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EMPIRICAL VERIFICATIONS OF SOME RADICAL INNOVATION DESIGN PRINCIPLES ONTO THE QUALITY OF INNOVATIVE DESIGNS

Bernard Yannou, Marija Jankovic, Yann Leroy

ABSTRACT

Product-service innovation projects in industrial contexts are not yet supported by clear theories and methodologies. In the last years we have developed and experimented on a new Radical Innovation Design (RID) methodology. After introducing the RID principles and design process, we explore the relationships between the *means* employed during the problem setting and the problem solving stages of the conceptual design on the one hand, and the value finally produced for the company at the end of this stage on the other hand. For that purpose, we have built a protocol around innovation projects involving 86 students in 19 projects of 5 types. 61 variables have been observed, generating 700 data vectors which have been learnt by Bayesian Networks. Thanks to additional contextual variables featuring the design participants, the projects and the jury members assessing the values of the results and the means, we have derived a number of non trivial findings to successfully lead radical innovation projects in industrial contexts within the stages embracing product planning and conceptual design.

Keywords: Radical Innovation Design, Bayesian learning, Bayesian simulation, innovation success factors, design principles, design outcomes, idea generation, product planning, conceptual design

1 INTRODUCTION AND MOTIVATION

As it has been mentioned by Shah et al in [1], "*A wide range of formal methods have been devised and used for idea generation in conceptual design. Experimental evidence is needed to support claims regarding the effectiveness of these methods in promoting idea generation in engineering design.*"

After years of innovative design education, the authors have defined a methodology called Radical Innovation Design (RID). This methodology for innovating on products, services and/or business models in industrial contexts, is taught for 4 years in our academic institution. This is a methodology which concerns both product planning and conceptual design stages in a more integrated manner than traditionally in New Product Development processes (see [2]) where the main innovative ideas, technologies and working principles are chosen within the product planning stage before starting the real design tasks, for strategical reasons (see Motte et al [3; 4] for a series of shortcomings in the integration of Engineering Design activities into NPD processes).

RID is based on a number of design principles already discussed in literature and new principles and tools within a design process of radical investigation of the more value creating product-service conceptual scenario within a specified industrial context. Often the result of the conceptual design stage is much more the result of a first set of constraints in the product planning phase (for complying with core competencies, existing working principles or technologies and company core values and existing market and product portfolio) followed by a conceptual design process which is highly stochastic, than of a radical exploration of value creation opportunities within the company context (see [5]). In addition [5], exploration of more innovative scenarios requires a constant strategical alignment and an actual top management commitment in the company, which makes a design project not isolated per se in the company, which makes the value of a resulting conceptual design dependent of the company context.

On the other hand, idea generation methods have been quite extensively studied but, most of the time, the quality of design outcomes is assessed independently of the company context, and sometimes adopted quality criteria concern more the means (number of generated ideas, intensity of conceptual design process) than the quality of the selected conceptual design solution in itself. In addition, these works do not point out clear levers to improve the design process or explain the reasons of the more or less value/quality of design outcome(s).

The objective of this paper is not to present further the foundations of RID methodology, but to experimentally validate some aspects of an RID process in terms of the effective value creation of the resulting selected conceptual design in the context of radical innovation in a company ecosystem (like described in [5]). More precisely, one wants to experimentally check if some recommended design methods and gate deliverables (called *means*) effectively influence and are in favour of the effectively delivered value of the selected design concept (called *results*). One wants also to discover findings about innovation management *in context* of the *design team* features, the *project type* features and the degree of *assimilation of innovation* principles and tools by the project participants (here assimilation of RID methodology).

For that purpose, a test bed of 19 design projects of 5 different types implementing the RID methodology with 86 students is presented. Sixty-one variables have been screened to characterize the project *means*, the project *results*, and to correlate these variables with *design team* and *project type features*. These observations have been summarized into different Bayesian Networks (BNs) through a primary unsupervised learning process and further finer supervised learning processes. We definitely believe in contextual truths since a variety of variables influence the innovation process, often with conditional or non linear effects.

