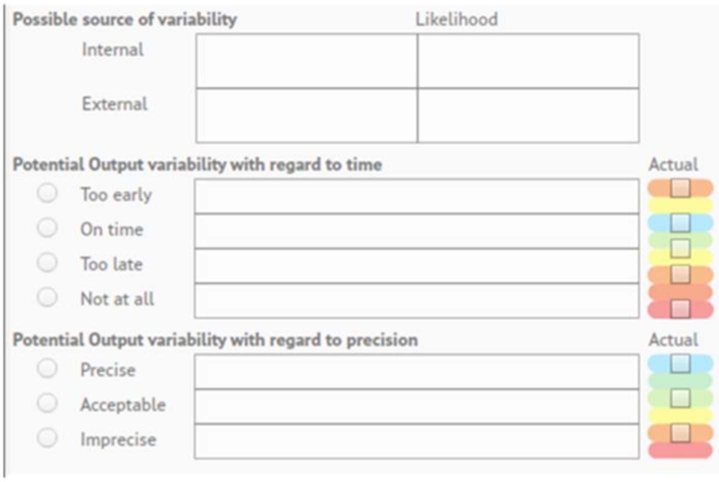
The interpretation of the model checks whether a link has been made (as imagined), the analysis needs now to question whether there are any circumstances under which something different can happen. "What if this interaction is not exactly what is expected?", "What if" and "what something else is possible in real life situations?" Traditionalists will recognise that this is exactly the same process required by the ICI HAZOP deliberations (Kletz, n.d.) on the implications of deviations from design intent (as imagined). These guide words "too much", "too little", "too soon", "too late", are familiar variabilities which can be used systematically function by function, aspect by aspect to tease out the web of interactive effects implied by the model; and checked against experience..

These implications are normally explored in a traditional FRAM analysis. But now with the addition of the FMI the software can prompt us through the sequence, highlighting the critical interactions at each step or instantiation.

More formal ways of tracking the propagation of these variabilities through the FRAM model have been proposed previously in various studies. (ref). Most rely on being able to change the development of the process – the emergence of different behaviours, by formulating a rule on the effect expected, in decision tables, (ref). Another approach relates the interaction of functional variabilities in a way such that these variabilities can be amalgamated randomly to produce a distribution of expected effects in a Monte Carlo analysis (Patriarca, n.d.). A more pragmatic approach (Hirose, n.d.)(ref), attempts to use Fuzzy logic to relate and combine these variabilities to assign a Degree of Variability (DOV) for a particular function Output and to continue the process sequentially with each of the new outputs in turn, in the next step. (ref). A similar approach has been attempted by treating each instantiation as a system of interlinked Bayesian Belief Nets, (Slater), whose predicted probability of success emerges as the result of the propagation of predictions of the probability of success of the contributing functions. So, there are a number of options available for completing this step, but perhaps the tried and tested HAZOP analogue would seem well worth pursuing.

3. A Formal, Structured and Systematic Analysis Process

The current FMV software (Hill R. , n.d.) has a feature which invites the analyst to specify what kind of function is involved in executing that step, (a Technical component (T), a Human operator (H), or an Organisational responsibility (O). The dialogue box below (Fig 1) suggests / allows the analyst to input a generic expectation, or an actual choice for specific scenarios or "What If" speculations.



So, the FMV Software can step through the instantiation and for each function ask the question, what effect will the variabilities in the outputs of each function in turn, have on the downstream functions' operation? The software then indicates this with the corresponding coloured bands on the hexagons. The upper band indicates the variability in Precision and the lower one in timing.

This feature then allows the introduction of a formal Structure to the analysis.

The systematic function by function exploration of the various Work as Done variations possible and the teasing out of the what if consequences for each in turn. This then lends itself to a formal record of the issues identified and opportunity to suggest adopting improvements or recommending solutions to them. This process would be significantly enhanced if this process is carried out by a team involved and experienced in the particular situations under examination.

How It would work In Practice?

The first step would be to build the FRAM model

- Define the system process procedure to be studied as a "Process Diagram", detailing the way the system was designed to operate successfully.
- With this information, the functions contributing can be identified and the interactions involved shown on a standard FRAM model (as described in the FRAM manual).
- This model can be tested in a walk through with key people involved.

The Model is then checked /verified formally using the FRAM Model Interpreter capability of the FMV software (FMI Manual). This gives

- A formal parsing (verification, model checking) of the FRAM model
- An identification of the Entry (starting), Exit (completing) function(s) and the Background functions' states at the start.
- A systematic, automatic walkthrough of the process, showing which interactions are active and which are not at every step.

Next a formal Variability and Propagation Analysis is done

- Using the animated, FRAM Model Visualizer (FMV) software to prompt the analyst / team to step through the process, systematically and sequentially allowing the model to predict emerging situations for assessment.
- This is probably best illustrated by considering the example below.

