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PRODUCT AND PROCESS MODELLING – STATE OF THE ART UPDATE

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Abstract

The present documents details the activity carried out within the Task 2.2 of the FORMAT Project, aimed at reviewing and updating the state of the art about the modelling techniques available to describe products and processes.

This document collects 29 among the most diffused modelling techniques to represent both products and processes.

The definition of such a set of modelling techniques follows the logic of choosing the most diffused modelling techniques in industrial engineering contexts, so as to identify constructs and concepts that are more familiar than others to experts and technicians that would, in future, use the methodology for Technological Forecasting to be developed within the FORMAT project.

In details the modelling techniques are presented into three main categories: one collects the techniques mainly aimed at modelling products; the second one, in turn, pools all the methods that are mostly addressed towards the modelling of processes. Finally, the third category includes both the techniques that are capable of catching and representing aspects concerning both products and processes. Within this category there are several modelling techniques for highlighting problems as well as related cause-and-effect relationships; but also modelling techniques for generically describing entities and their hierarchy, regardless if those entities pertain to products or processes

Approval status

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0. Index

1. Introduction

This document presents a review of the state of the art concerning modelling techniques for describing products or processes, according to the specific objectives of Task 2.2.

The whole analysis has taken into account 29 modelling techniques according to two criteria:

- Capabilities to map different facets of the modelling subject;
- Diffusion in industrial contexts.

The first criterion allows the focus of the search to be reduced from the whole set of modelling techniques available from literature to a smaller one with minimum amount of models, which collects, at least once, the relevant characteristics to be mapped for the purposes of the project.

The second criterion, in turn, aims at considering all the models that have witnessed a certain degree of diffusion in industrial practices. In reference to this consideration, some models that are currently and proficiently used in different contexts (such as computer science and programming) have been here disregarded. They have been substituted with models sharing the same logic, but more suited for the manufacturing context. For instance, UML and SysML are here neglected in favour of BMPN 2.0, which is more diffused in manufacturing industries and suitable to their needs.

The content of the review is presented into three sections. Section 2 presents modelling techniques mainly focusing, according to their characteristics, on products. Section 3 concentrates on modelling techniques mostly oriented towards the definition of process characteristics. Section 4, eventually, presents different modelling techniques, both for what concerns purpose and capabilities. Generally speaking, the modelling techniques of Section 4 are suitable to describe both products and processes, because of their general characteristics. More specifically, some of those methods aim at modelling problems, in terms of undesired effects and related causes; some others, indeed, are very general and define a few classes of characteristics to be modelled or general description for them.

Each modelling technique is described according to a repeatable structure. Each model is firstly described in general terms, and then its main constructs are presented together with an explanation of their meaning. The modelling technique is also usually presented together with a graphical representation that helps the comprehension of the relationships among constructs. For each modelling technique it is also presented an example of modelling in the domain of cleaning clothes, more specifically in the field of domestic washing machines. For each modelling technique it is also presented a brief link to (one of) the author of the modelling technique, the title of the contribution where the modelling technique is presented and a link to easily connect to that source on the World Wide Web. For what concerns the references it is important mentioning that the reviewer has taken into account contributions concerning practical applications of the models and not just peer-reviewed papers available in authoritative journals, in order to better point out the characteristics of the models from the contexts in which they are proficiently used.

2. Modelling techniques mainly focused on Products

This part of the document collects a set of 7 modelling techniques. They are mainly focused on the definition of features and characteristics of products. However, they can be used to represent aspects occurring also in industrial processes as well.

The first five modelling techniques presented in this Section are oriented towards the definition of interactions between components of the product. They have been reviewed all together because each of them have particular characteristics which are not available in other models, thus representing potential opportunities for the definition of a meta-model collecting all the singularities of the relevant techniques here reviewed.

The last two modelling techniques, in turn, shift the attention mostly on the way the products deliver their functions, thus considering the essence of interaction or the properties involved in the transformations.

2.1. Tool – Object – Product (TOP) - TRIZ

Brief Description of the Modelling Technique

This model aims at describing the functional transformation carried out by a specific entity, called *Tool*. This "*Tool*" element is often the product to be modelled or the part of it that directly carries out the function for which the product has been designed.

The entity that undergoes the function is called *Object* or *Product*. The former denomination corresponds to the state in which the entity to be transformed is in its original state, the latter to its transformed state. The interaction among Tool and Object is represented through an arrow.

It may represent desired (black) and undesired (red) functions, as depicted in Figure 2. Functions not completely satisfactory are represented with a dotted line.

Main constructs

- **Tool** as the entity directly delivering the function (box or simple text);
- **Object** as the entity that undergoes modifications (box or simple text);
- **Product** as the desired condition to be met by the object (box or simple text);
- **Functional Interaction** as the action of the tool on the object (arrow).

Graphical representation of the model

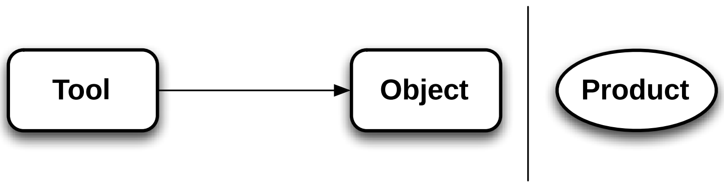


Figure 1: the characteristic constructs of TOP TRIZ and their relationships

Example of Application

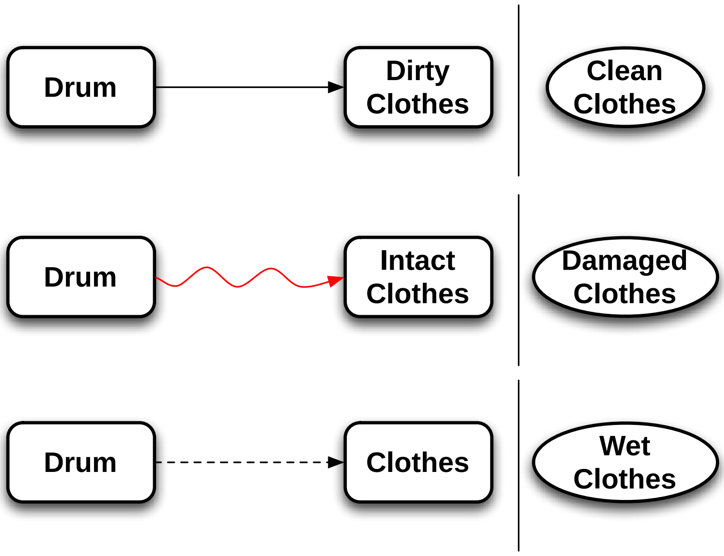


Figure 2: Three examples of application of TOP TRIZ modelling. From top: satisfactory function, undesired function, not-satisfactory function

Reference

Zinovy Royzen; Solving problems Using TOP TRIZ;
http://www.aitriz.org/articles/InsideTRIZ/30383036-526F797A656E.pdf

2.2. Substance-Field (Su-Field) Modelling

Brief Description of the Modelling Technique

This modelling technique describes functional interactions between elements. It is composed by a triad of entities and an interaction. Two entities are represented as *Substances*, which are concrete as well as abstract, and the other one describes a *Field* according to which the two substances interact. The interaction is depicted through an arrow whose direction explains which substance carries out the function and which one undergoes the modification imposed by the function.

Main constructs

- **Substance** as an entity interacting with, at least, another one. It may carry out a function or be its object (circle);
- **Field** as the set/domain of physical laws driving the interaction between two entities (as simple text: F and subscript with description);
- **Functional Interaction** as the action of an entity on another (as an arrow having the same meaning as in Figure 2 of Section 2.1).

Graphical representation of the model

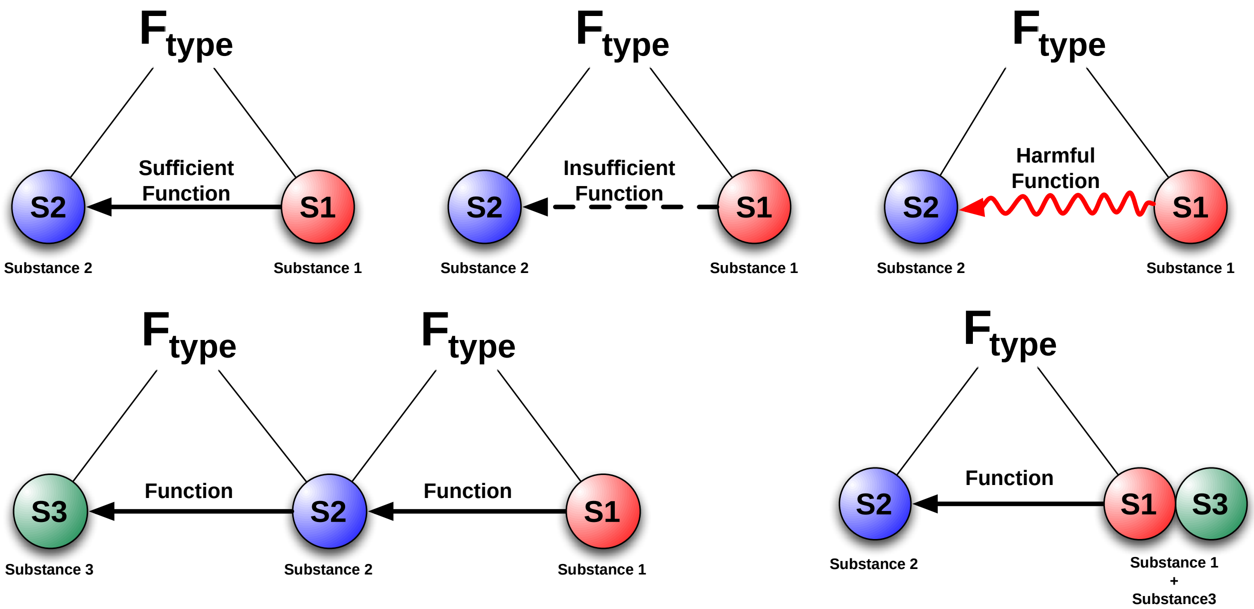


Figure 3: Examples of Su-Field Models. Different types of interaction (first row), Su-Field chain and combined action of two substances (second row).

Example of Application

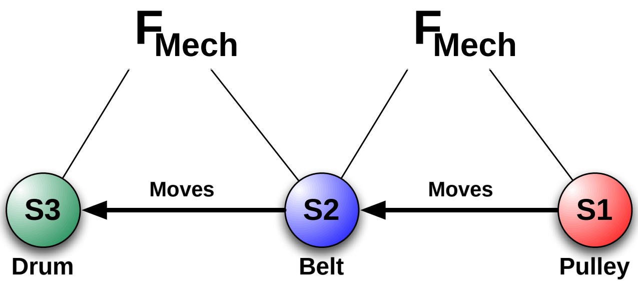


Figure 4: Su-Field chain about the power transmission of a washing machine

Reference

Genrich Altshuller, Creativity as an Exact Science;
http://books.google.it/books/about/Creativity_As_an_Exact_Science.html?id=ejJIIlj5m-UC&redir_esc=y

2.3. TRIZ Functional Modelling

Brief Description of the Modelling Technique

Modelling technique aimed at describing functional interactions among a wider group of different entities. Directed arrows representing functions connect entities to others.

This model allows both desired and undesired functions to be described, according to the changes undergone by the object of the function (a different entity). Figure 5 describes in a graphical way the differences between different categories of functions.

Main constructs

- **Element** is a system component as well as something in the environment (box);
- **Functional Interaction** as the action of an element on another (arrow)

Graphical representation of the model

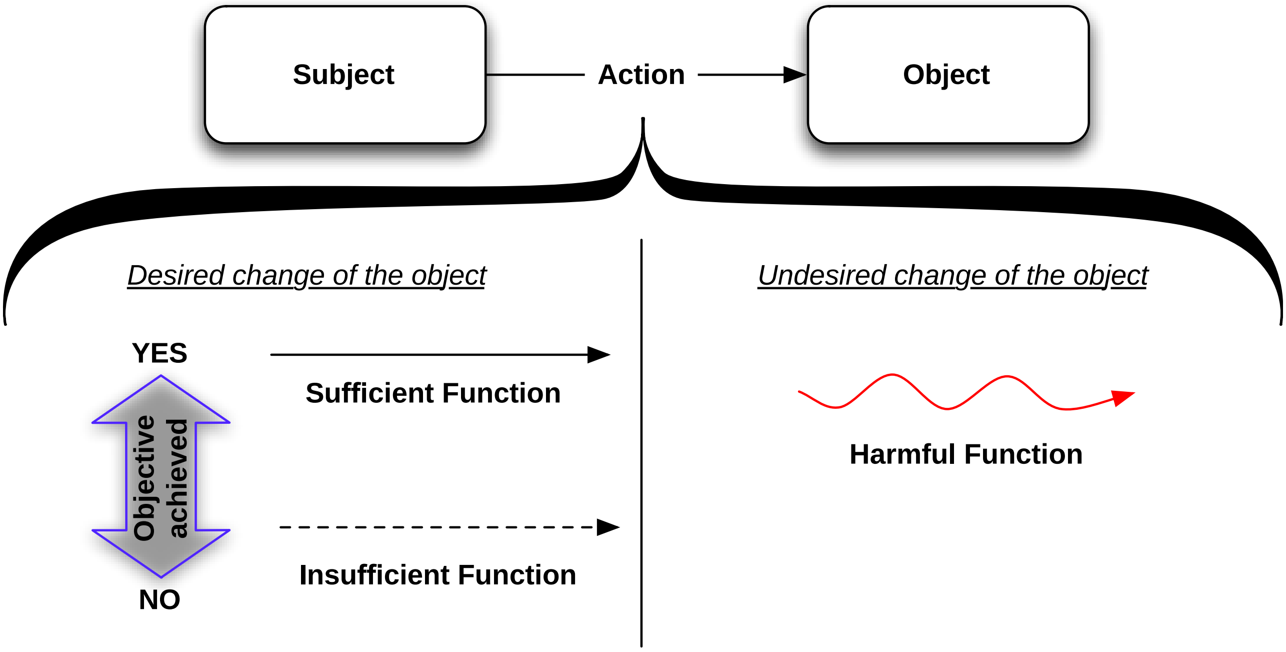


Figure 5: The Functional Model according to TRIZ on top. Below the bracket the differences among function classifications

Example of Application

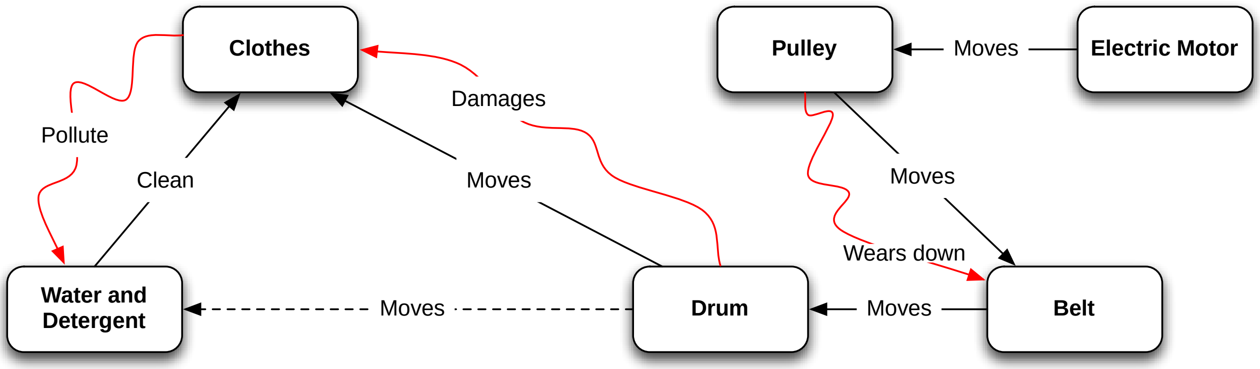


Figure 6: TRIZ Functional Model for a Washing Machine

Reference

Souchkov, V. BREAKTHROUGH THINKING WITH TRIZ FOR BUSINESS AND MANAGEMENT;
http://www.xtriz.com/TRIZforBusinessAndManagement.pdf

2.4. OTSM-TRIZ Functional Modelling

Brief Description of the Modelling Technique

Modelling technique having the same purpose of the one presented in Section 2.3. It differs from standard TRIZ Functional Modelling in the description of the function. This technique describes function using just four verbs (Increase, Decrease, Change, Stabilize) and a parameter or feature of the object that undergoes the modification carried out by the subject, as presented in Figure 7.

Main constructs

- **Element** as a system component as well as something in the environment. More in general an entity, even abstract;
- **Functional Interaction** as the action of an element on another, expressed with 4 standard verbs: increase, decrease, change, stabilize;
- **Parameter** as the characteristics of an element that changes according to the functional interaction.

Graphical representation of the model

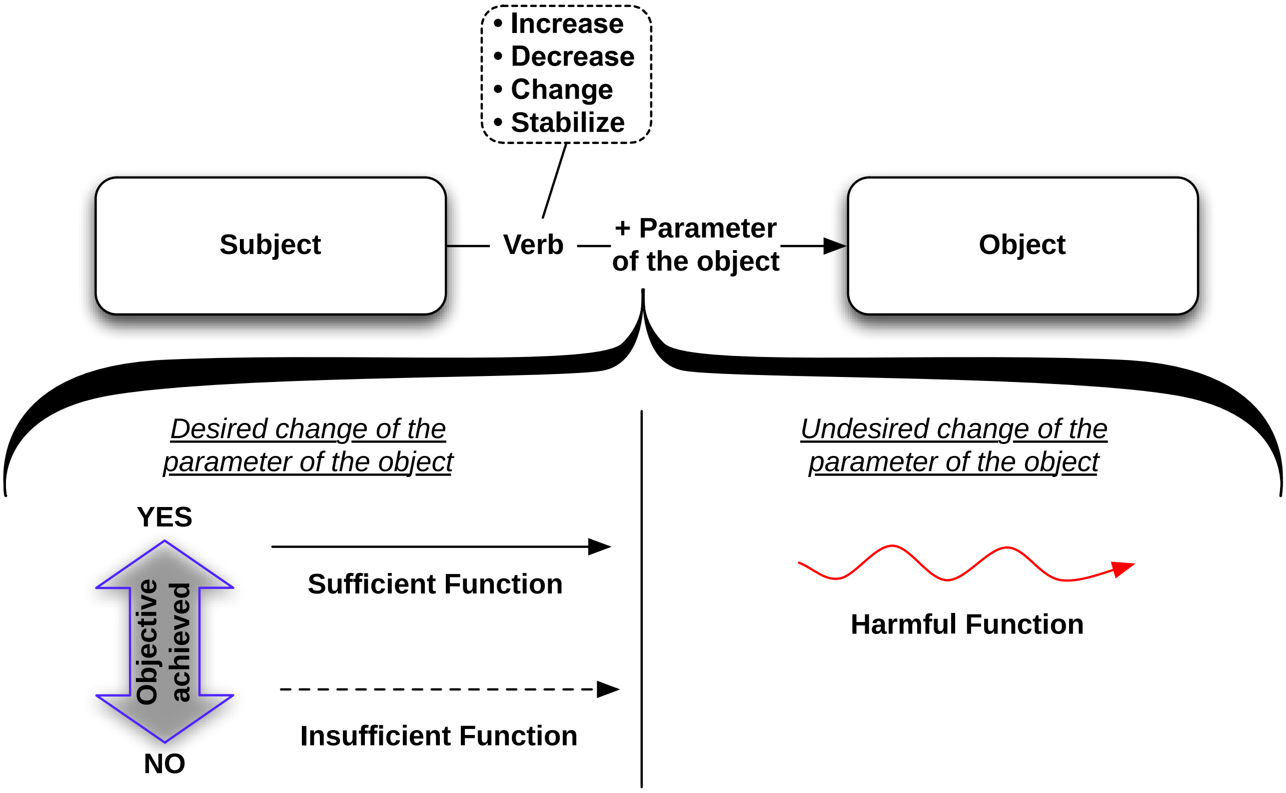


Figure 7: The OTSM-TRIZ Functional Modelling as a different characterization of classical TRIZ models of functions

Example of Application

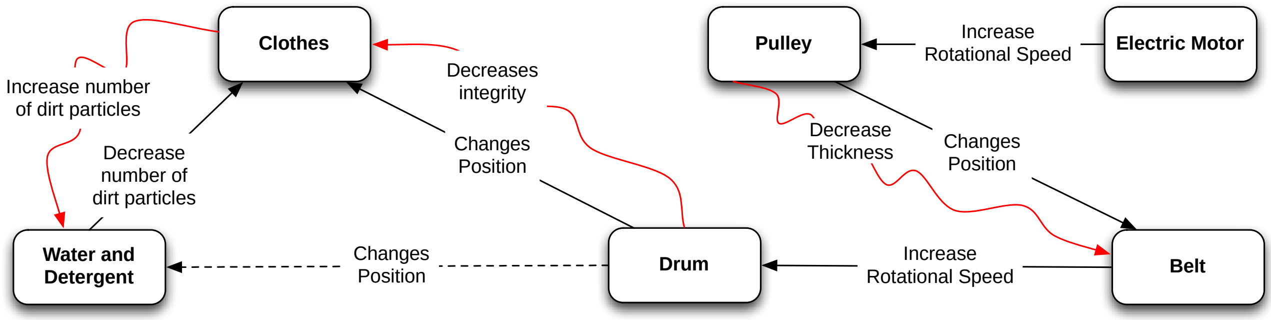


Figure 8: The same example of Figure 6, with the OTSM-TRIZ logic

Reference

Various Authors; TETRIS PROJECT Handbook; http://www.tetris-project.org

2.5. South Beach Notation

Brief Description of the Modelling Technique

This modelling technique represents system structure and problematic situations as the ones presented in Section 2.3-4. It allows more facets to be represented. An overall model describing its capabilities would go beyond the purpose of the review. Nevertheless, the part about the *Graphical representation of the model* collects all the main constructs as well as the different features that allow depicting personal perspectives or hierarchical relationships (Figure 9-12).

Main constructs

- **Agents** (as boxes of different shape, depending on the meaning of the agent - rectangle is an active entity; diamond is a choice; lozenge is a problem; blue rectangle is an effort; hexagon is knowledge)
- **Perspectives** (as differences in colour and line style for borders, box fillings and mutual connections expressing modeller's viewpoint -example- BORDER: green is useful, red is harmful, grey is neutral; ... FILLING: green is a goal, red is a risk... CONNECTIONS: dotted is potential; double is excessive; dashed is insufficient; ...)
- **Effects** (as the Directional or bi-directional lines between boxes, typically with a distinguishing arrow head at one or both end. They are influences between agents. Influences between agents can also exert influence, or be influenced.)
- **Separations and Situations** are modelling features that allow different models to be respectively subdivided and collected in order to focus on the different facets that may emerge at different detail level.