In the following of the paper, we start by briefly presenting in chapter 2 the principles of RID methodology. We continue in chapter 3 with a review of literature on conceptual design and idea generation. The experimental protocol (organization of projects) and the model variables are presented in chapter 4. After a brief presentation of Bayesian Networks in chapter 5, in chapters 6 to 7 we present some general findings. A short chapter 8 is dedicated to the quality of our BN models. Chapter 9 concludes with a revision and a reinforcement of our beliefs after the findings of our BNs.

2 THE PRINCIPLES AND FOUNDATIONS OF RID

Radical Innovation Design is a methodology to use in the context where the company objective is to *fundamentally innovate*, providing the company is already positioned in an ecosystem, i.e. it has a strategy, a market presence and a brand reputation, an existing product-service-technology portfolio, competitors and suppliers, and it disposes of certain financial, industrial and intellectual assets (including innovation know-how). Providing this practical company context (almost never considered as entries of an innovation process), how is it possible to innovate as much as possible to create a positive differentiation on the market and change the conventional rules of competition? This is typically the way of reasoning of the new Blue Ocean Strategy (BOS) marketing strategy developed by Kim and Mauborgne [6]. RID is fully compatible with BOS principles.

A second founding principle of RID is the *radicality* in terms of (1) exploration of value creation opportunities around the initial statement; (2) definition of a *perimeter of ambition* to focus on value promising product-service scenarios (also called *briefs*); (3) Systematic listing of value leads and value drivers (see the authors' work in the EADS company context [7; 8]) (4) Systematic creativity workshops on these value leads and combinations into consistent design concepts (5) Early validations about how it works (*proof of concept*) and what it is worth (*proof of value*).

A third important concept is that the conceptual design stage is considered as an *investigation process*. Investigation is understood as exploring all the potential leads and refining conceptual designs as well as their evaluations as long as they appear to be potentially value makers. This investigation and conceptual refinement process is known as *issue-based design* or *question-based design* and have been well developed by Bracewell, Aurisicchio and Wallace in the Dred system [9] [10] [11] or in CK-theory by Hatchuel and Weil [12].

A derived concept of this investigation process is the necessary *documentation*, *knowledge management* (including the *competences* of the design team members) and the constant evaluation of the probability to get a conceptual design of high utility. This documentation can be supported by an issue-based information system like the *Dred platform* [9]. But we also refer to the *Intermediary Design Objects* (IDO) concept first proposed by Jeantet and Boujut [13; 14] enabling, in a reflexive manner, to influence the designers in their choices between different concepts. These IDOs may be physical or virtual prototypes, sketches, questionnaires, etc. The quality and relevance of these IDOs are determining for the quality of the design outcome(s). *CK-theory* [12] also proposes strategic views of managing design knowledge and competences. Finally, Thompson and Paredis have proposed a relevant *Rational Design Theory* (RDT) in [15] which consists as RID to maximize the utility probability of a design concept. But one can note that very few theories or frameworks exist for bringing proof metrics to build these utility probabilities.

Let us mention a series of other RID concepts:

- *Usage* is the first space to navigate in before functions which are too much precise. The authors have developed a *Usage Coverage Model* (UCM) to better locate sets of usage that are worth to be covered by the design solution [16; 17] and they propose practical usage coverage indicators in [17].
- *Books of design knowledge* (inventories of Intermediary Design Objects) must be generated when possible because they are also a value creation within an innovative design project (e.g. books of patents, books of technologies, books of concepts...).
- A new way of *design collaboration* must be encouraged to avoid *silo innovations* in the different concerned disciplines; instead design team members must share their conceptual pathways map into a *co-innovation process* so as to share important decisions and trade-offs, and foster higher level system concepts.

These RID concepts may be summarized into the value machine described in Figure 1, which embraces both the product planning and the conceptual design stages.

