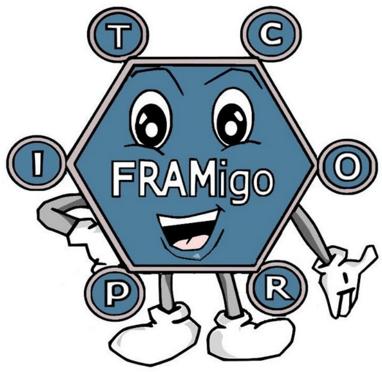
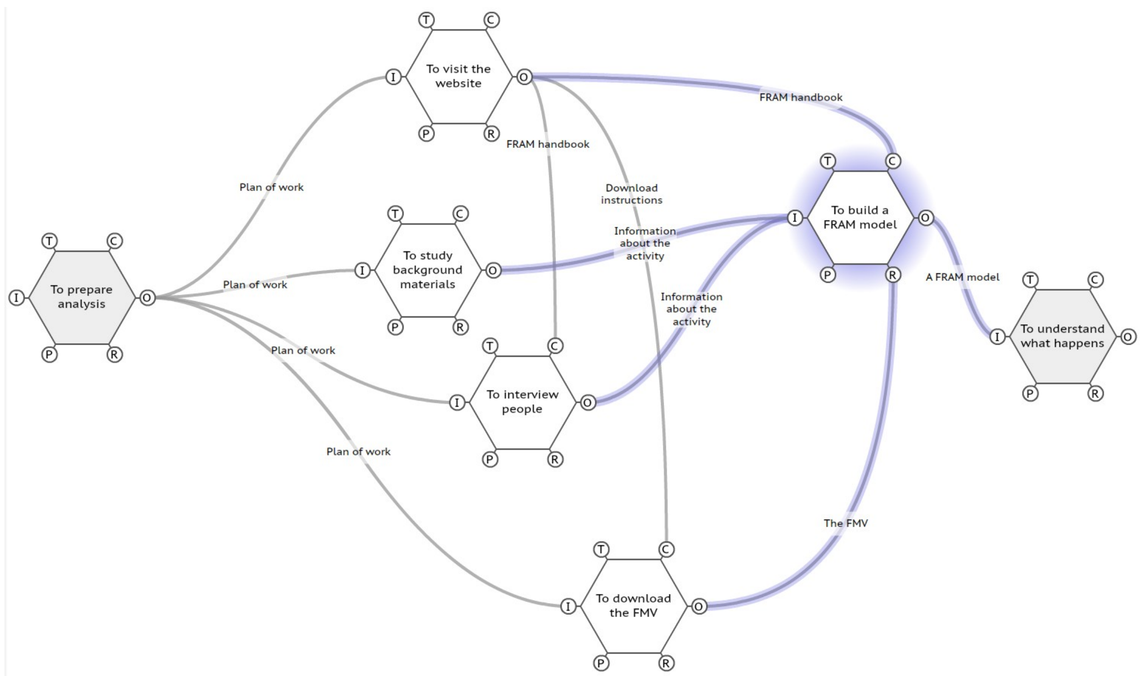
FRAM



The Functional Resonance Analysis Method
A Handbook on how to use the FRAM



A basic handbook on how to use the FRAM

Advice to Readers

This handbook is written as a practical guidance for the use of the Functional Resonance Analysis Method (FRAM) and the FRAM Model Visualiser (FMV). The FRAM represents a functional rather than a structural perspective on systems. To use this different understanding requires both familiarity with the underlying concepts and theories, and practical experience with the method. The handbook does **not** describe the theoretical background of the method as such. Readers who want to find out about that should either attend an authorised FRAM course, read the book about the FRAM (Hollnagel, 2021) or preferably both.

The handbook has been written to be part of a FRAM course, hence to be used with the support of an instructor. It is not intended to be and should definitely not be used as a simple cook book or step-by-step instruction manual. It is, however, probably inevitable that many people will try to use the method on their own, not least because courses are far from regular. This is not to be discouraged, as long as the above advice is kept in mind. Like any instruction manual, this brief guide is incomplete and should be complemented by an experienced user or instructor. If you do not personally know of someone who can provide such experience, it is highly recommended to get in touch with the FRAMily on LinkedIn.

Before going further, it is recommended to download and install the FMV. The FMV is in the public domain, hence free of charge. Instructions on how to do that can be found at https://www.zerprize.co.nz/Home/FRAM.

Common misunderstandings about the FRAM

There are a number of common misunderstandings about the FRAM which often can be found in papers and reports within the safety community. The three most serious ones are briefly described in the following.

- **The FRAM is not an accident analysis method**. Although the FRAM was developed in the context of the common understanding of safety around the turn of the century, it has not been developed for accident analysis or safety management but can equally well be used for task analysis, system design, etc. Examples of how the FRAM has been used in practice can be found in Patriarca et al. (2020).
- **The FRAM is neither a safety model nor a systemic model**. As explained below, the FRAM is a method by which to build a model, rather than a model that is the basis for a method.
- **The FRAM is not a flow model**. The common graphical rendering of a FRAM model, meaning a model built by the FRAM, does show elements (representing functions) and the potential couplings between them. But the intentions is to show how elements depend on each other and not how something – information, matter, or energy – flows between them.

About the Functional Resonance Analysis Method (FRAM)

The purpose of the FRAM is to analyse activities – how something *has happened*, how something *happens*, or how something *could happen* – in order to produce a representation of the activity in a systematic manner using a well-defined format. This resulting representation is a model of the activity in the sense that it captures the *essential features* of how something is done.[1] In the case of the FRAM, the *essential features* are the *functions* that are necessary and sufficient to account for the activity and the way in which the functions are coupled or mutually dependent.

The Four Principles of the FRAM

Practically all methods that are used to analyse something refer to an embedded model that describes and explains how the system being studied works or functions. (More formally, a distinction can be made between the *object system* that is being studied or analysed and the *model system* – or system model – that is the result of the analysis.) The embedded model, clumsy as the term may be, provides the rationale for the method and is usually taken for granted, hence soon forgotten. The embedded model defines or describes a set of parts and how they are related while the associated method provides a way to interpret what is being studied in terms of those parts and relations. The relations typically invoke the principle of causality (causes leading to effects or effects being preceded by causes) or some kind of hierarchical or temporal relation. A method can in this way be seen as implying or embedding a generic model of the phenomenon, or as being a model-*cum*-method and as providing a way to map the object system on the model. The embedded model thus guides the analysis, and in practice often imposes an *a priori* interpretative structure on the system being studied, hence on the model that is the result of the analysis. The value of the results of an analysis therefore depends on the appropriateness of the model that is behind the method.