Graphical representation of the model

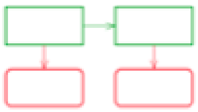
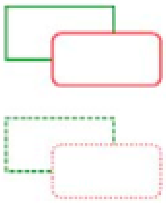
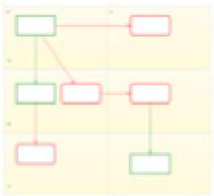
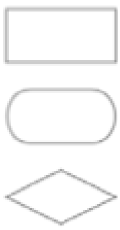
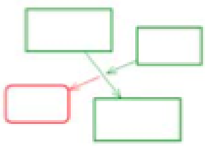
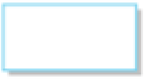
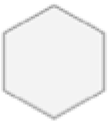
	Visualization	Definition	Synonyms
Situation 	One or more Southbeach models – line and box diagrams See http://soutbeach-examples.blogspot.com	Combination of circumstances, complex, critical or unusual problem, misalignment, a needed change etc.	Condition, case, plight, predicament, difficulty, state of affairs, circumstances, picture
Perspective 	Color, line style (see below)	What is useful, what is harmful? Goals and risks. What is insufficient, what is surplus? What is working, what is not working? What could be, what has been? etc.	Viewpoint, as one sees it, frame of reference, opinion, position, judgment, argument, observation, outward appearance, relative view, context ...
Separation 	Placement on a 1D or 2D grid, e.g. swim lane diagram, pool or consultants 2x2, NxM	Looking at a situation in many dimensions. For example, in the past, present and future, from above, from below. Southbeach defines several dimensions of separation. See below.	Dimension, property, attribute, distance between, independence, grouping, partitioning, degree of freedom, arrange by class or kind, area reserved for some purpose ...
Agent 	A rectangle or other simple shape, e.g. diamond, lozenge	An actor within the situation. Agents have effects on each other within the situation. Southbeach defines several kinds of agent. See below.	Actor, cause, performer, active element, key role, factor, force, means, operator, worker, broker
Effect 	Directional or bi-directional lines between boxes, typically with a distinguishing arrow head at one or both ends.	Influences between agents. Southbeach defines several kinds of effects. See below. Influences between agents can also exert influence, or be influenced.	Influence, consequence, result, outcome, upshot, side effect, by-product, repercussion, force, impact, production, implication operation, intention ...

Figure 9: Main constructs of the model

Agents

Agents are actors in a situation. The following kinds are defined:

	Visualization	Synonyms
Plain agent 	Rectangle	Actor, cause, performer, active element, key role, factor, force, means, operator, worker, broker
Choice 	Diamond	Option, alternative, selection, possibility, decision, pick list, path, route, way ...
Issue 	Lozenge	Question, crux, point in issue, matter raised, problem, trouble, precondition, hiatus, block, check, query, discussion, doubt ...
Action 	Shadowed blue rectangle	Proposal, effort, intervention, treatment, project, proactive step, planned activity, control, endeavor, positive influence ...
Knowledge 	Hexagon	Information, facts, context, assertion, opinion, belief, evidence, rumor, sacred cows, elephants in room, realities, principles, truth, laws ...

Perspectives

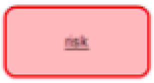
	Visualization	Synonyms
Useful 	Green	Positive, enabling, helpful, solution, worthwhile, profitable, beneficial, gainful, productive, valuable, effective ...
Harmful 	Red	Negative, inhibiting, harmful, disadvantage, problem, danger, contrary to interest, destructive, malign, subversive ...
Neutral 	Grey	Undecided, uninvolved, impartial, objective, remote, unaligned, indifferent, detached, ordinary, bland, isolated ...
Goal 	Green filled plus text underlined	Aim, purpose, intent, aspiration, ambition, ideal, objective, target, destination, terminus, home, pay off, finish, end ...
Risk 	Red filled plus text underlined	Hazard, danger, jeopardy, peril, liability, vulnerability, susceptibility, exposure, uncertainty, gamble

Figure 10: Agents and Perspectives details

Effects

Effects are influences of one agent on another, or between agents and effects. They are unidirectional.

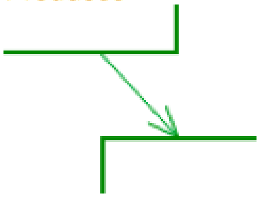
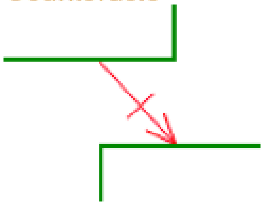
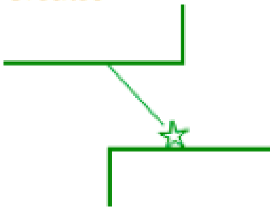
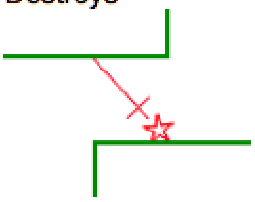
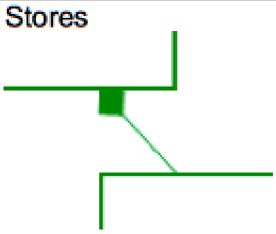
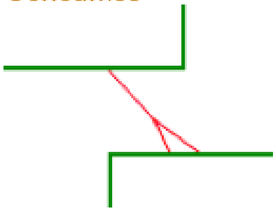
	Visualization	Synonyms
Produces 	Standard arrow head	Increase, exaggerate, grow, increment, enhance, magnify, heighten, deepen, reveal, provide, supply, output, return ...
Counteracts 	Standard arrow head with tick across line The counter effect to 'produces'	Inhibit, obstruct, reduce, mitigate, hinder, restrain, conflict with, clash with, work at cross purposes with, offset benefit of, neutralize, cancel effect of
Creates 	Star	Make, cause to be, generate, originate, conceive, invent, design, build, construct, manufacture, establish, reveal, launch, expose, show ...
Destroys 	Star with tick across line The counter effect to 'creates'	Remove, delete, degrade, ruin, break, terminate, overthrow, subvert, defeat, erase, eradicate, cancel, expunge, wipe out, dismantle, disguise, hide, kibosh
Stores 	Filled block (at the storage end)	Accumulate, stock, save, stockpile, amass, cache, warehouse, deposit, conserve, preserve, value, appreciate ...
Consumes 	Funnel at the end being consumed	Expend, deplete, weaken, drain, exhaust, empty, use up, devour, squander, waste, wear out, ruin, wipe out, dispose, lose, misuse

Figure 11: Effects details

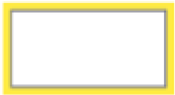
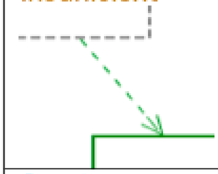
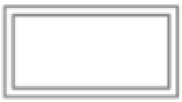
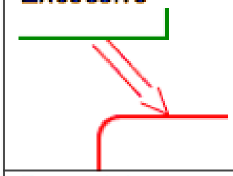
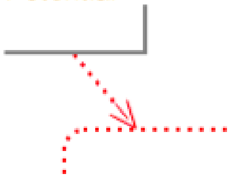
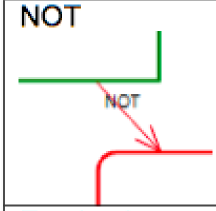
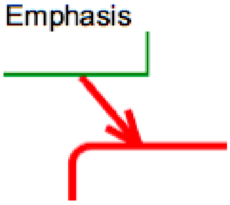
Historical 	Cross out shape	In the past, no longer, retired, obsolete, strike-out, old news, noncurrent, not in play, completed, defunct, dead, missing ...
Focus 	Yellow outline highlight	Center, spot light, nub, core, kernel, heart, concentration, substance, zero in on, key element, pivot, axis, meeting place ...
Insufficient 	Dashed line – agent or effect	Deficient, in adequate, lacking, in short supply, at a premium, in capable, underpowered, too small, too little too late
Surplus 	Doubled line on agent	Surfeit, excess, oversupply, extra, glut, redundancy, spare, reserve, additional to need, superfluous, duplication ...
Excessive 	Doubled line on effect	Beyond limits, disproportionate, undue, immoderate, extreme, too much, overkill, overload, strained, uncertain outcome
Potential 	Dotted line – agent or effect	Possible, imaginable, unrealized, latent, dormant, untapped, inactive, passive, hidden, undisclosed, undeveloped, deferred, waiting
Dysfunctional 	Broken line – agent or effect	Impaired, imperfect, damaged, not serving purpose, diminished in quality or utility, unsatisfactory, incomplete, inadequate
NOT 	The word 'NOT' on the effect line	Negation, e.g. A does not produce B
Emphasis 	Thickened line – agent or effect	Accent, stress, underline, importance, significance, prominence, salience, priority, weight, strength

Figure 12: Further details on Perspectives and Effects (more details available at the URL in the Reference)

Reference

Howard Smith and Mark Burnett; The Elements of Southbeach Notation 0.9; https://sites.google.com/site/southbeachhelp/notation

2.6. Model of Minimal Technical System

Brief Description of the Modelling Technique

Differently from the models presented so far, the model of the Minimal Technical System aims at defining the minimal set of entities that are required to make the whole system work for its purpose. The logic is to highlight that all the elements contained in the model do not have, by themselves, the capability to carry out the function of the system, but they can do it when combined in an appropriate synergy. The connections among elements represent a channel of flowing energy (bottom of Figure 13), which is required to make the system work (according to the original model developed by Altshuller). A variant has been proposed to also consider flows of material or signal among the elements of the model. The connection between the Control element and the others (one controllable element is sufficient to control the whole system) could be also logical.

Main constructs

- **Tool** as the entity directly interacting with the object of the function (bottom right box);
- **Engine** as the entity from where the energy (in general terms, the property) that makes the tool capable to deliver the function comes from (bottom left box);
- **Transmission** as the entity/ies transferring energy to the tool (bottom central box);
- **Control** as the entity that regulates system behaviour (top box).

Graphical representation of the model

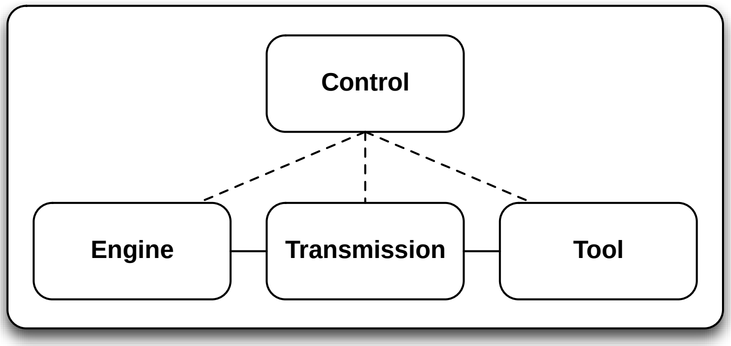


Figure 13: The four elements characterizing the Minimal Technical System model

Example of Application

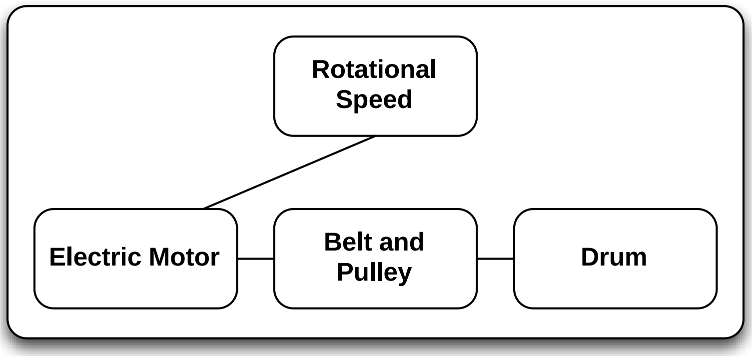


Figure 14: MTS Model for a washing machine

Reference

Genrich Altshuller, Creativity as an Exact Science; http://books.google.it/books/about/Creativity_As_an_Exact_Science.html?id=ejJIIlj5m-UC&redir_esc=y

2.7. SAPPhIRE Model

Brief Description of the Modelling Technique

The SAPPhIRE (**S**tate - **A**ction - **P**arts - physical **Ph**enomena - **I**nput - o**R**gans - physical **E**ffect) model has been designed to point out the way a system works, by considering its parts, their combination as well as triggers from outside the system borders capable to start or feed the system way of working. Moreover, the interactions among parts are described both in physical and in experiential terms, at different levels of detail.

The characteristic elements of the model are depicted in boxes; connections, in turn, are represented through arrows that change its meaning depending on the elements they connect. In details, the arrows may assume the meaning of: “Create”; “Activate” and “Interpreted as”, as depicted in Figure 15. The meaning of these arrows appear as being not so robust and repeatable, since in some model they loose their meaning, as shown in the example of Figure 16.

Main constructs

- **Action** as an abstract description or high-level interpretation of interaction;
- **State Change** as the change in property of the system and environment that is involved in interaction;
- **Physical Phenomenon** as the interaction between the technical system and the environment it is immersed in;
- **Physical Effect** as the physical principles or laws that govern the interaction;
- **Organs** as the properties and conditions of the system and the environment required for interaction;
- **Input** as the physical quantity -material, energy or information- that comes from outside the system boundary and is essential for interaction;
- **Parts** as the physical entities and interfaces that constitute system and environment.

Graphical representation of the model

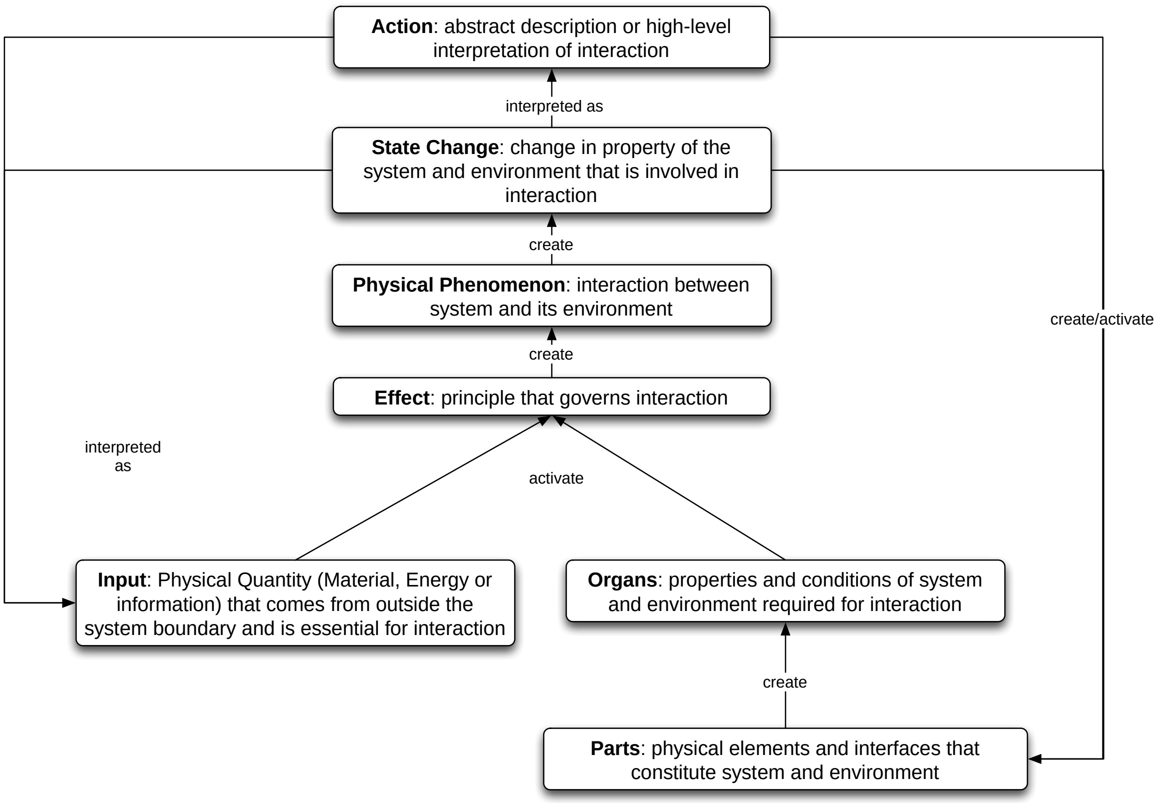


Figure 15: The SAPPhIRE model and its constructs

Example of Application

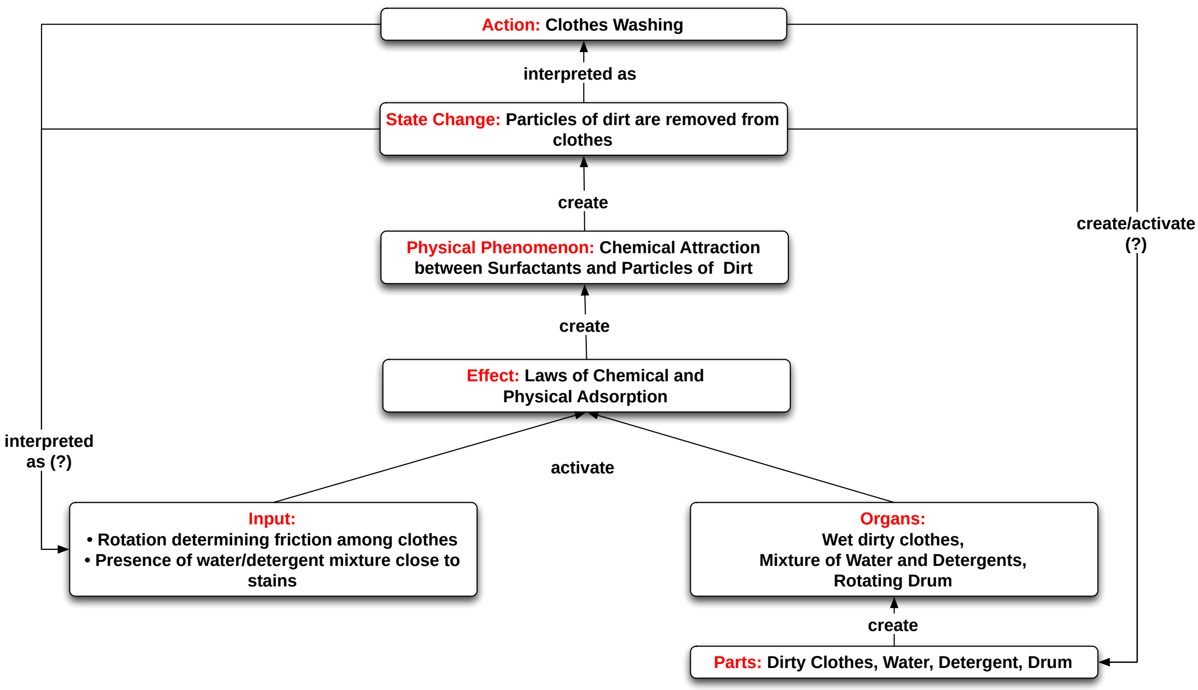


Figure 16: The SAPPhIRE Model for the washing phase of a washing machine

Reference

Amaresh Chakrabarti; A functional representation for aiding biomimetic and artificial inspiration of new ideas;
http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=330433

3. Modelling techniques mainly focused on Processes

This part of the document collects a set of 9 modelling techniques. They are mainly focused on the definition of features and characteristics of processes. This means they are both capable to describe industrial processes, as well as the different stages or steps a technical system or part of it carries out, in order to perform the overall function of the product.

Some of these techniques represent the different states of one or more entities along the process to be modelled; some others, on the contrary, focus on the events that trigger the transformations.

3.1. Energy – Material – Signal (EMS) Model

Brief Description of the Modelling Technique

This modelling technique is aimed at describing functions according to the transformations they operate on different flows, which can be classified under Energy, Material and Signal.

Despite this model focus on representing functions, a customized interpretation of this modelling approach also allows representing different behaviours. In other words, a desired function can be modelled by representing just the desired flow transformations (in red, Figure 18). Nevertheless, all the incoming flows can be modelled, this releasing from the ideal transformation to the actual function, including all the flows required for the system functioning (in black, Figure 18).

This kind of modelling technique is versatile since it allows to represent the functions at different levels of detail, with a fractal structure, as depicted in Figure 18, where the image on top represent the whole process, while the sequence of boxes at the bottom show a few different stages that characterize the overall process.

Main constructs

- **Function** as a black box representing an action carried out on a flow;
- **Input flow** as an arrow representing an entity -energy, material or signal- that will be transformed by the function (different arrows, for different flows);
- **Output flow** as an arrow representing an entity -energy, material or signal- whose state has been changed by the function.

Graphical representation of the model

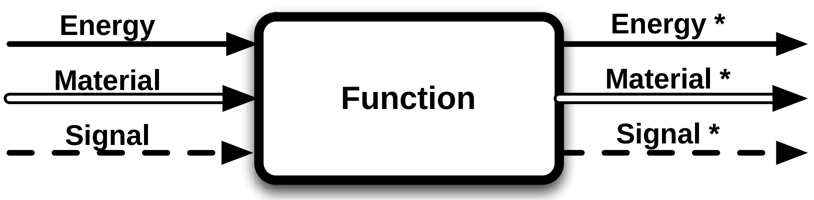


Figure 17: The core elements of the EMS model.

Example of Application

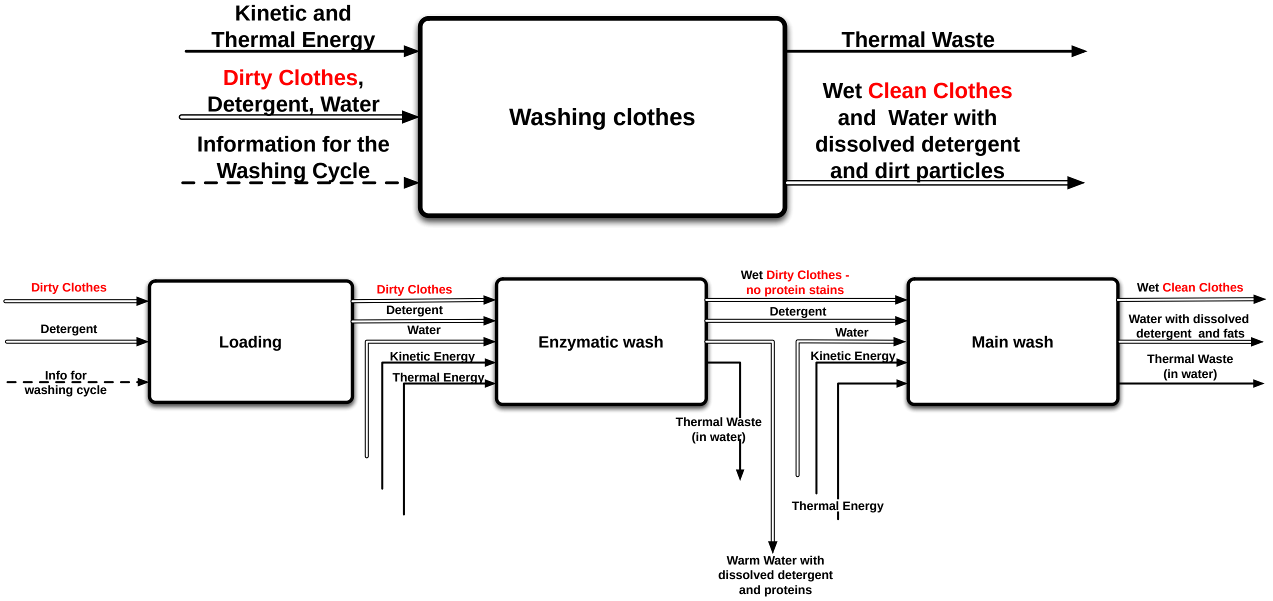


Figure 18: Example of the EMS modelling. Top: the overall process of washing clothes. Bottom: A more detailed perspective on the same process. Red text represent desired flows, black ones resources involved into the transformation

Reference

Gerhard Pahl, Wolfgang Beitz, Ken Wallace; Engineering Design: A Systematic Approach; http://books.google.it/books/about/Engineering_Design.html?id=8fuhesYeJmkC&redir_esc=y

3.2. System Operator

Brief Description of the Modelling Technique

The System Operator is a modelling technique for describing technical systems or processes according to different hierarchical levels with a time perspective. Structured as a matrix, usually 3x3, but with flexible dimensions.