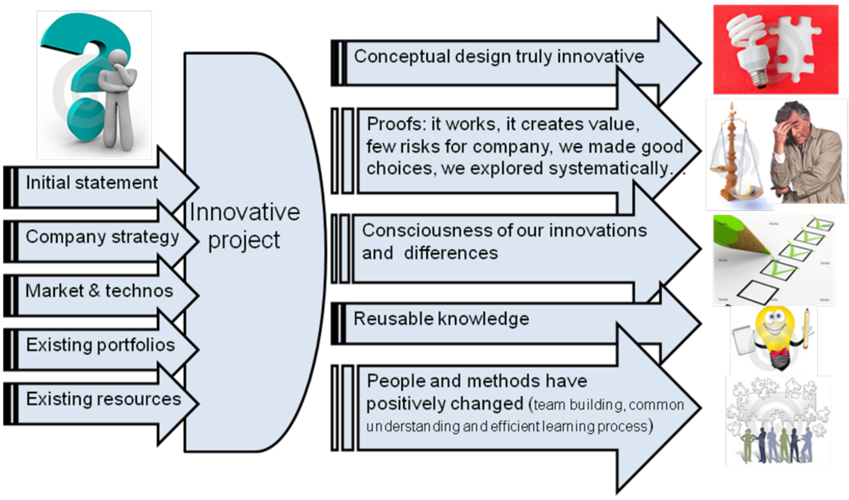

Figure 1: The value machine of an innovative project after RID methodology

Finally, the RID methodology is organized around a macro-process in two main parts – in a Simonian spirit -: the *problem setting* period (composed of 3 stages and roughly corresponding to product planning and strategic alignment of the company) and the *problem solving* period composed of 11 stages roughly corresponding to the conceptual design stage. These 14 stages may sometimes be facultative, use specific method and/or tools – sometimes new – and possibly lead to specific reports. These 14 stages are not detailed here for brevity but may be guessed in the *design means* variable series of Table 1.

3 LITERATURE REVIEW ON CONCEPTUAL DESIGN AND IDEA GENERATION

It is already largely accepted that the conceptual design process consists of generation of concepts, exploitation of these concepts and evaluation [18; 19]. Nevertheless, the question that persists is what is to be done to guarantee the positive outcome of this process of innovation? Several research streams tackle this issue: prescription and definition of the design process and support tools in design exploration [20-22], defining and exploration of the impact of creativity methods and ideation [23; 24], identifying the indicators that could help predict and that need to be into account in order to address the innovation [25; 26] and exploration of the correlation between design deliverables and outcomes [27-31].

The design activities in conceptual design are contained in two kinds of steps: divergent and convergent [22; 32]. Cross [20] thought of the conceptual design process as mostly being convergent with the necessity to contain a deliberate divergence in the search for novel ideas.

Pugh's model [22] underlines that "*it is essential to carry out concept generation and evaluation in a progressive and disciplined manner so as to generate better designs. This progressive and disciplined manner is illustrated as an iterative, repeated divergent and convergent process with the number of solutions gradually decreased*" (also cited in [21]).

Liu and Bligh [21] in their work propose "*a possible 'ideal' approach for the development of concepts, in which a process of repeated divergence and convergence is used. The approach consists of a series of generation and evaluation rather than a single step of generation and evaluation*". The development of this process is based upon the definition of the "Balanced" search given by Fricke [33] and support of design process using the FuncSION tool.

Definition of the success of design concepts is related to the notion of innovation. Astebro [25] in his work explores the impact of 36 innovation, technology and market characteristics on the probability of success in the early design stages. The author suggests that this forecast has a potential to be used as a screening tool for the early design reviews. These key success factors aim at examining the likelihood of one project to reach the market. In the study, 3 criteria address the issue of potential "technological improvement of the invention", 5 "technological opportunities", 3 "potential external constraints", 7 "measures of demand", 5 "innovation characteristics", price, 3 "cost measures", and the rest addresses appropriability conditions and various investment criteria.

