Problem definition methodology for the "Communicating Material" paradigm

Sylvain Kubler, William Derigent, André Thomas, Eric Rondeau

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S. Kubler, W. Derigent, A. Thomas, E. Rondeau

Centre de Recherche en Automatique de Nancy,
UMR 7039 – Nancy-Université, CNRS
Faculté des Sciences BP 239, 54506 Vandœuvre lès Nancy, France.
(e-mail: Sylvain.Kubler@cran.uhp-nancy.fr)

Abstract: Today, more and more new technologies of information and wireless communication are useful for social, economic and industrial life. Auto-ID technologies such as RFID are a good example of that. The actual limits of these new systems are relative to their granularity, since items are the smallest parts of an ubiquitous system (Internet of things). In this paper we propose a ”communicating material” new paradigm. Working on the credibility of this concept since some years, we highlight here its main technological and research perspectives.

Keywords: Communicating Material, System Engineering, Ubiquitous Computing

1. INTRODUCTION

Currently, barcodes are progressively replaced by RFID tags (Radio-Frequency Identification) which enable a wireless communication with the ”ambient environment”. Products equipped with such devices are called communicating products and improve traceability, quality monitoring and logistic network performances because they have some information capacity offering to the system a better ability to react to unforeseen changes. An important aim of industrial management essential was to control the product material flow all along the supply chain. Right from the sixties, Plossl (1993) showed that MRP2-based (Manufacturing Resource Planning) information systems could implement models reducing the gaps between the material and informational flows.This problem is still a hot topic today. An obvious way to suppress the synchronization problem between these two flows is to merge them : the material flow instrumentation via the use of technologies such as RFID is one solution, enabling products to be active by communicating information. A ”communicating product” is thus an independent system, composed by a unique and single product connected to a communication device. As a result, it can wirelessly communicate with some computer facilities. This product can eventually carry information going from a simple reference (like a link to a database) to a more or less complex data set, accessible to the user when needed, by reading the tag attached to the product. Moreover, this product can eventually take simple decisions so that, under certain conditions, it could adapt its behavior to current circumstances, in spite of what was planned initially.

These last years, IFAC (International Federation of Automatic Control) [Ollero et al. (2002), Nof et al. (2006)] promoted the development of these concepts. More recently, the Holonic Manufacturing System (HMS) paradigm proposed the product should be given data storage and data processing capacities to interact with its environment [Van Brussel et al. (1998)]. The Intelligence in Manufacturing community [L Monostori . and Morel (2003), Morel and Grabot (2003)] demonstrated the pertinence of reconfigurable, modular and adaptable manufacturing systems. In order to implement the capacities exposed previously, Banaszak and Zaremba (2003) showed the product needs technologies not only to carry data but to carry information and knowledge. These products are either called *intelligent* or *communicating* products. Beyond these interpretations we will make no distinction between these two terms in this article.

Even so, this concept already showed a certain number of limits which are discussed later : discrete reading, risk of tag damage, problem of information transfer when cutting the product in several parts, . . . To overcome the previous problems, the concept of ”communicating material” is proposed. It leads to an important paradigm change because the product does not communicate using a tag, but becomes intrinsically communicating, in his wholeness. In fact, in our vision, all the material which composing the product has this communicating property thanks to built-in specific micro-components. Besides, these components can give the product some capacities such as the data storage (the material would act as a computer hard disk and would update its data all along its life cycle), a decision making capacity (smart composite), or others.

The rest of article is organized as follows : A discussion about the paradigm change (passing from the communicating product to the communicating material) is introduced in section 2. Section 3 presents a state of the art on the concept of communicating products, by presenting works related to the intelligent product paradigm. Section 4 focuses on developing a rigorous innovation approach in order to organize hierarchically the objectives to achieve and to decline them in various research and technological problems. Finally, the last section uses this approach within the context of the communicating material.

2. OPPORTUNITY OF A NEW PARADIGM

Depending on studies that we have pursued for several years, we detail in this second section some reasons leading to the opportunity of this new paradigm (passing from the ”communicating product” to the ”communicating material”).