Main constructs

- **System** as a reference detail level for describing an entity - represents a row of the matrix;
- **Super-System** as the entities that are not part of the system, e.g. the environment in which the system is immersed and the entity with which it interacts - it represents a row of the matrix, to be further split into more rows;
- **Sub-System** as the entities that compose the system, its components - it represents a row of the matrix, to be further split into more rows;
- **Present** as a reference time interval for describing the condition of one or more entities - represents a column of the matrix;
- **Past** as the time interval preceding the "Present" one during which conditions of one or more entities are described - represents a column of the matrix, to be further split into more columns;

- **Future** as the time interval following the "Present" one during which conditions of one or more entities are described - represents a column of the matrix, to be further split into more columns.

Graphical representation of the model

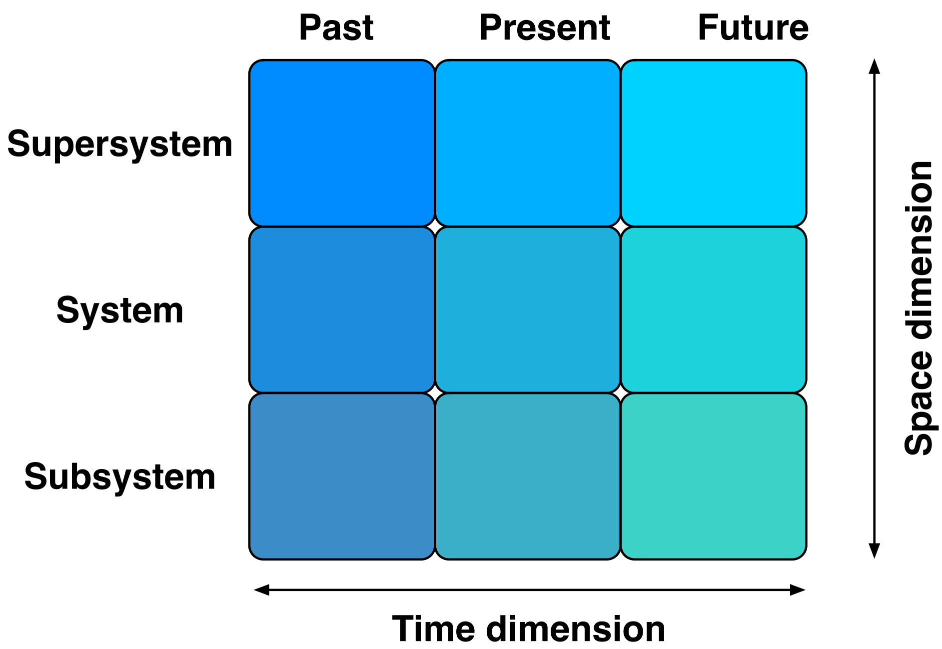


Figure 19: The System Operator most common scheme.

Example of Application

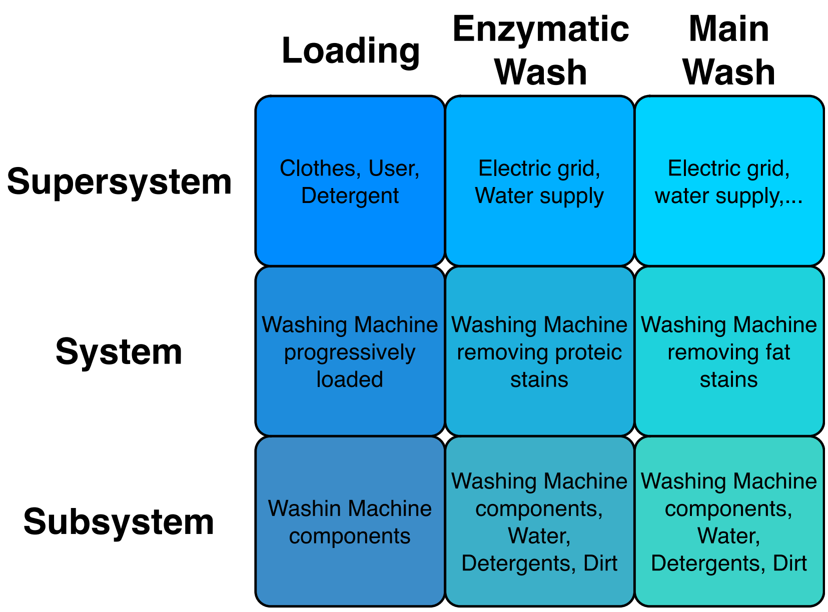


Figure 20: The System Operator concerning the washing process carried out by a Washing Machine. More dimensions on the time and space axes could have been considered as reasonable.

Reference

Genrich Altshuller, Creativity as an Exact Science;
http://books.google.it/books/about/Creativity_As_an_Exact_Science.html?id=ejJIIIj5m-UC&redir_esc=y

3.3. High-level Petri-Net Graph

Brief Description of the Modelling Technique

It is a modelling technique capable to represent discrete events systems such as processes or products functioning (e.g.: collections of real or abstract objects and discrete actions which modify or consume objects from some collections and create objects in other collections). The graphical modelling technique can be easily translated in mathematical language and vice versa according to the rules governing the Petri Nets.

Main constructs

- **Token** as objects that are part of the system or of the process, they are collected in Places. Represented as bold black dots. According to the definition, they are: *A data item associated with a place and chosen from the place's type*". They could be further characterized as "Simple Token", which is a valueless token, normally represented by a black dot, and used in Place/Transition nets.
- **Place** as a node of a net, normally represented by an ellipse or circle in the net graph. It collects tokens. The Marking of a place is a potential configuration of its tokens. This kind of nodes describes states that characterize specific steps of a process;
- **Transition** is a node of a net, normally represented by a rectangle -empty or black filled- in the net graph. Each transition in the graph consumes at least one token from a place and moves it to a different place, usually changing one of its characteristics. Specific combination of transitions can be used to model logical blocks;
- **Arc** as a directed edge of a net, which may connect a place to a transition (input arc of a transition) or a transition to a place (output arc of a transition). It is normally represented by an arrow.

Graphical representation of the model

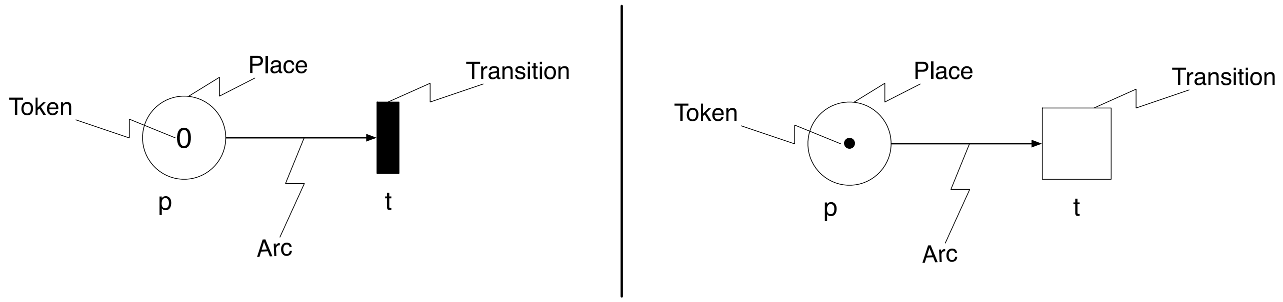


Figure 21: Two slightly different representation of the main constructs of a High-level Petri Net Graph. The meaning of elements, however, does not change in the two representations.

Example of Application

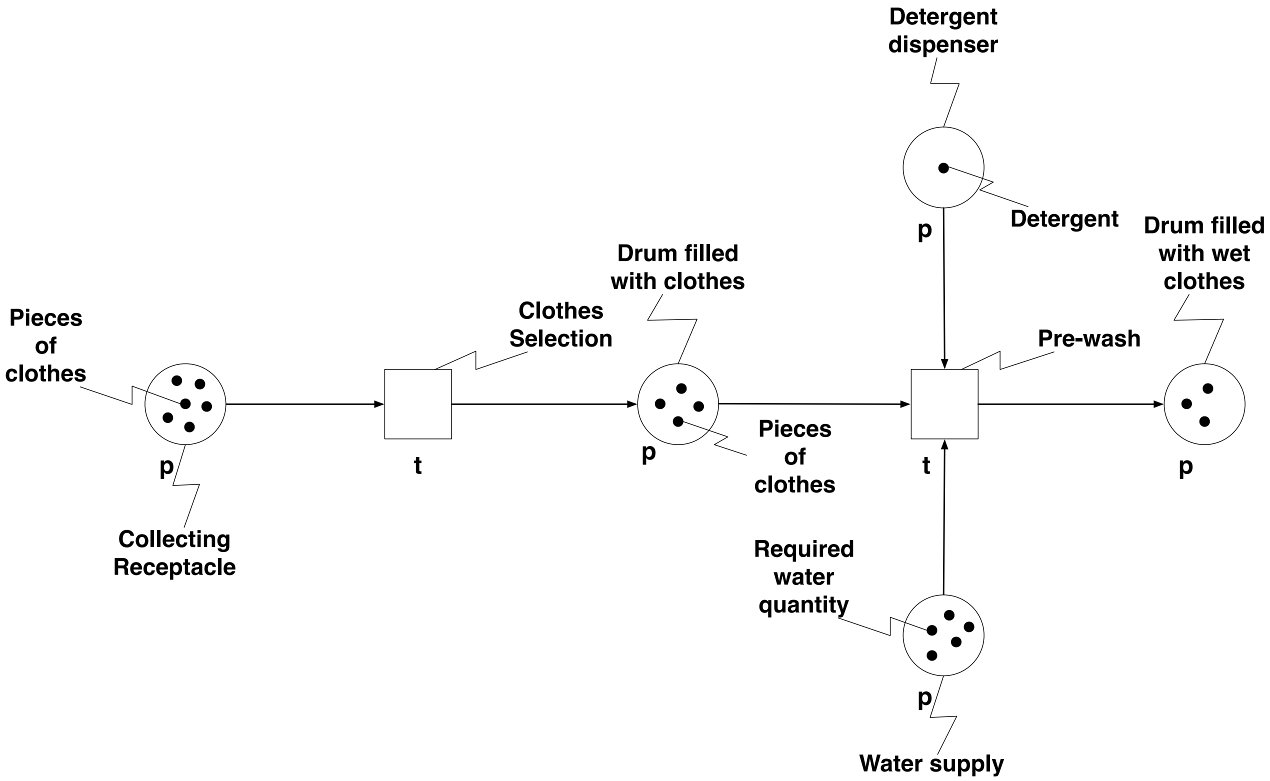


Figura 22: Part of a washing cycle carried out by a washing machine and represented through the Hig-Level Petri Net graphs.

Reference

Final Draft International Standard ISO/IEC 15909 Version 4.7.1 October 28, 2000; High-level Petri Nets - Concepts, Definitions and Graphical Notation; http://www.informatik.uni-hamburg.de/TGI/PetriNets/introductions/pn2000_introtut.pdf
http://www.petrinets.info/docs/pnstd-4.7.1.pdf

3.4. Dane/SBF Modelling

Brief Description of the Modelling Technique

This modelling technique, as the one presented in Section 3.3, describes a process as a sequence of states. It is characterized by three different representations. One concerns the Function, which is described as the transition from an initial (Given) state to a final (Makes) desired state. The detailed sequence of states is collected in the model concerning the Behaviour of the Technical System. The element composing it and their relationship, in turn, are represented in the Structural model. The rules to connect substances (energy and "liquid" flows) and components in a Structural Diagram (see Figure 24, right) are not formally explained in the papers where the modelling technique is presented.

Main constructs

- **Structure** as the entities composing the system, being them abstract or concrete. Components contain substances having properties;

- **Function** as the initial and final conditions of a transformation together with a brief overview of characterizing behaviour;
- **Behaviour** a sequence of states from the initial condition, to the final condition, each step representing an intermediate state;
- **Structural Connections** as arrows that link different components;
- **Behavioural Connections** as arrows that link different states.

Graphical representation of the model

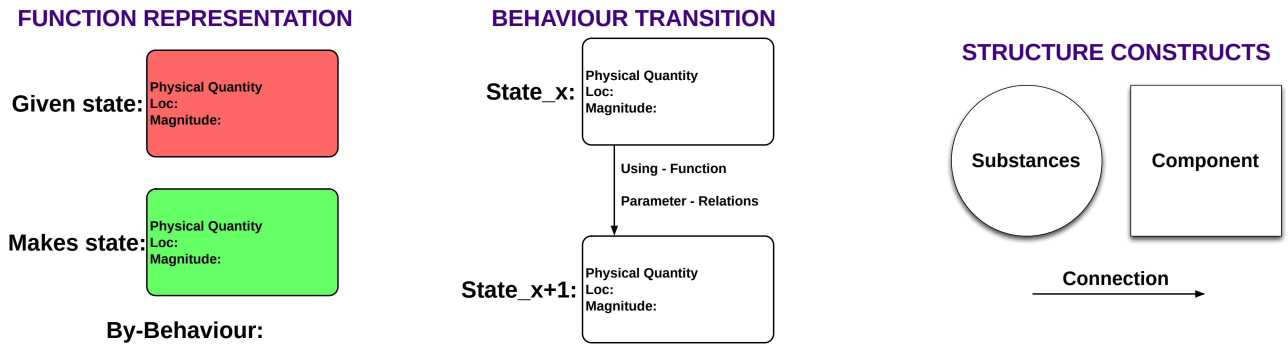


Figure 23: From left: a) the representation of function as the transition from an initial state to a goal state; b) the elementary transition between two states, with details about the characteristics that change in the transformation, represents behaviour; c) the components and the connections

Example of Application

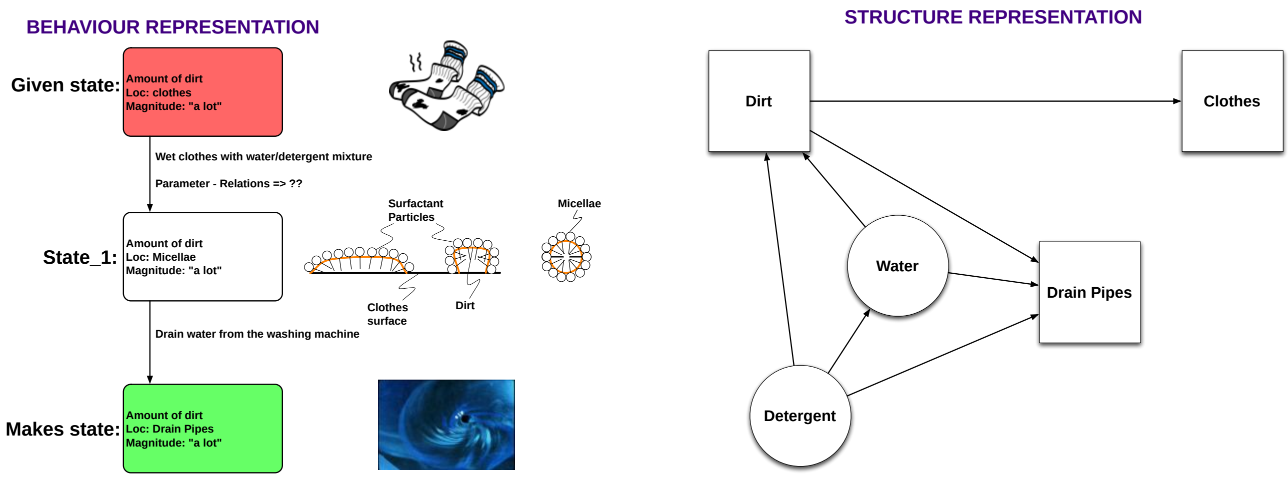


Figure 24: The sequence of states that characterize the process of cleaning clothes in a washing machine (Left) and the interaction among substances and components involved in such transformation (Right).

Reference

Goel, Rugaber, Vattam; Structure, behavior, and function of complex systems: The structure, behavior, and function modeling language; http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=3004176

3.5. Functional Tree

Brief Description of the Modelling Technique

It is a modelling technique capable to represent dependencies between functions (lower levels should correspond to elementary functions, by following an organizational chart logic). Such a modelling technique, therefore, allows functions to be structured at different levels of detail so as to understand the different behaviours chosen for a process as sublevels of an originating function.

Main constructs

- **Function** as boxes expressing an action to be carried out during a process. Each complex function should be decomposed into elementary functions;
- **Connections** as lines linking function boxes. They express dependencies among functions; hierarchies among functions are not described with line directions, but according to the nesting level of a function.

Graphical representation of the model

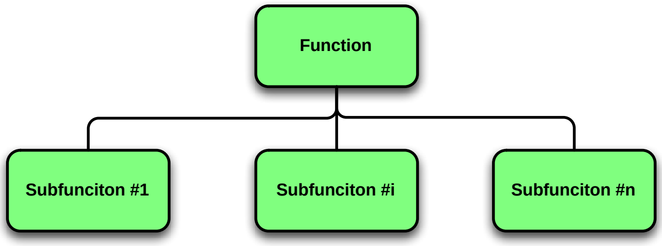


Figure 25: The most general and elementary structure for a Functional Tree model

Example of Application

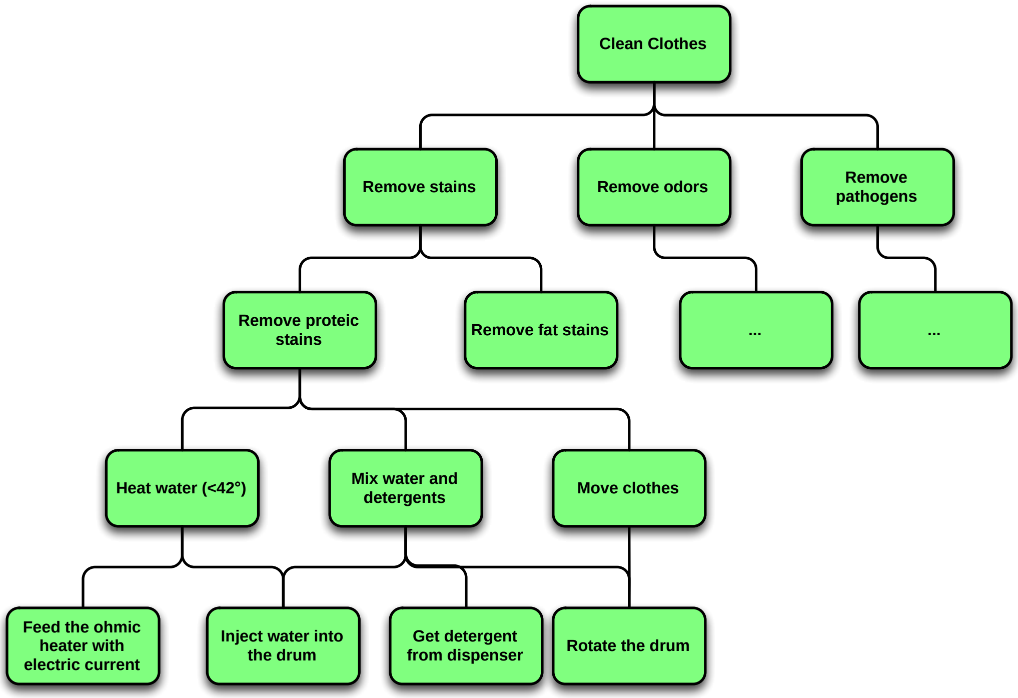


Figure 26: Example of Functional Tree with behavioural characteristics at different sublevels

Reference

David L. Hallowell; Tree Diagrams for Six Sigma: Plain and Simple?
http://www.isixsigma.com/tools-templates/affinity-diagramkj-analysis/tree-diagrams-six-sigma-plain-and-simple/

3.6. IDEF0

Brief Description of the Modelling Technique

This is a modelling technique to represent functions as the transformations between an input and an output flow, by also taking into account the necessary resources capable to carry out such transformations as well as the rules that control them (Figure 27). Such a model allows functions to be represented according to a codified fractal structure that properly maps dependencies and inclusions among them. The examples of Figure 28-30 show how the same function can be detailed in different levels, so as to highlight different facets, each level is characterized by a code (e.g. Ax, where x is a distinctive number that can be organized into x)

Main constructs

- **Function** as a black box transforming inputs into outputs, expressed by means of verbs and specifications;
- **Inputs** as an arrow representing a flow of substances, information, or energy that gets transformed by the function (left side of the box, incoming);
- **Outputs** as an arrow representing the outcome of the function carried out on the input flows (right side of the box, outgoing);
- **Control** as an arrow whose label specifies the conditions required for the function to produce correct outputs (top side of the box, incoming);
- **Mechanisms** as an arrow representing the means that support the execution of a function (bottom side of the box, incoming).

Graphical representation of the model

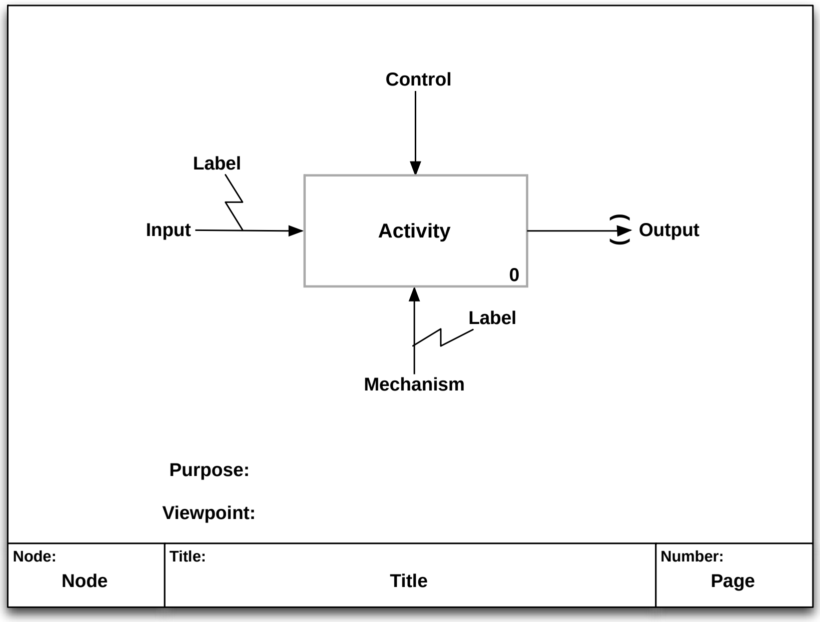


Figure 27: The general features characterizing an IDEF0 Model: The Function (activity) and its characteristics flows (arrows).