Where commonly used methods for the study of socio-technical systems try to describe relations derived from an embedded model, and therefore represent model-*cum*-method approaches, the purpose of the FRAM is to do the opposite. The FRAM proposes that everyday events and activities can be described in terms of the functions involved without predefining specific relations, levels, or structures. Instead the FRAM assumes that the functioning of a system, hence the outcomes of an activity or process, can be understood in terms of the four basic principles described in the following. The FRAM thus does not have an embedded model, not even a non-linear one, and makes no assumptions about how the system under investigation is structured or organised, nor about possible causes and cause-effect relations. It describes the functions using six aspects, but the method does not exclude that additional aspects might be useful, nor that a completely different set of aspects might be possible. The FRAM can be described as a method that is used to produce a model, instead of a method that is derived from a model, and can therefore be seen as representing a method-*sine*-model approach. Since the main purpose of the FRAM is to build a model of how a set of activities are carried out (and to create instantiations from that model) the method must stand on its own hence be more detailed than most other methods.

The FRAM describes what happens in terms of functions. These are derived from what it takes to achieve an aim or perform an activity, hence from a description of Work-as-Done rather than Work-as-Imagined. The functions are not defined *a priori* nor are they necessarily ordered in a predefined way such as a hierarchical (superordinate-subordinate) or temporal (preceding-following) relation. Instead they are described on their own and any proposed relations between them must be based on experience from working with the system, from generic practice, and/or from design assumptions, thus on empirically established functional dependencies rather than assumptions of an embedded model.

1 The resulting FRAM model has sometimes been likened to a mind map.

Descriptions of functions using the FRAM are scale invariant. This basically means that the processes that give rise to phenomena on a small or a large scale can be described in the same way. The obvious advantage of scale invariance is the simplicity of the method and the parsimony of explanations. The latter is perhaps most important, because it eliminates the need of large sets (or even taxonomies) of categories, that both can be cumbersome to use and artificially constrain the depth and breadth of an analysis.

First Principle: The Equivalence of Successes and Failures

Explanations of how systems function or how everyday events develop typically rely either on decomposing the systems into meaningful physical parts or components, such as people and machines, or on decomposing the event into individual actions, process stages, or steps in a sequence. Outcomes are explained in terms of linear cause-effect relations among the parts or steps. Unacceptable or adverse outcomes in particular are attributed to malfunctions or failures of components or the incorrect performance of an activity or a step, thus preserving a congruence between the valence of causes and the valence of consequences. When a cause in this way has been found, the response is to try to fix it, preferably by removing or eliminating it and if that is not possible then to try to reduce the likelihood that it will happen again.

This “find-and-fix” approach implies what may be called a “hypothesis of different causes” which states that things that go well and things that go wrong happen in different ways and have different causes. If that was not the case then the endeavour to “find and fix” the causes of unacceptable outcomes would also affect the occurrence of acceptable outcomes. This hypothesis explains why safety management usually pays little or no attention to the expected and acceptable outcomes, to activities that go well.

The FRAM takes a different approach, namely that things that go well and and things that go wrong happen in much the same way. According to this *principle of equivalence*, acceptable outcomes as well as unacceptable outcomes are due to the ability of organisations, groups and individuals successfully to adjust what they do to expected and unexpected situations. When something is done, it is done with the intention of bringing about an acceptable outcome. This is also what happens in most, and indeed nearly all, cases. But since the adjustments are approximate rather than precise, the outcomes may every now and then be different from what was expected and intended or even be outright unacceptable. The fact that the outcomes are different does, however, not mean that the explanations also must be so. As Ernst Mach observed, “Knowledge and error flow from the same mental sources, only success can tell one from the other”.

Second Principle: Approximate Adjustments

There are two main reasons why today’s socio-technical systems cannot be specified in minute detail. One is that neither humans nor organisations are “machines”. The other that socio-technical systems are not designed and built but “grow” in a more or less predictable fashion. Indeed, this has been the case for a long time, although it only recently has become widely recognised. Since work and work environments are therefore always underspecified, it is necessary that work is continuously adjusted to the existing conditions (resources, time, tools, information, requirements, opportunities, conflicts, interruptions) in order for it to go well. These adjustment are made by individuals, by groups and by organisations and take place at all levels, from the performance of a specific task to planning and management. Furthermore, since resources (time, materials, information, etc.) almost always are limited and uncertain, the adjustments will typically be approximate rather than precise. This is rarely critical because the approximations usually are close to the mark and because people mostly know what to expect and are able to compensate appropriately. The *principle of approximate adjustment* can thus be seen as an elaboration of the principle of equivalence. It explains why things predominantly go well, but also why they occasionally go wrong.

Third Principle: Emergent Outcomes

Our understanding of the world around us, not least in relation to how we manage it, rests on what has been called a *causality credo*[2] – a belief in cause-effect or cause-consequence reasoning. As a fundamental principle causality means that two events can be related so that the first (the cause) is solely or partly responsible for the second (the effect) and the second is solely or partly dependent on the first. An effect can in turn be a cause of, or causal factor for, many other effects, and so on. The first part of the causality credo states that outcomes happen because something has happened before, but also implies that if the outcomes are adverse or negative – such as an accident – then the cause is also negative – such as a malfunction or an error. Cause and effect are assumed to have the same valence. The second part states that causes can be found and treated by a process of rational deduction, given sufficient information and time. The third part concludes that all accidents therefore are preventable (the so-called zero harm principle). The two first principles of the FRAM offer an alternative way of understanding how things happen by pointing to the role of performance adjustments. The FRAM further recognise that the consequent variability of individual functions rarely is large enough to serve as the only cause of an effect, in particular as the only cause of something going wrong. Neither is the variability usually so different from what normally is done that it can be classified as a failure. The variability of two or more functions may on the other hand combine in unexpected ways that can lead to outcomes that both are unpredictable and disproportionate in magnitude – negative as well as positive. Acceptable and unacceptable outcomes can in this way be explained as *emerging* from variability due to the everyday adjustments rather than as a result of single or multiple cause-effect chains arising from a malfunction or failure of a specific components or parts.

Fourth Principle: Functional Resonance

As an alternative to linear causality and cause-effect reasoning, the FRAM proposes that the variability of two or more functions can coincide and thereby either be dampened or amplified. The variability of one function may in this way come to affect the variability of other functions in analogy with the phenomenon of resonance. In physical systems, classical (or mechanical) resonance means that a system can oscillate with larger amplitude at some frequencies than at others, known as the system's resonant (or resonance) frequencies. At these frequencies even small external forces that are applied repeatedly can produce large amplitude oscillations, which may seriously damage or even destroy the system. Stochastic resonance extends this to systems with weak (subliminal) signals and irregular variability. In analogy with that functional resonance is defined as the detectable (supraliminal) variability that emerges from the unintended interaction of the everyday (subliminal) variability of multiple functions. Functional resonance is more formally defined as the noticeable performance variability in a socio-technical system that can happen when multiple approximate adjustments coincide. Since there is considerable regularity in how people behave and in how they respond to unexpected situations – including those that arise from how other people behave – functional resonance offers a systematic way to understand outcomes that are both non-causal (emergent) and non-linear (disproportionate).