Current research works about Intelligent Products within the framework of logistic suppose that each product is a small and

Table 1. Communicating product *vs* communicating material

Characteristics	Communicating Product	Communicating Material
Information location	localized	continuous
Embedded memory	limited	extensible
Resistance to the losses of tags	critical	less critical
Services location	localized	continuous

non decomposable unit. In this context, each product has its own informational part, most of the time located on a single RFID tag which only stores the ID of the product, referring to its complete information saved in an external database. However, in a manufacturing process, products are rarely non decomposable and they are subjected to different transformations of several types (assembly/disassembly, welding, milling, sawing, . . .). Depending on the transformation type, the information located on a certain area of the material might be moved to another location and perhaps modified. As a result, tools to manage data over the communicating product are needed. It is really difficult to implement these tools when considering the actual intelligent product architecture, because the informational part is stored in a fixed location on the product preventing it to be moved to another location. To solve this problem, the information will be continuously and intrinsically spread into the material. Moreover, accessing to the product information located in a distant database is not always possible and it could be interesting to store all the information into the product itself. But, currently, there are no commercial tag offering sufficient capacities coupled with small sizes. As explained before, the communicating material consists of a multitude of tag which offers an extensible and higher memory, according to the material dimensions and the tag density (formulated rows 1 & 2 Table. 1). The resistance to losses on a product integrating a single RFID tag is more critical than a object whose its material is entirely (and intrinsically) composed of tags. Indeed, if single tag is broken then all the information related to the product is lost (row 3 Table. 1). Similarly to communicating products, communicating material could provided several type of services (e.g. the monitoring, actuating notion or still information processing) [Akhras (2009)].The main contribution of the communicating material is the capacity to provide services all over its surface (formulated row 4 Table. 1).

Thus, we aim to develop a new material which will be communicating from his natural state and in its entirety; it is the major distinction with the communicating product paradigm. Afterwards, it would be interesting to implement on the material the functions necessary for information management (to solve the previously mentioned problems). By the way, numerous projects interested in similar research topics are published as the SFIT axis (Smart fabrics and Interactive Textiles) from the next European FP7 call, which aims to develop new textile material with interactive functionalities. ISIS (a society hosted by the University of Brême) is currently working on sensory materials. The EMRS (European Materials Research Society) is also interested in this field and hosted a symposium around this topic during Spring 2010. Thus, one can easily see that giving enhanced functionalities to materials is a hot topic today, which seems to be promised to important research opportunities.

3. STATE OF THE ART

Today, works to make the material ”communicating” are extremely rare. However, they find their sources in works aiming to give to products an active role in their life cycle (intelligent products) and those which goal is to functionalize the material, without making it intelligent (sensorial textiles). In what follows, we present works on these two research axes.

3.1 The ”intelligent product” paradigm

Meyer et al. (2009) offers a very complete state of the art on this theme. It seems that the term ”intelligent product” has been mentioned for the first time in Ives and Vitale (1988) in a context of after-sales services. In the IMS community, McFarlane et al. (2003) is the first to show interest in intelligent products that he defines as being a physical product to which an informational representation is added. According to the intelligence type to implement within the product, various technologies are used. The ”intelligence” concept, when it is interpreted as ”information management”, is often implemented through self-identification technologies such as RFID. When this concept is used for decision making, more advanced technologies are used, like wireless sensors for instance.

3.2 Ubiquitous computer paradigm and functionalization of the material

The efforts of material functionalization have been numerous since the birth of the ubiquitous computing concept, formulated by Weiser (1991). This concept proposes a world where computing systems, miniaturized to the extreme, are invisibly integrated in objects around us. These latest become then able to receive, store, process and transmit information.

Functionalizing the textile materials by adding electronic components takes place in the developed works within the topic of digital ubiquity. The smart textiles, or e-textiles, are materials combining microsystems, information technology and textiles. This e-textile participates in ambient intelligence and is related to the ”wearable computer”. Given our interpretation of ”communicating material”, e-textiles is to date the form of ambient intelligence that is the most similar to communicating material.

The ECE [Bradley Department of Electrical & Computer Engineering] from Virgina tech has worked for a long time on e-textiles. The issues concern computer architecture specifications, communication study (wired or wireless), software to implement in the e-textile, . . . [Zeh (2006)]. No instance of e-textiles integrating solutions based on RFID tags spread into the material has been listed. Indeed, these tags are difficult to connect on the cloth. The works on e-textile are nevertheless numerous and concern a wide range of military [Wilson et al. (1999), Park et al. (1999), Lind et al. (1997)], academic [Stanley-Marbell et al. (2003)] or commercial applications.