Example of Application

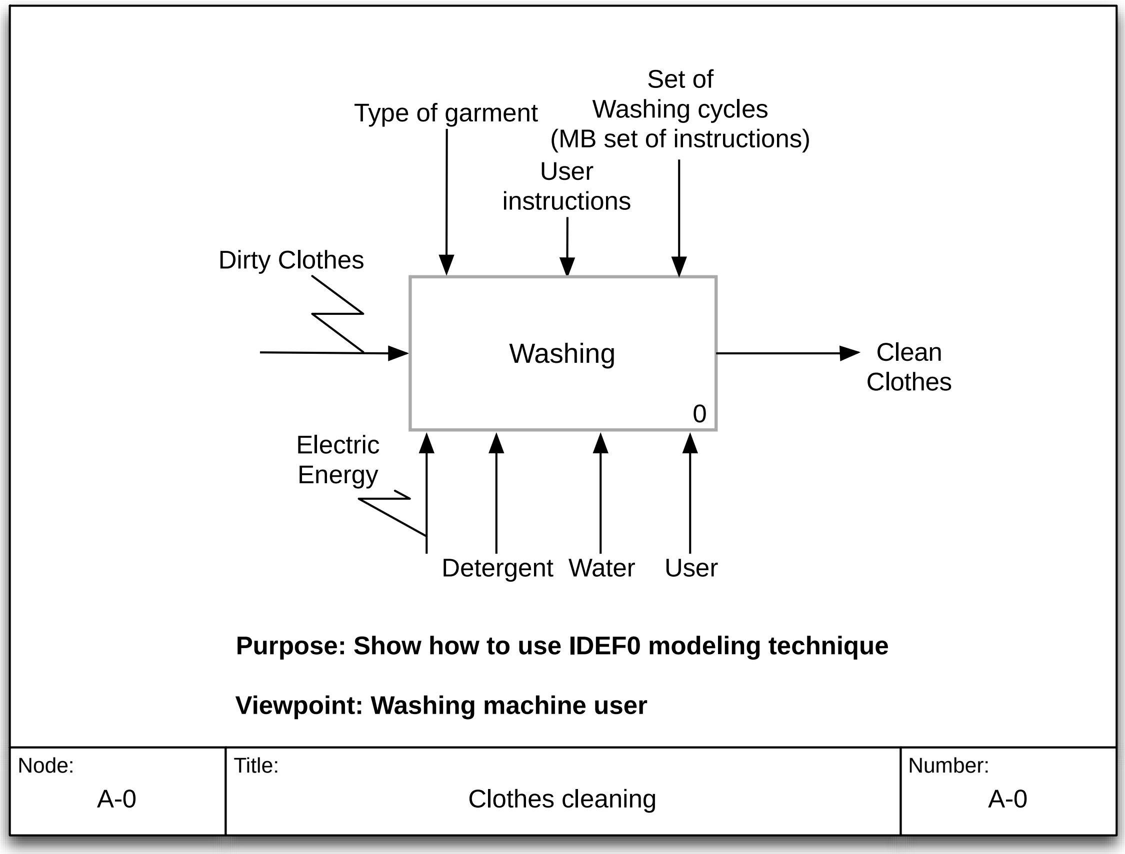


Figure 28: Diagram describing the overall function of cleaning clothes with a washing machine

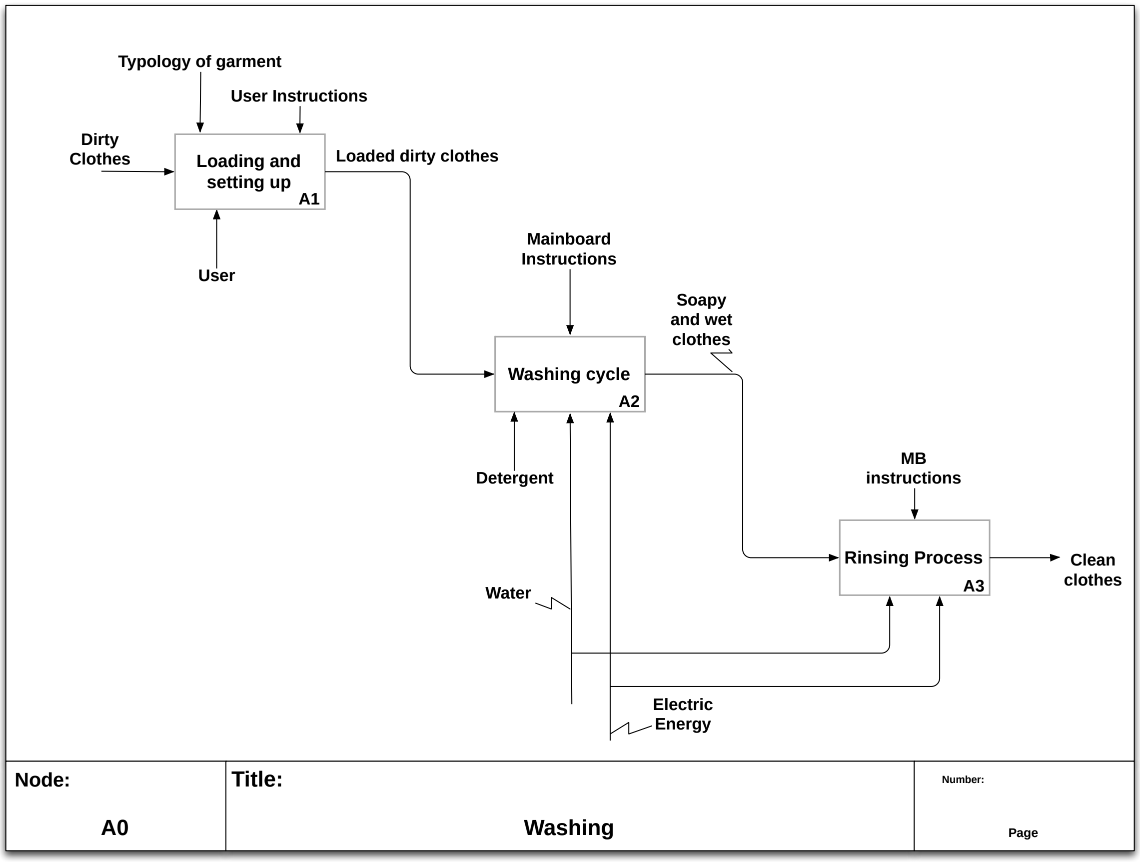


Figure 29: The three main phases of the clothes cleaning process as carried out by a washing machine. Please note that this model split the Function of Figure 28 into three sub-functions.

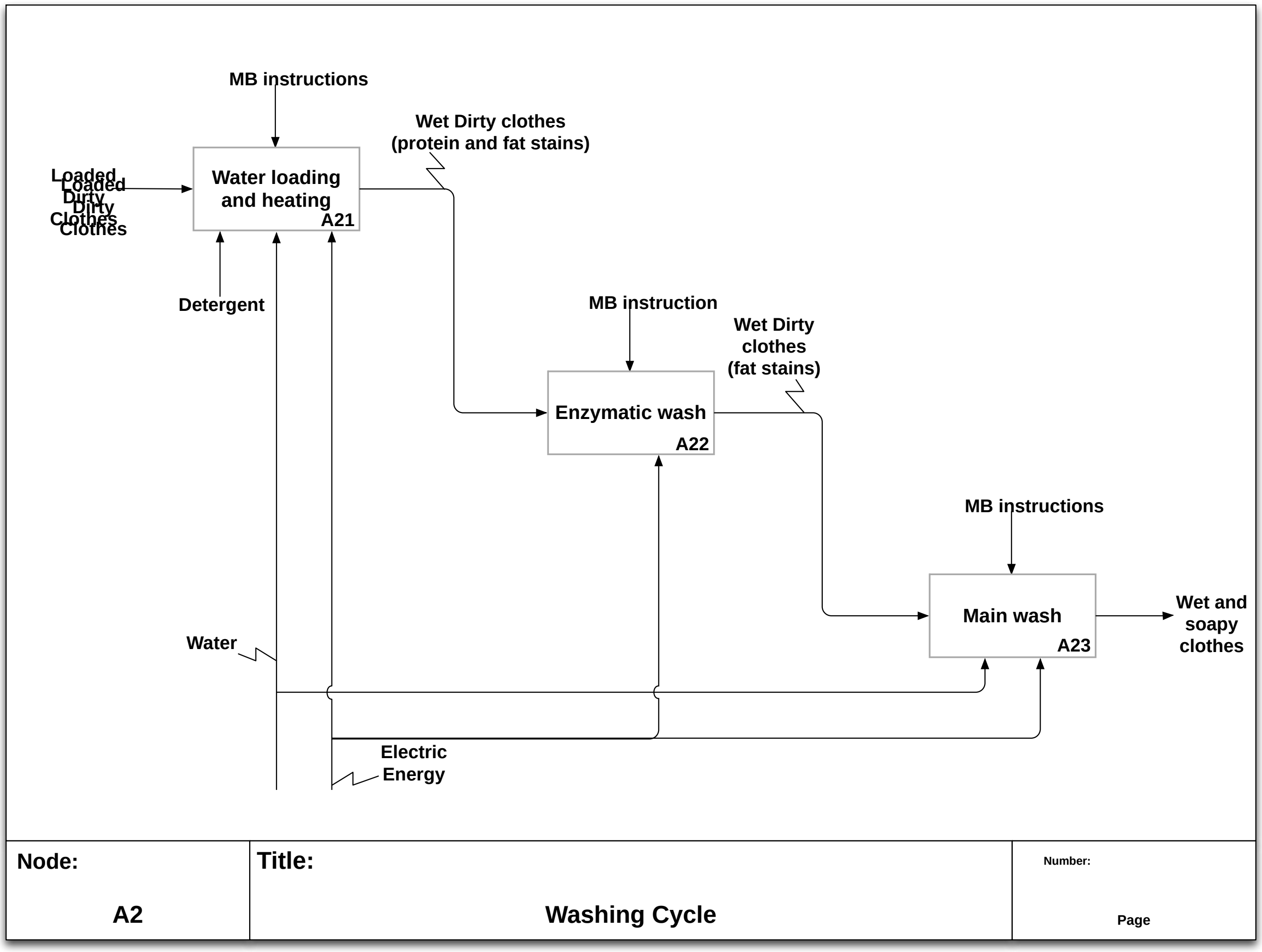


Figure 30: A more detailed description of the phases concerning the washing stages of the washing machine. Please note that this diagram is detailing box A2 of Figure 29.

Reference

Federal Information Processing Standards Publications; INTEGRATION DEFINITION FOR FUNCTION MODELING (IDEF0); http://www.idef.com/pdf/idef0.pdf

3.7. IDEF3

Brief Description of the Modelling Technique

This modelling approach aims at representing both processes and transformations of objects. It is constituted of two different modelling techniques: "*Process schematic*" (Figure 32) which describes how a sequence of action occurs (using just *Unity of Behaviours*) and "*Transition schematics*" (Figure 33) in which is described how *Objects* change their status (e.g. one of their parameter) along a process (using both Objects and UoBs). Also this kind of modelling approach allows different hierarchical level to be mapped according to a specific code that maps relationships, as done by IDEF0 (Section 3.6).

Main constructs

- **Units of Behaviour** as boxes representing actions to be carried out within a process. Each action can be further characterized into sub-actions according to a fractal structure;

- **Objects** as circles describing entities and their statuses. They can be used for both tangible and abstract entities. A Transition schematics diagram can also have multiple objects: the one transformed change its status, the other one just have descriptions and links to other objects, junctions or UOB;
- **Junctions** as logical blocs -AND, OR, XOR even with a synchronous perspective in Process Schematics diagram- They split or joins different links coming from/going to UOBs or Objects to introduce priorities and alternatives;
- **Links** as arrows connecting UOBs or Objects. Arrows direction determines precedencies or constrained precedencies. Dashed connections represent just relational links.

Graphical representation of the model

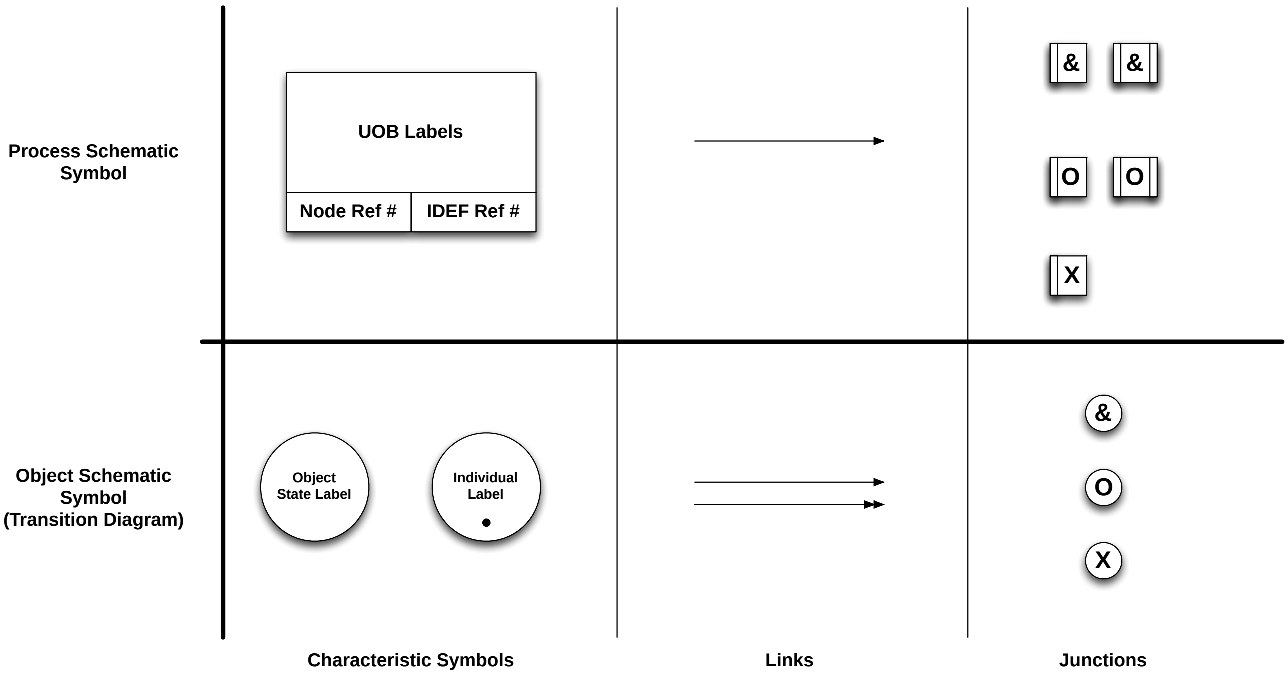


Figure 31: Main constructs, organized according to the modelling technique they pertain in the IDED3 context.

Example of Application

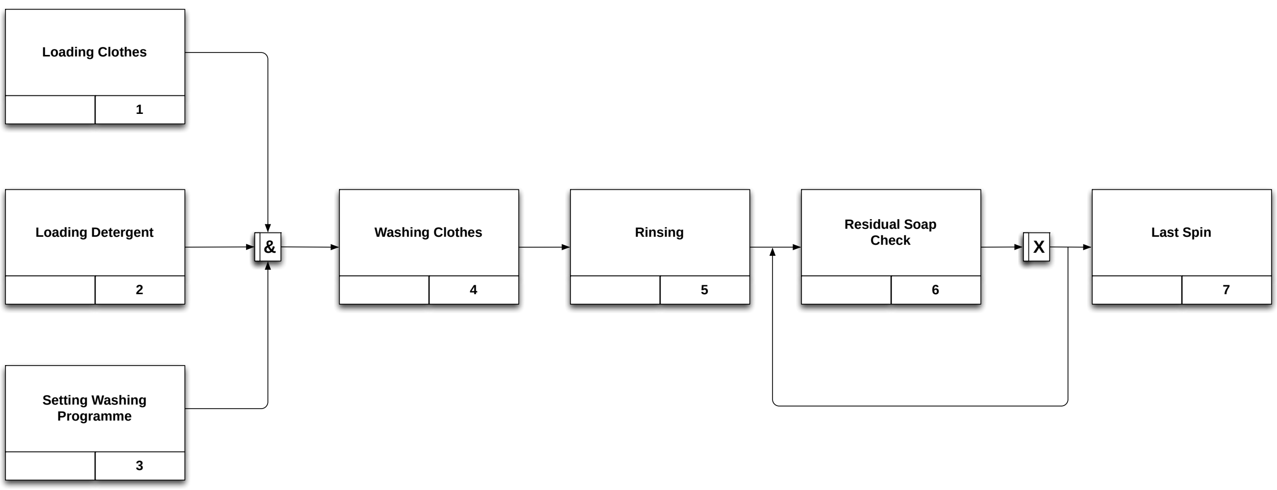


Figure 32: Example of Process Schematic diagram for what concerns the complete cycle carried out by the washing machine.

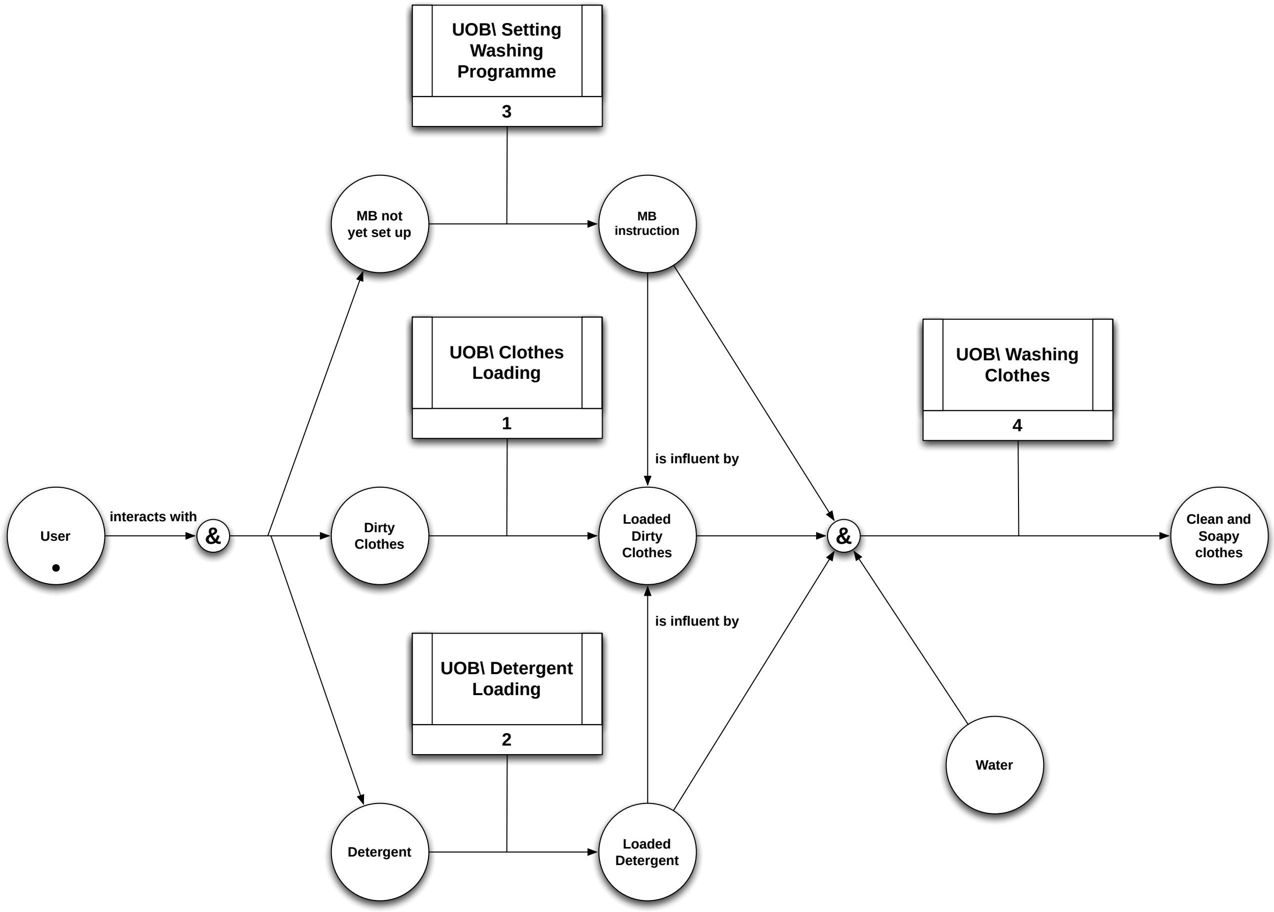


Figure 33: Example of Transition Diagram, showing the different states that are necessary to obtain clean clothes at the end of the cycle to remove stains (not yet rinsed)

Reference

Richard J. Mayer, Ph.D. Christopher P. Menzel, Ph.D. Michael K. Painter Paula S. deWitte, Ph.D. Thomas Blinn Benjamin Perakath, Ph.D.; INFORMATION INTEGRATION FOR CONCURRENT ENGINEERING (IICE) IDEF3 PROCESS DESCRIPTION CAPTURE METHOD REPORT; http://www.idef.com/pdf/Idef3_fn.pdf

3.8. Event-driven Process Chain (EPC)

Brief Description of the Modelling Technique

This is an event-based modelling technique capable to represent business processes and map relationships between Organizational Units within and in between departments. Each Function carried out along the business process can be further detailed according to a fractal/hierarchical structure (from process to process by means of "Process Path": a symbol of an Event with superimposed a Function, as described in Figure 34).

Main constructs

- **Event** as hexagons describing under what circumstances a function or a process starts/ends or which state a function or a process results in;

- **Function** as boxes with rounded corners describing transformations from an initial state to a resulting state. In case different resulting states can occur, the selection of the respective resulting state can be modelled explicitly as a decision function using logical connectors;
- **Input** as boxes describing what kind of resource will be used during a Function to produce an event or an output. They can describe both material and information. According to literature they do not map incoming flows of energy;
- **Output** as boxes describing what kind of resource will be used during a Function to produce an event or an output. They can describe both material and information. According to literature they do not map incoming flows of energy;
- **Organization Unit** as an ellipse with a vertical line on the left side. It describes which person or organization within the structure of an enterprise is responsible for a specific function. It is connected to a Function through an Organization Unit Assignment;
- **Supporting Systems** as rectangles with additional vertical lines at both sides. They describe each kind of resource that can be used for a given function with the purpose of supporting its execution;
- **Information Flow** as a straight arrow connecting an Input to a Function or a Function to an Output;
- **Logical Connectors** as polygons having 14 edges. They represents logical operators -AND, OR, XOR- that may merge or fork several control flows into one control flow or vice versa;
- **Control Flow** as a dashed arrow that connects events and functions or logical connectors in order to describe the chronological sequence of actions and logical dependencies between them;
- **Organization Unit Assignment** as a line connecting a Function With an Organization Unit so as to represent who is responsible for the process phase.

Graphical representation of the model

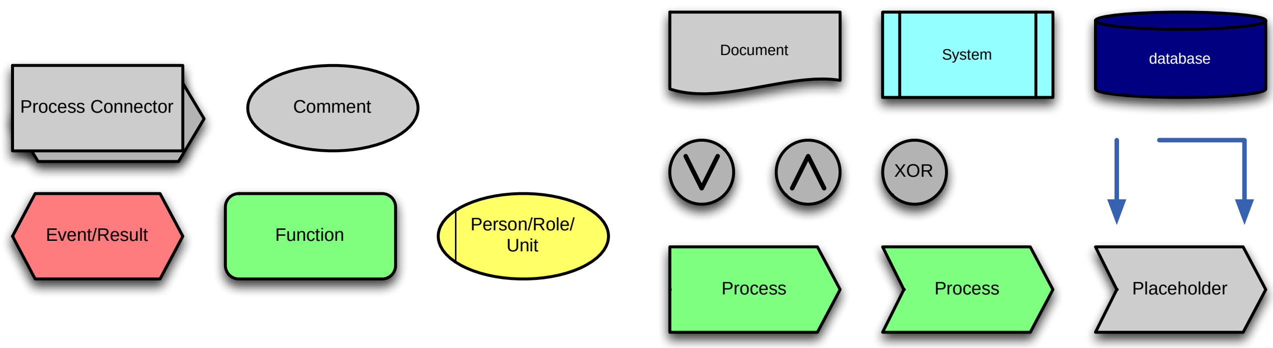


Figure 34: The graphical representation of the main constructs.