In terms of exploration of design means and results, 3 types of means have been particularly investigated: sketches, prototypes and text documents. Maria Yang [30; 31] in her work addresses the major issue of the relation between the quantity of generated sketches and the quality of design outcomes. Moreover, she explores the relationship between the time of sketching in the design process, notably early in the design, and the impact on the outcomes. The author found that the quantity of concepts is statistically significantly correlated with project grades. As for the timing, Maria Yang found that the early sketching and prototyping [29] is correlated to project grades. Correlation between the textual design documentation and team design performance [27; 34; 35] suggests that the evidence of correlation exists between the semantic coherence of documents and successful product team outcomes. Nevertheless, authors also mention the possibility that the teams with low performance can create highly coherent documentation.

Another key question is characterization and measurement of the quality or effectiveness of idea generation process and how this is related to the innovation. There are two main research streams working on this question: cognitive psychologists and design study theorists. Shah and Vargas-Hernandez [24] in their work give a global overview of the research in these fields and propose four separate effectiveness measures: *novelty*, *variety*, *quality* and *quantity*. *Novelty* is a measure of how unusual or unexpected an idea is as compared to other ideas. *Variety* is a measure of the explored solution space. *Quality*, in this context, is a measure of the feasibility of an idea and how close it comes to meet the design specifications. *Quantity* is the total number of ideas generated.

Many ideation methods have been developed to aid designers generate alternative designs. Formal idea generation methods are broadly classified into two categories—*intuitive* and *logical*. Surveys of idea generation methods can be found in [36; 24; 37].

4 EXPERIMENTAL PROTOCOL OF INNOVATIVE PROJECTS

4.1 The course and the innovative projects

The course SE2200 named DIPS for "Design and Innovation of Products and Services" has lasted 33 hours spanned on only 2 months in October and November 2009. 86 students have been involved in this course consisting in 11 3-hour sessions along which RID principles and its 14 stages and corresponding methods and tools have been taught. This course has been evaluated through innovation projects, each student being committed in a 4 or 5-member design team assigned to a given project.

5 project subjects have been presented within the first course session, they were:

1. Plastic bag facilitator (practical, sustainable, reliable way to move purchased goods)
2. Innovative carpool system/service (with no required registration and few waiting times…)
3. CDrom storage in different usage situations
4. Protection bag for weigh machine of African children (for 0to5-year children healthcare follow-up)
5. Non wood-based African stove (to save forests)

All the subjects have been roughly sketched into *initial statements* by existing dysfunctions and present usages rather than by clear expectations; the problem setting remained then to be done properly, and the result could not be defined in the beginning as a product, a service or a combination of both types. The two last subjects were in the framework of a Non Governmental Organizations that were effectively in African countries and with which we had contacts at this time. 3 clear organizational contexts have also been defined for the three first subjects to get legitimacy for value validation.

19 project teams have been defined (4 teams on 4 projects and 3 teams for the last project). The 19 design teams have been composed by us (the *educational team*) in respecting a distribution of genders, of students coming from foreign countries and from different primary educations as much as we could know thanks to their on-line profiles. It turned out that some of them did never participated before to an innovative design project and even to a team project for the majority! It also turned out, on the contrary, that some projects were assigned with several students having a previous experience of innovative projects. We finally managed to assign one female per design team. During the first lecture session, the team members had 20 minutes to commonly exclude 2 projects they did not want to work on; this procedure has been chosen for four reasons: (1) To let a certain freedom to choose for students and not to be demotivated from the beginning (2) To let us the possibility to allocate 3 to 4 teams to a given subject (3) To be like in a professional situation where the subject of the project is not really/fully chosen (4) To start compromising within the newly formed design team.

In the educational team, we have devoted one of us to be the design expert of a subject and the project resource facilitator for the corresponding 3 or 4 projects but with absolutely no role in terms of project management.

This 2-month period has consisted of a "flash innovation" training and an intense project period. Students did not invest more than 50 extra hours in addition of the 33-hour course (including 16-hour applied tutorials onto projects), but the results have been positively amazing.

4.2 The project examinations and data gathering

Very strict document management and examination procedures have been applied. During the project lifes, the students were asked to upload their IDOs (Intermediary Design Objects) in dedicated sub-directories of a partitioned collaborative platform: possible written reports for the 14 RID stages and other IDOs (see table 1).

