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UNCERTAINTY MANAGEMENT IN INNOVATIVE PRODUCT DESIGN

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ABSTRACT

The development of innovative products and/or services constitutes a factor of enterprise competitiveness. Contrary to "routine design", innovative product design entails a part of uncertainty that has to be controlled. This paper is about uncertainty management in innovative product design. The basic assumption that is made here is that managing "innovative product design" must go beyond the technical concerns and include all the business processes and concerns that participate to the performance of Innovation.

A specific methodology (DSM© - *Dynamic Systems Management*) is presented to help project managers design graphically the processes and systems required in product innovation. This method consists in designing and modeling in a pragmatic way the various project steps of product innovation, from the initial idea to final business operations. The article takes the example of an industrial firm launching innovative electronic devices on the consumer market (MP3 readers, flat TV, set top Box…). Top managers, engineers and experts can share their views of the required process including the technical and social resources.

Heuristics allow controlling the model and its evaluation consistency. This method has been used successfully on several innovative design projects, using software developed in order to support the method. This global approach is based on process and enterprise modeling, and on BPM (Business Process Management). Its originality is to be applied on innovative design projects and also to be lighter to use than usual BPM methods.

Keywords: Innovative product design, uncertainty management

1 BUSINESS INNOVATION & UNCERTAINTY MANAGEMENT

1.1 Turbulence and Adaptation

Organizations must adapt to environmental turbulences

Business environments force public and private organizations to launch products more frequently, and put a growing pressure on organizations to speed their process of product innovation and development [1]. Organizations are placed in constant conditions of change and evolution, they must regularly adapt themselves to their changing environment [2]. As the Environment changes, businesses must adapt to these changes by creating their own future [3], they have to respond to "strategic surprises" that make the business life uncertain and discontinuous [4]. Eventually organizations and businesses are open systems in interaction with their environment, their processes are constantly modified in order to be adapted to the new environment [5], and business development - through new products, technologies and markets - is the uncertain solution that they take in reaction.

Innovation as a response to changes in the business environment

Organizations face environment changes through innovations in technology, target markets or processes [6]. In conditions of strong international competition, fast technological evolutions and changing consumer needs, innovation is the primary way for businesses to adapt [7]. Innovative Product development is the way many organizations increase their capacity to adapt and evaluate in their environment [8]: Hewlett-Packard used new product development to move from an instrument company to an IT company [9]. Speed in adaptation has become a strategic key competence for many organizations, and speed is now a critical parameter in product innovation [10], [11], [12]. Going into the market on time, even with a 50% over budget only creates a 4% decrease in profitability, and being 6 month late on the market decreases by 30% the profitability over the next 5 years [13]. Even if there are dangers and uncertainty in developing product very fast, it is often essential for business adaptation and survival [14].

1.2 Risk and Uncertainty in the innovation process

Planning & Scheduling the process of Innovation

Basically, Project Management consists in planning, implementing and controlling activities. Most of "planning methods" are aimed at scheduling activities in order to identify the best network of activities [15]. PERT (Program Evaluation and Review Technique) and CPM (Critical Path Methods) as a whole are Project Management techniques based on the description of an "ideal flow of activities" that consider processes as deterministic [16]. Project planners are considered as able to generate the best network of activities [17]. Those techniques include two different management actions and competences: project planning to determine the network of activities, and project scheduling to identify the duration and resources allocated to the activities [18].

Risk analysis in the Process of Innovation

Critical Path Methods have been enlarged in order to include risks analysis in their process of analysis [19], [20]. The GERT technique include a Monte Carlo simulation graph that make probability calculus possible [21], [22]. The GERT approach, and the revisited Q-GERT approach enable to move from a "critical path" analysis to a critical analysis of each task (probability for a task to be on the critical path) [23], [24].

Some authors extend the previous techniques in order to rework the process of activities with simulations [25], and others use a matrix method to help organizing the tasks in a product design according to the information flows [26]. Some works on risks are focused on the best way to structure flows in order to minimize iterations in the process of innovation and design [27]. In such "risk approaches", tasks and processes are considered as results of decisions. Risk management requires alternative plans, contingency plans, and suggest to use sequential decision making tools (dynamic programming, decision trees) [28], [29].

