IfNot: a Function-based Approach for both Proactive and Reactive Integrations of New Productive Technologies

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Abstract

This paper presents an approach to functional modeling for the integration process of new productive technologies, based on a FBPS (Function/ Behavior/ Process/ Structure) representation of the new technological solutions. Our approach (called IfNot, i.e. functional integration of new technologies) includes new data processing based on a mapping model that allows the comparison of new solutions according to company internal expectations, even if information and knowledge about them are incomplete

Introduction

It is no longer necessary to demonstrate that the competitive capacity of a company largely depends on the quality of the development of new technologies (Nevens, Summe and Uttal 1990). The performance of a new productive technology is not clearly estimated in terms of marketing and is not directly associated with a market share growth, but its introduction plays a major role in the search for improved internal performance and an increase in competitiveness (Birnbaum-More, Weiss and Wright 1994). Furthermore, some important economic risks appear with new technologies: namely overlooking or giving up a potentially useful technology as well as misusing or under-using it, at the other extreme, investing too much in an useless technology.

In order to face up to this strategic challenge and to limit or anticipate these major risks, engineers have to manage coherence between what is expected from a new technology and its performance during each stage of its life. We propose to call this process functional integration. Within a manufacturing company, this process is complex and brings about organizational and technical problems: many protagonists with different knowledge areas, responsibilities and motivations are involved; knowledge of both technology and expectations is incomplete; rapid decisions regarding costly investments are necessary.

With this in mind, we propose a model that allows the evaluation, from the earliest stage, of the performance of a technology, including novel technology, with regard to uncertain and evolving internal requirements[1].

This model is based upon a teleological representation of the technology, taking into account its functional, behavioral, processing and structural aspects, as well as mapping relationships between functional and performance criteria.

The paper is organized as follows: section 1 establishes the justification of the functional approach for the integration process; section 2 presents a mapping model (between some internal expectations and a new technology) based on a F/B/P/S representation of a new technology and on the notion of functional performance; in section 3, we propose some functional reasonings on this model and discuss its pertinence in order to support both proactive and reactive integration processes. Finally, some conclusions and perspectives are given.

1 Integration Mechanism: Why a Functional Approach ?

1.1 Definitions

Let us propose some definitions in order to situate our problematic and to explain why the functional approach seems to be relevant here.

- New productive technology

  A set of knowledge and practical experiences in a technical field, based on scientific principles, implemented **in order to** supply products and production goods and to provide services, or to increase their value by processing, and for which there is **no expertise** in a given environment.

This definition links the life stages of a technology to industrial contexts; we are not interested in the intrinsic concept of life cycle (emergence, growth, maturity, decline (Westkämper and Bertling 1994; Werther 1997)), away

[1] This research work benefits from a Peugeot-Citroen company (PSA) grant, and experimentations of the model are running for the study of High Speed Machining (HSM).

from its introduction environment. A technology can be both new in a context and used routinely in another.

- Integration of a new technology

  A process focused on connecting the components of the technological **system**[2] and on providing their **compatibility** as well as the correct **working** of the whole system.

The process thus specified is at the crossroads of **technological development** (introduction (Bennett 1993; Thomas, Saren and Ford 1994) or innovation (Maïsseu 1995; Roberts 1995)), and **product development** (product design (Pahl and Beitz 1988; Salomone 1995) and process design (Warnecke, Schulz and Filser 1994; Yu and Popplewell 1994)).

1.2 A Need

Integration is a multi-**actor** process, involving product and process-planning designers, R&D engineers, strategic managers, manufacturers and suppliers. In the context of mechanical mass production, organizational problems are significantly constrained by a **time factor**: decisions involving costly investments have to be made quickly. In addition, the issue of integration is a complex decision-making problem due to the multiple objectives of the protagonists. Moreover, actors are handicapped by a **lack of data** about the new **technology** (no expertise), about its integration environment (**objectives** and **products** are defined late), or about links between the technology and its environment (**constraints** and **potentials**).

Given that R&D can not test every application of a new technology, that designers can no longer prototype every product solution brought by a new technology, and that process planning designers can not try every process solution, it is now essential to provide them with support that helps to integrate new technologies into the production process as quickly as possible and with full knowledge of the problematic.

1.3 IfNot: Using Functional Modeling for a Complex Industrial Issue

Just as designers no longer design products without wondering which needs these have to fulfil, R&D engineers have to consider which technical and industrial expectations the potential gains of a new technology could satisfy. Performance of a new technology is interesting only if it is to be used functionally.