EXAMPLE APPLICATION

1. Assemble the data on the process

The example considered is the loading and departure of a ferry from a port berth. It is chosen as this is a routine process normally successfully carried out many, many times in ports all over the world. The specific illustration taken, the Herald of Free Enterprise's departure from Zeebrugge, is selected on the grounds of familiarity and the ready availability of authoritative details. It is illustrative only – and the full details are available in the official report (htt)(https://www.gov.uk/maib-reports/flooding-and-subsequent-capsize-of-ro-ro-passenger-ferry-herald-of-free-enterprise-off-the-port-of-zeebrugge-belgium-with-loss-of-193-lives)

The relevant details are set out as quotations below-

"On the 6th March 1987 the Roll on/Roll off passenger and freight ferry HERALD OF FREE ENTERPRISE under the command of Captain David Lewry sailed from Number 12 berth in the inner harbour at Zeebrugge at 18.05 G.M.T.

The HERALD and her two sister-ships were built for the Dover-Calais run. They were built with very powerful engines, capable of rapid acceleration, in order to make the crossing at high speed. It was intended that they would disembark their passengers and vehicles rapidly and then without any delay embark passengers and vehicles for the return voyage. On the Dover-Calais run these ships are manned by a complement of a Master, two Chief Officers and a Second Officer. The officers are required to work 12 hours on and not less than 24 hours off. In contrast, each crew was on board for 24 hours and then had 48 hours ashore.

The HERALD was manned by a crew of 80 hands all told and was laden with 81 cars, 47 freight vehicles and three other vehicles. Approximately 459 passengers had embarked for the voyage to Dover, which they expected to be completed without incident in the prevailing good weather.

At Zeebrugge (1) only two deck officers were available, (2) only one deck could be loaded at a time, (3) it was frequently necessary to trim the ship by the head, and (4) the bow doors could be closed at the berth. Because of these differences, with proper thought the duties of the deck officers at Zeebrugge would have been organized differently from their duties at Calais. No such thought was given to the matter, with the result that immediately loading was complete the Chief Officer felt under pressure to leave G deck to go to his harbour station on the bridge.

There was a light easterly breeze and very little sea or swell. The HERALD passed the outer mole at 18.24. She capsized about four minutes later. During the final moments the HERALD turned rapidly to
starboard and was prevented from sinking totally by reason only that her port side took the ground in shallow water. The HERALD came to rest on a heading of 136" with her starboard side above the surface. Water rapidly filled the ship below the surface level with the result that

not less than 150 passengers and 38 members of the crew lost their lives. Many others were injured. The position in which the HERALD came to rest was less than 7 cables from the harbour entrance.

Bow and stern doors

It is necessary to give a more detailed description of the lower car deck (G deck) and its doors. The HERALD, in common with other modern Ro/Ro ferries, had an enclosed superstructure above the bulkhead deck. For this to be considered as contributing to the ship's intact stability it must be weathertight.

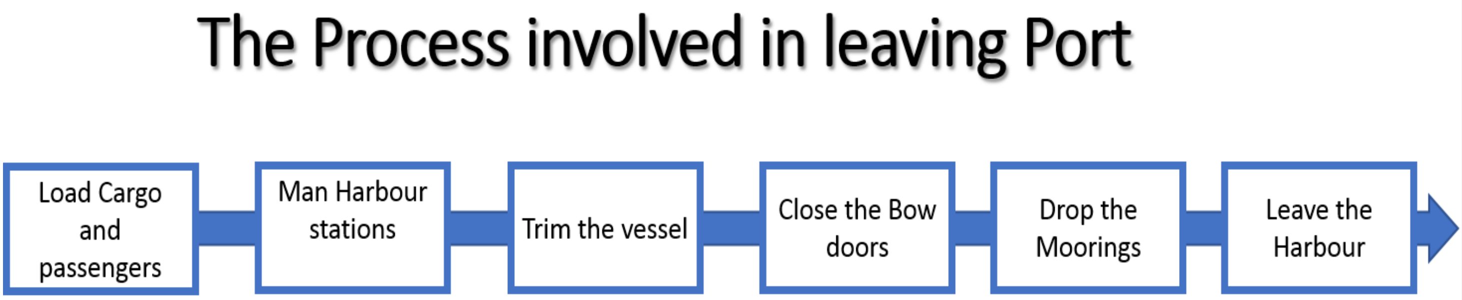
It should be noted that the term "weathertight" does not imply that the condition is of a lower order of tightness than "watertight". Watertight is applied to doors and bulkheads where there is the possibility of water accumulating at either side. Weathertight applies to doors or openings which are only required to prevent the ingress of water from the side exposed to the weather.

All the vehicle deck bow and stern doors were hydraulically operated and were so arranged that they swung horizontally about vertical axes, on radius arms. Their weight and movement were supported by rubberised rollers (or wheels).
The doors stowed against the ship's sides when open. They met at the centre line so that one door
stowed to port and the other to starboard. The inner bow doors were lock gate type. They opened in a forward direction and stowed against longitudinal bulkheads to port and starboard.