Example of Application

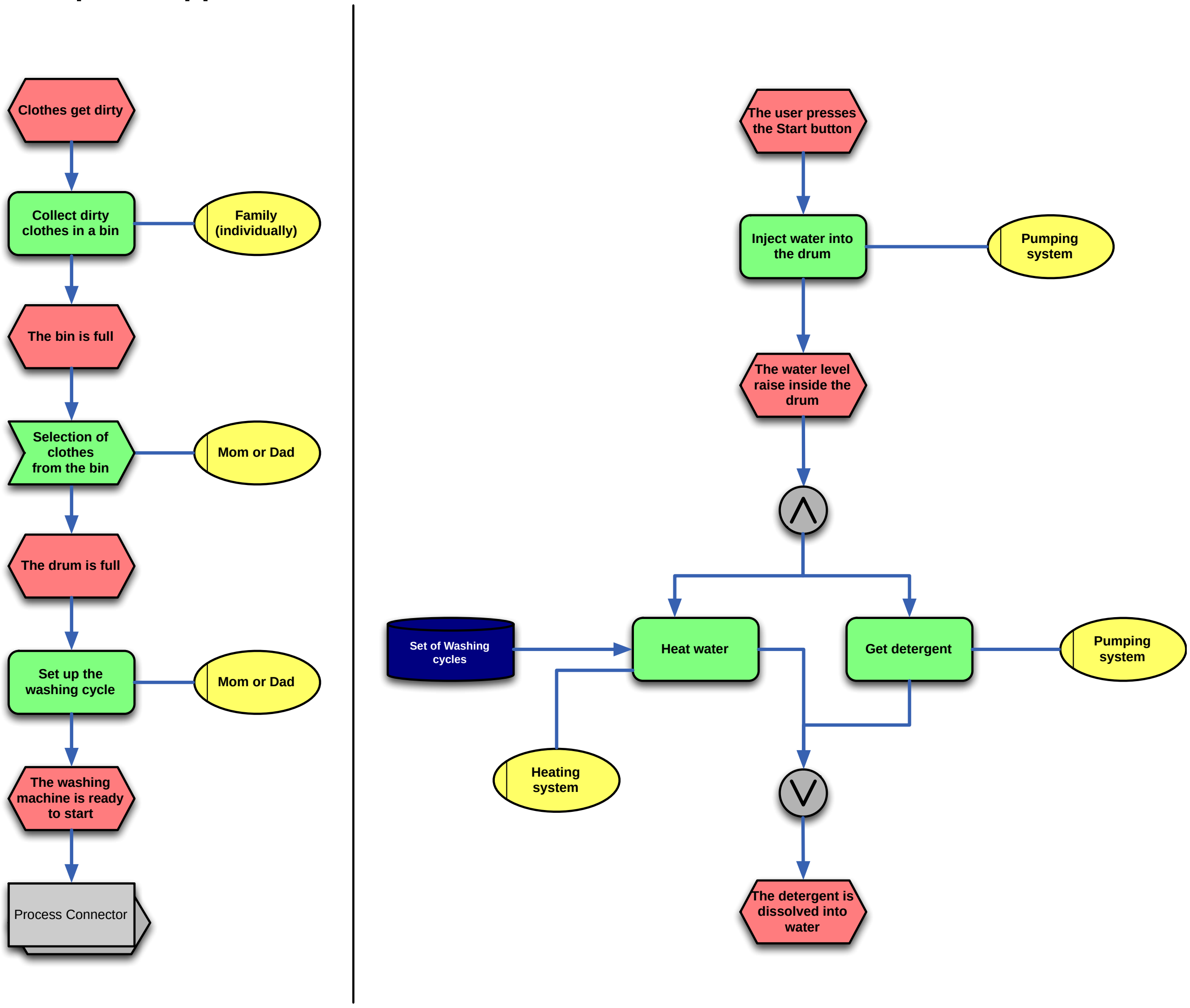


Figure 35: Two different examples concerning the actions occurring in washing cycles. The left diagram presents the action necessary to prepare the washing machine before it starts working. The diagram on the right, on the contrary, considers the process from within the washing machine and organizational units are considered as different subsystems.

Reference

"Ferdian (15986) Information and Communication Systems Masters Program & Roberto Bruni"; A Comparison of Event-driven Process Chains and UML Activity Diagram for Denoting Business Processes & Methods for the specification and verification of business processes;
http://www.sts.tu-harburg.de/pw-and-m-theses/2001/Ferd01.pdf
http://www.cli.di.unipi.it/~rbruni/MPB-11/19-EPC.pdf

3.9. Business Process Model and Notation (BPMN) 2.0

Brief Description of the Modelling Technique

This modelling technique is derived from the UML and SysML. It is more commonly used in industrial context, because it is most suitable to meet the expectation of those who have to model business processes. Moreover, in industrial practice it seems to be more intuitive and less complicate to be used. It is divided into three different models: Business Process Model, Choreography Model and Conversation Model. Among the three, the business Process Model represents the one of interest for the FORMAT project. The next paragraph collects its main constructs that are also graphically presented in Figure 36-37. Figure 38 presents a trivial example of the modelling technique concerning the procedures for preparing a washing machine cycle within a family.

Main constructs

- **Events** as circles of different colours (green = initial; double-line, yellow = intermediate; red or bold border = final). They describe conditions happening during the process. They can be also further characterized by icons specifying the kind of event (e.g: order received by a letter,...);
- **Activity** as a rounded-corner rectangle and describe what the company performs. An Activity can be atomic or non-atomic (compound). They could be further detailed in Task and Sub-Process- having a small plus sign in the bottom centre of the shape;
- **Gateway** as a diamond shape. It represents where the Sequence Flow diverge or converge. Thus, it will determine traditional decisions, as well as the forking, merging, and joining of paths. Internal Markers will indicate the type of behaviour control;
- **Sequence flow** as a solid arrow connecting Events and Actions in order to depict the sequence of steps carried out during the process;
- **Message Flow** as a dashed line with an open arrowhead. It shows the flow of messages between two separate Process Participants (business entities or business roles) that send and receive them (e.g. two swim lanes);
- **Association** as a dotted line with a line arrowhead. It associates data, text, and other artefacts with flow objects. Associations are used to show the inputs and outputs of activities;
- **Swim lanes** as big rectangles containing the model entities that pertain to a specific organizational unit. Each swim lane describes who is doing what. Such swim lanes, arranged side-by-side, constitute a Pool, whose name is reported at the top of the swim lanes;
- **Data** as a paper sheet with the top right corner folded inwards. It represents the data required or produced during an activity;
- **Group** as a dashed-line rectangle with rounded corners. It collects elements pertaining to the same concept. It does not affect the meaning of the graph;
- **Annotation** as a left square bracket where the modeller can provide additional information. They are connected to model constructs by means of dotted lines (no arrow).

Graphical representation of the model

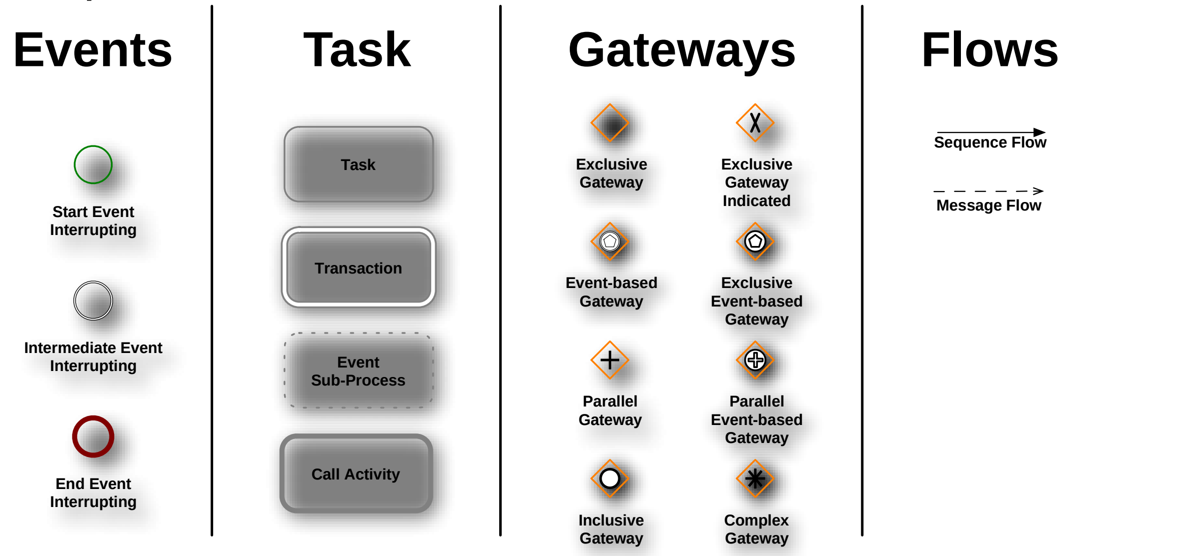


Figure 36: Graphical representation of a typical set of BPMN 2.0 constructs, details in the references.

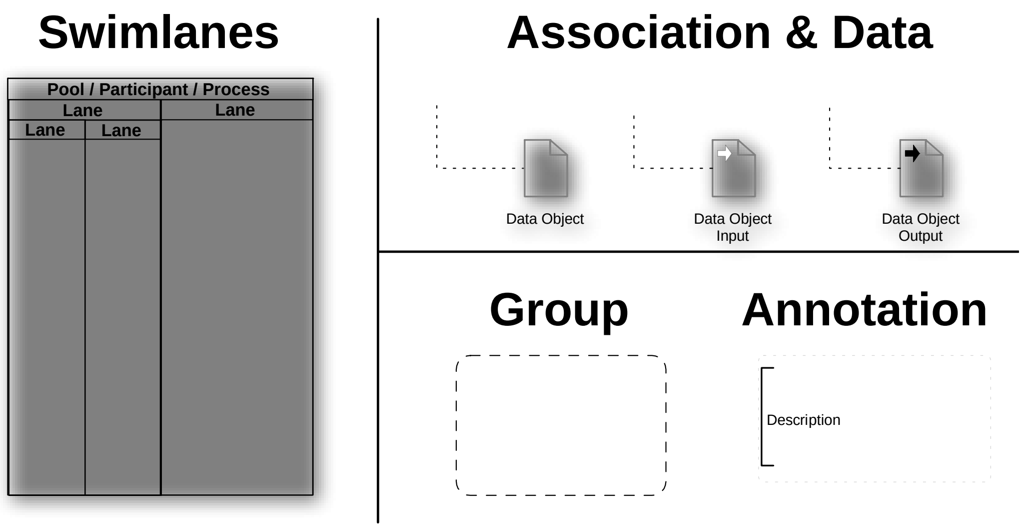


Figure 37: Graphical representation of the set of BPMN 2.0 constructs that enriches the collection presented in Figure 36. More details, especially for what concerns different kind of events, gateways and tasks in the references.

Example of Application

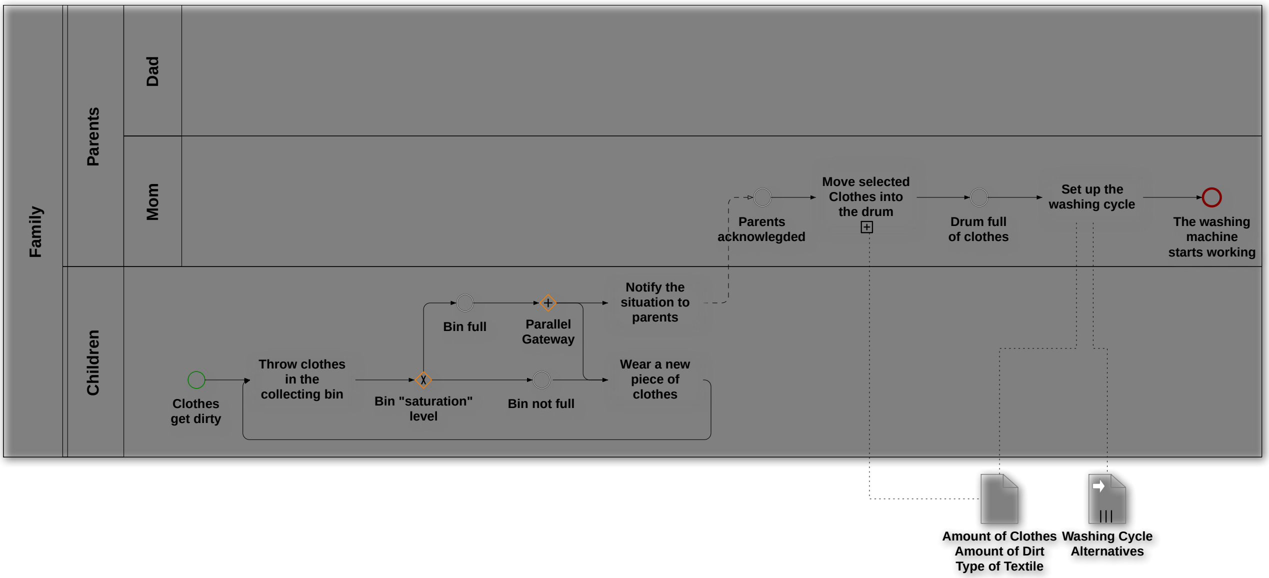


Figure 38: A process model concerning the different actions to be carried out in a family to prepare the washing machine for a cleaning cycle.

Reference

Object Management Group & Stephen A. White; Business Process Model and Notation (BPMN) & Introduction to BPMN; http://www.omg.org/spec/BPMN/2.0 & http://www.omg.org/bpmn/Documents/Introduction_to_BPMN.pdf and for a general overview of constructs and different modelling techniques of the BPMN family, a quick view is available at http://bpmb.de/poster

4. Multi-purpose Modelling Techniques

4.1. Element – Name – Value Model

Brief Description of the Modelling Technique

The ENV Model is a reference language to describe animated and unanimated things according to their name and characteristics. This modelling technique is useful to support the definition of specific entities and its potential can be better exploited if combined with other modelling technique that use symbols, but also language elements.

Main constructs

- **Element** as a generic entity such as a substance, an energy or a signal - animated or unanimated;
- **Name of a Parameter** as a feature or attribute of an Element that may assume more than a value;
- **Value of a Parameter** as specific values for a given Parameter of an Element.

Graphical representation of the model

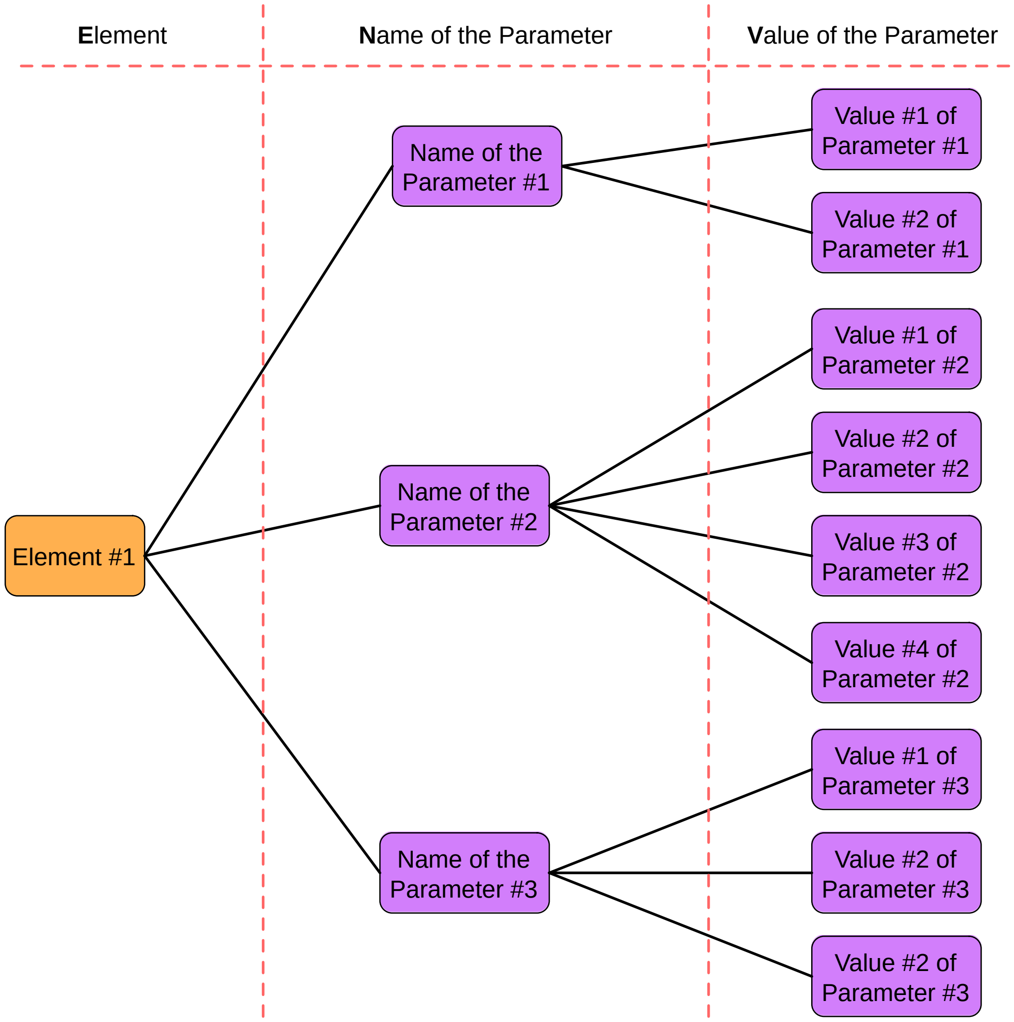


Figure 39: The overall structure of the ENV model. The same element can have multiple parameters that, in turn, may assume values in a wide range of alternatives

Example of Application

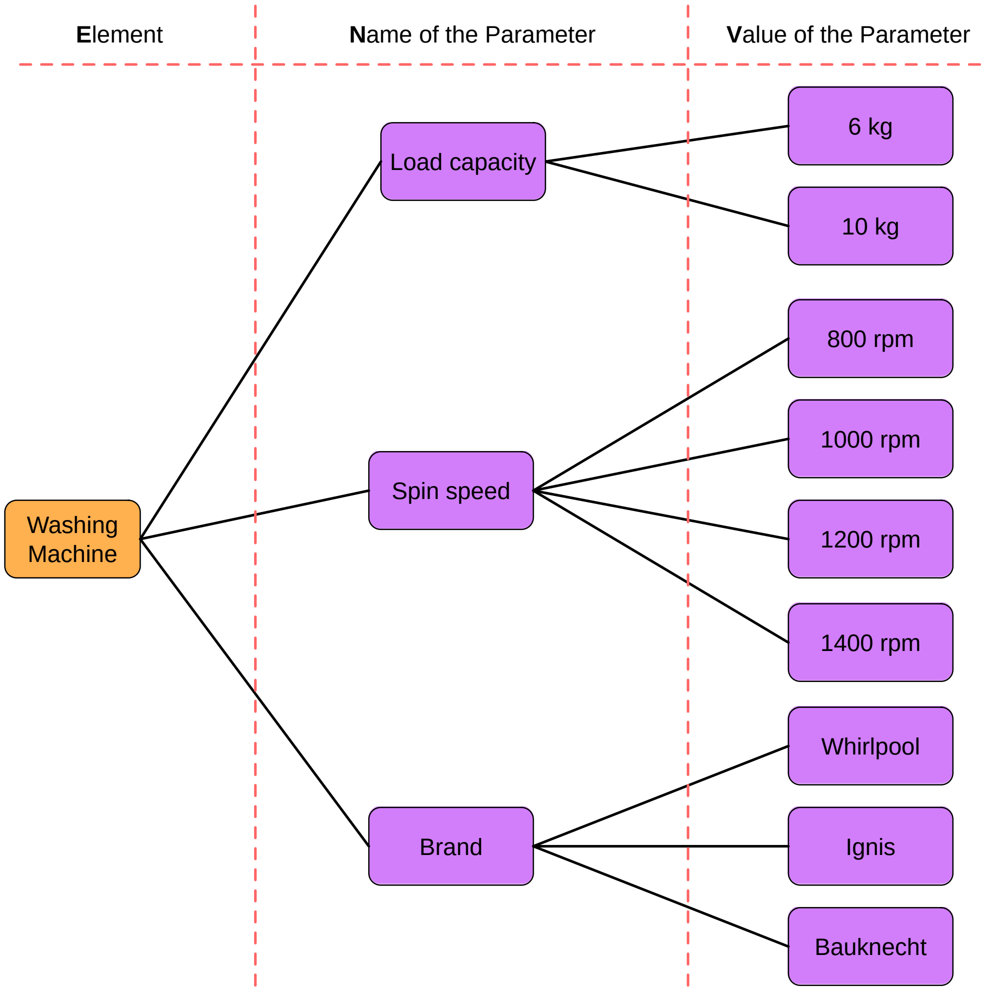


Figure 40: an example of ENV model applied to the washing machine. Please note that a just a few parameters are modelled and for each of them just a few values have been shown

Reference

Various Authors; TETRIS PROJECT Handbook; http://www.tetris-project.org

4.2. NIST Functional Basis

Brief Description of the Modelling Technique

Set of standardized entities describing generic transformations and flows with a hierarchical structure. This Functional basis, therefore, does not represent per-se a model, but it supports the modelling activity if combined with different modelling technique in order to work within a common framework in which things sharing the same denominations share also the same meaning.

Since this Functional Basis is not a modelling technique per-se, the example of application is not available. It is sufficient noticing that each of the verbs of the other models (e.g.: IDEF0 as well as EMS) can be described by one specific verb of the functional basis. Moreover, the input and output flows can be characterized and described with the same basis concerning flows (organized, as well, in three categories: Energy, Material, Signal)

Main constructs

- **Function** as the generic action that modifies an attribute of an entity that otherwise would have been different - hierarchically subdivided in more classes;
- **Flow** as the generic set of entities whose attributes can be modified, organized in energy, material and signal and subdivided hierarchically in subclasses.