In design, researchers focus their attention on the functional representation of a product to compensate for the lack of precise information on product structure during the early stages of design (Bradshaw and Young 1991; Winsor and MacCallum 1994; Aldrich 1995; Malmqvist 1995; Mukherjee and Liu 1995; Suh 1995; Chakrabarti and Bligh 1996; Umeda et al. 1996). Design is then viewed as a process during which an abstract formulation of a problem, in terms of needs, is successively transformed and materialized into a detailed description of a manufacturable product. In diagnosis, researchers focus their attention mainly to make explicit links between a structural breakdown and the non-achievement of a function (Abu-Hanna et al. 1994; Chandrasekaran 1994; Chittaro 1995; Hunt, Pugh and Price 1995; Kumar and Upadhyaya 1995; Goel and Stroulia 1996).

Besides, in process planning, researches on support-tools are focused on computer aided systems (Ham and Lu 1988). These systems are useful when expertise exists. But it is difficult to use them when a new technology with unknown factors is being introduced. Furthermore, they are not quite suitable to process design in mass production. On the other hand, research in the area of technology management is focused on organizational skills (Lutz 1994; Werther, Berman and Vasconcellos 1994), but on the other no computer aided system is designed to support them.

We propose to adopt a **functional view** of the meeting point of both technological and product development mechanisms, which allows the evaluation of the **potentials** of one or many technologies with regard to users **expectations** in an approach called **IfNot**[3] (see figure 1). The different layers of IfNot, which allow such a mapping to be studied, are presented in figure 2.

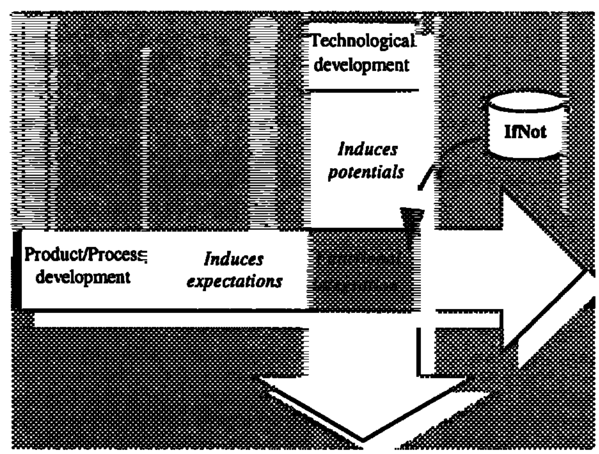

Figure 1: Positioning of IfNot approach.

[2] A system composed of the concerned technology, and of the products and processes that are part of its development environment, as well as of their potential and real links.

[3] French acronym «Integration fonctionnelle de Nouvelles technologies»: «Functional Integration of New Technologies».

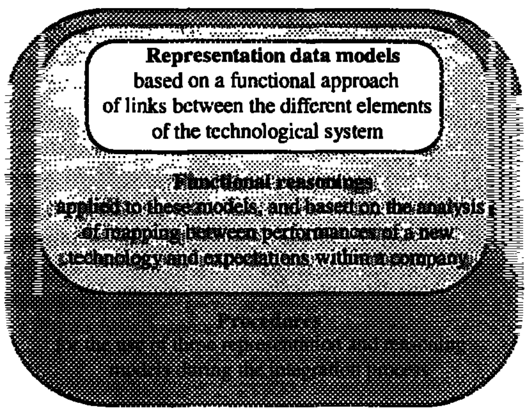

Figure 2: The 3 layers of IfNot

2 From Technology to Expectations through Functional Performances

2.1 A Function/ Behavior/ Process/ Structure Data Model

The data model is composed of two submodels: expectations and technological solution. The **expectations** model is based on a hierarchical breakdown of a global goal into functions. The **technological solution** model is composed of three submodels: behavior, process and structure. A technological solution fits the global goal through function satisfactions (Magner-Canet 1997). The detailed conceptual data models of these submodels are not presented here. We only introduce the main characteristics which are useful to explain the mapping analysis.

Expectations Model (F)

The expectations model represents expectations of product and process designers about a new technological solution. It includes the **referential** (the context in which a new technological solution is expected to perform its functions), as well as the desired **effect** of the solution on the referential[4]. Every leaf-function is characterized by one **functional criterion**, an elementary objective level and an elementary acceptance domain, and every mother-function is characterized by a global functional criterion, a global objective level and a global acceptance domain[5].