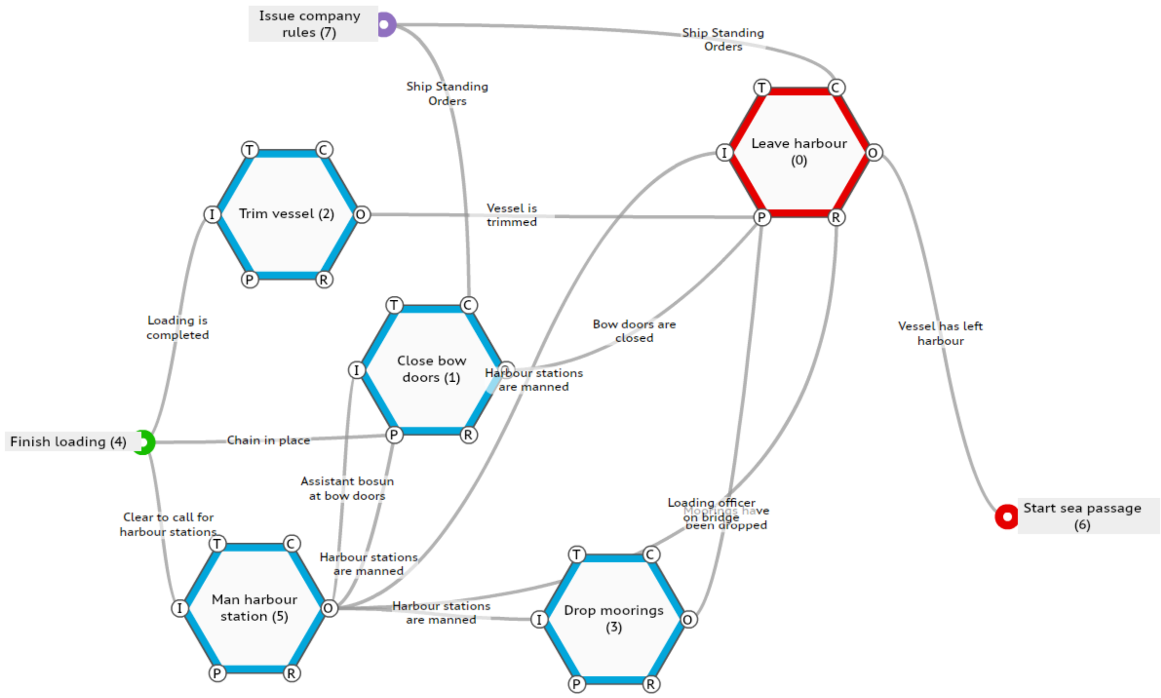
In the closed position, water-tightness was maintained by compressing tubular neoprene seals around the outer periphery of the doors. Closure of the doors and the compression on these seals was maintained by a system of clamps and dogs which were hydraulically operated. The dogs were forced by hydraulic cylinders into box shaped blind-ended apertures in the deck head and on the car deck. There were limit switches which controlled the distance during which full pressure needed to be applied.

The hydraulic pressure to the opening/closing rams was piped through directional control valves which were actuated by a lever in the control box. This control lever, like the clamping lever returned to the off position when the operator released it. There was an alarm bell which rang whilst the doors were in motion. The bell was a safety device to prevent anyone being caught unawares and in the event, should not have been switched off.
There is no reason to think that there was any fault which would have prevented the doors from being closed hydraulically.

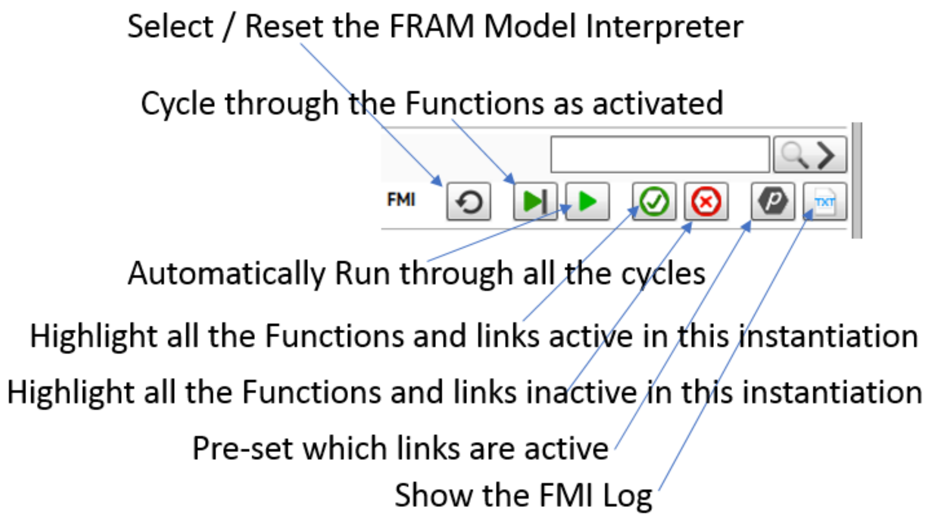
The example will use a much-simplified process just including the main Tasks that need to be executed to enable safe departure from harbour – As shown in the simplified process flow diagram below