Graphical representation of the model

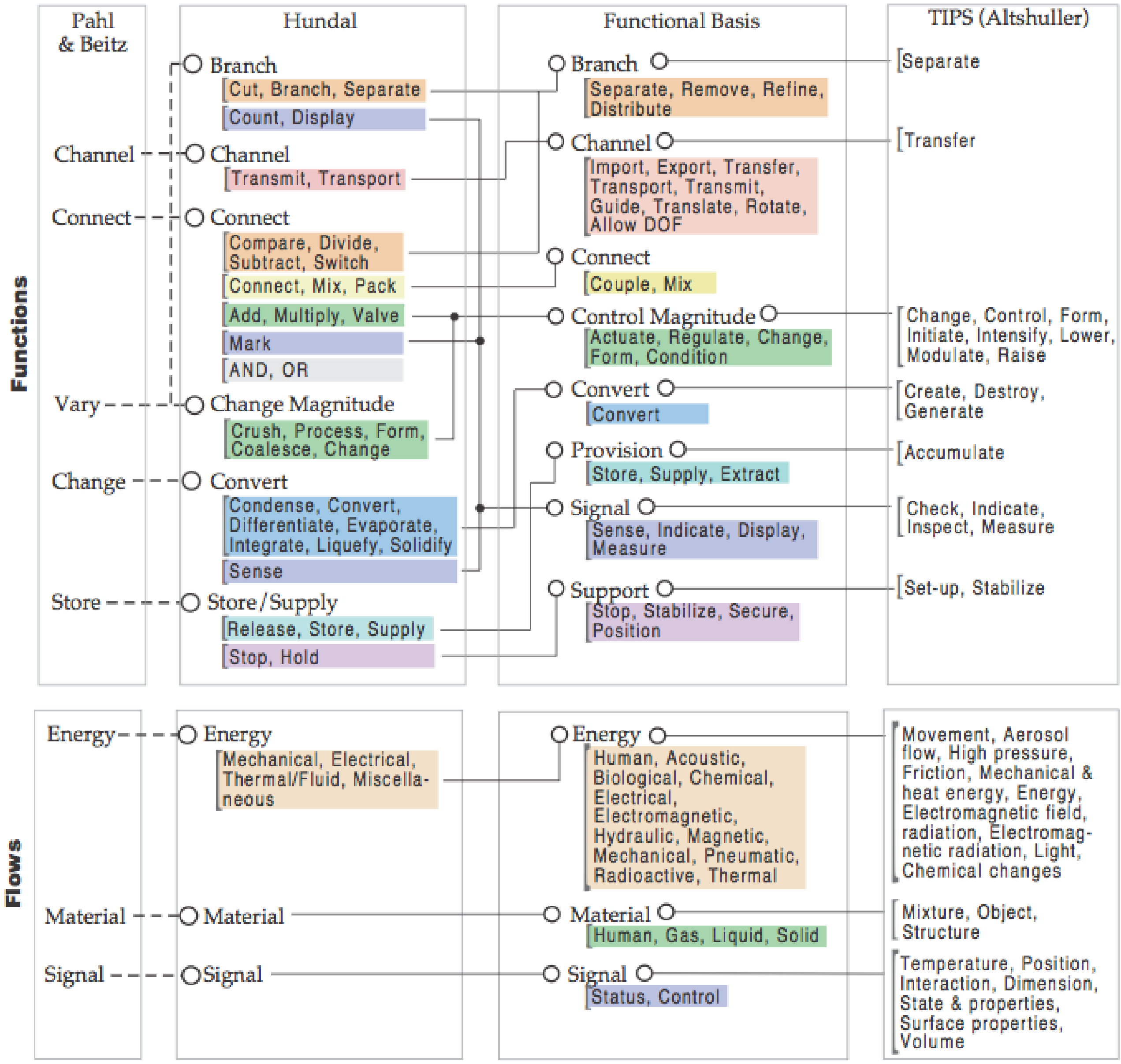


Figura 41: Functions and Flows according to NIST Functional Basis in the third columns from left. The other columns collect the perspective of different authors on the same concepts.

Reference

Julie Hirtz, Robert B. Stone, Daniel A. McAdams, Simon Szykman, and Kristin L. Wood; A Functional Basis for Engineering Design: Reconciling and Evolving Previous Efforts; http://www.mel.nist.gov/msidlibrary/doc/szykman_RED.pdf

4.3. Entity-Relationship Diagram (ERD)

Brief Description of the Modelling Technique

A modelling technique which integrates different layers of analysis: it allows the mapping of functions and entities involved in such functions together with their attributes and related assumed values. It is the core concept from which more structured modelling techniques have been based on. It is commonly use to characterize the elements within a database.

Main constructs

- **Entity** as a box describing an agent (animated or not) that has a role in the modelled process;
- **Relationship** as a diamond describing an association between two entities. It could be a function, but also a parental relationship for describing hierarchies;
- **Attribute** as textual description of the characteristics of entities and relationships that can be measured with values within a range -called domain-, formally is a function -math meaning- which maps from an entity set or a relationship set into a value set or a Cartesian product of value sets;
- **Value** as textual or numerical descriptions to be assigned to an attribute of an entity as a result of a measurement or evaluation.

Graphical representation of the model

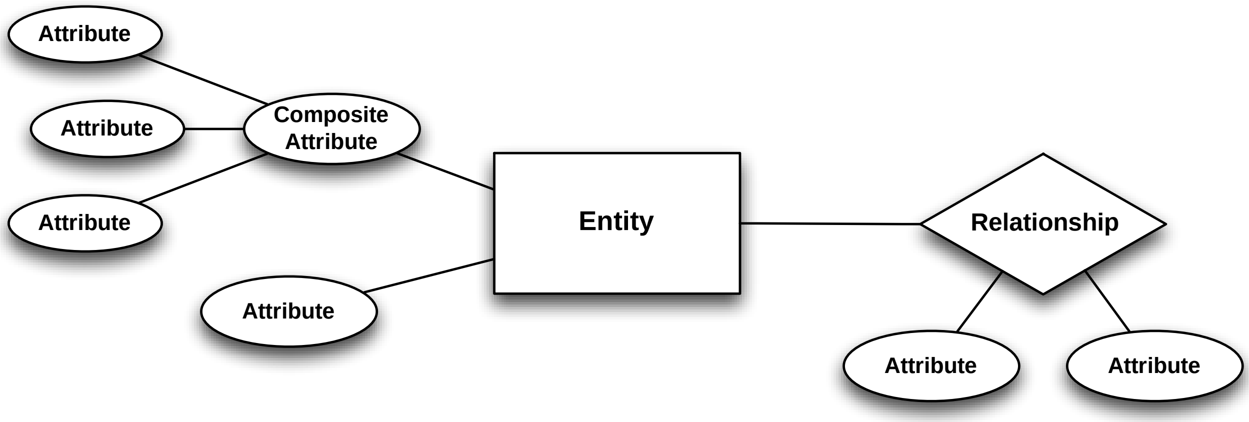


Figure 42: Graphical representation of the Constructs of the ER Diagram

Example of Application

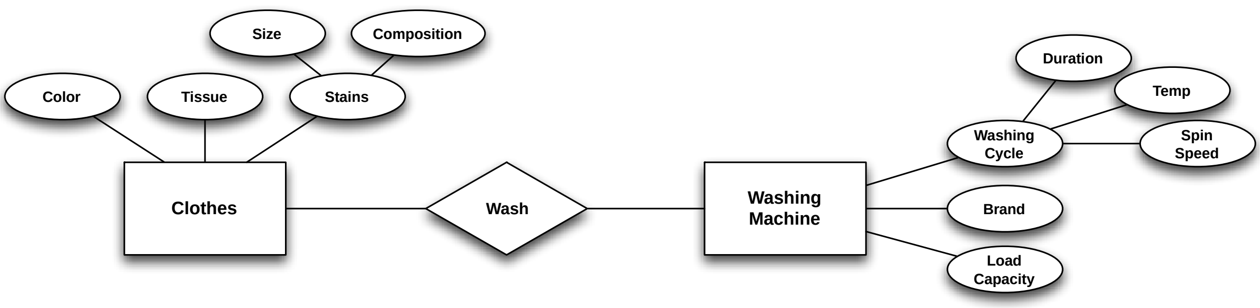


Figure 43: Example of ERD concerning a washing machine.

Reference
PETER PIN-SHAN CHEN; The Entity-Relationship Model-Toward a Unified View of Data; http://csc.lsu.edu/news/erd.pdf

4.4. extended ERD (eERD)

Brief Description of the Modelling Technique

A modelling technique which integrates different layers of analysis: it allows mapping functions and entities involved in such functions together with their attributes and related assumed values. It is the core concept from which more structured modelling techniques have been based on. Differently to what have been proposed in Section 4.3, it adds several constructs to the standard ER/ERD by Chen. It has several commonalities with the ENV model presented in Section 4.1. It is, therefore, as the ERD, a method of representation that can be conveniently used to describe both elements pertaining to processes or products.

Main constructs

- **Entity** as a box describing an agent -animated or not- that has a role in the modelled process;
- **Relationship** as a diamond describing an association between two entities. It could be a function, but also a general relationship for describing hierarchies or similar. Each relationship could be characterized by means of instances of Entities connected by the relationship itself;
- **Attribute** as textual description of the characteristics of entities and relationships that can be measured with values within a range -called domain-, formally is a function. Moreover, the same attribute can be further decomposed in sub-attributes, according to the "composite attribute" construct;
- **Value** as textual or numerical descriptions to be assigned to an attribute of an entity as a result of a measurement or evaluation;
- **Cardinality** as a couple of numbers in brackets placed on a connection, being it between an entity and a Relationships as well as Entity and Attributes. It represents the maximum and minimum number of relationship occurrences in which an entity occurrence can participate. For Attributes it represents the range of variability for its values;
- **Generalization** as a double-line arrow connecting Entities according to a parental relationship. The arrow goes from the most specific entity to the most general one;
- **Identifiers** as black filled circle connected to black dots by a line, the dots on the connections between Entities or Relationships and their attributes. They highlight which attributes identify uniquely instances of an entity.

Graphical representation of the model

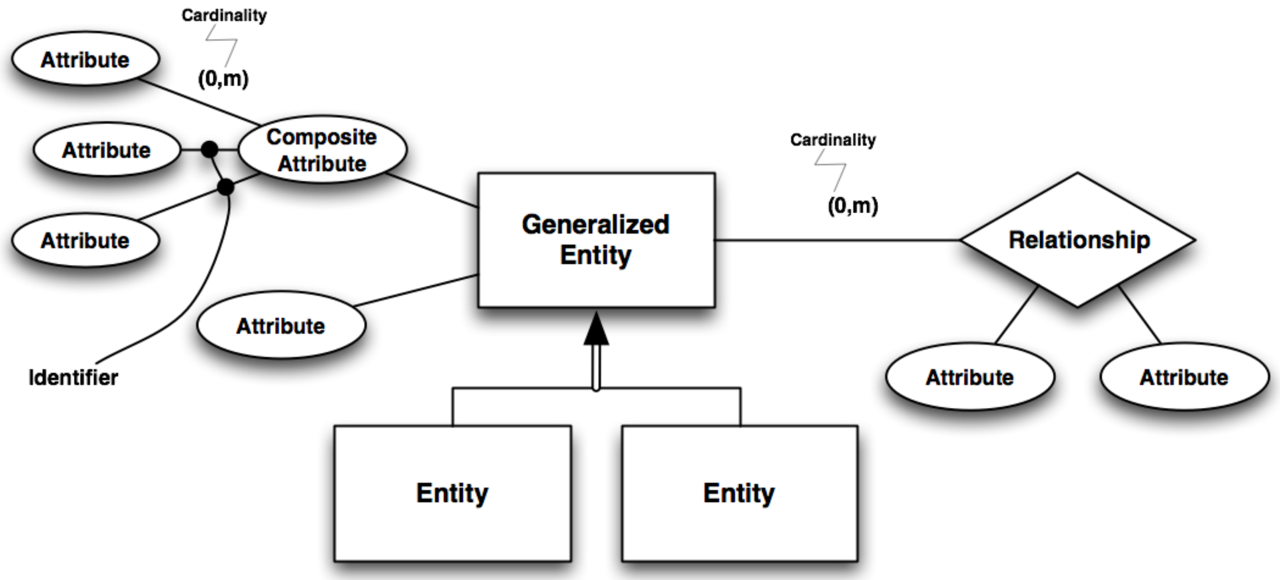


Figure 44: The constructs of the eERD enriches the set of basic construct of the ERD model presented in Figure 42

Example of Application

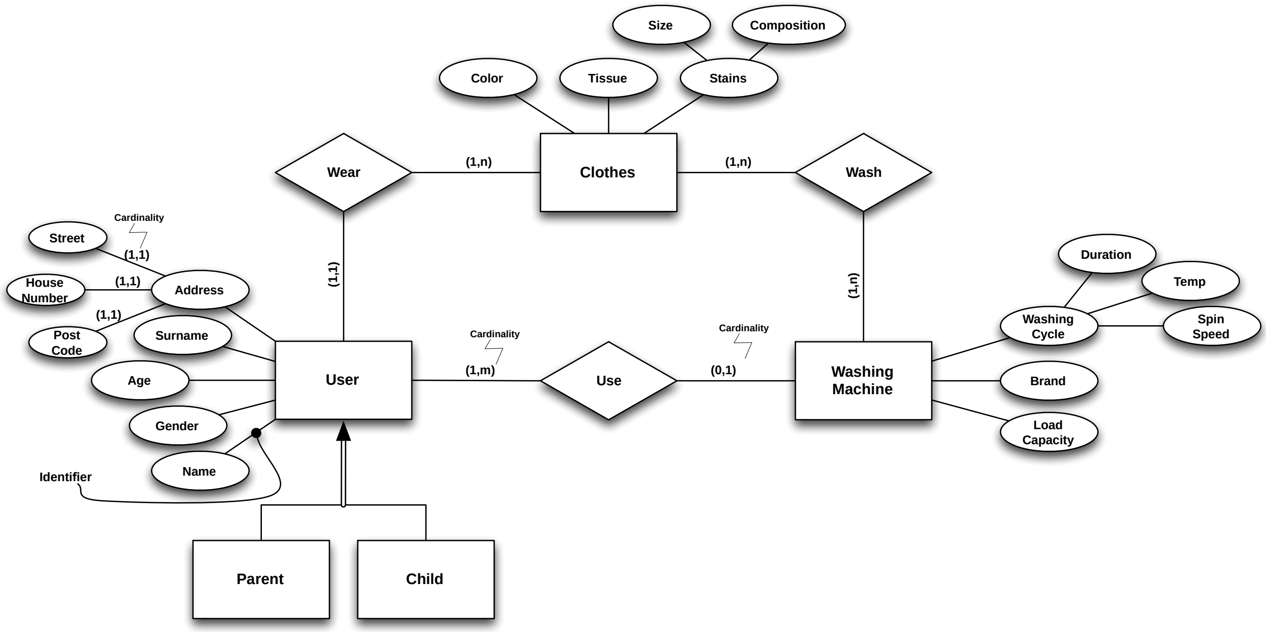


Figura 45: An example of the eERD diagram. Please note that it is analogous with the one presented in Figure 43. The relationships are, even in this case, exclusively functional. However, the eERD, a the ERD, does not imply it.

Reference

Bernhard Thalheim & John Mylopoulos; Extended Entity-Relationship Model & The (Extended) Entity-Relationship Model;
http://www.is.informatik.uni-kiel.de/thalheim/HERM/HERMinbrief.pdf
http://www.cs.toronto.edu/~jm/2507S/Notes04/EER.pdf

4.5. Design Structure Matrix

Brief Description of the Modelling Technique

This modeming technique is suitable to describe both products and processes. This generic way of modelling, indeed, focuses on the relationships that link together the system components according to their functional interaction or the phases of a business process in terms of outcomes and inputs. It is organized as a matrix whose cells represent the relationships between elements in the first row and the first column. Such row and column collect system components (product modelling, Figure 47) and functional phases (process modelling, Figure 48). Such models are commonly used for reducing systems complexity by limiting the number of mutual interactions.

Main constructs

- **Process Modelling**
  - **Activities** as elementary steps of an articulated process, organized in rows and columns where the order represents a flow trough time;
  - **Dependencies** as non-null cells of the matrix representing relationships between two elementary steps of the same process (e.g. sharing output/input) so as to map the presence of feed-forward and feedback between process phases;
- **Product Modelling**
  - **Elements** as entities composing a product, organized in rows and columns;
  - **Interactions** as non-null cells of the matrix, the cell may contain a cross (simple indication of interaction), or a verb (description of the kind of interaction between elements), or the kind of exchange that occurs between elements (spatial, material, information, energy).

Graphical representation of the model

	Char #1	...	Char #i	...	Char #n
Char #1					
...	Relationship				
Char #i					
...					
Char #n					

Figure 46: Generic matrix characterizing the versatile essence of the model, which is suitable fro both products and processes.

Example of Application

	Drum	Clothes	Water/ Detergent Mixture	Heater
Drum		Moves	Moves	
Clothes				
W&D Mixture	Heats	Removes stain		
Heater			Heats	

Figure 47: Example of DSM for modelling products. The cells inside the matrix collects functional interactions that the element presented in the first column carries out on the element in the first row.

	Loading	Setting	Washing	Rinsing
Loading		Textile type,…		
Setting			Cycle settings	Cycle Settings
Washing				Amount of soapy water
Rinsing				

Figure 48: Example of DSM for modelling processes. The cells inside the matrix collect entities that links together different phases along the process. In detail the cell content represents an output of the phase in the first column and an input for the phase in the first row.

Reference

Tyson R. Browning; Applying the Design Structure Matrix to System Decomposition and Integration Problems: A Review and New Directions; http://axiod.com/technology/papers/4DSMs.pdf

4.6. Architecture of Integrated Information Systems (ARIS)

Brief Description of the Modelling Technique

Meta-Modelling technique capable to collect the elements of an EPC model diagram and structure them according to meta-categories for describing relevant facets/different views in industries. Nevertheless it is a process-oriented modelling technique (rather than a more classic "function oriented" modelling technique to model processes) capable to map different layers of the design process. Indeed, such modelling technique should be used in designing new process in an iterative fashion: from the definition of requirements (layer #1 or first iteration of the modelling activity), through design specification (layer #2 or second iteration of the modelling activity), to Implementation description (layer #3 or third iteration of the modelling activity).

Main constructs

- **Data view** as the left box or cylinder of the ARIS model, it collects the entity-relationship models [ERD] to design data models: entities -e.g. data objects of the environment that are processed by the system-, their attributes and relationships between entities. It contains Events and Statuses;
- **Function view** as the right box or cylinder of the ARIS model, it collects all the tasks performed on objects to support different company goals; it includes descriptions of procedures, processes, sub-functions and elementary functions. To represent mutual relationship among functions the Function Tree Hierarchy is used;
- **Organization view** as the rooftop of the ARIS model/house, it collects the relations between company units and the classification of these units in the organizational hierarchy. It also collects Users that are part of Organization Units. Connections link Users to Organization unit as well as a sub-unit to its higher level division/department according to a Son-Father relationship in an organizational chart;
- **Product/service view** as the lower box of the ARIS model - foundation of ARIS house-, it describes the products and services produced by the company as a result of human act or technical procedures;
- **Control view** integrates the previously mentioned views and defines the dynamic, behavioural aspects. The control flow of a process is described with an EPC extended with the description of the resources and data involved in the process, and timed and probabilistic aspects of the behaviour.)

Graphical representation of the model

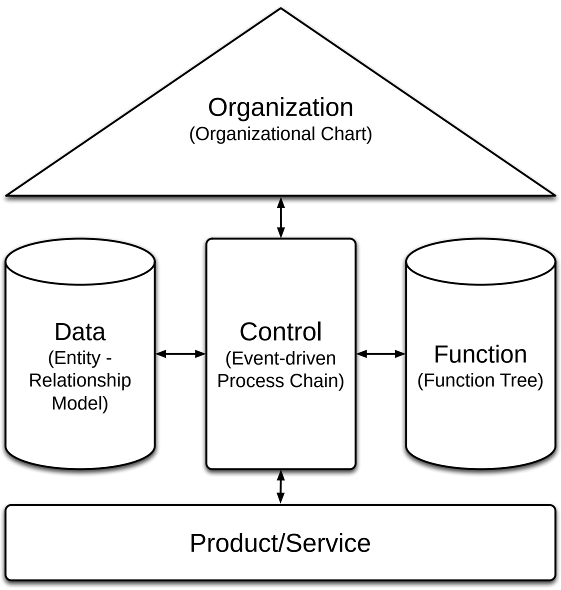


Figure 49: The ARIS structure presented as a house with basement, pillars and a rooftop. Within the blocks it is specified what kind of modelling technique is required (no indication in literature about product/service modelling).

Example of Application

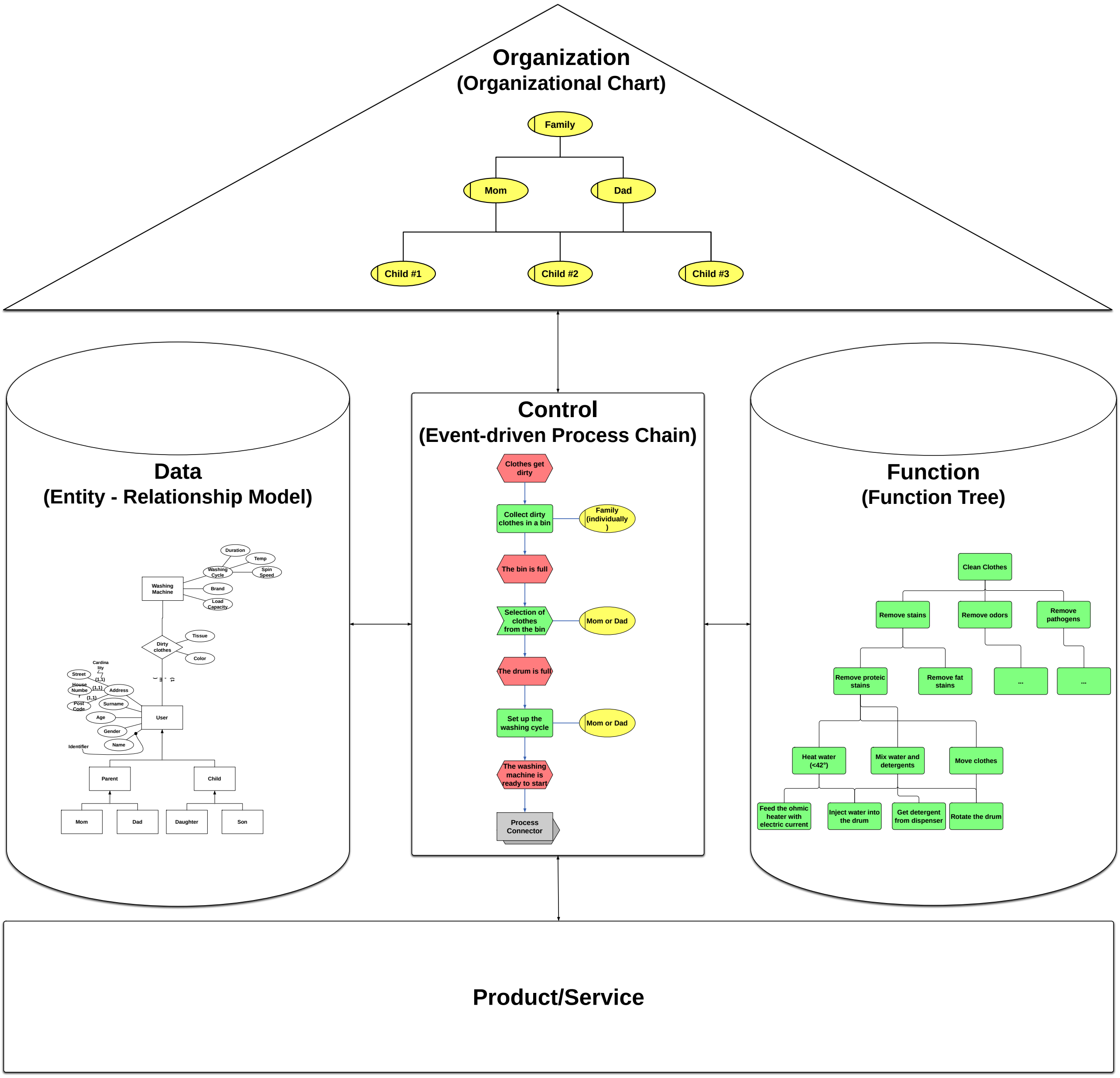


Figure 50: An example of the ARIS modelling technique. The elements of the EPC model contained in the Control view diagram (in the middle of the house) comes from the different blocks, e.g.: processes or functions of the EPC model are further detailed in the Function block in terms of hierarchical relationships.

Reference

A.-W. Scheer; ARIS : business process modelling;
http://books.google.it/books/about/ARIS_Business_Process_Modeling.html?hl=it&id=Jzuwm2uV7CQC

4.7. Ishikawa Diagram (Fishbone Diagram)

Brief Description of the Modelling Technique

The Ishikawa diagram, also known as Fishbone because of its characteristic shape, is a Cause-and-effect diagram that allows the chain of possible causes triggering undesired effects to be represented with a fractal perspective. Such modelling techniques, distinguishes different causes by taking into account their time precedencies, thus highlighting root causes with a clear graphical description. It is, therefore, a method for describing problems and it is suitable to map undesired situations in both products and processes.