3.3 Methods of requirement specifications

It seems that proposing a paradigm change of this type requires a system engineering approach rigorous enough to correctly setup the bases of a research field which could be broad. In order to do so, we wished to adopt a methodology to specify our

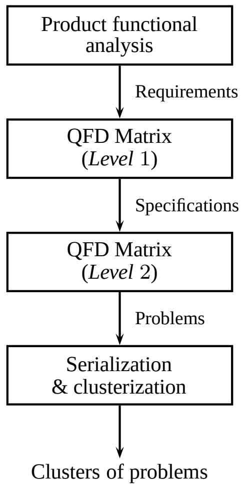


Fig. 1. General approach

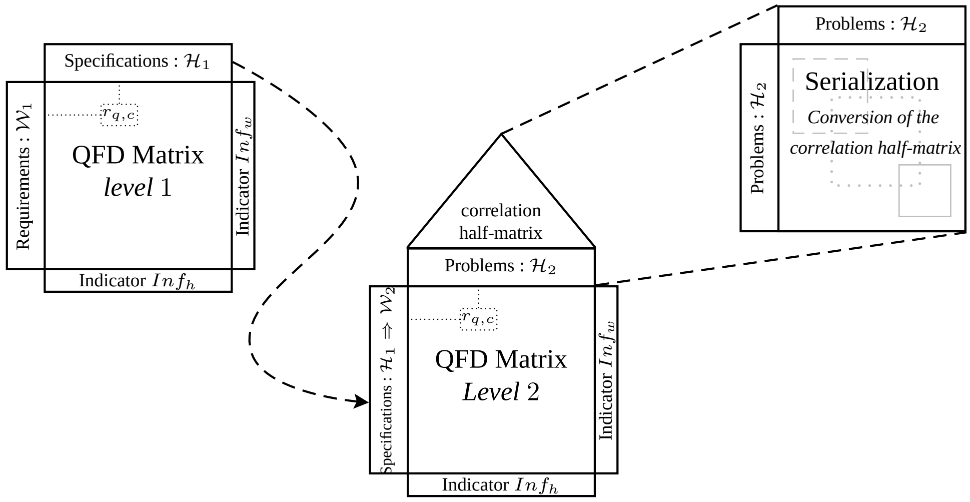


Fig. 2. Schematization of the proposed method

requirements and define the technological or scientific research fields inherent to this paradigm. As a result, in the following we expose some methodologies allowing to achieve these objectives by describing and presenting their limits, which justify our proposal. Thus, various approaches and communities have emerged, include :

- **INCOSE (International Council on Systems Engineering) :** Across all the system engineering tools offered by this community, there are methods and tools used by project executives, adequate to design, develop and check a system which offers an economic and highly efficient solution to the customer requirements.
- **AFAV (French Association of Value Analysis) :** This organism proposes several methods and integrated tools, such as the functional and value analysis. The functional analysis allows to establish specifications, but it does not allow to raise the problems to process from the objectives.
- **6 Sigmas :** Originally, it is a quality self-assurance method relying on statistics and that which found an evolution as a design methodology. Since this method includes the requirement specifications and that our objective is to specify the research fields from product functionalities, this method is not appropriate in our case.

Consequently, we focus on an approach allowing to organize the objectives and to decline them in various technological and scientific problems. This method is illustrated in section. 4.

4. METHODOLOGY OF PROBLEM DEFINITION

4.1 Introduction

As previously stated, the paradigm change must be studied. In this paper, we develop an approach relying on some tools of previously mentioned methods. On the basis of a functional analysis while allows to list the functions that the product can realize, we implement a matrix approach being inspired by the QFD (Quality Function Deployment, [Zaïdi (1993)]). On the one hand, this approach allows us to identify the technological and scientific problems relating to the product and on the other hand, the correlations between these problems. Finally, using an approach based on spectral algorithms [Fiedler (1975a), Fiedler (1975b)], these problems are gathered by problem families with strong correlations, that must be handled together. This approach is synthesized Fig. 1.