1.3 Fundamentals of "Dynamic Systems Management"

A focus on the "Strategic aspects" of Business Innovation

The Dynamic Systems Management (DSM©) proposed approach is a strategic approach of project management and innovation. One of the objectives of this modeling methodology is to help the managers and decision makers understand the multiple parameters impacting the innovation process in the organization. Innovating is not only a matter of creating a new technical product, but more developing a new product in a new "organizational context", a new "business environment". Therefore, the DSM approach suggests moving from a technical "Product Innovation" perspective to a broader strategic "Business Innovation" perspective including all the business processes (Figure 1). The product innovation process performance depends on many different types of processes that have a strong impact on the outcomes of innovation - which means the economic success of the product. The DSM modeling approach is a Strategic Management approach focused on Business Innovation.

A focus on "Complexity" in the Business Innovation Process

All the processes being part of the Innovation Process are connected together and create a very complex network of processes that can lead to failure very frequently. Innovative products may be based on "cutting edge" technologies but may not meet all legal standards, product designs may be ergonomic but may not be usable with the infrastructure and resources in place, product design may be creative and fashionable but may lead to very demanding and expansive industrialization processes. The global success of a product development process depends on multiple processes – design, R&D, marketing, distribution, supply, and logistics - that interact together at a global and strategic level of the business innovation process (Figure 1). The network of interactions between those processes should be designed in order to anticipate the potential dangers in the trajectory of innovation. The clear objective of the proposed methodology of design is to highlight the zones of danger, the critical areas of uncertainty where the major issues may come from. Before implementing strategies of control to mitigate risks, decisions makers and managers require a good vision of the potential new processes in their business innovation process.

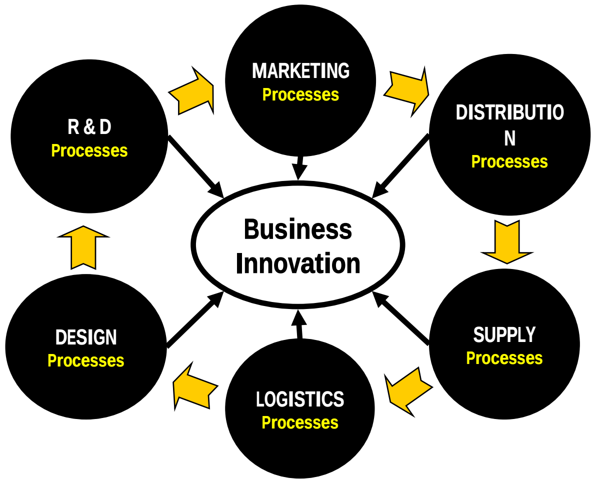

Figure 1. Business Innovation Network of Complexity

2 DYNAMIC SYSTEMS MANAGEMENT – THEORY & PRACTICE

2.1 Concepts of DSM

Systems of production to represent "Innovation process"

The innovative organizational process can be modelled as a chain of operational systems. Each system, as a link of the whole chain, is made of two types of connexions: (1) the internal process of "transformation" and (2) the external link of "delivery". The internal process of each system is a process of transformation, transforming the Initial Conditions of the system into a deliverable (Figure 2). Initial Conditions are of two types: the social type (technicians, managers, engineers, partners, customers, financers…) and the technical type (machines, materials, budget, documents…). Hence, each system is a socio-technical system. The technical type resources are classified in two categories: the ones available in the organization at the moment the analysis is made (represented as a square in the Figure 2) and the ones requiring to be produced (represented as a triangle in the Figure 2). As a consequence, all the organisational sub-processes of the innovation trajectory must be designed as systems of production or transformation. The fundamental key elements of design are the initial conditions of each system (system inputs) and the deliverable of each system (system output).

