On the definition of functions for the identification of system requirements

The evolution of technical systems depends on two different aspects (Figure 1): first, the emerging of new demands from the market and, second, the opportunity due to new scientific advancements resulting in the development of new technologies.

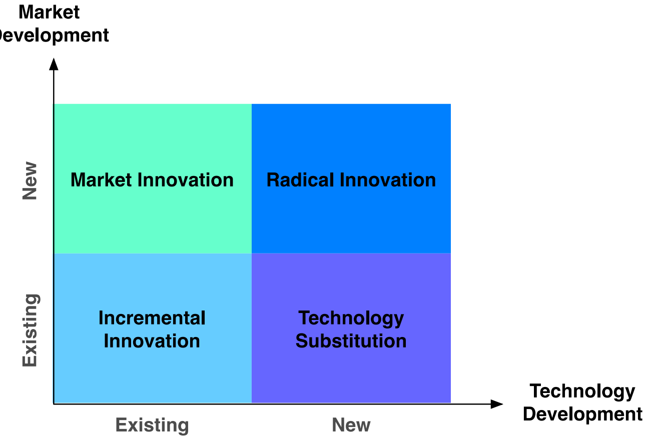

Figure 1: Innovation from the perspective of Market and Technology development. Diagram adapted from [1]

In this context the definition of requirements for technical systems is the key to understand what is supporting or preventing the technical evolution of products and processes. Indeed, system requirements represent the knowledge elements linking technology to the demands from market. From a more general perspective, Roozenburg and Eekels [2] divided requirements into those that have to be compulsorily satisfied (properly, requirements) and those whose satisfaction is just an attractive condition that has not to be necessarily met (wishes). Therefore, according to this viewpoint, it clearly emerges that requirements play a relevant role in defining the boundaries of each development activity, and can serve as well for those activities aiming at depicting the future evolution of products and processes.

In these terms, requirements are actually drivers and barriers along the path of technical evolution. In the first case they stimulate the search for new solutions. In the second case, on the contrary, they prevent the adoption of new solutions that may compromise the satisfaction such kind of requirements.

To this purpose, the identification of system requirements is paramount to define present and future characteristics that technical systems has to meet, with the purpose of both understanding which ones will be likely demanded by the market and which ones can be fulfilled by already existing or emerging technologies. However, it is impossible to define a homogenous set of requirements without specifying in advance what is the purpose of the technical system for which this analysis has to be carried out.

With reference to the diverse modelling techniques (29) examined within the activities collected in the Deliverable 2.2 of the FORMAT project [3], this white paper aims at describing how the EMS (Energy-Material-Signal) modelling technique [4] supports the identification of a framework according to which requirements can be defined, even with an evolutionary perspective.

Generalities about the EMS modelling technique

The EMS modelling technique aims at describing functions according to the transformations they operate on different flows, which can be classified under Energy, Material and Signal (Figure 2).

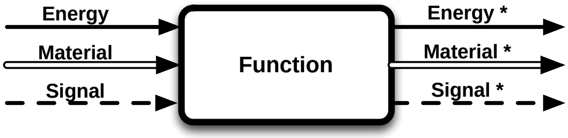

Figure 2: General structure of the EMS model

With reference to Figure 2, the typical constructs of this modelling technique follow:

- **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.

Despite this model focuses on the representation of behaviours [5] by considering all the flows required for allowing the system to work, its customized application allows designers to release from the real situation by just focusing on ideal transformation. In other words, the exclusive focus on the flows involved in the desired transformation aims at overlooking the resources needed by the technical system so as to favour the identification of the reason behind the existence of a technical system. Generally speaking, this kind of modelling technique is versatile since it allows the representation of the functions at different levels of detail, with a fractal structure.

To clarify these concepts, Figure 3 presents an example of modelling in the field of washing machine, as already published in [3]. The top part of Figure 3 represent the whole process of Washing Clothes, while the sequence of boxes at the bottom show a few different stages that characterize the overall process. Red labels refer to desired flows.