2 The causality credo is however rarely stated explicitly, but is simply taken for granted.

How to build a FRAM model

Having thus taken care of the preliminaries, we can proceed to describe how the FRAM is used. The Functional Resonance Analysis Method consists of four steps:

- Identify and describe the essential system functions and characterise each function by means of some or all of six basic characteristics (called aspects). Together, the functions constitute a FRAM model.
- Characterise the potential variability of the functions in the FRAM model, as well as the possible actual variability in one or more instantiations (or realisations) of the model.
- Determine the possibility of functional resonance based on dependencies / couplings among functions given their potential / actual variability.
- Develop recommendations on how to monitor and manage the variability, either by attenuating variability that can lead to undesirable results, or by enhancing variability that can lead to desired results.

This handbook will focus on the first step, but also say something about the second step. The third and fourth steps address important issues in system management for which a FRAM model can provide a valuable contribution, but will not be described here.

Identifying and describing functions

The building of a FRAM model must obviously start by identifying and describing the functions that taken together make up the activity being analysed. Once the functions, or an initial set of functions, have been identified, they are then described using the six aspects.

What is a function?

It is common in human factors – using the term broadly – to refer to tasks and task analysis, and sometimes even to activities and activity analysis. One way to start thinking about functions is to see them as corresponding to tasks and activities.

In the FRAM a function represents the means that are necessary to achieve a goal. More generally, a function represents the acts or activities – simple or composite – that are needed to produce a certain result. Unlike tasks, functions can be carried out in different ways and by different means.

- A function typically describes what people – on their own or together – have to do to perform a specific task and thus achieve a specific goal. Examples of human functions are to triage a patient or to fill a glass with water.
- A function can also refer to something that an organisation does. The function of the emergency room in a hospital, for example, is to treat incoming patients while the function of a restaurant is to serve food.
- A function can finally refer to what a technical system does either by itself, such as a washing machine or an "intelligent" assistant, or together with one or more people (an interactive or socio-technical function), such as a flight management system.

A FRAM function is thus more than a task as the term is commonly used. A function describes what needs to be done, but not necessarily how or by what means. There is a long tradition in human factors to categorise functions as either human, organisational, or technical depending on how they are implemented. This is, however, done mainly for practical reasons rather than because the categories represent any deep theoretical insights.

In the description of functions an important distinction can be made between tasks and activities, corresponding to the distinction between Work-as-Imagined (WAI) and Work-as-Done (WAD). A tasks describes work as designed, or as imagined by managers. An activity describes work as it is actually performed or done. The FRAM primarily focuses on activities as they are done or WAD, but can of course also be used to model WAI.

A general rule for the use of the FRAM is that a function should be described by a verb (verb) if it is a single word, or a verb phrase – in both cases using the infinitive form. For instance "(to) diagnose a patient" rather than "diagnosing a patient" or "(to) start a pump" rather than "starting a pump" or "pumping water".

Example: Preparing Delicious Cup Noodles

The example used to illustrate how to build a FRAM model is really simple. It is how to prepare cup noodles. Usually, the instructions are written on the lid, for instance as follows:

- Tear open half of the paper/plastic lid. ...
- Pour some boiling (100 C/212 F) water up to the inside line of the container.
- Put the lid on and weigh down the lid with a set of chopsticks or a light plate.
- Wait patiently for 2 to 3 minutes then stir the noodles well with chopsticks.
- Eat and enjoy.

Try to write the above five parts of the instruction as functions, i.e., using a verb phrase <To open half of cup lid>. Consider whether each part corresponds to a single functions or to more than one function. Also consider whether some functions (parts) are missing from the description, perhaps because they are taken for granted, because it is something that everybody knows, etc.

(If you think preparing cup noddles is too simple, you can try to model how to get money from an ATM instead. A description of that can be found on wikihow https://www.wikihow.com/Use-an-ATM.)

The first function

So where should the model building begin? A FRAM model can in principle start from any function because the method as such ensures that the model will be complete regardless of how it begins. Nonetheless, it may be a good idea to start with a function that is central to the activity being analysed.

Just describe the functions in plain text. Do not use the FMV at this point in time. You can describe the functions in the order they are presented above, which is basically the recommended sequence in preparing cup noodles. Or you could write them in alphabetical order or in any other way. It may actually be an advantage not to think in a sequence from the start but to write down the functions as they come to mind. The specific order is unimportant because a FRAM model is *not* a flow model. As you continue the method will ensure that the model includes all necessary functions.

Breadth before depth

When a FRAM model is developed it is advisable to describe all the important functions before beginning to consider the aspects of the functions. In the cup noodle example that would probably mean all the functions that are included in the instructions – perhaps leaving out the final consumption. For more complicated activities it is advisable to start by a handful, say four to six, main functions rather than to try to be exhaustive. This can be seen as applying the principle of breadth-before-depth. In other words, try to characterise the activity as a whole before you being to develop the details.

Many analysis methods implicitly support a depth-before-breadth approach. (A characteristic example of that is the root cause analysis.) In a depth-before-breadth approach the items or parts are analysed in detail one by one before their possible relations are considered. Examples of that are FMEA/FMECA and HAZOP. Using a breadth-before-depth approach prevents the analysis team from becoming distracted by the details of the investigation at hand, especially if the analysis is of an event that has happened.

Describing functions using the FMV

At this point in time you should begin to use the FMV. Depending on how many functions you defined, the outcome may look something like Figure 1.

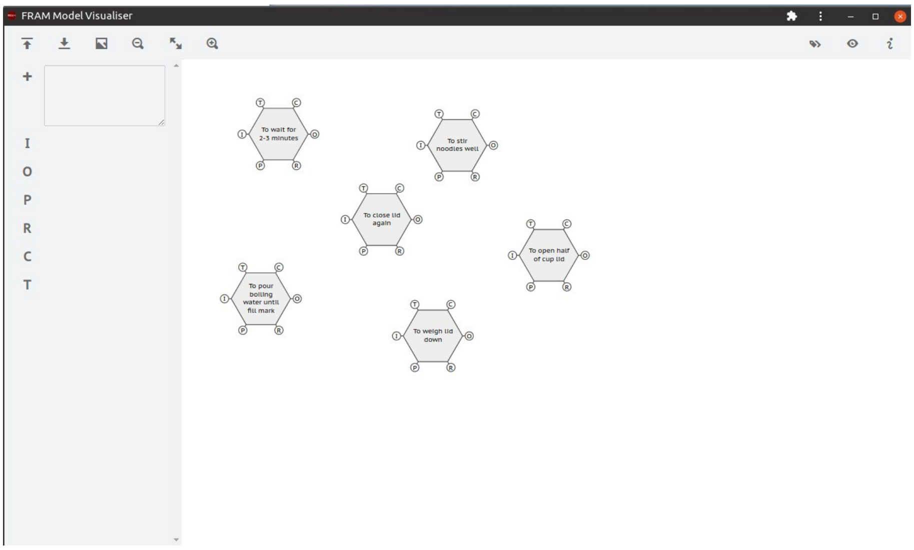


Figure 1: Six functions in the preparation of cup noodles

In this example six functions have been defined. To begin with they are only identified by their name, which is a verb phrase as recommended. They are not yet connected or coupled, and their position on the FMV canvas is not significant. It may be useful even for this simple example also to write something in the Description field, for instance who or what carries out the function. The Description field serves as a scratch-pad for things it may be useful to remember for later, things that were discussed but not included, etc.