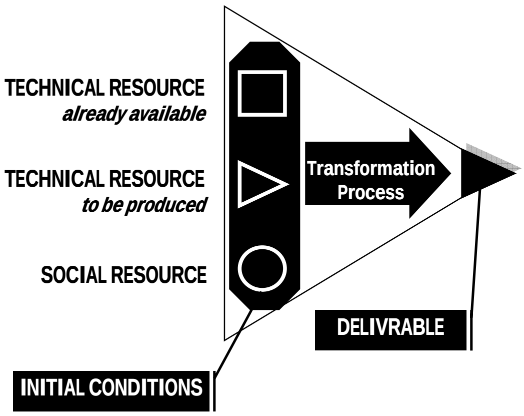

Figure 2. Systems as elementary parts of the Innovation Process

Systems Tree to represent "Innovation Trajectory"

All the systems of the product development cycle are connected in a logical way, each system [S_n] getting its technical resources from one or more preliminary system(s), the system [S_n] being itself a provider for one or some of the following system(s) [S_{n+1}]. A system [S_n] is connected to a preliminary system [S_{n-1}] if it requires a technical resource to be produced. The system [S_n] is connected to a following system [S_{n+1}], the deliverable of the system [S_n] being an Initial Condition of the system [S_{n+1}]. The network resulting is a Logical Systems Tree, all the systems being logically connected together so that they form a tree (Figure 3).

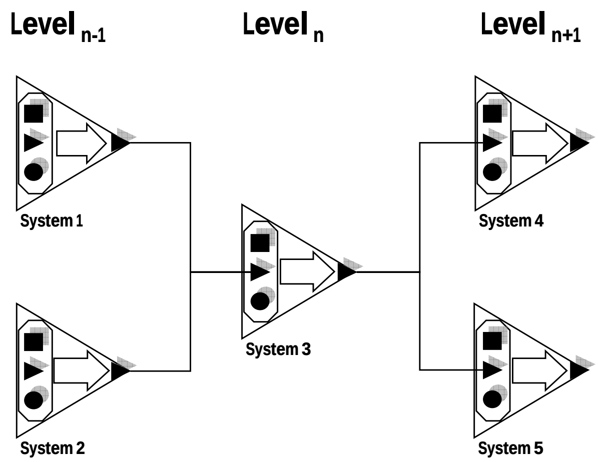

Figure 3. Systems as elementary parts of the Innovation Trajectory

Configurations to represent "Innovation Uncertainty"

Each link of the trajectory is a system that can be defined as a configuration. A configuration is a set of 4 indicators clarifying the role of the system in the trajectory of innovation. "Indicators 1 & 4" are based on the external links of the system, and "indicators 2 & 3" are based on the internal process of the system. The purpose of a configuration is to highlight the level of uncertainty of each system being a link in the chain of Innovation. Each criterion is supposed to reveal an aspect of the production system strength or weakness.

The degree of uncertainty of each system is evaluated internally and externally. The internal uncertainty is evaluated through the analysis of the system's Environment and the system's Process. The indicator used to categorize the level of uncertainty of the environment is "Instability" and the indicator used to categorize the level of uncertainty of the process is "innovation" (Figure 4). The system's process is assessed as being more or less Innovative. The system's environment is assessed as being more or less Unstable. By combining these two criteria, systems can be classified in 3 categories: classic systems (traditional process in traditional environment), new systems (new process in traditional environment or traditional process in new environment), and uncertain systems (new process in new environment).

The external uncertainty is evaluated through the analysis if the nature of the links that the system has with the rest of the chain. The system [n] is connected to preliminary systems [n-1] through the initial conditions that are required, and the system [n] is connected to following systems [n+1]. By combining these two criteria, systems can be classified in 3 categories that help understand the role of the system in the global product innovation dynamic: stable states (traditional initial & final states), new state (traditional initial state & new final state), and unstable states (new initial & final states). Each system (in our case system[n]) is in the middle of a branch of systems, based on the deliverables coming from the preliminary systems, and participating to the creation of the next step conditions. The preliminary systems that "provide" the initial conditions of the system[n] can be defined as system[n]

STATE[n-1]. The deliverable that is produced by system[n] is a preliminary condition for next step systems[n+1] ; we call it system[n] STATE[n+1] (Figure 4).
A configuration is in a “local model” of the innovation process dynamics. The whole trajectory of project innovation can be modelled as well as split into sub parts. A configuration is a small piece or element of the project dynamics. The advantage of a configuration is to include in one system its “internal characteristics” (the dynamic of the link itself) as well as its “external characteristics” (the dynamic of the string, the chain).