4.2 Quality Function Deployment (QFD)

The QFD approach takes into account the market needs and/or the future user wishes from the product design phase (or service), to develop the best design process in accordance with fixed quality imperatives. However, this approach initially needs to list the customer requirements. In order to do so, the product functional analysis is realized to extract all the requirements. These requirements are placed in the rows of the first level QFD matrix (Fig. 2 : *Matrix level* 1). They are also called *What* in the QFD method and form the set $\mathcal{W}_1$. A value P_w relative to the weight of the requirement w (with $w \in \mathcal{W}_1$) is also specified. Next, we search to list all the product specifications (the *How*), composing the set $\mathcal{H}_1$ enumerated by the columns of this matrix. Finally, we develop a relationship $r_{w,h}$ between *What-How*, based on 4 levels : 0, 1, 3, 9, where 0 means there is no relation between these elements and 9 a very strong one. Two influence indicators are calculated :

Inf_h that gives information about the relative influence of a single specification h ($h \in \mathcal{H}_1$) on all requirements :

$$Inf_h = \sum_{w \in \mathcal{W}_1} (P_w \cdot r_{w,h})$$

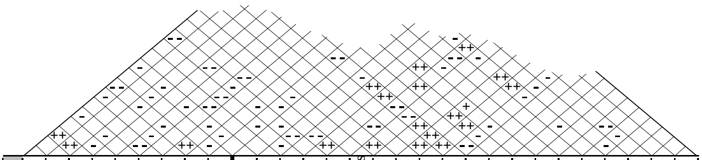
Inf_w that gives information about the relative influence of all specifications on a single requirement w ($w \in \mathcal{W}_1$) :

$$Inf_w = P_w \cdot \sum_{h \in \mathcal{H}_1} r_{w,h}$$

Secondly, we reiterate this approach to create the second level QFD matrix (Fig. 2 : *Matrix level* 2). The specifications (*How*) of the first level matrix become the *What* to solve of the second matrix, which compose the set $\mathcal{H}_2$. By this way, the "Quality" deployment is assured by constraints spreading, since the specifications ($\mathcal{H}_1$) become the *What* of the second matrix ($\mathcal{W}_2$). The underlined problems ($\mathcal{H}_2$), once solved, will then help to answer to the customer needs. In addition to the previous study, we here add the correlation half-matrix, being situated above the matrix (which exists for the matrix of level 1 in the original method, also known as the "roof" of the House of Quality). The aim is to seek the correlations between various problems or

	Customers requirements	P	Type of reader	Reading/Writing short delays	Protocol of communication	Protocol of data encoding	Adaptability of data to the needs	Type of tag	Volume of information	Completeness of information	Information format	Adaptability of information ranges	Information ranges	Resist to the external environment	Resist to the interferences	Data consistency	Resist to bit errors	Resist to inter-tag losses	ISO 14001 norm	Physical accessibility to the material	Types of norms	Tags invisibility	Data encryption	User identification	Tag price	Maintenance price	
	Specifications		Quality																				Se		Pr		
Quality	Must be able to be read/written	**6**	9	3	9	9	9	9	3	3	1	3			9	3	3	3		9	3	1	3	3			570
Quality	Store information	**6**		3		9	3	9	9	9	3	3	3	1	1	3	1	9			1		3	1			426
Quality	Resist to undergone treatments	**5**		1				3						9	9	9		9	9	3		3	1				280
Quality	Resist to losses	**4**		1	1			3	9	3	3	1		1	3		9	9			1		1				180
Quality	Respect the environmental norms	**5**												3	3				9								75
Quality	Respect the interoperability norms	**5**	3	1		9	1	1			1	1	1			3				9	9		3	1			215
Quality	Aesthetics must be the same with tags	**2**	3		1		3	9	9	3	3			1	3					1		9	1				92
Se	Avoid piracy	**3**				3			1														9	9			66
Px	Competitive purchase price	**1**						9	9													1			9		28
Px	Cheap maintenance price	**1**						3																		9	12
			0.8	0.5	0.6	1.6	0.8	1.7	1.4	0.9	0.5	0.5	0.2	0.7	1.4	1	0.6	1.5	0.9	1.2	0.7	0.4	0.9	0.6	0.1	0.1	