Assuming that you are satisfied with this initial model in the sense that there are no other functions that need to be included, the model development continues by characterising the functions using the six aspects.

What are the FRAM aspects?

In the FRAM functions can be characterised by means of six aspects named Input, Output, Preconditions, Resources, Control, and Time, respectively.[3] The general rule is that an aspect

3 The aspects can be thought of as features or dimensions of a function. In the FRAM, the six aspects are written with capital initials when they refer to aspects as part of a functional description (e.g., Time or Control), but without the capital initial when used in other contexts (e.g., timely or effective control).

of a function should be described when it is seen as necessary or appropriate by the analysis team, provided there is sufficient information or experience to do so. **It is not required to describe all six aspects of every function, and it can indeed sometimes be either impossible or unreasonable to do so.**

The guidelines for which aspects to describe and when, are given in the following. As a minimum, at least one Input and one Output must be described for all foreground functions. (The meaning of a foreground function is explained in the following.) Note, however, that if only the Input and Output aspects are described then the FRAM model is reduced to an ordinary flow chart or network diagram. As a general rule aspects should be described using a noun (noun), or a noun phrase. In other words, an aspect is described as a state or as a result of something – but not as an activity.

A brief description of the six aspects

- **Input**. The Input to a function is traditionally defined as that which is used or transformed by the function to produce the Output. The Input can represent matter, energy, or information. There is, however, another meaning that is just as important for the FRAM, namely the Input as that which activates or starts a function. The Input in this sense may be a clearance, an instruction, or even a command to begin to do something. Input can be seen as a form of data or information, or more generally as a state change that is recognised by a function as a signal to begin. It is for that reason that the description of the Input is always a noun or a noun phrase.

  Something that is defined as an Input to one function must clearly be defined also as an Output of another function – or functions. An Input cannot come out of nowhere.

  In the FRAM, designated foreground functions must have defined Inputs, while designated background functions need not have. The difference between foreground and background functions will be explained later.
- **Output**. The Output of a function describes the result of what the function does, for example, the result of processing the Input. In the cup noodle example an Output from the function <To wait for 2-3 minutes> could be [Tender noodles].[4] The Output can represent material, energy, or information – an example of the latter would be a permission or clearance, or the result of a decision. The Output describes a change of state – of the system or of one or more output parameters. The Output may, for example, be the signal to start a function. The description of the Output should be a noun or a noun phrase.

  Something that is defined as an Output from one function must clearly also be defined as either an Input, Precondition, Resource, Control, or Time of another function – or functions. An Output cannot be left dangling but must end somewhere.
- **Precondition**. In many cases it may not be possible to begin a function before one or more Preconditions have been established. These Preconditions can be understood as system states that must be [True], or as conditions that ought to be verified before a function is carried out. A Precondition does, however, not itself constitute the signal that starts the function. An Input, on the other hand, can activate a function. This simple rule can be used to determine whether something should be described as an Input or as a Precondition. It is however not necessarily critical for a FRAM analysis whether something is labelled Input or Precondition, as long as it is included in the model in one way or

4 Before the function begins the noodles are hard; after it has been carried out the noodles are tender. In this case the function is simply to wait – and also to keep track of the time.

another. A Precondition can, of course, not come out of nowhere but must always be defined as an Output from another function – or functions. The description of a Precondition should be a noun or a noun phrase.

- **Resources or Execution Conditions**. A Resource is something that is needed or consumed while a function is carried out. A Resource can represent matter, energy, information, competence, software, tools, manpower, etc. Time could, in principle, also be considered as a Resource, but since Time has a special status it will be treated as a separate aspect.

  Since some Resources are consumed while the function is carried out and others are not, it is useful to distinguish between (proper) Resources on the one hand and Execution Conditions on the other. A (proper) Resource is consumed by a function; it will be reduced over time and must therefore be renewed or replenished. An Execution Condition only needs to be available or exist while a function is active but is not consumed in the same way that a (proper) Resource is. (The difference between a Precondition and an Execution Condition is that the former is only required before the function starts, but not while it is carried out.) The description of a Resource (an Execution Condition) should be a noun or a noun phrase. Something that is defined as a Resource for a function (or for two or more functions) must also be defined as an Output from a function, or functions. Resources do not come out of nowhere. This is especially the case for (proper) Resources.

  An example of a (proper) Resource could be blood plasma used by a transfusion, e.g., during surgery. An example of an Execution Condition could be the competence to disassemble a machine before it is repaired. After the surgery has been completed, some or all of the blood plasma will have been consumed; after taking a machine apart the competence will be the same – if not actually increased.

- **Control**. Control is that which supervises or regulates a function so that it produces the desired Output. Control can be a plan, a schedule, a procedure, a set of guidelines or instructions, a program (an algorithm), a 'measure and correct' functionality, etc. Another, less formal type of control is social control or expectations to how the work should be done. Social control can be external, such as the expectations of others (management, organisation, co-workers) and is sometimes expressed explicitly. Social control can also be internal, for example, when we plan a job and mentally go through when and how to do it, or when we imagine what others expect of us. The description of Controls should be a noun or a noun phrase. Something that is defined as a Control for a function (or for two or more functions) must also be defined as an Output from another function, or functions.

- **Time**. This aspect represents the various ways in which time can affect how a function is carried out. Time, or rather temporal relations, could be seen as a form of Control, as when Time represents the order of two or more actions (sequencing conditions). A function may, for instance, have to be carried out (or be completed) before another function, after another function, or overlapping with – parallel to – another function. Time may also relate to a function alone, seen in relation to either clock time or elapsed time.

  Time could also be seen interpreted as a Resource, such as when something must be completed before a certain point in time, or within a certain duration. Time could, of course, also be interpreted as a Precondition, e.g., that a function must not begin before a certain time or that it must not begin before another functions has been completed. Yet rather than having Time as a part of either of the other three aspects it seems reasonable to acknowledge its special status by having it as an aspect in its own right. The description of Time should be a noun or a noun phrase. Something that is defined as a Time aspect for one or more functions must also be defined as an Output from another function, or functions.

Please remember that there is no requirement to define all six aspects for every function. In practice, you should only describe aspects if it seems to be relevant or necessary, based on knowledge about the activity. It is always possible to update a model either by describing additional aspects of functions or to remove definitions of aspects for some functions.

Keep in mind that there can be more than one entry for each type of aspect. A function may, for instance have a single Output that used by several downstream functions. Or it may have several Outputs that are used by several downstream functions. Similarly, a function may have multiple Inputs coming from more than one other function, multiple Preconditions, etc. Some functions may have two – or more – upstream couplings to their Input, Precondition, Resource, Control, or Time aspects. The decision of which aspects to describe for which functions is taken by the analysis team based on their understanding of and experience with the activity or process that is being analysed and modelled.