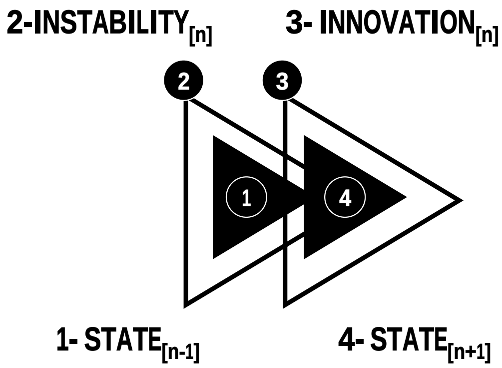

Figure 4. Systems as configurations

2.2 Evaluation systems of DSM

Presentation of the four indicators

The basic assumption of the evaluation system is that each system of the Logical Systems Tree is represented by its Initial Conditions (technical and social resources) and its specific deliverable (result of the system). All the initial conditions and the deliverables are identified by their name (factory, assembly line, prototype, engineers, competitors, surveys…). The Evaluation system is based on four indicators and each indicator is assigned number “1” or number “2”. Number “1“ is used to describe situations of certainty, and number”2” is used to describe situations of uncertainty.

1. Evaluation of Instability: The Initial Conditions are at the center of the assessment of Instability. The assessment of instability is ”1” when all initial conditions have already been operated together. The initial conditions are considered as “stable” when initial conditions have already been used or experienced. The initial conditions are considered as “ unstable” and ranked as a ”2” when one or more of these conditions is/are new. The “instability” criterion must reveal if the system is made of business conditions that are going to be used for the first time or not.

2. Evaluation of Innovation: innovation is evaluated by comparing initial conditions and the deliverable that those conditions must produce. A system is considered as “not innovative” – ranked as “1” - if the initial conditions identified have already produced a comparable deliverable in the past. The system is considered as “innovative” – ranked as “2” - if the initial conditions identified have never produced such a deliverable in the past. The innovation criterion must reveal if the system is going to produce the deliverable for the first time or not.

3. Evaluation of Initial State: the initial state is evaluated by comparing the initial conditions of a system and the preliminary systems that have to produce them. The preliminary state is considered as certain if all the initial conditions coming from preliminary systems have already been produced in the past. The preliminary state is uncertain if some initial conditions are going to be produced for the first time. The initial state criterion-must reveal the capacity of the project to provide the expected initial conditions, at the level of performance or quality that is expected by managers and engineers.

4. Evaluation of final State: the final State is evaluated by comparing the deliverable of a system and the next system or systems that the deliverable must compose. The Final State is

considered as certain if the deliverable that must be produced have already been produced with the level of quality that is expected in the next systems that are going to use this deliverable. The final state criterion must reveal the capacity of the system to produce the deliverable that is expected in the next systems of the project.

Synthetic form of the evaluation system

The configurations can be classified in taxonomies depending on their meaning in the project trajectory. Configurations enable two types of conclusions: conclusions on the system itself, and conclusions on the relation of the system with the rest of the trajectory (before and after). Each configuration identifies its specific dynamics, and reveals its role in the whole trajectory. Mixing the internal and the external levels of uncertainty can help categorize the configurations. The internal level of uncertainty brings additive explanation to the external level of uncertainty.

Table 1. Evaluation system of Uncertainty in Configurations

	STATE [n-1]	INSTABILITY [n]	INNOVATION [n]	STATE [n+1]
DESCRIPTION	capacity of the preliminary system(s) to provide the expected Initial Conditions	degree of instability of the Environment of the system, the instability of the business conditions	degree of innovation of the transformation process of the system	capacity of the system to provide the expected result (final condition) to the following system
STATEMENTS	The Initial Conditions of system [n] have already been produced by the preliminary systems [n-1], with the level of quality required in system [n]	The Initial Conditions of the system have already been operated	The process of the system has already been implemented to produce the result	The deliverable of system [n] has already been produced with the level of quality expected in the following system(s)
POSSIBLE ANSWERS	1 – YES, the preliminary systems [n-1] have experienced Initial Conditions [n] level of quality. <u>The Initial State is traditional</u> 2 – NO, some preliminary systems [n-1] have not yet experienced Initial Conditions [n] level of quality. <u>The Initial State is new</u>	1 – YES, all the conditions have been experienced. <u>The Environment is traditional</u> 2 – NO, some conditions of the system are new. <u>The Environment is new</u>	1 – YES, the process has been experienced to produce a similar result. <u>The Process is traditional</u> 2 – NO, the process to implement in order to get the deliverable is new. <u>The Process is new</u>	1 – YES, system [n] has a certain state [n+1] of performance. <u>The Final State is traditional</u> 2 – NO, system [n] has an uncertain state [n+1] of performance. <u>The Final State is new</u>