Fig. 3. Matrix QFD : First level



	Specifications $\mathcal{C}_1 \Rightarrow \mathcal{Q}_2$	P	Area covered	Offered throughput	Frequency range	Type of reading	Power system	Tag memory	Insulate type	Controlled environment	Existing norm	Tag integration	Data allocating software	Data encapsulation	Tag density	Material memory	Adaptability to terminal devices	Access to useful info	Info to conserve/modify	Data integrity	Associated data model	Data classification	Data aggregation methods	Updates/propagation	Bit error correction code	Inter-tag redundancy	Areas accessible in read./writ.	Order of tags to read	Order of tags to write	Type of encryption key	Identification key	
	Problems		Technological									Scientific																				
Technological	Type of reader	**0.8**	9	9	9	9	3			9	9				9	3	3	1									9	1	1			63
Technological	Reading/Writing short delays	**0.5**		9		9		9	3	3	3	1			9	3	1	9	1	1	1				1	1	9	9	9			46
Technological	Protocol of communication	**0.6**			9	9			1	3	9				3																	[illegible]
Technological	...	**...**	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..										..	...
Technological	Types of norms	**0.7**			9						9																					19
Scientific	Tags invisibility	**0.4**		1	1		1				1	9															1					7
Scientific	Protocol of data encoding	**1.6**											9	9		3	9		1		1				1	1		3	3			70
Scientific	Volume of information	**1.4**	9	3		9		9						3	3	9			9	3	9				1	9	9			9	3	137
Scientific	...	**...**	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Scientific	User identification	**0.6**														3															9	7
			0.3	0.4	0.4	0.3	0.2	0.4	0.4	0.4	0.4	0.3	0.2	0.4	0.6	0.8	0.3	0.1	0.4	0.2	0.3	0.1	0.2	0.2	0.4	0.6	0.6	0.2	0.2	0.3	0.2	

Fig. 4. Matrix QFD : Second level

How, which may be positive or negative and of variable values. Indeed, some process can damage themselves, others reinforce each other. In our case, they are expressed according to 5 levels : $++, +, 0, -, --$. Indicators of the *Matrix level* 2 (Inf_h, Inf_w, $r_{w,h}$) are calculated like previously, taking into account not the sets $\mathcal{Q}_1$, $\mathcal{C}_1$ but the sets $\mathcal{Q}_2$, $\mathcal{C}_2$.

Note that we do not use the QFD tools in a classic way. Indeed the matrix of level 2 highlighting the problems, it is important for us to show the positive and negative interactions for organize hierarchically the problems to solve.

4.3 Organization of the problems to solve

The challenge is to organize the problems to solve ($\mathcal{H}_2$) by considering their interdependence. The purpose is to gather these problems according to their negative or positive correlations. In order to achieve this step, we propose to define clusters of problem by relying on some spectral algorithms and especially on the serialization algorithm developed by Atkins et al. (1998). The principle of this algorithm is the following : Given a set of elements n to order, and a correlation function $f_{(i,j)}$, which corresponds to an attraction level between two elements i and j, in order to find them side by side in the sequence, the aim is to find optimized sequence between elements according to their consistency specified by the correlation functions. So if π is the permutation of elements and $\pi_{(i)} < \pi_{(j)} < \pi_{(k)}$ then $f_{(i,j)} \geq f_{(i,k)}$ and $f_{(j,k)} \geq f_{(i,k)}$.

The correlation half-matrix represents the relationship graph between problems. We have seen that these relationships can be positive or negative, so it is necessary to transform the half-matrix in a matrix suitable for the *Atkins* algorithm. In concrete terms, we substitute the symbols $++, +, 0, -, --$ by values 20, 10, 1, 50, 100 respectively. Only the matrix diagonal keeps the value 0. The minimal value 1 indicates that there is no interaction between problems but ensures that the graph is connected (essential condition to apply the spectral algorithm). The arbitrary choice of values $20, 10, 50, 100$ highlights the correlation by overwhelmingly favoring the negative correlations, aiming to underline the problems which are the most difficult to solve. Once the problem sequence is determined via the *Atkins* algorithm, the purpose is then to form several problem clusters that will be simultaneously processed, these clusters composing the set $\mathcal{C}$. To do so, the values 50, 100 are first gathered in at least one cluster. To facilitate the study, the clusters are limited to a reasonable size. Finally, we calculate for each cluster the contribution rate rt_c to the final project (given below), where

$c \in \mathcal{C}$ and $\mathcal{H}_{2_c}$ is a subset of $\mathcal{H}_2$ only composed of problems belonging to cluster c.

$$rt_c = 100 \cdot \frac{\displaystyle\sum_{h \in \mathcal{H}_{2_c}} Inf_h}{\displaystyle\sum_{h \in \mathcal{H}_2} Inf_h}$$

For instance, processing all problems belonging to cluster c whose contribution rate is 20 means answering to 20% of the whole problematic, i.e. the set of problems related to the product (illustrated before : $\mathcal{H}_2$).