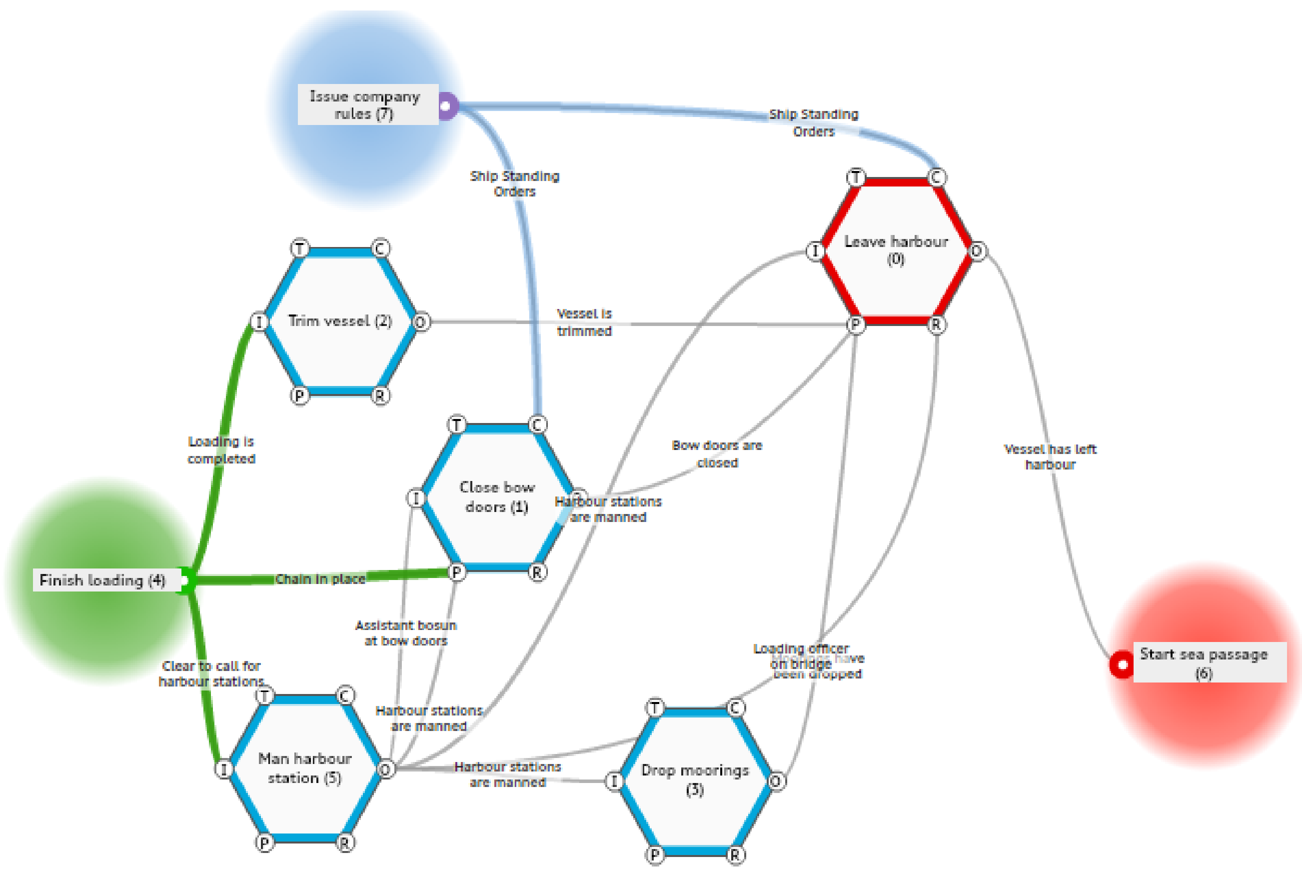
2. We can now build a FRAM model of the process and procedures as specified in the description to systematically probe the variabilities of the Aspects and Functions. A simplified FRAM model built from this information is illustrated below



3. The model can now be checked for completeness and correctness, using the FRAM Model Interpreter facility in the FMV software.



As seen from the FMV highlights and the analysis log below, the model first correctly identifies the entry Function (Finish Loading - Green) and (Start Sea Passage - Red), the exit functions. There are no orphans or loops and the cycles of activation progress smoothly; i.e. the sequence of activation of the upstream and downstream functions match the description of the process from the information acquired.



So as shown in the illustration below, the FMI Log parses / passes this simple model as valid and tabulates the functions and aspects active in the different cycles of the instantiation.