- Functional criterion X_i

  Characteristic adopted to estimate the satisfaction of a leaf-function, regardless of the technological solution that performs it.

- Elementary objective level o_i

  The best desired value for the functional criterion X_i.

  Of course, such an objective value can depend on values attained by other criteria for a particular solution, but this is a first approximation.

- Global functional criterion Xg_i

  Characteristic adopted to estimate the satisfaction of a mother-function, expressed according to its daughter-functions criteria.

- Global objective level og_i

  Objective level of a mother-function expressed according to its daughter-functions objective levels.

  $$og_i = fg_i\,(og_{i1}, og_{i2} \dots og_{in})^6$$

- Elementary (/global) acceptance domain D_i ($/Dg_i$)

  Discrete set or interval of desired elementary (/global) objective levels o_i ($/og_i$).

Technological Solution Model (BPS)

The technological solution model represents intrinsic characteristics of a new technological solution. It includes the structure (regardless of the way it is used), the process (conditions of use of the structure regardless of its morphology), as well as the behavior of the structure under these conditions[7].

The concept of performance criterion was introduced in order to characterize results of the behavior of a structure under specific conditions of use, regardless of the performed functions, before knowing if these results were functional or not, i.e. if they correspond to a real need or not[8]. It was necessary to characterize a new technology in an intrinsic manner whatever use it may have in the future. Again, a performance criterion P_j is defined by a performance level p_j and a performance domain D_j.

2.2 Functional Performances versus Performance Criteria: a Step towards the Mapping Model

Functional Performances

When trying to compare an expectation and a potential, the question is: how can a potential function be made explicit? There is a paradox between innovation and representation: all the functions of a new technological solution cannot be exhaustively listed. It is impossible to carry out a direct mapping between an expectations tree and a functional potential tree. Consequently, in order to link the functions to the morphology of a new technology, functional criteria are expressed here according to performance criteria, and are projected onto a particular solution.

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[4] For a productive technology, the referential can be either technical or industrial (material characteristics of the processing part, production plant characteristics, etc.), and can include the effects (desired hole diameter, desired production rate, etc.).

[5] The terms of functional criterion, objective level and acceptation domain are assumed to [NFX50-151].

[6] If the daughter-functions are leaf-functions, their estimation level is elementary.

[7] For productive technology, structure represents the equipment (machines, tools, etc.), process represents the process planning (sequences, operations, etc.), and behavior emerges from the application of a process to a structure (quality, cost, time).

[8] Structural performance criteria: tool material, purchase price, etc.; Process performance criteria: tool rotation speed, path control, etc.; Behavior performance criteria: roughness, tool cost, sequence time, machining length, etc.

- Mapping function f_i

  Given functional criteria X_i, and given performance criteria P_j, we assume that a mathematical function f_i exists so that:

$$X_i = f_i\ (P_j)$$

Then, in order to evaluate a new technological solution performance considering a particular specification, we introduce a functional filter of the solution by the notion of **functional performance**, which is the projection of a criterion X_i on the performances p_j of this given solution.

- Functional performance pf_{ij}

  A result obtained in a precise domain by the behavior of a structure under specific use conditions, considering the performed functions.

$$pf_{ij} = f_i\ (p_j)$$

- Functional performance domain D_{ij}

  A discrete set or interval of possible functional performances pf_{ij} which represents the projection of a criterion X_i on the performance domains D_j.

$$D_{ij} = [\mathrm{Min}\ (f_i(x)), \mathrm{Max}\ (f_i(x))] \text{ with } x \in D_j$$

Given $\{P_j\}$, the set of performance criteria of a particular technological solution, given $\{X_j\}$ the set of functional criteria of a particular specification, and given $\{pf_{ij}\}$ the set of functional performances of the solution considering this specification, we notice that a particular technological solution has a finite set $\{P_j\}$, but includes as many sets $\{pf_{ij}\}$ as potential specifications.

Micro-mapping

The micro-mapping analysis is the comparison of a functional performance pf_{ij} (or of the functional domain D_{ij}) of a given technological solution with the elementary objective level o_i (or with the elementary acceptance domain D_i) related to a leaf-function (see figure 3).

The variables resulting from a micro-mapping analysis are the **absolute micro-mapping gap** and the **relative micro-mapping gap**.