5. APPLICATION TO "COMMUNICATING MATERIAL"

In this section, we apply the approach elaborated before within the framework of the communicating material. We established functional specifications from a generic functional analysis resulting of various studies relating to user cases representative of the life cycle (scenario of traceability in factory to detect product defaults like holes, scenario of a custom officer checking a shipment of communicating materials in a truck, ...). Thus, we have formalized the customer requirements in various categories : *Quality*, *Security* and *Price*. The QFD matrix of first level is presented Fig. 3. In what follows, we will present the requirements, specifications and problems which are the most important. The aim of this paper is not to be exhaustive but to facilitate the understanding with some examples. We figure out from the indicator Inf_h that the choice of the tag type, the volume of information or still the resistance against data losses are specifications having the greatest impact on the customer requirements. In the same way, the indicator Inf_w shows that the requirements "must be able to be read/written", "must be able to contain the information", and "resist to undergone treatments by the material throughout its life cycle" are respectively the most important.

Next, we fill the second level QFD matrix and the correlation half-matrix, illustrated Fig. 4. Note that the specifications ($\mathcal{H}_1$) related to requirements ($\mathcal{W}_1$) concerning the "price" will not be developed in the matrix of level 2, because the main objective is to raise the scientific and technological problems, without taking into account the financial aspect (for the present).

Then, we make the serialization of problems (via the *Atkins* algorithm), presented by the matrix Fig. 5. We define 4 clusters :

- ***Instrumented the material*** **:** it is mainly composed of issues related to the achievement of the communicating material in its natural state. It concerns the choice of tags and RFID reader to implement, or still the integration/the fixation of "tag systems" in a fibrous composite or in a textile. The encountered problems in this cluster are principally problems of choice of solution with respect to the technological constraints.
- ***Accessing the material information*** **:** the aim is to develop a middleware allowing to exploit the physical layer (composed of tags and readers), to explore and optimize various architectures (tag-reader-middleware) for several applications. More specifically, it addresses issues like the accessibility of material, the tags order to read/write, ...
- ***Processing information*** **:** the previous clusters are responsible for design the communicating material as well as methods to access it. In this group, we wish to develop an embedded information system within the material, able to offer some services expected by users involved in the life cycle, from the design phase to the exploitation phase : for instance, the material could be used to traceability in a factory, to struggling against the brand piracy (custom officer), or to backing up data of final users. In order to implement this information system, it is necessary to define the conceptual specifications of the data model supporting the exchanged information throughout its life cycle, to study the mechanisms needed for allocating data on the communicating material and to specify the protocols and applicative services answering to actors needs. Furthermore, these specifications will be followed by a data model validation regarding to the reliance level offered by the information system (consistency of distributed data) and a validation of protocols and services by emulation on the one hand and on a software platform interfaced with the middleware developed earlier on the other hand.
- ***Ensuring security & completeness of the information*** **:** like the cluster "*Processing information*", it studies the adaptability of data and focuses specifically on issues concerning information completeness. During its life cycle the material will be modified because of physical transformations (assembly/disassembly, ...), informational transformations (data access, data addition - deletion by several users) and of accessibility constraints (partial reading/writing of the material, ...). It raises issues like the choice of data to keep/modify within the material (at a given moment of its life cycle), or the reduction of the data volume via some methods of aggregation - desegregation. It is also in this cluster that will be processed the data security (encryption, user identification, ...).

Finally, the contribution rate rt_c of each cluster is computed (Fig. 5). We figure out that the cluster *Processing information* is therefore the heart of the project. Indeed, it has the greatest contribution rate with 58%, but it is also the only cluster in interaction with three others. Every cluster can be associated with a specific view of the system. Indeed, we evolve from a physical view of the system, intrinsically technological (*Instrumented the material*) towards an informational view of the system (*Processing information*).

6. CONCLUSION

In this study, we showed the relevance of this new paradigm. Thus, we have established an innovative approach in order to organize hierarchically the objectives to achieve and to decline them into various scientific and technological issues. This generic approach can be used in contexts other than the one exposed in this paper.

The different clusters require specific scientific skills. In order to implement the communicating material, it is necessary to identify the best scientific and industrial partners to answer problems highlighted by every clusters. As a result, it is important to implement a project structure between the partner teams in order to process these problems through mutual cooperation.