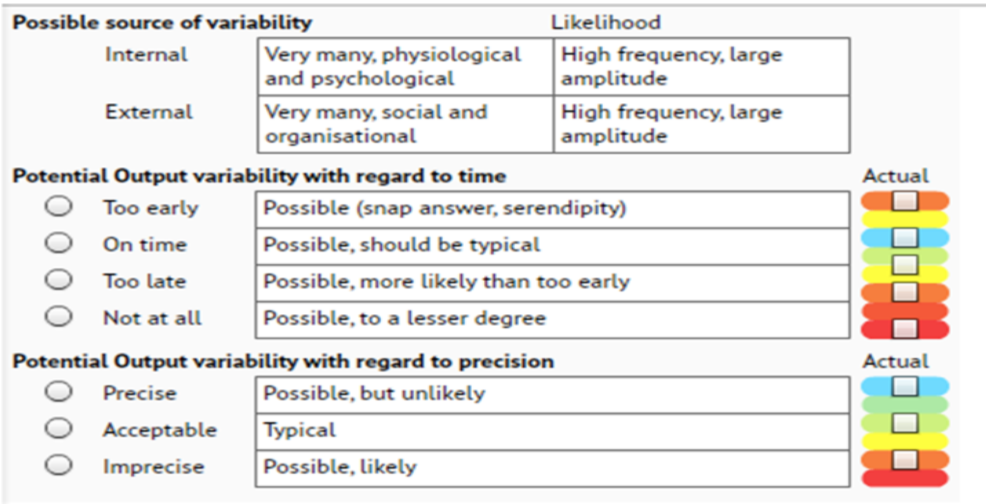
FMI LOG

```
FRAM Model Interpreter - FMI Basic (July 2020)  -----  (c) Erik Hollnagel, 2020
FMI session log: Fri Aug 21 17:42:47 GMT+0100 2020

Entry function <Finish loading (4)>
Exit function <Start sea passage (6)>

Interpretation Profile
Function <Leave harbour (0)>
    Input: All     Precondition: All     Resource: All     Control: All     Time: All
Function <Close bow doors (1)>
    Input: All     Precondition: All     Resource: All     Control: All     Time: All
Function <Trim vessel (2)>
    Input: All     Precondition: All     Resource: All     Control: All     Time: All
Function <Drop moorings (3)>
    Input: All     Precondition: All     Resource: All     Control: All     Time: All
Function <Finish loading (4)>
    Input: All     Precondition: All     Resource: All     Control: All     Time: All
Function <Man harbour station (5)>
    Input: All     Precondition: All     Resource: All     Control: All     Time: All
Function <Start sea passage (6)>
    Input: All     Precondition: All     Resource: All     Control: All     Time: All
Function <Issue company rules (7)>
    Input: All     Precondition: All     Resource: All     Control: All     Time: All

Summary of FMIlog
Begin initialisation
---  MODEL INITIALISATION COMPLETED.
Entry function <Finish loading (4)> has been activated
Background function <Issue company rules (7)> has been activated
BEGIN CYCLE 1
Function <Trim vessel (2)> has been activated
Function <Man harbour station (5)> has been activated
BEGIN CYCLE 2
Function <Close bow doors (1)> has been activated
Function <Drop moorings (3)> has been activated
BEGIN CYCLE 3
Function <Leave harbour (0)> has been activated
BEGIN CYCLE 4
Exit function <Start sea passage (6)> has been activated

End
```

4. The analyst can now start to examine the effects of variabilities in the coupling of the functions. For each Function (Starting with the Background and then the Entry function(s)), the software allows the systematic inputting of the expected variabilities, for that function, in that process.
   As a guide, the software offers a checklist table to choose a range of expected variabilities depending on Function type. It first offers a choice of possible generic behaviours to be expected, for that function: for example, if it is typically executed by Technology (T), Human Hand (H), or an Organisational (O) responsibility. For example, to close the bow doors in an illustrative analysis of the Herald of Free Enterprise Harbour departing process, would have been executed by a Human (H).

Name	**Close bow doors (1)**
Description	Closing the bow doors before the vessel leaves harbour. This is done by the assistant bosun.
Function Type	Human ▾ More »

5. The FMV software then offers a dialogue box with options to specify potential variabilities to be expected in this function in terms of precision and timing, as shown below!

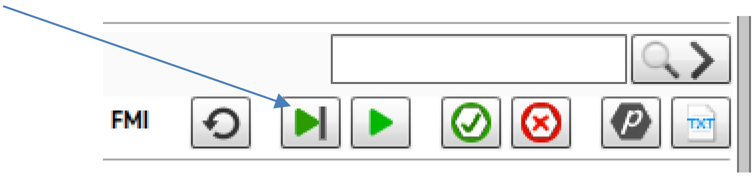


Possible source of variability			Likelihood
	Internal	Very many, physiological and psychological	High frequency, large amplitude
	External	Very many, social and organisational	High frequency, large amplitude