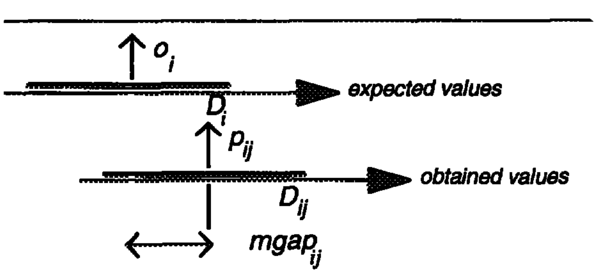

Figure 3: Micro-mapping gap.

- Absolute micro-mapping gap a-$mgap_{ij}$

  The distance between an elementary objective level o_i (or an elementary acceptance domain D_i) and a functional performance pf_{ij} (or a functional domain D_{ij}).

$$\text{a-}mgap_{ij} = d([o_i], [pf_{ij}])$$ [9]

- Relative micro-mapping gap r-$mgap_{ij}$

  The relative distance between an elementary objective level o_i (or an elementary acceptance domain D_i) and a functional performance pf_{ij} (or a functional domain D_{ij}).

$$\text{r-}mgap_{ij} = d([o_i], [pf_{ij}]) / \mathrm{width}(D_i), \text{ if } \mathrm{width}(D_i) \neq 0$$

(with $\mathrm{width}(D_i) = \mathrm{Card}(D_i)$ if X_i is a discrete variable or

$\mathrm{width}(D_i) = \mathrm{Max}(x) - \mathrm{Min}(x)$ with x element of D_i)

For example, the micro-mapping of a particular High Speed Machining solution with the leaf-function «reduce the cost» of a special specification is studied (see figure 4)[10].

Global Mapping

The global mapping analysis is the comparison of all of the functional performances pf_{ij} (or of all the domains D_{ij}) of a given technological solution with the global objective level og_i (or with the global acceptance domain Dg_i) related to a mother-function. The variable resulting from a global mapping analysis is the global mapping gap. The global mapping gap is then considered as a set of micro-mapping gaps.

We notice here that the dissatisfaction emerging from the mapping gap is subject to evolution. Indeed, it may depend on two factors: **technology maturity** and **state of the need**. First, evolution of technology maturity causes a time variation of the mapping: noted gaps vary with time. Secondly, evolution of expectations causes a factual variation of the mapping: noted gaps vary with events, mainly related to product/process development projects.

3 From Mapping to Integration Process through Functional Reasoning

The main objective of the data processing included in IfNot is to support integration processes. The first integration tactic, called **proactive**, is a bottom-up approach «from technology to product (or to process)». Its main objective is the characterization of the new technology, its internal promotion, its optimization according to the industrial context, and the optimization of the industrial context according to the technology. The data processing which is necessary for this approach has mainly to support **design** mechanisms (of new technological solutions), as well as **mutual adaptation** mechanisms (Leonard-Barton 1988) (see figure 5).

The second integration tactic, called **reactive**, is a top down approach «from product (or from process) to technology». Its main objective is the search for solutions to an expressed need: find a technology which provides technical progress or/and industrial progress. The data

[9] The micro-mapping of a new given technological solution with a given leaf-function is of inverse proportion to the micro-mapping gap.

[10] This function is part of a generic data model which includes more than 100 functions.

processing which is necessary for this approach has mainly to support **selection** mechanisms as well as **modification** mechanisms (see figure 6).

The mapping model coupled with constraints propagation techniques (Gzara 1997) can be the basis for several **functional reasonings** (currently under study), which are necessary to the approaches introduced above. The elementary processing related to this coupling induces the reduction of elementary acceptance, global acceptance, performance and functional performance domains, through propagation of the mapping functions as well as of other relationships inside the F model (between global functional criteria and functional criteria) or inside the BPS (between behavioral, process and structural performances). We propose eight main reasonings:

- Synthesis

  Design of a BPS technological solution into a structural acceptable domain, or design of a potential specification F into a functional acceptable domain.

- Correction

  Change of some characteristics in order to minimize mapping gaps (increase of satisfaction):

  - modification of levels and/or domains of performance criteria of a technological solution (direct modification of S and P and indirect modification of B)
  - modification of objective levels and/or acceptance domains of functional criteria (modification of F).

- Comparison

  Comparison of two BPS technological solutions on the basis of a same specification F or comparison of two specifications F on the basis of a same technological solution BPS (comparison of mapping gaps).

- Verification

  Verification of the compatibility of the domains of every models variables, between F and BPS or into BPS (validation of synthesis, corrections or optimizations, or hypothesis validation).

- Optimization

  Optimization of a new BPS technological solution or of a specification F according to mapping gaps and on the basis of comparisons and corrections.