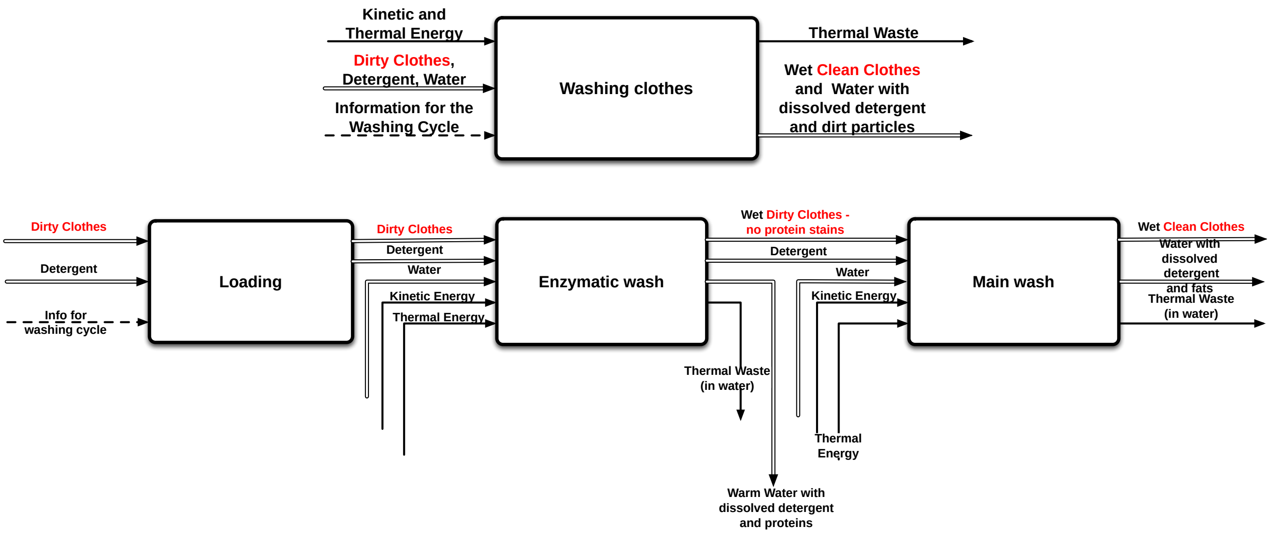

Figure 3: Example of application of the EMS model to system for washing clothes.

As said, the exclusive focus on desired transformations is the key to focus on the reason behind the existence of a certain technical system. Following this logic, the function of the technical system is directly and strictly related to the demands emerging from the market.

Therefore, the identification of such flows to be transformed, as well as the definition of their characteristics to be changed, is critical to identify both the current situation and the future potential evolution of the function. The following section proposes an example of application of the modelling technique so as to identify both the current function of a packaging system and its potential evolution in the next future.

EMS modelling and the evolution of the function characterizing packaging technology

The EMS model for a given technical system can be defined according to the individual intuition of the modeller or, on the contrary, it can be carried out with a more repeatable logic that stems from the meaning of the main constructs characterizing the model.

In this perspective, the function of a packaging system can be intuitively defined as "*protecting a certain good/product*". With a more thorough analysis it clearly appears that this is not a function as it is meant in the framework of the EMS model. Indeed, the content of the package, which according to this formulation seems to be the entity on which the package carries out its function, does not undergo any modification. Moreover, the motivation of the presence of the packaging on a certain good is to prevent any modification it may occur on it. From a certain perspective it is possible to say that the EMS logic has been applied even here as a verification of the formal correctness of the definition of the function.

The EMS can be obviously used even with a proactive approach, so as to correctly identify all the specific constructs and formally define the function of the technical system. According to the experience of the author, this activity can be carried out with better effectiveness by self-asking the following questions:

"Are there entities on which the technical system exerts an action aimed at changing one or more of their features? If yes, are they related to Energy, Material or Signal?"

Whenever the first question has a positive answer, it is necessary to identify these entities and classify them consistently with their nature (EMS), even by using the NIST Functional Basis as a support [6]. For what specifically concerns the case of the packaging, the answer to these questions is relatively straightforward. Nevertheless, those who are not acquainted with the functional logic, can still have problem in defining this function because of the standard way of considering the system as "*the product and package that envelopes it*". Indeed, this viewpoint does not allow to significantly modify the intuitive formulation "*to protect a product*".

In such a situation it is useful to consider that a technical system is something that artificially works against the natural sequence of events [7] occurring (or potentially occurring) in the environment and that may trigger an undesired situation. On the basis of this consideration, the modeller can proceed with the definition of the function by self-asking the following questions:

"What is the property of the environment (meaning all the things that are not included within the system under investigation) that the technical system is going to change or to counteract? What entity owns this property?

For answering the abovementioned question, it is therefore necessary to understand what are the entities that are outside the system under exam that may also interact with our system. In the case of the packaging, the property to be counteracted by the technical system is kinetic energy. There exist a lot of different entities having a certain amount of kinetic energy, but only those directed towards the packaged product have to be significantly taken into account. The nature of these elements implies that the designer has to consider them as Material elements: it means that the system aims at "*deflecting*" solids of a certain size (e.g.: other packaged products), but also liquids (e.g.: water potentially compromising electronic components) and particulates (e.g.: dust). Thus, the current function of the Packaging system is, in the current scenario, to "*change the momentum* (e.g.: direction & magnitude) *of materials* (thus, their kinetic energy)", as depicted in Figure 4.