A short definition of the six aspects can be seen in Figure 2.

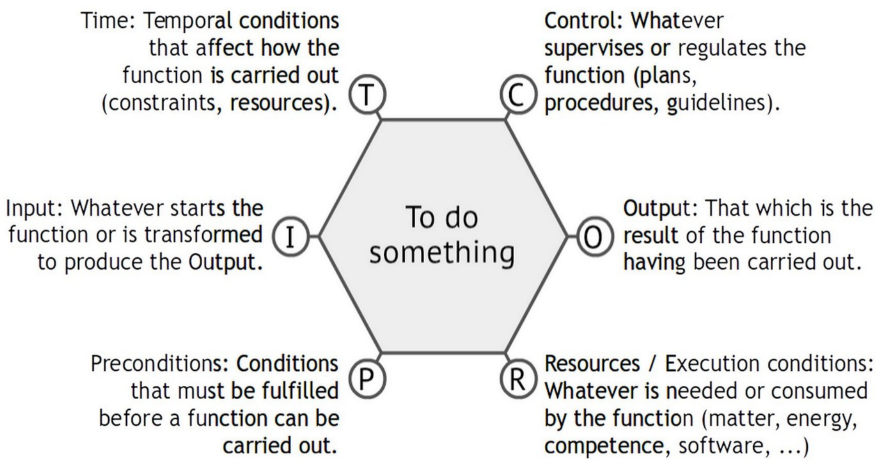


Figure 2: The six aspects used to characterise functions

Aspects in the cup noodle example

We can illustrate how aspects are defined by adding some details to the initial model of how to make cup noodles. Before you read any further, please try to do it on your own, following the guidance given above.

We have already seen that one possible Output from the function <To wait for 2-3 minutes> is [Tender noodles]. (Beginning with this function also demonstrates that they can be considered in any order.) If we stay with that function, one necessary question is when it starts. In this example the answer is that the waiting begins when the noodles have been covered with boiling water. So we can now define an Input for the function as [Noodles covered with boiling water]. We can then continue to consider the four remaining aspects (P, R, C, and T) and ask whether there is a need to describe them. Waiting for 2-3 minutes does not seem to require any Preconditions, nor any specific Controls. There could arguably be the need of a Resource, namely a clock or a timer. But for the time being we shall disregard that. But it is necessary to define the T aspect, since the 2-3 minutes are important for the preparation of the noodles. We therefore describe the Time as [2-3 minutes]. Having done that, the model may now look as in Figure 3.

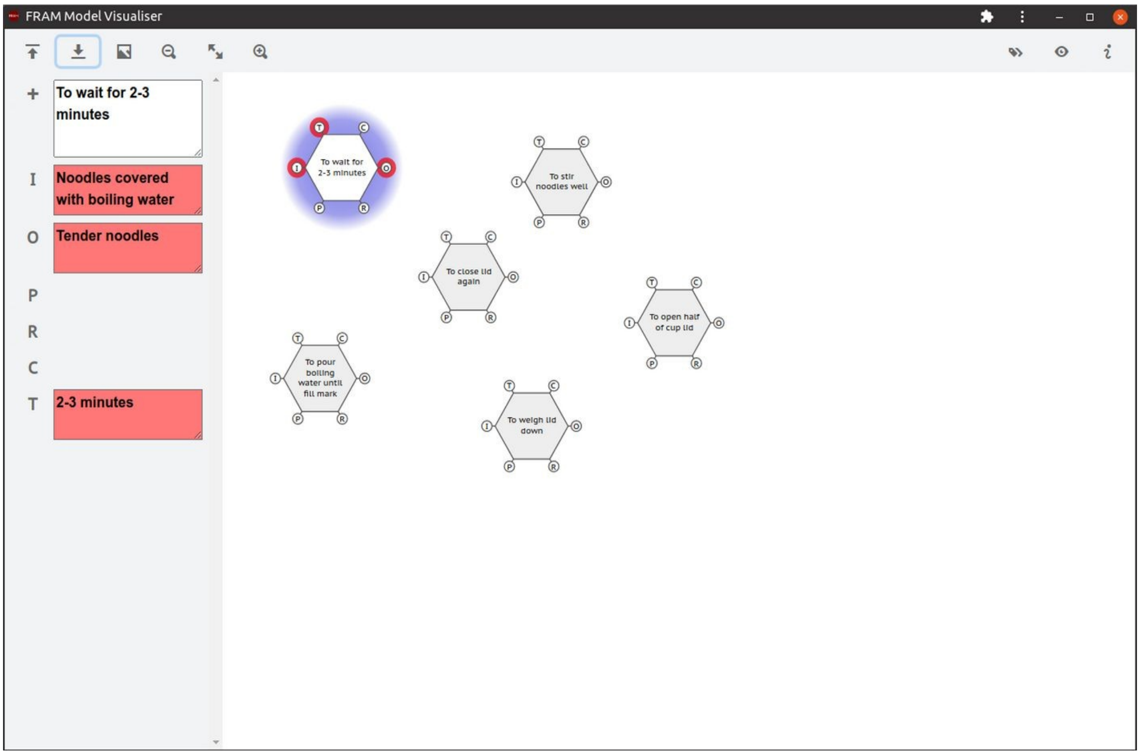


Figure 3: Cup noodles - the first function

Orphans

In the description of the aspects it was repeatedly mentioned that aspects have to come from somewhere and end somewhere. When an aspect is shared between two functions such that it is the Output of one function and an input to another function – meaning an Input, a Precondition, a Resource, a Time or a Control – it defines a dependence or coupling between the two functions. When an aspect in this way is shared between two functions, a thin line will also be drawn to represent that coupling.

An aspect that only is defined for one function is classified as an **orphan**. In Figure 3 the three aspects that have been defined for <To wait for 2-3 minutes> are all marked by a red ring in the graphical model and by a red background in the text description. This is done automatically by the FMV to point out that an aspect only has been defined for one function, hence is incompletely described. In the specific case two of the aspects (I and T) must come from somewhere and therefore be defined as Outputs from other functions, while one aspect (O) must end somewhere and therefore be defined as an (I, P, R, C, or T) for another function. A natural next step is therefore to complete the description of orphan aspects.

If we first look at the Input [Noodles covered with boiling water] then that seems to be an obvious Output from the function <To pour boiling water until fill mark>. If we then look at the Output [Tender noodles], then that would reasonably serve as an Input to <To stir noodles well>, since the stirring clearly should not begin until the noodles are tender. But the Time aspect [2-3 minutes] does not seem to be an Output from any of the six functions in the current version of the model. It therefore becomes necessary to introduce a new function that provides this Output. That function could be that the user reads the instructions on the lid or, perhaps less straightforward, the writing of the instructions at some earlier time. Although it is tempting, the function cannot simply be called <Instructions> since that is not an action or a verb phrase. In the example we will choose to introduce a new function called <To read the instructions> which has the Output [2-3 minutes]. (As a consequence of that it also seems reasonable to change the name of <To wait for 2-3 minutes> to be simply <To wait until tender>, since the time now is specified by the Time aspect.) The result is a new version of the model which may look as in Figure 4. (The positions of the functions have been rearranged.)