Table 1: Design means variables

D1	Proper redefinition of ideal need	**D12**	Perceptual assessments of concepts (semantic differential profiles)
D2	Definition of stakeholders	**D13**	Proper Functional Analysis
D3	Definition of present usage contexts	**D14**	Concept sketching
D4	Primary inventory of knowledge and competence needs	**D15**	Detailed concept
D5	Production of books of knowledge	**D16**	Eco-Design
D6	Project management of problem setting period	**D17**	Development of associated services and business models
D7	Clear definition of justified brief(s)	**D18**	Detailed usage analysis of chosen concept
D8	Listing of innovation leads (expectations, dysfunctions, and differentiations)	**D19**	Feasibility analysis (technologies, production, commercializing, patenting...)
D9	Organization of creativity (brainstorming workshops from innovation leads)	**D20**	(D20=D1:D6) Overall quality of problem setting
D10	Concept generation by consistent combinations of ideas	**D21**	(D21=D7:D19) Overall quality of problem solving
D11	Explicit investigation/refinement process of conceptual pathways		

The jury has been composed of 8 members (the *educational team*); 4 of them are *experimented* in design innovation (at least Associate Professors) and 4 are *confirmed* since they are PhD students in design engineering, all familiar with RID methodology. The jury members were not allowed to scrutinize the collaborative platform directories before the oral defense occurred. One wanted to evaluate the student projects as it could have been in a real company, i.e. by experimented people, asking proofs for validating a conceptual choice in order to engage a further company investment. This

evaluation was to be done in a limited time (15 minutes of presentation, followed by 15 minutes of questions/answers "*like if we were in front of the steering committee of a design department at a go/no-go step*"), with a necessary lack of knowledge from the jury members of the project complexity.
Two jurys have been formed, each composed of two experimented and two confirmed members, for examining respectively 9 and 10 projects. During the oral sessions, the jury members have assessed 13 *design results* variables for each defended project; these variables are commented in Table 2. During this day, the students have been asked too to personally fill an anonymous questionnaire to get information on:

- The *design team* features with 10 variables, see Table 3 (e.g., team atmosphere, extra time dedicated to the project, personal satisfaction…),
- The degree of *assimilation of innovation* principles and tools of RID methodology with 8 variables, see Table 4.

Table 2: Design results variables

The final result is innovative, mature and sufficiently validated			
R1	Final perception of the chosen concept by the jury	**R4**	Convincing proofs of concept (the concept effectively works and deliver services in expected situations)
R2	Convincing proofs of value creation	**R5**	Other feasibilities (economical: cost vs perceived value, competitiveness, societal acceptance, sustainable properties, usage and perceptions, market launchability...)
R3	Well adapted perimeter of ambition and innovation type (smooth/disruptive) to company ecosystem	**R6**	Finally, the chosen concept has a high potential of value creation!
A design process which is consciously driven by value/utility probability and which is traced			
R7	Intelligent problem (re-)setting	**R10**	Intermediary Design Objects are synthesized in books which provide value
R8	Sufficient exploration of briefs and concepts	**R11**	The design process is traced and may be repeated in a slightly different context
R9	Traceable problem solving process, identified decision steps and clear decision alternatives		
Increasing in knowledge and skills			
R12	Consciousness of our innovations, values created and differentiations	**R13**	People have positively changed to a shared understanding of project stakes, results, design methods and other people skills
Aggregate variables (summations)			
R14	(R14=R1:R13)	**R16**	(R16=R7:R11)
R15	(R15=R1+R2+R3+R4+R6)	**R17**	(R17=R7:R13)

Finally, after the oral defense day, three last evaluations have been made by the 8 jury members:

- The *design means* have been carefully examined and evaluated through 19 variables (see Table 1) and thanks to a well understood maturity scale. For that purpose, a double evaluation has been carried out by, respectively, one experimented and one confirmed jury members. The two same persons have evaluated the 3 or 4 same projects corresponding to a same subject. But, no one of the two has been before the project expert. Thus, they were supposed to be novice on this innovation issue whereas skilled in innovation management. These evaluation data do not have been averaged, so as to be able to compare evaluation discrepancies between senior and junior experts (some interesting findings have been revealed about the natures of (in)tolerances).
- The *project types* have been characterized by 9 variables (see Table 3) in terms of their subject, nature of knowledge to explore and innovation type (more or less product or service). These evaluations have been averaged for simplicity.
- The jury members have been characterized by 2 variables (see Table 4) in terms of their seniority in design engineering and innovation management, during the oral examination (evaluation of design *results*) as well as during the evaluation of the design *means*.