- Explanation

  Highlighting of incompatibilities between F and BPS and explanation of an dissatisfaction source (concerned variables and constraints).

- Analysis

  Functional understanding of a new BPS technological solution through functional performances.

- Simulation

  Behavioral simulation (of a S under conditions P) driven by a functional specification F.

The data model allows the integration, at any moment and in the form of constraints, of each item of new knowledge emerging from the development process of the new technology (behavior laws, engineering constraints, relationships between performance criteria (physical laws or experimental results)), and thus to improve the quality and the significance of proposed reasonings.

Conclusions

A method of mapping analysis between a new productive technology and a particular integration environment has been presented. The analysis is based on a functional data model, which represents information such as company expectations, or behavior, processes and structures of new technological solutions. Besides our original application domain, the new technology integration process, we also propose our own definitions to explain the use of FBPS data in the mapping model. Mapping gaps are estimated according to functional characteristics (functional criteria, and functional performances) and thus allow technical information to be transformed into functional information, as well as to acquire a functional understanding of a new technology.

Our micro-mapping can be compared to a non-quality factor evaluation. Indeed, when a company tries to improve its products and internal processes through a Total Quality Management (TQM) approach, internal (relatively to the company) and external (relatively to customers) quality/performances indicators are built up in a functional manner. These indicators are used to control the feedback on practical actions in order to reduce the gap between desired performances and current performances. Furthermore, there is a similarity between global mapping and a TQM approach where every person, at any responsibility level, manages his own performance indicators.

Mapping is also the basis for reasonings (comparison, verification, correction, explanation, etc.) which are useful with regard to proactive integration of a technology (adaptation, design, etc.) and with regard to reactive integration of a technology (selection, modification, etc.). Such a model was designed in order to support the integration process from a technical advance identification to the regular use of the technology. Its main objectives are:

- to help R&D actors **to integrate expectations** of product and process designers **as soon as possible** in new productive technologies development projects
- to help product and process planning designers **to integrate potentials** of new productive technologies **as soon as possible** in new product and process development projects

in order **to face up** together **to late decisions** about products, processes and technologies.

We have also worked on the design of generic models for specific classes of technologies, which will be the subject of another publication: a generic functional tree for specific processing technologies, with associated functional criteria, as well as generic behavior, process and structure models for machining technologies. Further work involves the implementation of the model in a software platform, and its application to other technologies.

From the (F) model side	Given referential: parts number (3,000) • Estimation criterion Xi: cost • Elementary acceptance domain: Di =]0; 155] FF (cost of competitive solution)
From the (BPS) model side	Economic behavior law: tool cost = tool price / tool life x parts number • Performance criteria Pj: tool price, tool life, tool cost, machine cost (pj (or Dj)): 200 FF, 6,000 (or [5,000; 6,000]) parts, 100 (or [100; 120] FF, 50 FF)
Micro-mapping	Mapping function fi: Xi = tool cost + machine cost • If levels pj are known: • pfij (HSM sol.)/Xi = fi (pj) = 100 + 50 = 150 FF • r-mgapij = 0% • If only domains Dj are known: • Dij (HSM sol.)/Xi = fi (Dj) = [150; 170] FF • r-mgapij = 0% if Dij = [150; 155] and r-mgapij ∈]0; 9]% if Dij =]155; 170]

Figure 4: HSM example.

DESIGN

- synthesis of structures (S) and of use conditions (P) that generate a behaviour resulting in expectation satisfaction, among the set of possible behaviors of the structure (its **variety** (Le Moigne 1990)
- management of the technology **morphogenesis** representation of the P/S evolution of technological solutions
- **stability** search through permanent satisfaction of expectations (Le Moigne 1990): verification of the mapping

MUTUAL ADAPTATION

technology adaptation

- **materialization** of the technological solutions (their internal organization gives shape to the main function to which they adapt themselves (Simondon 1958))
- **adaptation of S and/or P** towards a minimal gap (structural adaptation, see reference system of balancing (Le Moigne 1990))

expectations adaptation

- **adaptation of functions** towards a minimal gap (this mechanism is rarely tackled because the expectations generally come from an external need that can not be changed: but internal specifications can be changed for global optimization)

Figure 5: The main proactive mechanisms.

SELECTION

- **comparison** of different solutions according to functional criteria
- **selection** of the technological solution that bring the best mapping

MODIFICATION

- **minor modification** of the technological solution: the most often modification of P but not S (**functional adaptation** see reference system of balancing (Le Moigne 1990))

Figure 6: The main reactive mechanisms.

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