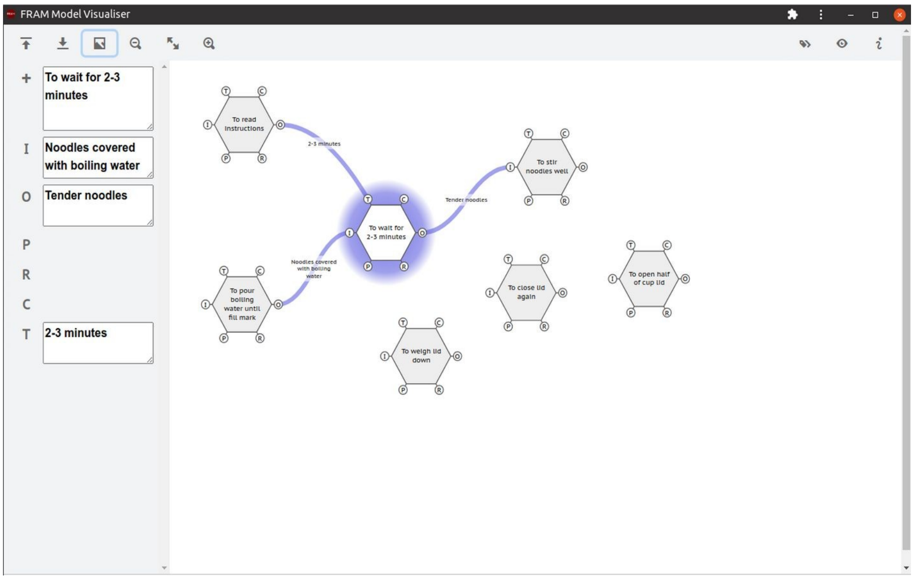


Figure 4: Cup noodles – the second version of the model

The development of the model can now be continued, for instance by looking at the other functions in the same way and try to define as many of their aspects as seems reasonable and possible.

Couplings

As explained above and as shown by the development of the "cup noodles" model, every function in a FRAM model is characterised using some or all of the six aspects. If the same values (names) are defined for aspects of different functions – for instance the Output of one function and the Time of another – then this defines a potential coupling between the functions. This is shown by the FMV as a line that connects the two aspects. The line is not shown as having a direction (for instance by an arrowhead), but the logic is clearly that the Output goes from one function to other functions.[5]

The significance of the couplings is perhaps easier to see if the model is elaborated a bit further. An example of what that could look like is shown in Figure 5. Apart from the definition of further aspects of the functions, the most conspicuous differences between Figures 4 and 5 are that the functions have been rearranged on the FMV canvas, that two functions have been collapsed into one, and that three additional functions have been introduced, namely <To boil water>, <To make preparations>, and <To enjoy cup noodles>, respectively. (The reader may have produced a different expansion, but that is perfectly acceptable.)

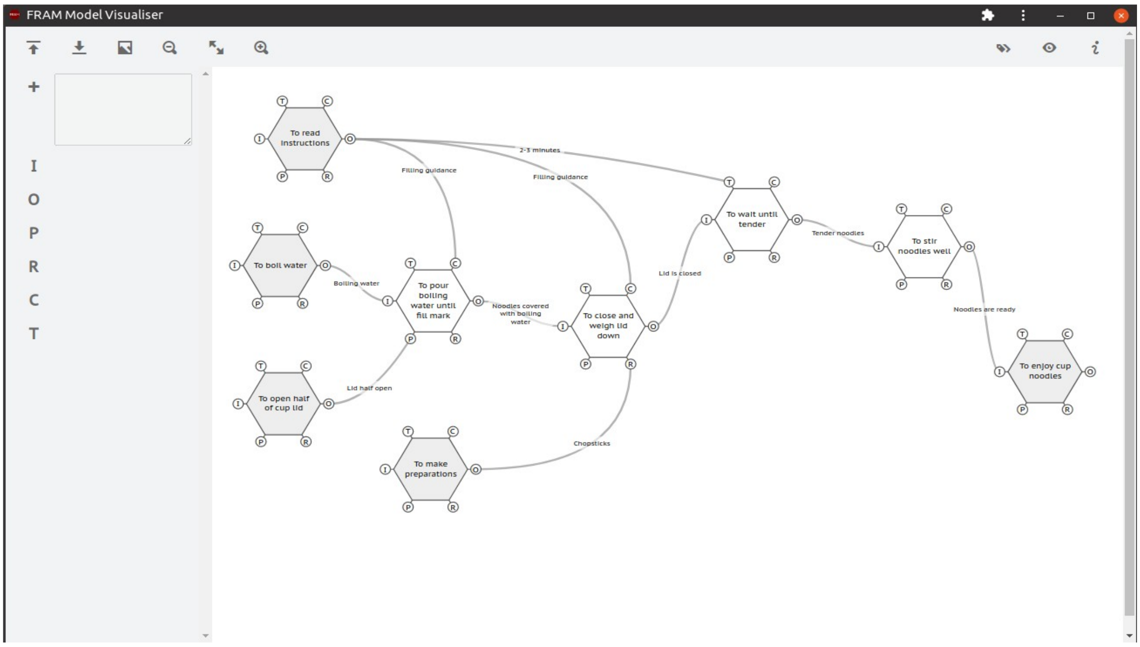


Figure 5: Cup noodles - the third version of the model

The basis of the FRAM is the description of the functions that make up an activity or a process. The description starts by the functions themselves, and not by how they are ordered or related. The relationships are not specified nor described directly and the FMV in fact does not allow lines or connectors to be drawn between functions. Relationships are instead specified indirectly via the descriptions of the aspects of functions. The common technical term for such relations is couplings. In Figure 5, for example, the Output [Lid half open] from <To open half of cup lid> is also defined as a Precondition of the function <To pour boiling water until fill mark> – reflecting the simple fact that it is impossible to pour water into the cup unless the lid is open or half open. Because the two functions share the same aspect, they are potentially coupled.

The couplings in a FRAM model are generally n-to-n (or many-to-many) rather than 1-to-1. For example, the function <To read instructions> has two different Outputs which serve as Control for three other functions. One Output, [Filling guidance], is defined as a Control

5 The couplings cannot be drawn directly, but appear automatically when they have been defined.

aspect of both <To pour boiling water until fill mark> and <To close and weigh down lid>. The other, [2-3 minutes], is defined as a Time aspect of <To wait until tender>.

The shared aspect attributes model define the *potential couplings* because a FRAM model describes the potential or possible relationships or dependencies between functions without referring to any particular situation. In an **instantiation** of a FRAM model, only a subset of the potential couplings can be realised; these represent the *actual couplings* or dependencies that have occurred or are expected to occur in a particular situation or a particular scenario. An instantiation of a FRAM model thus represents how a subset of functions can become mutually coupled under given conditions or within a given time frame. The couplings realised for a specific instantiation do not vary but are assumed to be are 'fixed' or 'frozen' as long as the conditions exist. For an event analysis the instantiation will typically cover the entire event and the couplings that existed at the time. For a prospective analysis, the duration is the time required for the activity under consideration to be completed. This can vary significantly, from the few minutes it takes to prepare cup noodles to the weeks or months required for a large-scale industrial or business operation.