To validate the concept pertinence, we currently develop a specific demonstrator where the material is intrinsically communicating (i.e the material itself become communicating). Taking into account the technologies limits, we are building a prototype that integrate *Hitachi* μchip (dust of tags) spread *into* the material. As said previously, our perspectives is to give at the

Cluster 1 **:** Instrumented the material $rt_1 = 25$

Cluster 2 **:** Accessing the material $rt_2 = 40$

Cluster 3 **:** Processing information $rt_3 = 58$

Cluster 4 **:** Security & Completeness $rt_4 = 30$

	Offered throughput	Frequency range	Type of reading	Tag integration	Power system	Insulate type	Area covered	Controlled environment	Tag density	Existing norm	Order of tags to read	Areas accessible in read./writ.	Data allocating software	Order of tags to write	Tag memory	Data encapsulation	Updates/propagation	Inter-tag redundancy	Associated data model	Adaptability to terminal devices	Material memory	Bit error correction code	Info to conserve/modify	Data classification	Data aggregation methods	Data integrity	Identification key	Type of encryption key	Access to useful info
Offered throughput	0	20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Frequency range	20	0	50	50	50	1	20	50	1	50	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Type of reading	1	50	0	1	1	1	1	1	100	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Tag integration	1	50	1	0	50	50	50	50	50	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Power system	1	50	1	50	0	50	50	50	1	1	1	1	1	1	100	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Insulate type	1	1	1	50	50	0	50	20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Area covered	1	20	1	50	50	50	0	100	100	1	1	100	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Controlled environment	1	50	1	50	50	20	100	0	50	50	100	100	1	100	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Tag density	1	1	100	50	1	1	100	50	0	1	1	50	100	1	50	1	20	1	20	1	20	1	1	1	1	1	1	1	1
Existing norm	1	50	1	1	1	1	1	50	1	0	1	50	1	1	1	50	1	1	100	50	50	1	1	1	1	1	1	1	1
Order of tags to read	1	1	1	1	1	1	1	100	1	1	0	50	1	1	1	10	1	1	50	1	1	1	1	1	1	1	1	1	1
Areas accessible in read./writ.	1	1	1	1	1	1	100	100	50	50	50	0	1	50	1	1	50	1	50	50	20	1	20	1	1	20	1	1	1
Data allocating software	1	1	1	1	1	1	1	1	100	1	1	1	0	1	100	50	1	1	50	1	1	1	1	1	1	1	1	1	1
Order of tags to write	1	1	1	1	1	1	1	100	1	1	1	50	1	0	1	10	1	100	50	1	1	1	1	1	1	1	1	1	1
Tag memory	1	1	1	1	100	1	1	1	50	1	1	1	100	1	0	100	1	50	1	1	100	50	1	1	1	1	1	1	1
Data encapsulation	1	1	1	1	1	1	1	1	1	50	10	1	50	10	100	0	1	1	20	1	100	1	1	1	1	1	1	1	1
Updates/propagation	1	1	1	1	1	1	1	1	20	1	1	50	1	1	1	1	0	1	50	1	1	1	10	1	1	1	1	1	1
Inter-tag redundancy	1	1	1	1	1	1	1	1	1	1	1	1	1	100	50	1	1	0	1	1	100	1	1	1	1	1	1	1	1
Associated data model	1	1	1	1	1	1	1	1	20	100	50	50	50	50	1	20	50	1	0	100	100	1	20	100	50	20	1	1	20
Adaptability to terminal devices	1	1	1	1	1	1	1	1	1	50	1	50	1	1	1	1	1	1	100	0	1	1	1	1	1	1	1	1	20
Material memory	1	1	1	1	1	1	1	1	20	50	1	20	1	1	100	100	1	100	100	1	0	50	100	1	20	1	50	50	1
Bit error correction code	1	1	1	1	1	1	1	1	1	1	1	1	1	1	50	1	1	1	1	1	50	0	1	1	1	1	1	1	1
Info to conserve/modify	1	1	1	1	1	1	1	1	1	1	1	20	1	1	1	1	10	1	20	1	100	1	0	1	20	20	1	1	1
Data classification	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100	1	1	1	1	0	1	1	1	1	1
Data aggregation methods	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	50	1	20	1	20	1	0	20	1	1	1
Data integrity	1	1	1	1	1	1	1	1	1	1	1	20	1	1	1	1	1	1	20	1	1	1	20	1	20	0	1	1	1
Identification key	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	50	1	1	1	1	1	0	1	1
Type of encryption key	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	50	1	1	1	1	1	1	0	1
Access to useful info	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	20	1	1	1	1	1	1	1	1	0

Fig. 5. Fiedler serialization matrix

material itself functionalities (such as carrying a data model, capacities to react to external Event, . . .).