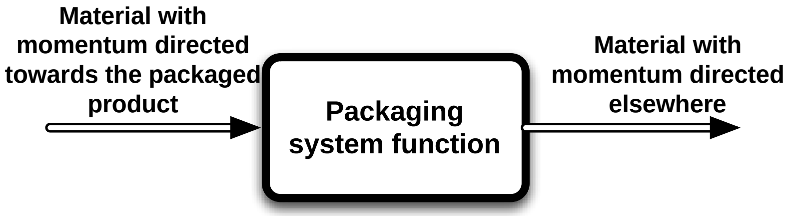

Figure 4: Functional description of the technical system "package"

Stemming from this preliminary model, it is possible to further develop the analysis by checking if any other kind of flow (in this case Energy or Signal) can be managed by the packaging system. Indeed, from a certain perspective the packaging system aims at changing an energy flow that, in the current situation, is mainly mechanic and related to solid objects. Therefore, the general demand of "deflecting" energy can become more general in the future by involving different kind of energies, meaning that the packaging has to evolve towards a more versatile way of functioning. To this respect the function can be redefined, more in general, as **"*to change* direction and amplitude of an energy field"**, as depicted in Figure 5.

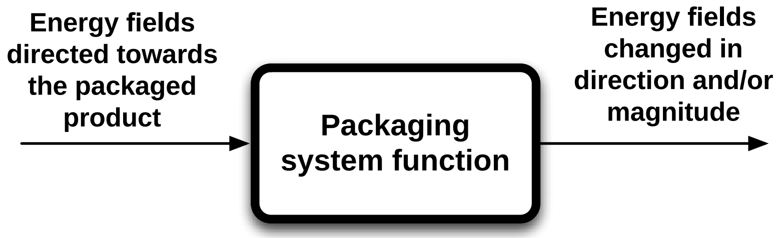

Figure 5: The expected evolution for the function carried out by the technical system "package"

Therefore, the function presented in Figure 5 allows the modeller to also take into account those requirements that haven't been yet considered for the technical system but that, in the future, should be met by those who manufacture and deliver products. Among the different energy fields that are, or could become, critical, it is important mentioning: mechanical energy, electrostatic energy (dust), heat, light.

The identification of requirements for the technical system goes beyond the purposes of this paper, nevertheless it is worth mentioning that checklists, such as the one proposed in [2], or criteria (e.g. those proposed in [8]) supports the definition of more complete design specifications.

Conclusions

This brief white paper describes in the detail an example of functional modelling, which constitutes the basis to define requirements for both the current situation and, with a small step of generalization, the future expected function of the technical system. In this paper the author chose to propose an example with the EMS model, but the diverse modelling technique reviewed for the Task 2.2 of the FORMAT project allow, at different extent, to apply the same logic for the same purpose.

The authors are currently developing the FORMAT methodology by considering both functions and requirements to be integrated in a integrated modelling framework where products and the related manufacturing processes coexist, being their evolution driven by a common dynamics, as witnessed in [9]. These aspects will be surely presented in the future deliverable of the project as well as in dedicated white papers.

References

[1] Cross, N., (2008). Engineering design methods: strategies for product design (Vol. 58). Chichester: Wiley.

[2] Roozenburg, N. F., & Eekels, J. (1995). Product design: fundamentals and methods (Vol. 2). Chichester: Wiley.

[3] Becattini N., (2013). PRODUCT AND PROCESS MODELLING – STATE OF THE ART UPDATE - Deliverable of the Task 2.2 of the FORMAT Project, available at http://www.format-project.eu/deliverables/public-reports-and-white-papers/deliverable-2.2/view

[4] Pahl, G., Wallace, K., & Blessing, L. (2007). *Engineering design: a systematic approach* (Vol. 157). Springerverlag London Limited.

[5] Gero, J. S., & Kannengiesser, U. (2004). The situated function–behaviour–structure framework. *Design studies*, *25*(4), 373-391.

[6] Hirtz, J., Stone, R. B., McAdams, D. A., Szykman, S., & Wood, K. L. (2002). A functional basis for engineering design: reconciling and evolving previous efforts. *Research in engineering Design*, *13*(2), 65-82.

[7] Simon, H. A. (1996). The sciences of the artificial. MIT press.

[8] N. Becattini, G. Cascini, P. Petrali, A. Pucciarini, "Production processes modeling for identifying technology substitution opportunities", In 11th ETRIA TRIZ Future Conference, pp. 17-34, 2011.

[9] Utterback, J. M., & Abernathy, W. J. (1975). A dynamic model of process and product innovation. *Omega*, *3*(6), 639-656.