2.3 Implementation of DSM

The General approach of DSM

Different characteristics must be respected when applying the DSM methodology:

1. <u>Legitimacy and work with professionals</u> : DSM is a practical modelling method that is made to help product manager, business developers, engineers, project teams, market developer to model the processes of development that are required in order to innovate quicker and better. The quality of the analysis depends on the expression of people concerned by the processes.

2. Design and reveal uncertainty: DSM is a mosaic approach of Business Innovation that must help formalizing the processes of product innovation and development. Many of these processes are uncertain and will have to face risks and dangers when being implemented. In company too many business processes are not described and then not analysed correctly in their capacity to be critical.

3. Discuss and share visions: the DSM approach must be applied in order to help the innovation teams visualize and rationalize their visions, strategies and tactics of development. The graphs that are generated are means of communications, used as a common language between different types of experts (market developers, engineers, financers, suppliers, users, technicians…).

The Technical steps to implement DSM

The analysis is made in three different steps:

1. Modelling the global process of innovation: the model is built separating "operational processes" and "entrepreneurial processes". The linkages of operational systems and entrepreneurial systems are presented in the same document in order to highlight the necessary innovations to implement in order to achieve the result that is presented as the final operational process.

2. Modelling the specific systems of innovation: the specific entrepreneurial systems are isolated and connected together so that the process of development and innovation is clearly revealed. Systems are prepared to be analysed in detail so that uncertainty is revealed.

3. Evaluating the zones of uncertainty: the entrepreneurial process is assessed applying the configurations tree system of evaluation. Each system is evaluated with the four indicators presented above.

The Business conditions of use

The DSM methodology can be used at different moments of the project management cycle, and with different objectives in mind:

1. Project planning: DSM is a methodology that is an alternative way of planning projects. As Gantt charts and Pert diagrams would do, the Logical systems Tree aims at modelling the trajectory of projects. The advantage of this modelling approach is to make possible the analysis of degrees of uncertainty in the trajectory of innovation.

2. Project strategy: from the Logical Systems Tree, the evaluation system of uncertainty helps building a Logical Configurations Tree. This LCT is a central tool to build strategies of actions in conditions of uncertainty. A second fundamental interest of the DSM approach is to help the project managers think about their strategies of Business Innovation.

3. Project controlling: once the innovation trajectory is under process, the business systems may change, their conditions may be modified. The DSM approach can also be used to control the evolution of uncertainty in the trajectory of innovation. The Logical Configurations Tree is used as a referential that helps project managers understand the way uncertainty increases or decreases over time.

3. INDUSTRIAL EXAMPLE: ELECTRONIC DEVICE

The product innovation process presented below (Figures 5 and 6) is based on the product development process applied in a leading industrial company working in the domain of consumer electronics. This process was modelled in order to highlight major issues and opportunities of improvements in the global innovation process.