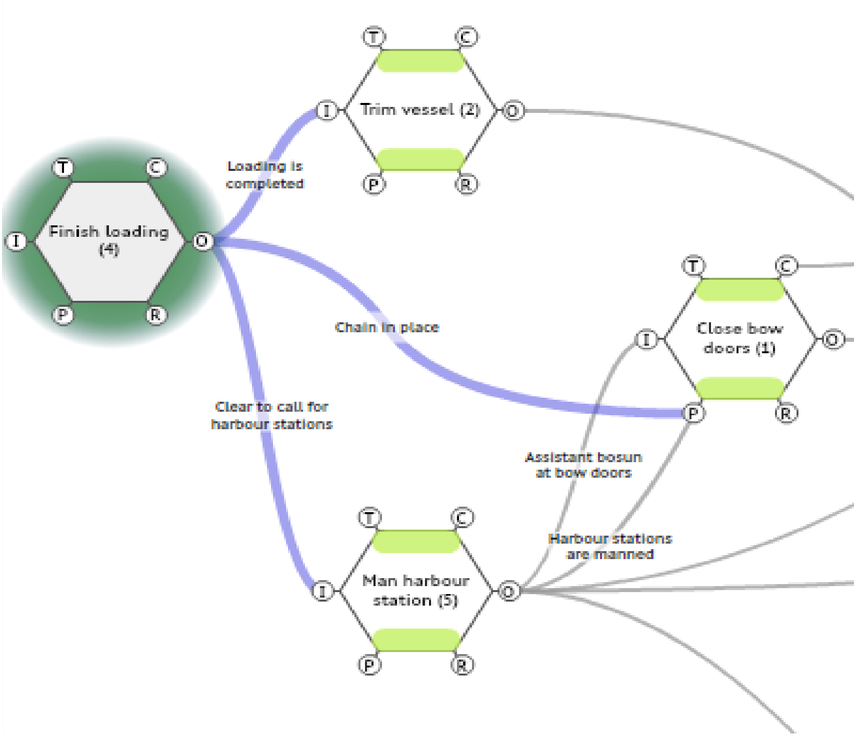
Potential Output variability with regard to time		Actual
Too early	Possible (snap answer, serendipity)	
On time	Possible, should be typical	
Too late	Possible, more likely than too early	
Not at all	Possible, to a lesser degree	

Potential Output variability with regard to precision		Actual
Precise	Possible, but unlikely	
Acceptable	Typical	
Imprecise	Possible, likely	

With these initial selections, the first cycle of the FMI sequence is then activated from the panel below and the functions active in the first step are highlighted.



The example below shows the initiation of the Leaving Berth process in the Herald of Free Enterprise analysis. Issues inherited from the Background and Entry function(s) are automatically highlighted on the first functions in the process, depending on the effects of the upstream Background and Entry functions. The green bands indicate that both Timing and Precision are Acceptable.



It is to be expected that the Function “To Finish Loading”, could have significant variability in its execution. Delays from weather, industrial action, BREXIT type disputes or just slow handling can all lead to a delay in activating the next set of functions needed to prepare for departure. As long as the next set of functions cannot be initiated until the loading is complete, the boat is going nowhere and remains safely berthed.
So in this example there are no issues found with the preparation phase.

6. The process is now repeated for each of these initial Functions and if we look more closely at the function – “To close the Bow Doors”, it can be seen that correctly its Output – “Bow Doors are closed”, is a precondition for the function – “To leave the Harbour”. The outputs from the other two functions are also preconditions. This means that “as imagined”, the boat cannot leave the harbour unless all three initial functions have been correctly executed (“Acceptably”, and “On time”).

   But from the official inquiry report we can get an insight into how this process was actually “done”. In fact, the working practice (WAD) had become so accepted, that it had become enshrined in a “rule” – Standing Order 01.09 – which said-

   “Heads of Departments are to report to the Master immediately they are aware of any deficiency which is likely to cause their departments to be unready for sea in any respect at the due sailing time”

So far so good but it then goes on to say –

“In the absence of any such report, the Master will assume at the due sailing time, that the vehicle is ready for sea in all respects.”

So, all these Outputs in the FRAM model, were in fact not preconditions, and not even crucial “Resources” as the Master could execute the function to leave without any of the outputs being present. He came to rely on the absence of any report at the time of sailing as sufficient to confirm that the ship was ready for sea.