Foreground (FG) and background (BG) functions

The cup noodle example has already shown how the description of functions can be expanded and how new functions become necessary. This raises the perspective that a model can be expanded forever, since there always will be details that conceivably can be added. The FRAM, however, includes a practical stop rule that puts a limit to the size of the models.

Functions in the FRAM can be characterised either as *foreground functions* or *background functions*. The terms have nothing to do with the type of functions that are involved, but with the role of a function in a particular model – and of course also in the instantiations of the model. A function is considered as a foreground (FG) function if it is part of the study focus, which in practice means that the variability of the function may have consequences for the outcome of the event or process being examined. A background (BG) function is similarly a function which is assumed not to vary or to be stable during the duration of the process or activity being analysed.

In Figure 5, there are four FG functions and five BG functions. Foreground functions are white while BG functions are shaded grey. The determination of whether a function is a FG or a BG function is made automatically by the FMV using the following rules:

- A function that only has an Output (or Outputs) is designated a BG function.
- A function that only has an Input (or Inputs) is designated a BG function.
- All other functions are designated FG functions.

Because BG functions are assumed to be stable while the activity takes place, there is no need to expand them further by describing their Preconditions, Controls, etc. A BG function can therefore be seen as being part of the boundary of the system being analysed. A BG function could, for example, be a Resource (the right level of staffing or the competence of the staff) or an instruction (Control). A person's competence must generally be assumed to be stable (not varying) during the execution of a task, just as an instruction also must be assumed to be stable. This does not mean that the competence is sufficient or that the instruction is correct, but only that they are assumed not to vary during the time it takes to perform the task. While the execution of an instruction may vary, the instruction itself only changes in case it is corrected or modified. The instruction is therefore only variable when considered over a longer time span, which is typically many times longer than the duration of the event. In that case the focus would change to be the writing and maintenance of the instructions, which means that this becomes the activity being modelled.

BG functions may be used as a way to stop the expansion of functions and limit the scope of a model. But a BG function can at any time be changed to a FG function, for instance by defining one of its other aspects (P, R, C, or T) which in turn means that the model must be expanded. The terms FG – BG function thus refer to the relative importance of a function in the model and not to the "nature" of a function as such. If the study focus changes, a function may change from being a designated FG function to become a designated BG mode, and vice versa.

In most cases the BG functions serve as the source of an Output that has been defined as an (I, P, R, C, or T) aspect of one more other functions.[6] Figure 5, however, also includes the BG function <To enjoy cup noodles> for which the Input rather than the Output has been defined. This function is needed because the Output [Noodles are ready] from the function <To stir noodles well> must be defined for (at least) one other function, i.e., the Output must end somewhere. In this case it seems natural to introduce the function <To enjoy cup noodles> not least because that presumably is the purpose of preparing the noodles in the first place.[7] But since the model represents the activity of *preparing* the cup noodles, it is not necessary to go into the details of how the noodles are consumed. A FRAM model will typically have several BG functions that serve as sources or Entry functions as well as one or more BG functions that serve as drains or Exit functions.

Upstream and downstream functions

While the terms FG and BG represent a function's role in a model, the terms *upstream* and *downstream* are used to describe the temporal relationship between a function that currently is in focus and other functions. The interpretation of the FRAM model traces the potential couplings as they lead from function to function. This means that there will always be one or more functions that are in focus, i.e., whose variability is currently being considered. The functions that have been in focus before, which means functions that already have been carried out, are called upstream functions. Similarly, the functions that follow the function (or functions) that is in focus, are called downstream functions. During an analysis, any function can change status from being downstream, to come into focus, and to become an upstream function.

A FRAM model describes the functions and their potential couplings for a typical situation, but not for a specific situation. It is therefore not possible to say with certainty whether a function always will be performed before or after another function. That can only be determined when the model is instantiated. **A FRAM model is therefore not a flow model or a network where links or transitions are permanently defined**. By contrast, the labels FG function and BG function are valid both for the FRAM model as its instantiations. An instantiation of the model uses detailed information about a particular situation or scenario to create an instance or a specific example of the model. This corresponds to a temporal organisation of functions that reflects the order in which they will take place in the scenario, depending on how much variability there is. An upstream function is a function that for a given instantiation is performed **before** others, and therefore may affect them. Functions that – in the instantiation – take place **after** other functions and therefore can be affected by them, are called downstream functions. The terms upstream and downstream function are thus relative and not absolute.

6 This can also be called an Entry function.
7 This can also be called an Exit Function.

Continuing the development of a model

The model in Figure 5 shows how an initial FRAM model of an activity can be developed. Even in this simple example there are several things that need to be developed further, for instance how the boiling water is produced. The continued model development can be guided by the following questions:

- Is there a need of additional functions in the model, i.e., are there parts of the activity that have not been described because they are taken for granted?
- Are there any FG functions where the Input has not been defined? If the Input to a function is missing it means that the function will never be carried out, in which case there is no need to include it in the first place. Similarly, are there any FG functions where the Output has not been defined? If the Output is missing from a FG function it means that the Output is never used for anything, in which case there is no need to include the function in the model. Note, however, that this only applies to FG functions, but not to BG functions, cf., above.
- Are there any functions with orphans where the FMV has marked an aspect with a red ring?
- Are there any BG functions from which the Output could be variable? In that case they need to be considered in further detail or “expanded”.

It is important throughout the model development to look critically at the model and make sure that it “makes sense” vis-a-vis the activity in focus. This can for instance be done by showing it to people who are familiar with the activity in question but who are not part of the analysis team.

An important issue is the information needed to develop a model and where it can be found. The example of preparing cup noodles has been chosen because it describes something that most people either have sufficient knowledge about or can easily imagine. But that cannot be assumed to be the case for a FRAM model of a “real” activity. In these cases information must come from extensive formal or informal knowledge and experiences with the activity. (See Appendix A for a summary guidance on how to do so.) In many cases the analysis team includes people who have at least part of that experience; in other cases the identification and elicitation / recording of that requires supplementary work such as interviews, site visits, case studies, etc.

Interpreting a FRAM model

The FRAM is a tool to describe or represent how an activity usually is carried out. The activity is described in terms of the functions necessary for carrying it out, the potential couplings among the functions, and the typical variability. A FRAM model can be used to understand how the variability and adjustments of one function can affect other functions and thereby the activity as a whole. Functions can mutually dampen each other (absorb variability), so that a situation is stabilised. Functions can also mutually reinforce each other (amplify variability) through functional resonance so that a situation becomes unstable and leads to unexpected and often unwanted results. The description of the potential couplings can be used to understand emergent outcomes and also how the building up of these can be monitored and managed.