REFERENCES

Akhras, G. (2009). Smart composites - application and perspective. Comptes Rendus des JNC 16 - Toulouse.

Atkins, J.E., Boman, E.G., and Hendrickson, B. (1998). A spectral algorithm for seriation and the consecutive ones problem. *SIAM Journal on Computing*, 28, 297–310.

Banaszak, Z. and Zaremba, M. (eds.) (2003). *Special issue on internet-based distributed intelligent manufacturing systems*, volume 14. Journal of Intelligent Manufacturing.

Fiedler, M. (1975a). Eigenvectors of acyclic matrices. *Czechoslovak Mathematical Journal*, 100(100), 607–618.

Fiedler, M. (1975b). A property of eigenvectors of nonnegative symmetric matrices and its applications to graph theory. *Czechoslovak Mathematical Journal*, 25(100), 619–633.

Ives, B. and Vitale, M. (1988). After the sale: leveraging maintenance with information technology. *MIS Quarterly*, 12(1), 7–21.

L Monostori ., B. and Morel, G. (eds.) (2003). *Intelligent Manufacturing Systems*. 7th IFAC Workshop, Budapest, Hungary.

Lind, E., Eisler, R., Burghart, G., Jayaraman, S., Rajamanickam, R., and McKee, T. (1997). A sensate liner for personnel monitoring applications. In *Digest of Papers of the First International Symposium on Wearable Computing 1997*.

McFarlane, D., Sarma, S., Chirn, J.L., Wong, C.Y., and Ashton, K. (2003). Auto id systems and intelligent manufacturing control. *Engineering Applications of Artificial Intelligence*, 16(4), 365 – 376. Intelligent Manufacturing.

Meyer, G.G., Främling, K., and Holmström, J. (2009). Intelligent products: A survey. *Computers in Industry*, 60(3), 137.

Morel, G. and Grabot, B. (2003). Editorial of special issue. *Engineering Applications of Artificial Intelligence*, 16(4), 271 – 275. Intelligent Manufacturing.

Nof, S., Morel, G., Monostori, L., Molina, A., and Filip, F. (2006). From plant and logistics control to multi-enterprise collaboration. *Annual Reviews in Control*, 30(1), 55 – 68. 2005 IFAC Milestone Reports.

Ollero, A., Morel, G., Bernus, P., Nof, S.Y., Sasiadek, J., Boverie, S., Erbe, H., and Goodall, R. (2002). Milestone report of the manufacturing and instrumentation coordinating committee: From mems to enterprise systems. *Annual Reviews in Control*, 26(2), 151 – 162.

Park, S., Gopalsamy, C., Rajamanickam, R., and Jayaraman, S. (1999). The wearable mother-board: An information infrastructure or sensate liner for medical applications. *Studies in Health Technology and Informatics*,, 62, 252–258.

Plossl, W. (1993). La nouvelle donne de la gestion de la production. Afnor gestion, Paris.

Stanley-Marbell, P., Marculescu, D., Marculescu, R., and Khosla, P. (2003). Modeling, analysis and self management of electronic textiles. *IEEE Transactions on Computers*, 52, 996–1010.

Van Brussel, H., Wyns, J., Valckenaers, P., Bongaerts, L., and Peeters, P. (1998). Reference architecture for holonic manufacturing systems. *Computers in Industry*, 37(3), 255 – 274.

Weiser, M. (1991). The computer for the twenty-first century. *Scientific American*, 265(3), 115–124.

Wilson, P., Carey, C., Farrell, B., Gassner, J., Haugsjaa, P., Pan, M., Teverovsky, J., Winterhalter, C., and Fairneny, J. (1999). Electro-optic fabrics for the warrior of the 21st century. Technical report, Georgia Tech.

Zaïdi, A. (1993). *QFD. Quality Function Deployment. Une introduction*, volume 01. Lavoisier.

Zeh, C.M. (2006). *Softwear: A Flexible Design Framework For Electronic Textile Systems*. Ph.D. thesis, Virginia Tech, Virginia, USA.