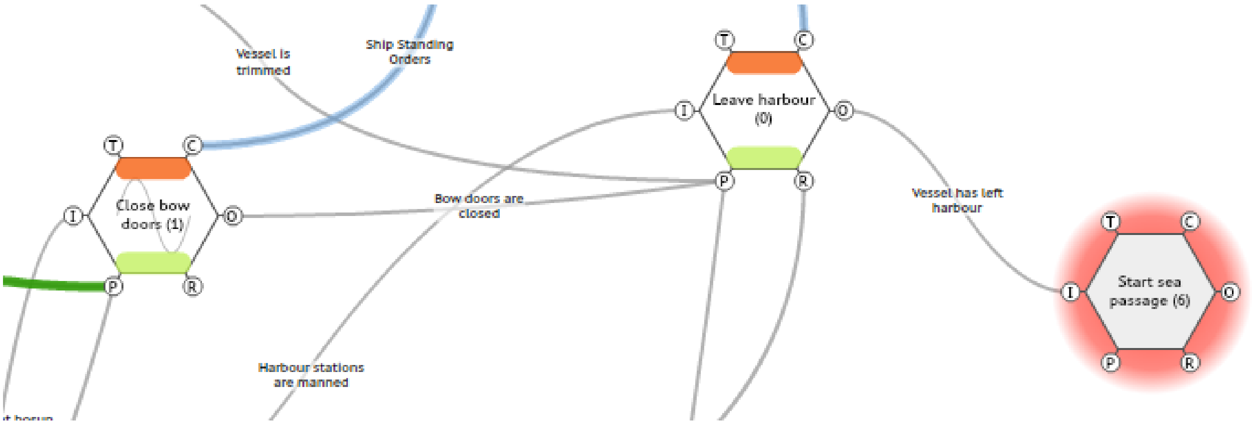
So, when probing for variabilities in the output of the function “To close the Bow Doors”, there is a real possibility that time, or other pressures, could result in the output being too late, or effectively “Not at all” closed.

Possible source of variability		Likelihood
Internal	Very many, physiological and psychological	High frequency, large amplitude
External	Very many, social and organisational	High frequency, large amplitude

Potential Output variability with regard to time		Actual
○ Too early	Possible (snap answer, serendipity)	
○ On time	Possible, should be typical	
○ Too late	Possible, more likely than too early	
◉ Not at all	Possible, to a lesser degree	

Potential Output variability with regard to precision		Actual
○ Precise	Possible, but unlikely	
◉ Acceptable	Typical	
○ Imprecise	Possible, likely	

This FMV software button then highlights with red bars the downstream implications that without the bow doors being closed, the ship cannot leave the harbour successfully. So if the analyst was systematically working though the “Book” of Standing orders as to how the operation should be carried out, there is an immediate query on this rule which had presumably been adopted as a result of an “Efficiency / Thoroughness trade off” (ref) to save time in turning the ferries around.



7. Having found an issue, there would then need to be a HAZOP type Log kept noting the scenario, the effect and recommendations as to action. Note this applies equally to both positive process improvements discovered as to potential problems avoided.

SWIFTFRAM LOGSHEET

Project:	SWIFTFRAM Documentation Description (From the FMI txt files)		**Function “Close Bow Doors”**	
Aspect	*Critical Variability Identified*	**Possible Consequence**	**Recommendations**	**Priority**
Precondition(s)	From the Standing Order 01.09, the Master can sail without confirmation that the Bow Doors are closed	Ingress of Water and possible capsizing / sinking	Revise the Standing Orders to ensure the required precondition(s) is/are present!!!. Relay / Use the closing doors alarm to alert /inform the Bridge that the operation / precondition is in progress.	Urgent / very HIGH!!!

9. The process is repeated with the FMV software prompting the discussion as it steps through the process.

10. WITH THE ANALYSIS COMPLETE, a better process model may well result, and the animated software allows the analyst to talk it though with the team (ground truth) and present key points to management - e.g. "Closing Bow Doors remotely and manually with no interlocks is probably a bad idea!"

BONUS - A Dynamic Record –

As with a normal set of P&ID's, these FRAM Models constitute a record of the processes as actually undertaken (as operated) and can be used as "living" reference documentation to be utilised and updated easily when any changes are made or foreseen – what if?!.

Discussion

The above example has shown that a structured what if technique can provide valuable documentation. What it is enabling and describing is a 'What if' at an instantiation level. In this example -What if the bow doors where not closed then what is the downstream effect? Then the method allows a systematic testing of the Model by considering and documenting all the other scenarios or instantiations in turn. This has been shown to be readily and conveniently accomplished using the variability propagation tracing capability of the software and adding some discipline around the documentation. Also, using the FMI is key to both providing and choreographing a structured approach.

The alternatives discussed are more complicated. For example, it could involve 'Decision Tables' that would consider the upstream variability that affected a functions inputs in both Time and Precision, and for each combination determine the expected variability of the Output.

There is a more automated approach possible, as we have shown with the Fuzzy Logic approach, or an algorithm using default tables for different types of functions. A major challenge with this automated approach is that it bypasses the need to develop an in-depth understanding of how the system is supposed to behave, which is an essential and crucial attribute of the FRAM analysis methodology. Another challenge is that the number of theoretically possible combinations quickly becomes overwhelming for a single function when you have multiple Aspects.

But there seems to be a strong argument for pursuing the approach which builds on the proven strengths of the HAZOP and FRAM approaches. Combining these two approaches and by using systematic 'What if' questioning at the function level, allows the building of a useful (unique?) record of issues identified and improvements noted, considering the potential variability of all the functions involved.

From HAZOPs there is plenty of evidence of a benefit in formally documenting the thoughtful consideration of what can affect the variability of each function.