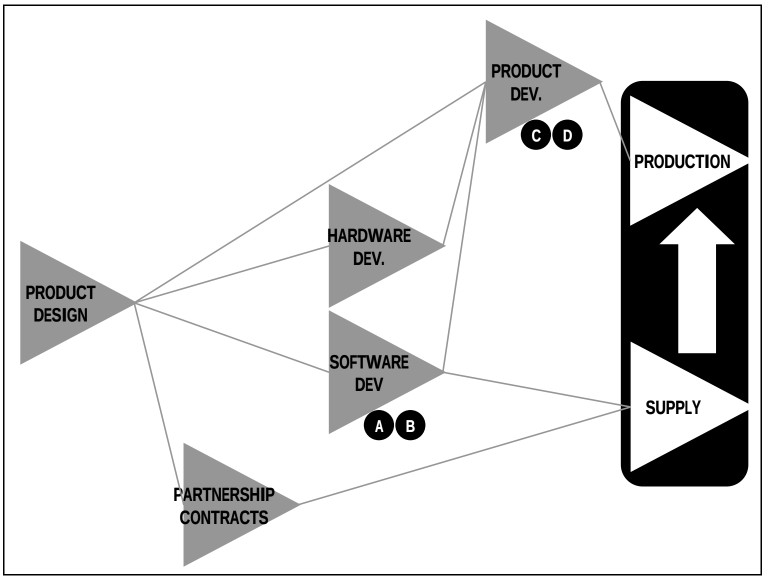

Figure 5. Electronic device (MP3, Flat TV, Set topBox) – Global Processes

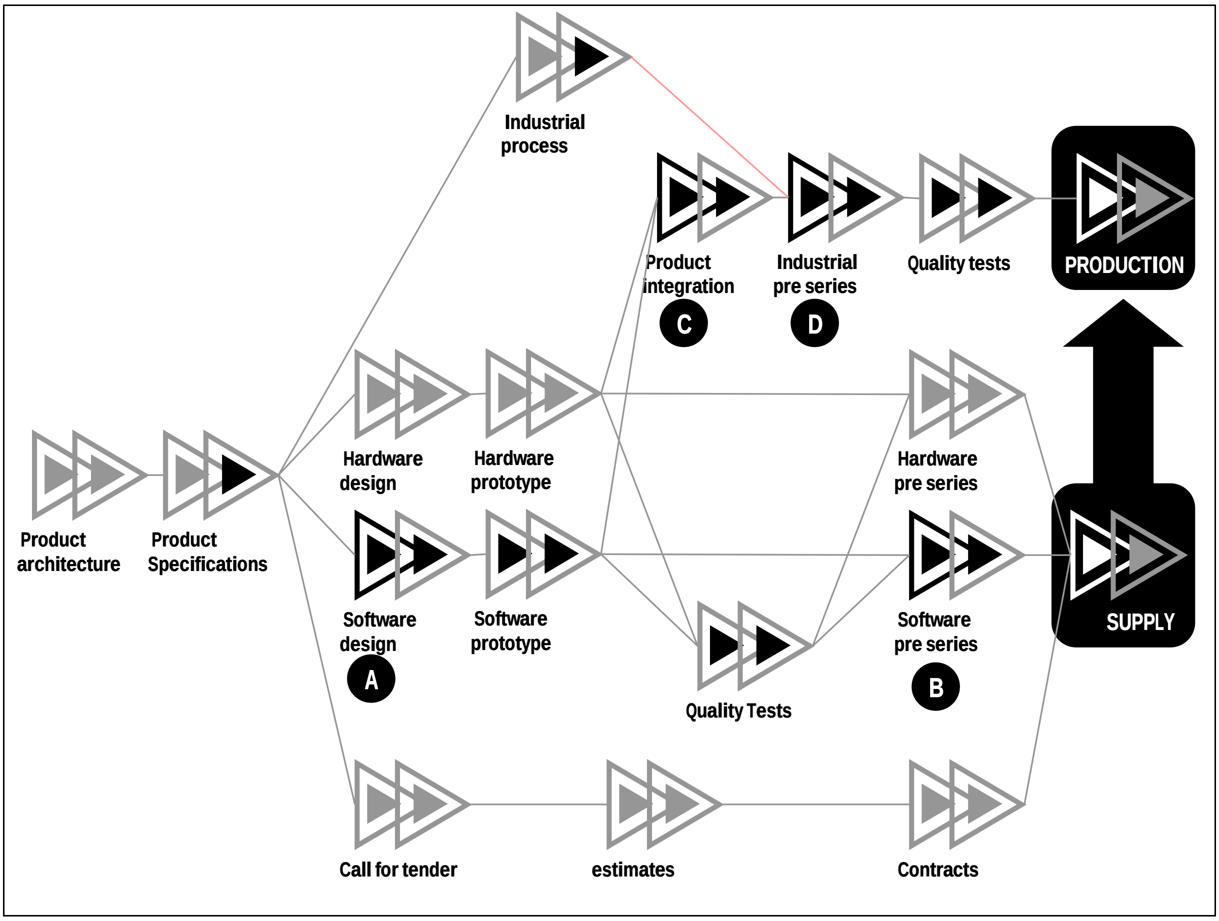

Figure 6. Electronic device (MP3, Flat TV, Set topBox) – Local Configurations

The Logical Configurations Tree reveals zones of uncertainty in the development process. Those zones are more likely to be jeopardized. Our analysis reveals that the zones that are more uncertain are also zones where the industrial company has problems in reality.