A total of 61 variables have been directly evaluated; they sometimes characterize one design participant within a project (student), one subject, one jury member, or the project means and results but evaluated by a different number of jury members. 6 new variables have also been further generated (see Tables 1 and 2) so as to be considered in the data regression. Those variables are assessed on a 7-

level maturity scale {-1 = not done; 0 = done but not understood or false; 1 = weak, naive, incomplete, some defects; 2 = average, obvious lacks; 3 = Quite good but still incomplete, lack of maturity; 4 = Good, non trivial and meaningful result; 5 = excellent, innovative}.

Table 3: Main contextual variables[1]

***Design team features* (through personal anonymous questionnaires)**			
S1	Personal motivation (**degree**)	**S6**	Project team size (**number**)
S2	Lively atmosphere perceived by design members (**degree**)	**S7**	Number of committed students (**number**)
S3	Presence rate at lecture sessions (**%**)	**S8**	Degree of understanding of expected results and deliverables (**degree**)
S4	Presence rate at tutorial sessions (**%**)	**S9**	Personal degree of satisfaction of the accomplished work (**degree**)
S5	Additional time spent on projects out of lecture and tutorials (**number**)	**S10**	Feeling to believe to the feasibility of the chosen design concept (**degree**)
***Project type features* (averages from the jury member assessments) PID**			
1.	Plastic bag facilitator	**4.**	Protection bag for weigh machine of African children
2.	Innovative carpool system/service	**5.**	Non wood-based African stove
3.	CDrom storage		
Levels of skills/knowledge/investigation required to be productive (for all Ki, maturity scale from 1=not necessary to 5=fundamental)			
K1	Engineering knowledge	**K5**	Usage knowledge
K2	Technological knowledge	**K6**	(K6=K1:K5) Overall amount of knowledge required to be productive
K3	Market knowledge	**UK**	Present Usage Knowledge of the team members
K4	Social knowledge	**P/S**	Percentage of Product versus Service in the solution (% between 0 and 1 being the Product part)

Table 4: Secondary contextual variables

Jury members features			
RV1	Jury member of the *means* (**expert** or **confirmed**)	**RV2**	Jury member of the *results* (**expert** or **confirmed**)
RID assimilation: Do the objectives of the RID lecture have been reached? (through personal anonymous questionnaires)			
F1	How to start an innovation project?	**F5**	How to communicate in a design project with team members who do not have the same education (engineers, industrial designers, business students)?
F2	How to maximize design creativity?	**F6**	How to find a standard of communication, of action/roles, of project/task and knowledge management?
F3	How to maximize value of an innovative project?	**F7**	How to do better than silo-innovations, not to work in a client-supplier mode but more to co-innovate?
F4	How each designer can be a part of an innovative design team?	**F8**	The problem setting stage has been well achieved before starting the problem solving

5 PRINCIPLES OF BAYESIAN NETWORKS AND BN MODELING IN DESIGN

The definition of the Bayesian network and the potential advantage of using this approach in design studies have been discussed and experimented in previous works of the authors [38; 39]. Because a Bayesian network is a complete model for the variables and their relationships, it can be used to answer probabilistic queries about them. For example, the network can be used to find out updated knowledge of the state of a subset of attributes when other attributes (the evidence attributes) are observed. This process of computing the posterior distribution of attributes given evidence is called probabilistic inference. Various inference algorithms can be used to compute marginal probabilities for each unobserved node given information on the states of a set of observed nodes. The most