After having described the initial set of functions, the model building continues by making sure that all aspects are completely specified, using the following rules:[8]

8 This is actually done automatically by the FMV as described earlier.

- Every [Input | Precondition | Resource | Control | Time] aspect of a FG function must also be defined as an Output of another function.
- Every Output from a FG function must be defined as an [Input | Precondition | Resource | Control | Time] aspect of another function.

It may seem daunting to describe so many functions especially because some of the new functions will have aspects that in turn require more functions. This is where the importance of distinguishing between FG and BG functions becomes useful. Since BG functions only need their Output to be defined, they can be used to stop the expansion of the model.

The process of checking whether all aspects have been defined is built into the FMV. An additional check of the syntactical correctness of a model can be done by the FRAM Model Interpreter. Details about that can be found at https://safetysynthesis.com/methods/fram-model-interpreter.

Summary

The FRAM is a *method* that helps you to develop a model or a representation of how something happens or could happen, hence better to understand it.

- **Where to begin**: A FRAM analysis can in principle begin with any function. The method will show the need for other functions to be included, i.e., functions that are coupled or linked through the six aspects.
- **Level of description**: There is no single, correct level of description. A FRAM model will typically include functions described on different levels.
- **Level of detail**: If there can be significant variability in a FG function, then it may be useful to describe this in further detail, for instance by replacing it by several specialised functions.[9]
- **Foreground – background**: Functions are pragmatically labelled as being either FG or BG functions. BG functions can be seen as constituting the boundaries of a model.
- **System boundary – stop rule**: The analysis may go beyond the boundaries of the system as initially defined. (Indeed, most systems have boundaries that are based on how they are structured rather than on how they function.) The expansion of a FRAM model stops when it reaches a BG function. If it turns out that a BG function can vary and thereby affect FG functions, then it should be turned into a FG function.

Document history

A first version of this handbook was published by the Centre for Quality in September 2013. The handbook was written in Danish as support for the courses held by the Centre. The handbook contained extensive examples from health care.

It soon turned out that there was a demand for an English version of the handbook, which was prepared with the invaluable assistance of Jeanette Hounsgaard and Lacey Colligan. This version was published in June 2014.

The English version has been used extensively in Denmark and other countries as a part of FRAM courses. While some courses focused on issues in the management of health care, others considered a broader range of industries. There has therefore for some years been a

9 The Pro-version of the FMV has a built-in facility for that.

need for a version of the handbook that was in English but which did not focus specifically on health care. The 2018 version of the handbook was an attempt to answer that need.

The current (2021) version is a revision of the 2018 version. The revision is needed because further developments of the FRAM, and in particular of the FRAM Model Interpreter (FMI), means that some of the original parts of the method no longer are necessary. The current version focuses on how to use the FRAM and the FMV to build a model but stops short of how to analyse a model. Descriptions of of how this can be done can be found at
https://safetysynthesis.com/methods/fram-model-interpreter

The current version of the FRAM Handbook may freely be copied and distributed as a whole but not in parts. It may not be put for sale or commercialised in any way.

References

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Appendix A: How to get the information needed to describe functions

The best sources of information about the activities being analysed are the people who actually carry them out. They can either be people at the workplace under consideration, people who work in a similar workplace, or people who have had extensive experience with the work. Although interviews are the primary tool of investigation, other methods such as focus group discussions may be considered, just as the interviews may be supplemented by field observations, reports, etc.

Preparing for Interviews

Before the interviews it is important to think through the purpose of the study: how much information is needed and how will that information will be helpful? It is essential to prepare as well as possible before going into to the field, for instance by consulting available information sources such as rules and regulations, documents, protocols, job descriptions, etc. Data on turnover of personnel, equipment, procedures and organisation and major events or changes to the function can also be valuable. This information can be the basis for the set of questions that should guide the interview. It is important to find out as much as possible about the physical and environmental conditions of the workplace. This may require examination of the architectural drawings, photos or videos etc.

The interview questions should focus on daily activities, established practices, and their characteristic variabilities. So, instead of asking about successes or failures, questions should focus on the daily routines and habits – things that might be taken for granted or passed over – or even suppressed if the focus was an adverse event.

Examples of Possible Questions

The following questions may by their content and form give some ideas about how an interview could be conducted. The questions are, however, meant as a source of inspiration rather than as a checklist.

- When do you start this activity? What 'signals' that you can begin?
- How do you adjust the activity to different conditions? How do you determine how and when to adjust?
- How do you respond if something unexpected happens? For example, an interruption, a pause required by a more urgent task that takes priority, a missing resource, missing or surprising information, etc.
- How stable is staffing? Is staff allocation permanently assigned or adjusted daily? What happens if staffing is short?
- How stable is the environment? Supplies? Resources? Demands?
- Are there often undesirable conditions that you have to tolerate or get used to?
- How do you prepare for your work (documents, instructions, colleagues, etc.)? What do you do if these resources are not available?
- Which preconditions and/or other factors are normally taken for granted?
- What information do you need (equipment, services, etc.)? What do you do if it is not available?

- Does time pressure affect your work?
- What skills and competence do you need? Do everyone performing this work have the required skills and competence? What happens – how do people compensate – when that is not the case?
- What is the optimal way to perform this work? *Is* there an optimal way?
- How often do you have to make changes or adjustments to the ways you work?

The Interview

The interviews should if possible take place at the actual place of work. A tour of the workplace is often useful to get a feeling for the local environment. The interviewer may bring a valuable set of 'new' eyes to things that workers may have become 'blind' to. It is also important to prepare the interviewees for the process. They must first and foremost agree to participate in the interview and understand the purpose of the interview.

It can be useful if two interviewers conduct the interviews together: one can then concentrate on the dialogue, and the other on taking notes. One of the interviewers may well be recruited from the work domain, but they must be aware of and try control their own biases and preconceptions. It can be helpful to record the interview if the interviewees explicitly agree.

How to document the Interview

The first step is to type or transcribe the notes from the interview and consider these together with information previously obtained during the preparations. The team needs to identify the important functions and arrange the material so that the information is sorted by functions. If possible, some FG and BG functions can be identified already at this stage.

For each FG function, one should try to identify as many of the six aspects as reasonable. Information about Input and Output represent the bare minimum required.

For each function, you should provide the following:

- **Function Name**: it is important to find a short and clear name that describes the activity. This should be written as a verb or verb phrase.
- **Description of the function**: try to describe the function in as much details as necessary (free text description). The description should include who performs the function – not necessarily a specific individual but the organisational role. This description can be as long or as short as you wish. It is also useful to enter any points that came up during either the data collection or the discussions in the analysis team, lest they should be forgotten
- **Characterisation of some or all of the six aspects**. Each relevant aspect should be described to the extent possible with the information available and to the extent necessary to best describe the function. Remember that a function can have more than one Input, Output, Precondition, etc.

The description of the functions and aspects should be made by means of the FMV. This is a powerful software tool that helps structure the information and also provides some useful features that automatically checks the completeness of the model as it is built.