Main constructs

- **Problem/effect** as the undesired effect that should be avoided represented on the right part of the graph;
- **Causes** as the triggering events that may concur or fully determine the emergence of a problem);
- **Branches** as lines connecting causes to effects, organized according to different categories - equipment, process, people, materials, environment, management) Multiple descriptions are available and should be conveniently defined in specific cases. Root causes represented on smaller branches.

Graphical representation of the model

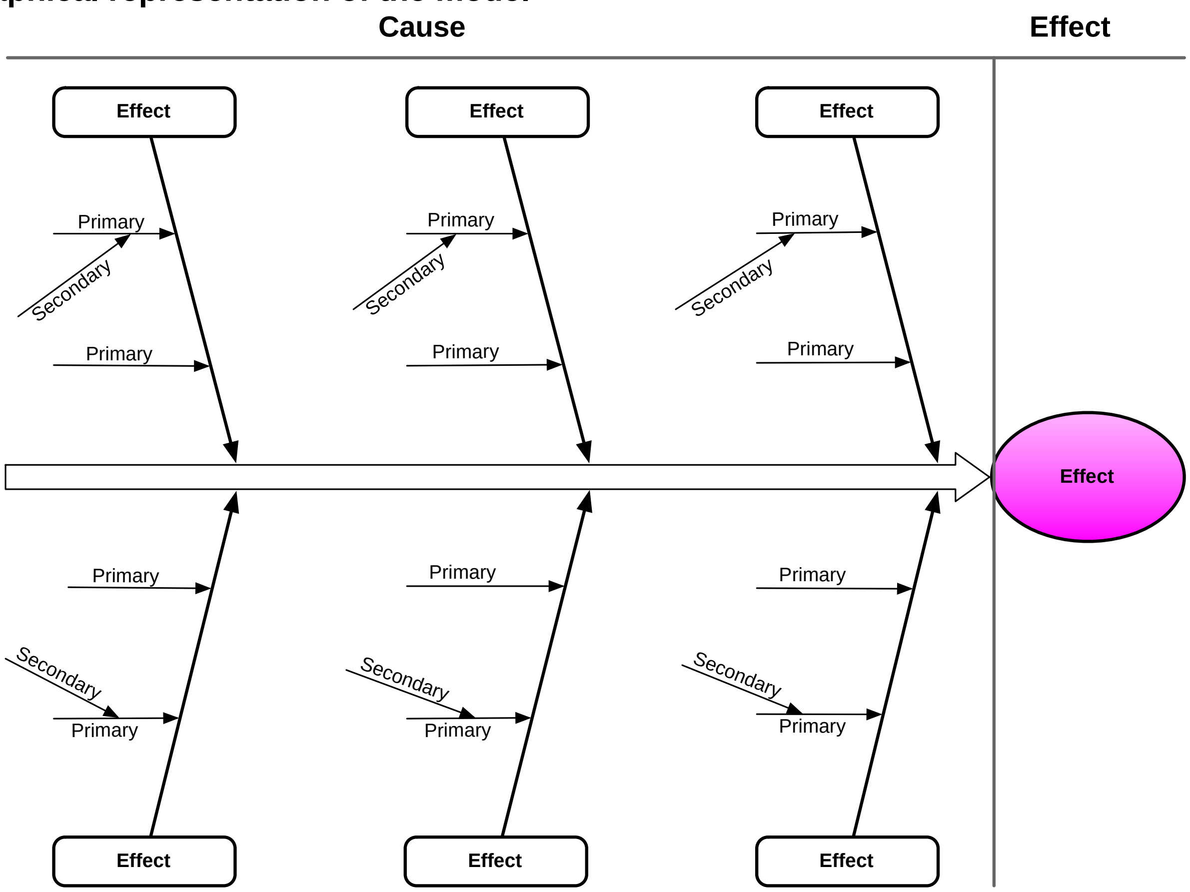


Figure 51: The generic shape of an Ishikawa diagram where the different causes can concur to the emergence of an undesired effect (problem)

Example of Application

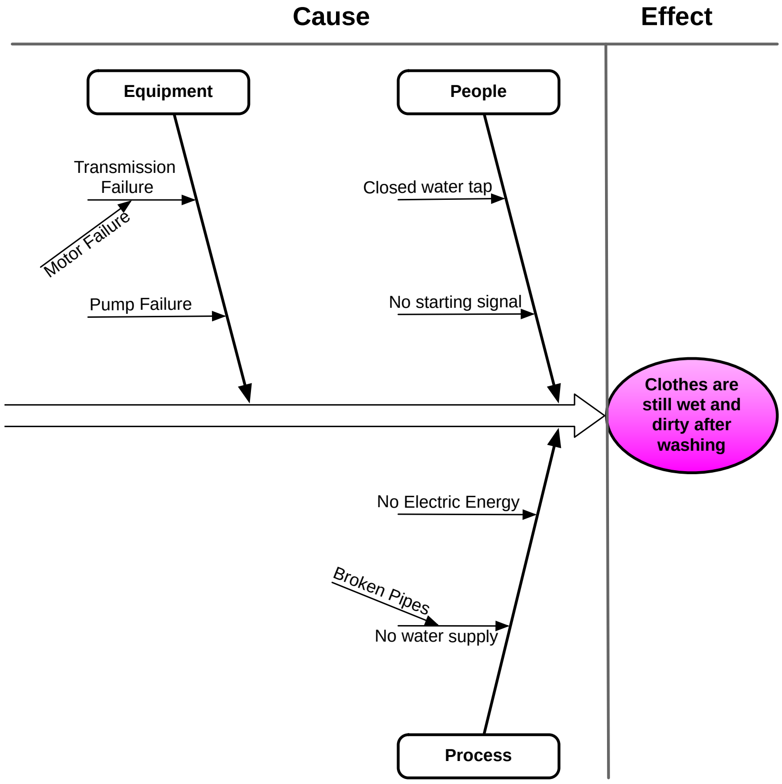


Figure 52: An example of Ishikawa diagram concerning the problem of having dried and dirty clothes after a washing cycle.

Reference

K. Ishikawa; Original Sources available in Japanese;
http://en.wikipedia.org/wiki/Ishikawa_diagram

4.8. OTSM-TRIZ Network of Problems

Brief Description of the Modelling Technique

This modelling technique is suitable to describe both problems and solutions occurring in both process and product with a very wide perspective.

Main constructs

- **Problems** as boxes identifying an unsatisfactory condition, being it related to the presence of side effects, heavy consumptions of resources as well as low performances;
- **Partial Solutions** as boxes representing design choices capable to contribute to solve a problem (completely, partially, hypothetically);
- **Constraints** as boxes representing limitations to be strictly taken into consideration;
- **Questions to experts** as boxes highlighting lacks of knowledge;
- **Solving links** as lines connecting Problem boxes to Partial Solution boxes;
- **Cause-and effect Links** as lines connecting Partial Solutions boxes to Problem boxes according to a causal relationship;

- **Subdivision Links** as lines connecting more problem boxes that details an overall problem.

Graphical representation of the model

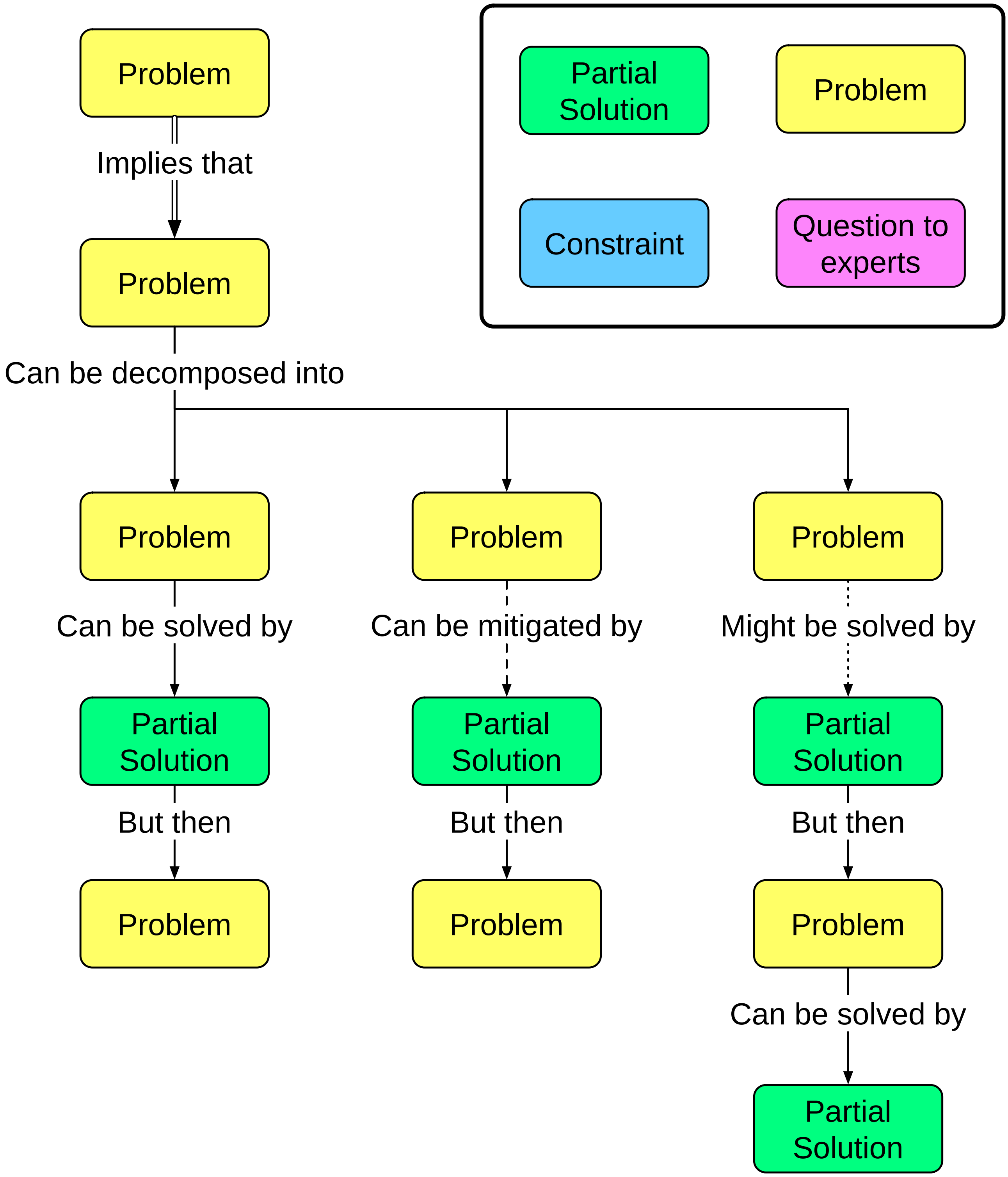


Figure 53: An example of possible connections among nodes in the network of problems. The focus is on the different types of link, together with their graphical representation. The black box on right top presents the elementary nodes of the network.

Example of Application

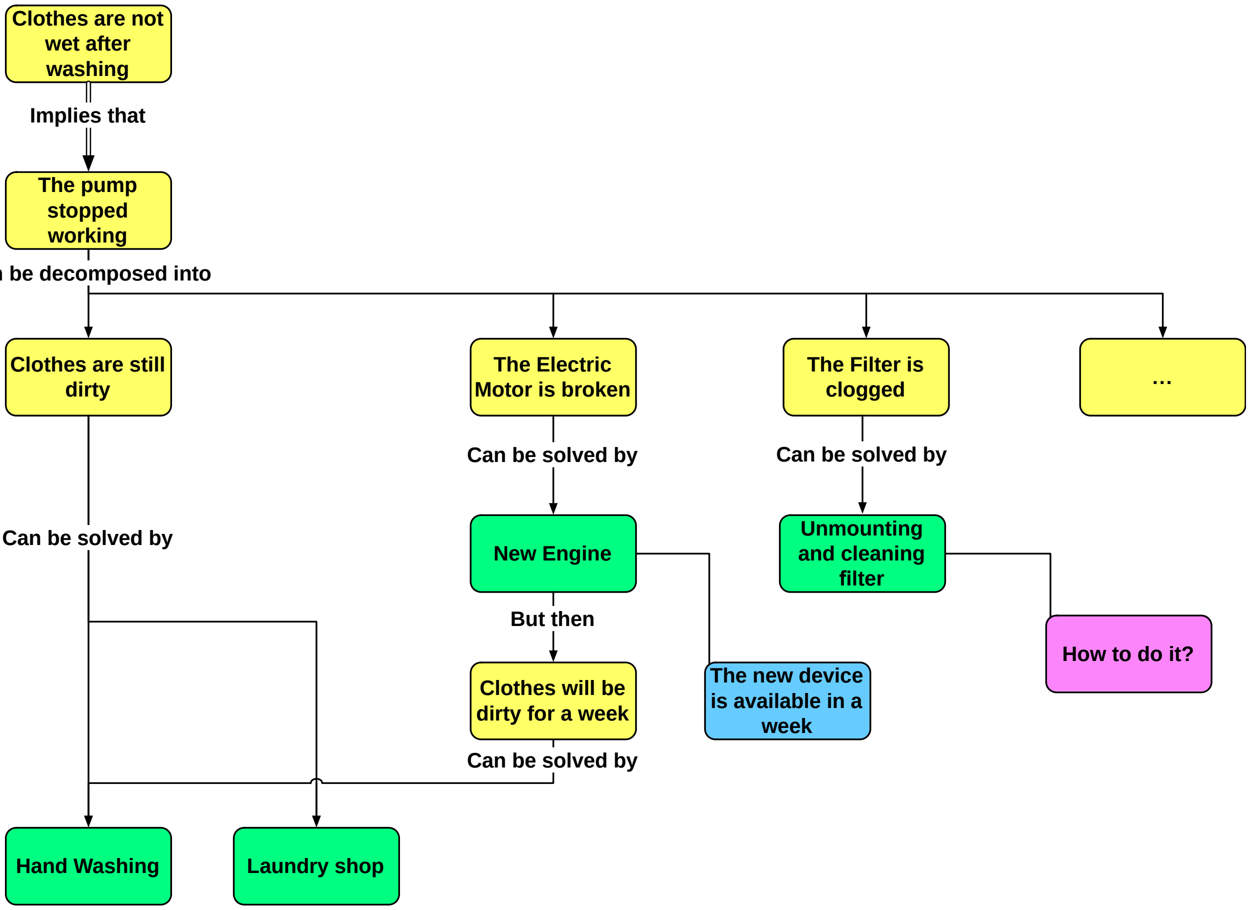


Figure 54: Network of Problems concerning a problem that may emerge in using a washing machine

Reference

N. Khomenko; From TRIZ to OTSM-TRIZ: addressing complexity challenges in inventive design; http://inderscience.metapress.com/content/1l7yk36qbtlgu93t/

4.9. OTSM-TRIZ Contradiction Model

Brief Description of the Modelling Technique

Modelling technique to describe problems, therefore suitable to describe undesired situations in both products and/or processes. Its structure is based on the ENV model (section 4.1). It is organized as a triad of interacting elements. The characteristics values assigned to a parameter of an element of the technical system, being it a product or a process (Control Parameter, Figure 55 on the left side) produces satisfaction and dissatisfaction on two different requirements (Evaluation Parameters, Figure 55 on the right side) that appear as non-mutually compatible.

Main constructs

- **Evaluation Parameter** as a parameter (see ENV model) having two opposite states: a value to be achieve and one to be avoided;

- **Control Parameter** as a parameter (see ENV model) having two opposite states representing two design alternatives.
-

Graphical representation of the model

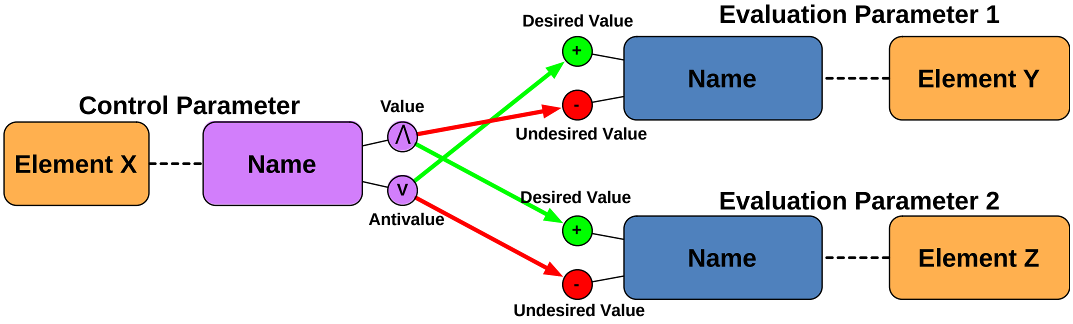


Figure 55: The most general model describing a Contradiction according to OTSM-TRIZ

Example of Application

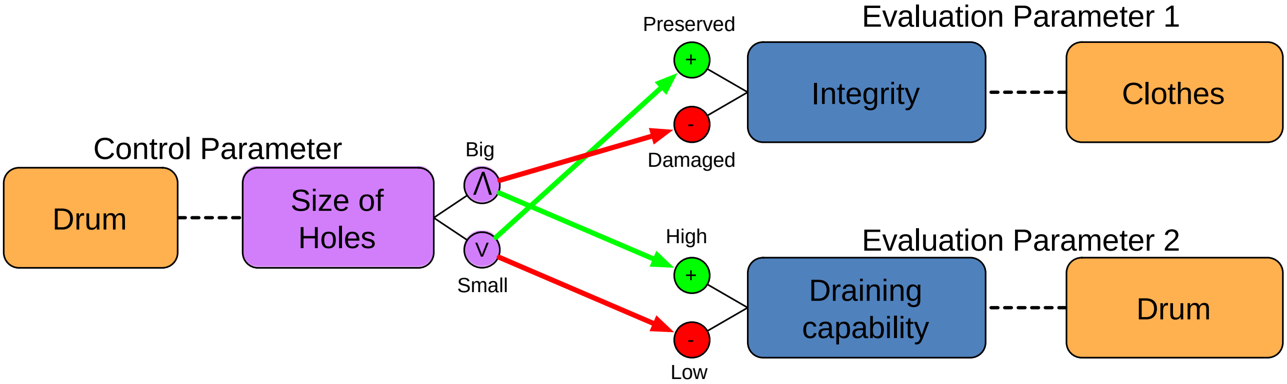


Figure 56: an example of Contradiction concerning the washing machine.

Reference
Various Authors; TETRIS PROJECT Handbook; http://www.tetris-project.org

4.10. Fault-Tree Analysis (FTA)

Brief Description of the Modelling Technique

The Fault-Tree Analysis is a modelling technique capable to represent problems with a top-down approach and, thus, is suitable to address issues emerging in contexts concerning both product and process. Such modelling technique has undergone different variations according to the different contexts in which it has been used. Figure 57 collects constructs that are commonly shared among the various alternative versions, while Figure 58 presents an example so as to clarify the potential of this modelling technique in investigating potential causes of a problem.

Main constructs

- **Events** as boxes containing a description of the situation that may occur before a problem - further detailed with reference symbol describing the kind of event -eg. Expected, conditioning, elementary,...;
- **Conditions** as logical gates/operators (e.g.: AND, OR, XOR,…) that connect independent events that, independently or in combination, trigger a new event.

Graphical representation of the model

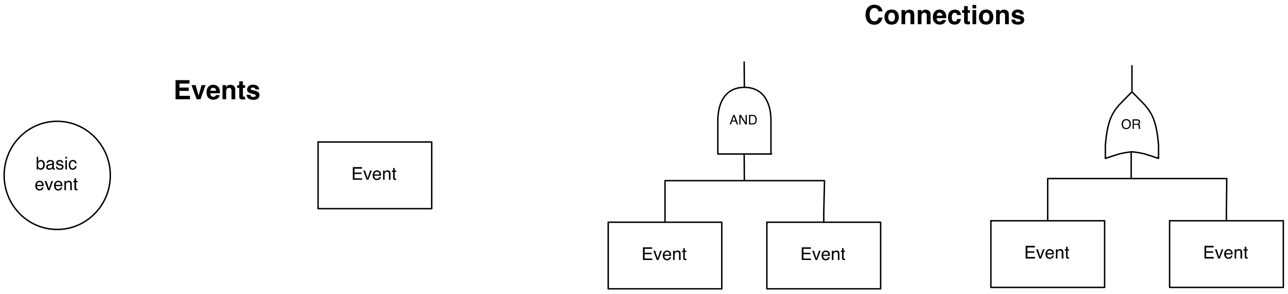


Figure 57: The elementary components of the TFA model. Left: Events; right: Connections. Further characterizations are possible.

Example of Application

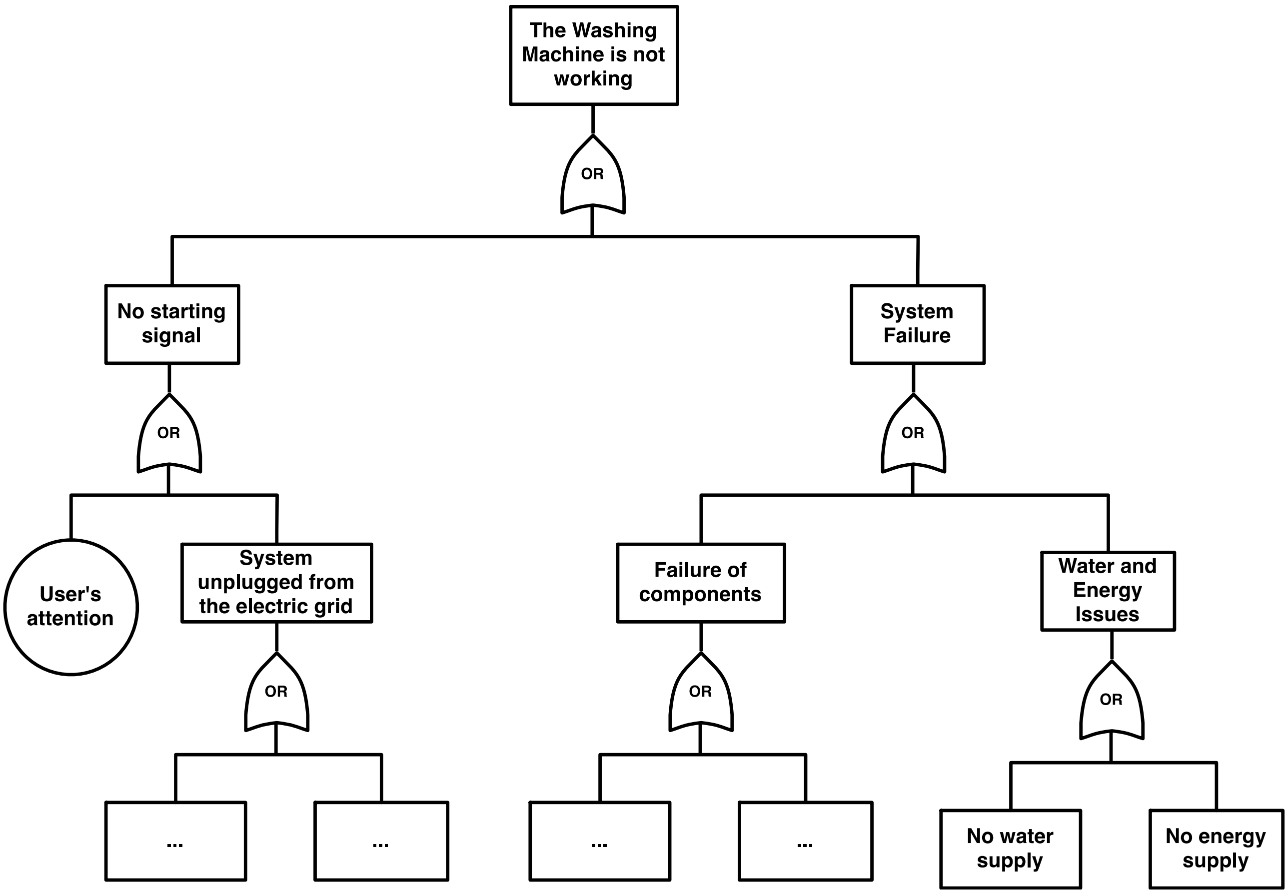


Figure 58: an example of application of the TFA approach to a problem concerning the field of washing machines in a domestic environment

Reference

H.A. Watson (developer) NOW NASA; "Fault Tree Handbook with Aerospace Applications Applications"; http://www.hq.nasa.gov/office/codeq/doctree/fthb.pdf

4.11. Issue-Based Information System (IBIS) notation

Brief Description of the Modelling Technique

The IBIS notation is a modelling technique suitable to describe problems (Issues) and solutions (Answers) for both products and processes. Moreover, it is not generally aimed at representing technical details, it rather model different perspectives on the same subject in order to clarify pros and cons behind design decisions. It has several nuances to describe positive or negative viewpoint or evidences, depending on their relevance and criticality.