Table 2. Evaluation system of the "Electronic device" product

	STATE [n-1]	INSTABILITY [n]	INNOVATION [n]	STATE [n+1]
A- Software design	**2** Specifications brought by the company have never been produced at this level	**2** The supplier in charge of developing the software design has never worked with such specifications	**1** The suppliers have already produced software designs from initial conditions like the one provided	**2** The suppliers have never produced design with the level of quality expected in the specifications
B- Software pre series	**2** The "Quality tests" and "Software prototype" expected have not been produced yet with this level of expectation	**2** the "quality standards" and the prototype developed are initial conditions that have never been operated together	**1** The supplier is able to produce pre series from such initial conditions	**2** The expected level of performance of pre series have never been produced
C- products Integration	**2** The "Software prototype" has never been produced as expected	**2** The "software prototype" is an initial condition that was never used as described in the process	**1** The company has already produced "integrated products" from the initial conditions determined	**2** The expected integrated product level of quality is new
D- Industrial pre series	**2** The "industrial process" and the "product integration" have never been produced at the level expected	**2** The "industrial process" and the "integrated product" are two conditions that will be experimented together for the fist time	**1** "Pre series" have already been produced with such initial conditions	**2** The expected level of performance and quality of pre series have never been achieved

The systems that are identified in the Table 2 are the most critical ones in the sense that they are the most uncertain in the whole trajectory of innovation and development. These zones of innovation are the ones where the potential impacts on "delay", "cost" and "quality" may happen more naturally. As a consequence, this analysis is a "strategic roadmap" for managers of innovation. This roadmap highlights the organizational systems where the strategic actions have to be implemented, and where the management of uncertainty must be put into practice.

By experience, the following list of <u>real problems</u> that had to be addressed developing innovative "electronic devices" is mainly associated with uncertainties highlighted with the DSM method:

- Software Programs from sub contractors are not good
- Integrated product is not qualitative enough for clients
- Specifications are not clear enough for sub-contractors
- The quality tests and controls can not be finished on time
- Sub-contractors do not meet the company quality standards
- Change of "sub-contractors" in the middle of the innovation process create an increase in uncertainty
- Sub-contractors do not work together and produce incompatible product sub-parts
- The prototype developed forces to strongly modify the industrialization process

- The suppliers prototypes are good but their industrialization is impossible regarding the quality standards.

CONCLUSION

We have seen that product innovation must be represented as a Business Development process. Product innovation processes must be analyzed trough a more global perspective, considering the “Business Context” in which the product is created, implemented and included. Launching a new product requires combining and managing different natures of Business Processes (R&D, marketing, supply, industry…). All these Business Processes of Innovation interact together in a complex way and create conditions of uncertainty in the innovation trajectory.

Project Managers, Innovators, Business Developers, Research Engineers must visualize the complexity that is present in their activities and reveal the zones of uncertainty that require more attention. The Dynamic Systems Management (DSM) approach is a language that all the actors engaged in the innovation process should apply in order to address the global complexity. DSM software has been developed so that decision makers, analysts and expert can make their models easily. The Logical Configurations Tree is the backbone of the methodology; it works as a referential model of the Innovative Product Design that can help “share the vision of development”, “built strategies of actions” and “monitor the evolution of uncertainty” in the trajectory over time.

The Complexity and Uncertainty that are parts of Business Development force us to open the discussion on “how to manage” situations with high degrees of uncertainty. The first step would be to take into account that different natures of uncertainty lead to different types of control. It is important for project managers and project boards to be aware that some processes will be controllable (no over budget or over delay) because they are more “certain” and that other processes are more likely to be over budget and delay because their inherent uncertainty degrees make them much less controllable. The classic “Project Management” approach emphasizes the role of project control, which means monitoring resources and deliverables, and mitigating risks. Situations of uncertainty emphasize the importance of applying alternative ways of controlling processes in the project. One of the challenges that uncertainty brings to the domain of Product Innovation is the necessity to visualize complexity, highlight uncertainty and build strategies of experimentation necessary to innovate.

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