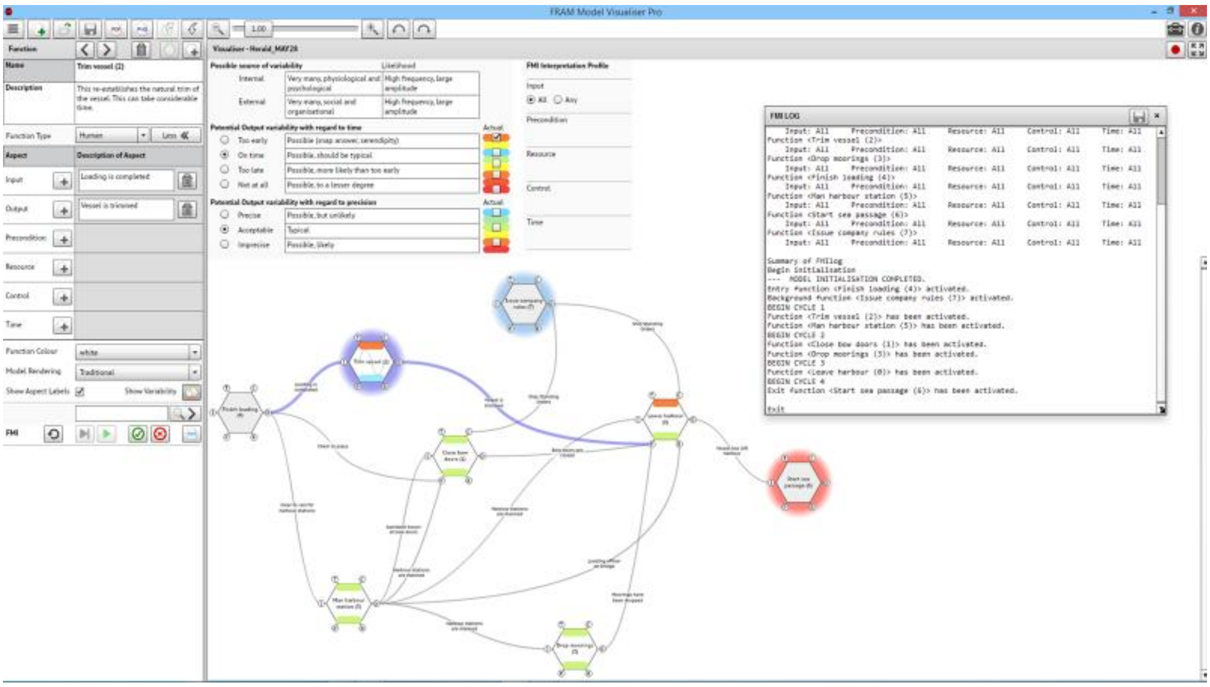
There would still be the potential of an overwhelming number of combinations for a function with many Aspects. Instead of considering the 'What if' of every combination, there has been a suggestion to ask a slightly different question: 'What would' cause the function to produce a given Output? For example, if the Function is normally considered to be "On time" and "Precise", considering the upstream inputs, what would cause it to be Imprecise (or late)? Is it any one of the Aspects being imprecise, or all of them, or a specific combination? This way you can build up a partial table describing a range of specific condition you would like to test.

Another idea to potentially automate and take a step closer to an algorithm-based approach, is to apply rules by considering the criticality of a function's Aspects. For example, is this given Precondition 'Critical', such that it must be present for an Output to be generated. Or is it 'Preferred', or even 'Optional'.

A major benefit of FRAM is the insights gained from the collaborative building and understanding of the system being modelled. To provide a structured approach to the deeper analysis and documentation of potential instantiations would also be a huge benefit.

SUMMARY AND CONCLUSIONS

This paper has explored the potential benefits of developing a better approach to formally analysing how a complex system functions and how these insights on the effects of propagating variabilities in functional interactions could be used to predict behaviours in future. The extra benefit of a formal record of resulting insights would also be invaluable for the more intelligent assessment of the implications of the changes that are inevitable as systems age and technology (over) develops.



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THE HAZ-OPS MAN COMES TO CALL....
GO CLAMBERING, HENDRIKKKS.
I GO; FOR INFO.
3
H GOES TO GATHER INFORMATION
MEANWHILE; BACK AT THE COMMANDEERED FOREMANS OFFICE...
WE MUST NOW THINK AND THINK AND THINK AND PLOT AND PLAN AND CALCULATE AND DESIGN UNTIL ALL IS SAFELY SAFE.!
YES YES
SO... THEY GET THEIR HEADS DOWN...
PLOT PLAN
PLOT PLAN
I WISH H WERE BACK
THAT'S IT; FINISHED! WHAT A RELIEF.
WON'T H BE SURPRISED
7
QUICK; QUICK... LOTS MORE INFO..
THERE IS NO SUBSTITUTE FOR GENUINE UP-TO-DATE INFORMATION.
phlonce.