Main constructs

- **Issue** as a question mark that represents problems or questions yet to be solved - it may also be further characterized in resolved, insoluble or rejected issue;
- **Answer** as a bulb representing an idea/concept capable to solve an issue - it may be also further characterized in accepted, likely, unlikely and rejected ideas;
- **Pro Argument** as a plus symbol representing an opinion or an evidence supporting an answer, shedding light to a reason for its implementation - it may be also further detailed in Dominant and Failing pro argument;
- **Con Argument** as a minus symbol representing an opinion or an evidence weakening an answer, shedding light to one of its drawbacks - it may be also further detailed in Dominant and Failing pro argument.

Graphical representation of the model

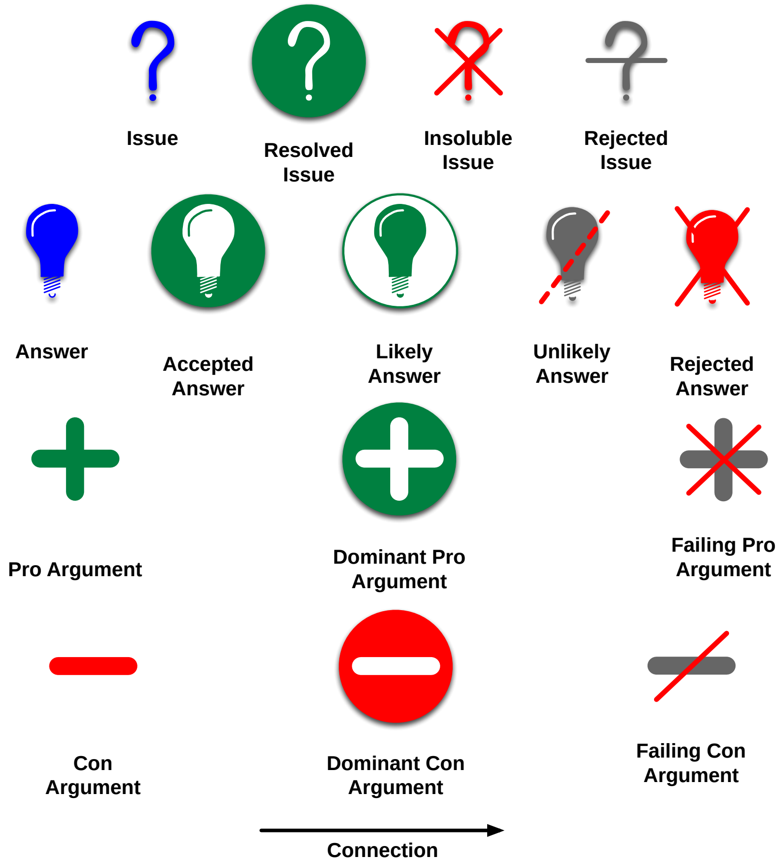


Figure 59: The constructs of the IBIS notation as used in the designVUE software

Example of Application

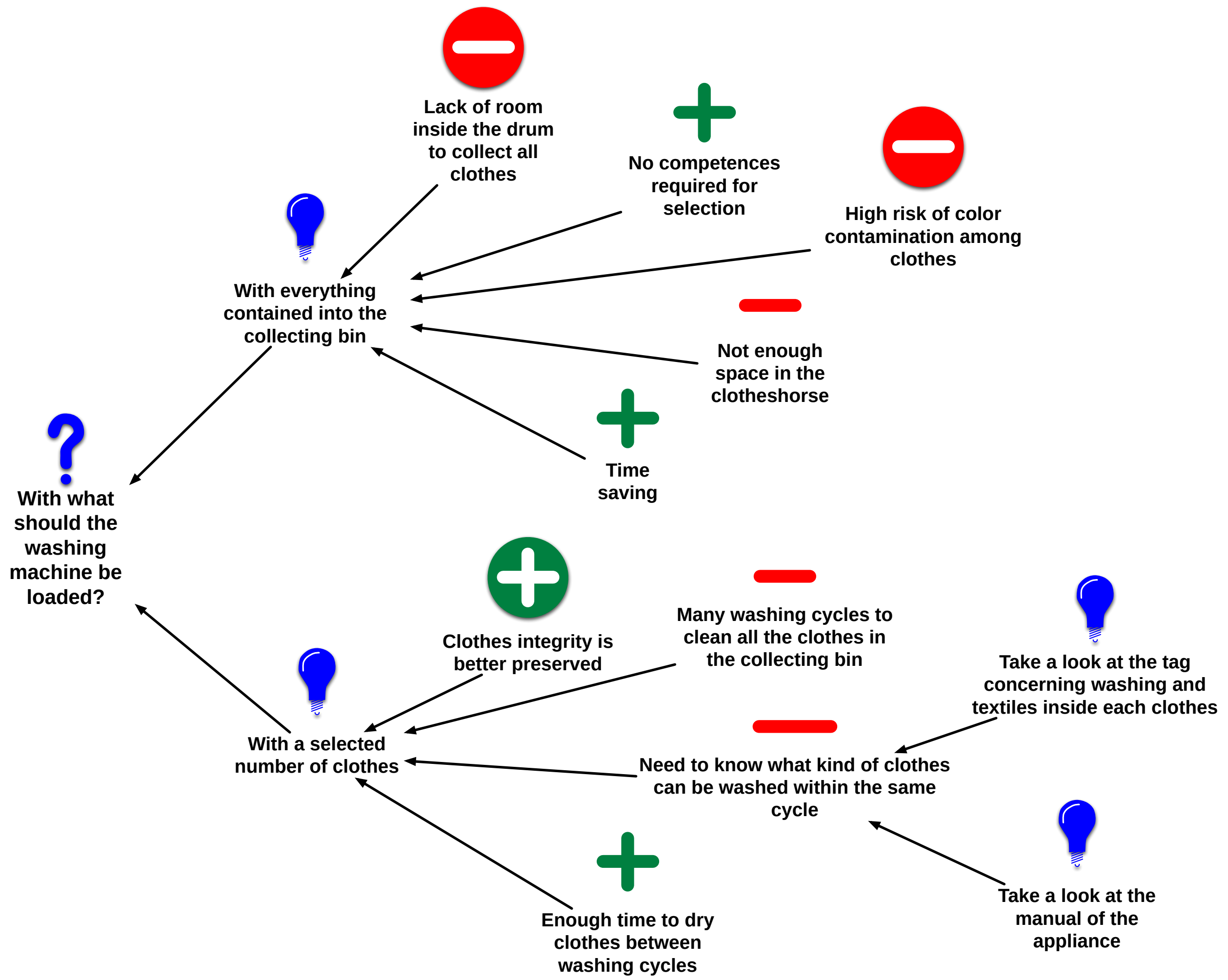


Figure 60: An example of application of the IBIS notation in the field of washing machine. The example concerns the problem of properly loading the washing machine.

Reference

Marco Aurisicchio; designVUE manual; https://workspace.imperial.ac.uk/designengineering/Public/VUE/Documentation/designVUEManualV1.pdf

4.12. FMEA/FMECA

Brief Description of the Modelling Technique

FMEA is the acronym for Failure Mode and Effect Analysis. Its aim is to prevent problems that are expressed in terms of effects as well as modes of problem emergence. This analysis is carried out through a model organized in tables that collects different components presenting criticalities. For each of such components undesired effects, failure modes as well as potential causes are depicted together with diverse numeric indicator concerning the criticality of problems, with the purpose of pointing out potential direction of intervention to prevent their emergence.

Such table has not a fixed structure, since its first row (Figure 61) can be tailored to meet individual industrial exigencies.

Main constructs

- **Element** as the entity that may undergo an undesired effect -organized in row;
- **Function** as the action carried out by the Element in the same row;
- **Potential Failure Effect** as different effects that may compromise the integrity of the element or its functioning;
- **Potential Failure Modes** as different modalities that may trigger failure effect;
- **Potential Causes** as the different reasons behind the modalities triggering a failure effect;
- **Occurrence rating** as a numeric index qualitatively describing the frequency of appearance of a failure effect;
- **Current controls** as the means to verify if a failure effect has appeared;
- **Time related parameters** as numerical values describing quantitatively the frequency of failure effects - following a statistical model fro predicting occurrences of failures;
- **Criticality Indexes** as numerical values that qualitatively characterize the seriousness of a failure effect.

Graphical representation of the model

Item	Function	Potential Failure Effect	Potential Failure Mode	Potential Cause	Occurrence Rating	Current Controls	Time related parameters	Criticality indexes
The entity undergoing the undesired effect	The Function of the Item compromised	The consequences of a failure mode on the Item	How the effect occurs	What triggers the effect	Numeric scale for frequency	Means to verify the effect	Statistics-based parameter for failure frequencies	Numeric scale for failure seriousness

Figure 61: An example of FMEA table together with a brief description of the meaning of the elements pertaining the first row

Example of Application

Item	Function	Potential Failure Effect	Potential Failure Mode	Potential Cause	Occurrence Rating	Current Controls	MTBF	Severity
Drum	Rotate the clothes	Clothes get soaked from bottom without any mechanical action	The belt is broken	The pulley worn out the belt	2 (on 10)	Visual Control of belt conditions of wear	2000h	10 (on 10)
Drum	Rotate the clothes	Clothes get soaked from bottom without any mechanical action	The belt is disconnected from the drum	Excessive vibrations of the drum	3 (on 10)	Washing Cycle at maximum loading with balanced load	1000h	9 (on 10)

Figure 62: An example of FMEA with two occurrences of problems pertaining to the drum of the washing machine.

Reference

US Department of Defense; "PROCEDURES FOR PERFORMING A FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS" http://www.fmeainfocentre.com/handbooks/milstd1629.pdf (ORIGINAL SOURCE, Now several updates adapted for different purposes available)

4.13. Function – Behaviour – Structure (FBS) Framework

Brief Description of the Modelling Technique

This framework is intended to describe the different cognitive processes occurring in design. It is not, therefore, directly aimed at describing products or processes. Nevertheless, the model introduces different variables to characterize the single cognitive processes. Such variables may pertain to different conceptual characteristics as Function, Behaviour and Structure.

It could be useful to adopt this model in order to highlight the emergence of problems in a product or process by comparing the Behaviour that is expected by the design proposal (conceived at an abstract level) and the real Behaviour as concretely demonstrated by the designed structure. Differences between the two behaviours represent possible problems (Figure 65).

Moreover, such a model is also useful to organize and collect the available technological alternatives, being them abstract as it happens during an ideation process, as well as concrete when it is necessary to frame analogous technical solutions in homogeneous clusters (Figure 66).

Main constructs

- **Function** as "what the system is for", the action that it carries out and the reason for which it exists;
- **Behaviour** as "how the system works" (how its parts interact with each other); it cab be distinguished in
  - **Expected Behaviour** (Be, in Figure 63), representing the conceived behaviour for a given function;
  - **Behaviour of the Structure** (Bs, in Figure 63), representing the actual behaviour as produced by the element composing the system when they interact to carry out the function;
- **Structure** as "what the system is" or "...is made of".

Graphical representation of the model

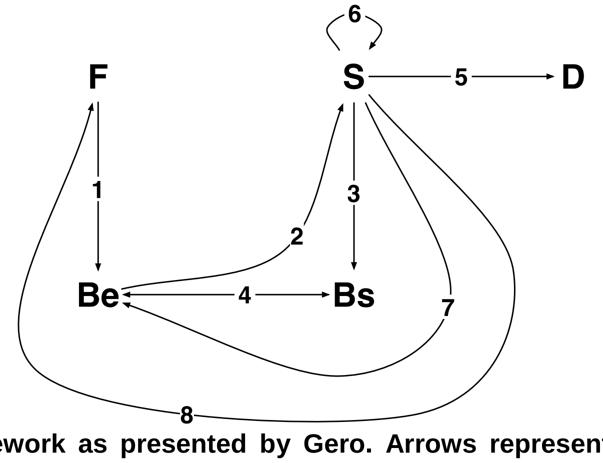


Figure 63: The FBS framework as presented by Gero. Arrows represent cognitive processes that links different variables.

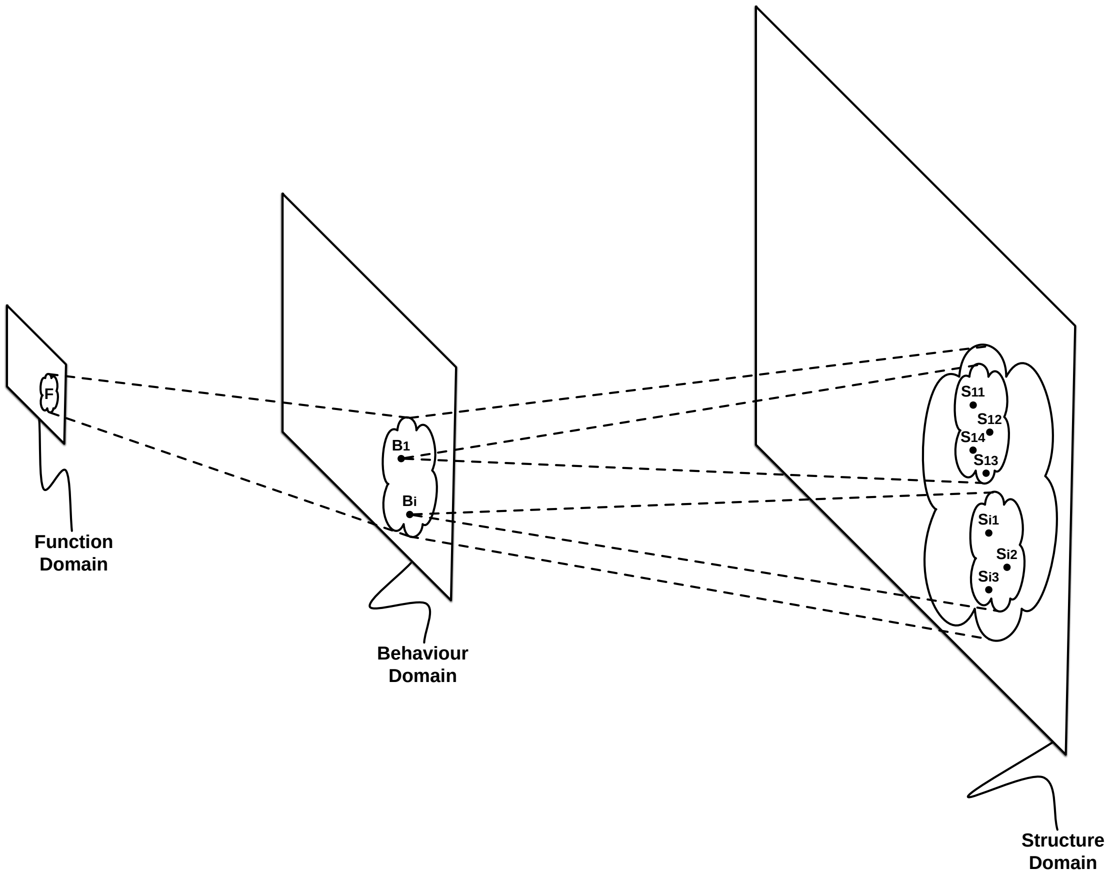


Figure 64: The different solutions can be organized according to the appropriate layer they pertain to. For each function (F) it is possible to identify more than a Behaviour (B) capable to carry it out. In turn, more than a single structure can potentially present the same behaviour. A clearer example of this concept is presented in the example of Figure 66.

Example of Application

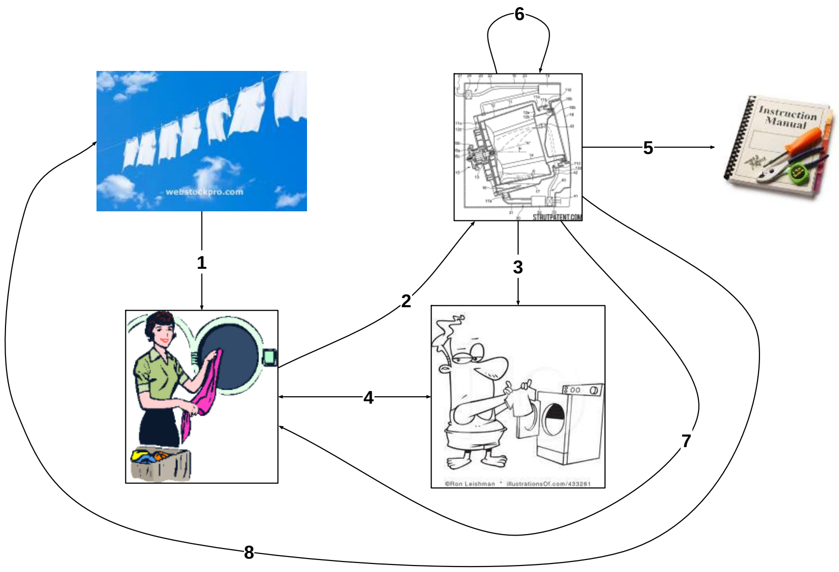


Figure 65: The example of the FBS framework used for the purpose of identifying problems. To clean clothes it is conceived to use a washing machine (arrow labelled 1); to such a behaviour it is associated a structure (2), whose results can be determined by its analysis (3). The outcomes emerged by the analysis can be compared to the expected ones (4) and discrepancies can highlight the presence of problems

Figure 66: The organization of different solution according to the pertaining domain. All the presented solutions accomplish the function of cleaning clothes (left image). The washing machine to produce such a results can be characterized by different behaviours. Among them there are the ones using a drum whose axis could be horizontal (on the top of the figure) or vertical (on the bottom of the figure. Alternative structures are presented on the same line.

Reference

John S. Gero; Design prototypes: A knowledge representation scheme for design; http://aaaipress.org/ojs/index.php/aimagazine/article/viewFile/854/772

5. Conclusions

The review of the state of the art has examined 29 different techniques in order to cover all the relevant constructs that can be useful to model the information that can be useful in a technology forecasting study..

The modelling techniques are presented into three different sections, according to the purpose of the modelling technique; one more focused on product modelling, then the ones oriented to process modelling and, then, modelling technique having a supporting role or capabilities to represent both products and processes.

The analysed capabilities of the different techniques suggest that an appropriate selection of the modelling technique to support technological forecasting should be based on a different classification that organizes the modelling techniques according to the characteristics constructs they use. This activity will be carried out within the Task 2.5.

Moreover, it is important to understand that the modelling technique to be used within the FORMAT methodology should take into account a plurality of different needs or, at least, exigencies, as presented in Figure 67.
This new classification allows to better match the different exigencies to be satisfied, not just in terms of concepts to be modelled, but also in terms of time required for the analysis, knowledge and expertise to complete the model,…

To this purpose, as it has emerged during the ToK meetings, it is important to define if the FORMAT methodology can benefit from selecting a subset of models to be adopted as a reference or, on the contrary, build a new modelling approach from scratch by just collecting the relevant features from the different modelling techniques reviewed. Moreover, it is also possible to structure the methodology so that the modeller has the opportunity to choose which is the best modelling technique for the situation at hand and to his/her specific experience.

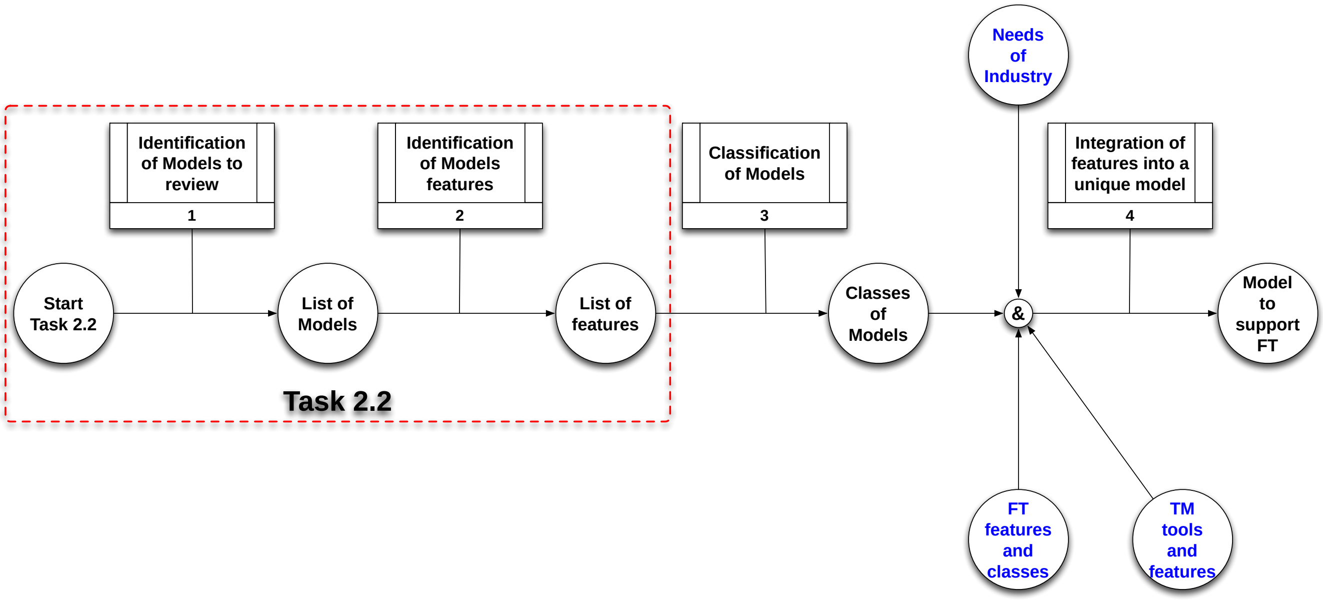


Figure 67: The activity to be performed in order to properly define an appropriate modeling technique to be tailored on the FORMAT project exigencies

In this context, the best option should be determined by also taking into account the results of the different tasks and harmonize them in Task 2.5 also by blending, if possible, the three above proposed alternatives.

6. Bibliography

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