[1] The *degree* scale of Table 3 is a 7-level maturity scale {-1 = Don't know; 0 = Null; 1 = Insufficient; 2 = Average; 3 = Quite good; 4 = Good; 5 = Very good}.

classical one relies on the use of a junction tree (see [40]. 76). Inference in BN [41] allows then taking any state attribute observation (an event) into account to update the probabilities of the other attributes. Without any event observation, the computation is based on a priori probabilities. When observations are given, this knowledge is integrated into the network and all the probabilities are updated accordingly. For the present research work, we use BayesiaLab software, a powerful commercial platform built upon serious research in computer science (see [42]).

6 UNSUPERVISED LEARNING AND GENERAL FINDINGS

As evoked in chapter 4.2, the 61 primary observed variables have not been generated with the same frequency, by the same people at the same occasions. A certain data replication has been made to obtain a certain number (about 700) of data vectors of dimension 67 (including the 6 aggregate variables) which can be comparable. The whole dataset fed a primary unsupervised Bayesian learning to result in a first BN representing the main conditional probabilistic relations between variables. Such an approach does not focus on a particular explanation target but establishes probabilistic relationships between observed variables so as to represent at best experimental data. The initial learning was performed through Maximum Weight Spanning Tree algorithm and the Minimum Description Lengh score (see [43; 44] for complete descriptions). The choice of such a score-based approach, compared to a constraint-based approach, was motivated by the small size of our dataset, like it has been done before by Ben Ahmed & Yannou with limited experimental data from perceptual assessment workshops [38]. The whole dataset was first subdivided into two subsets: the *training* and the *testing* sets with respective sizing of 80% and 20%. The testing set was then used to validate relationships discovered after processing the training set. The final BN architecture is depicted in figure 2.

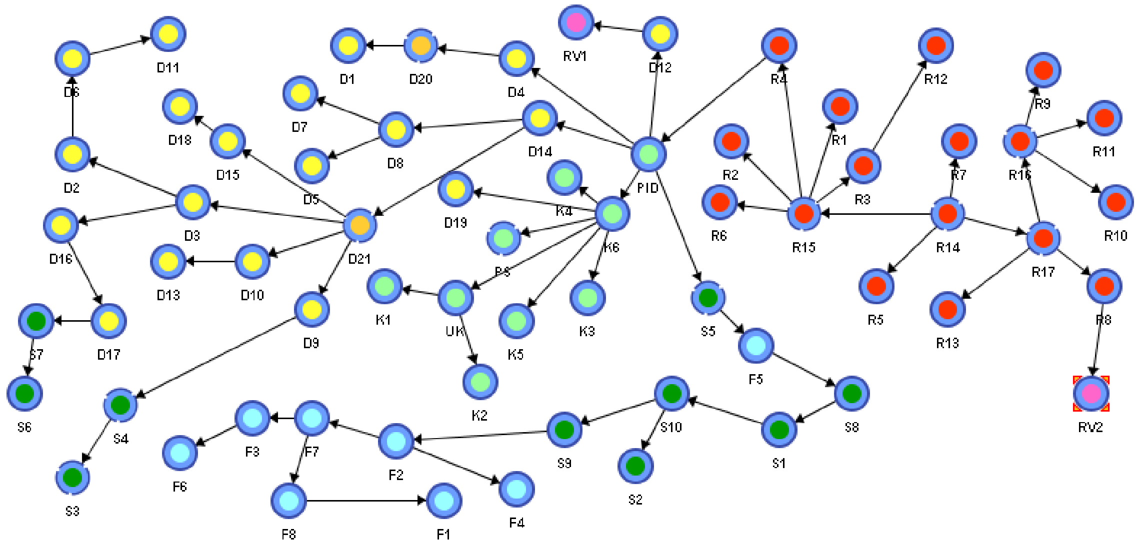

Figure 2. Unsupervised network with 67 variables of about 700 data vectors

The most remarkable finding of the Unsupervised BN is that the variables are mainly clustered according to their respective categories. *Results* and *means* are not directly connected. The junction node between those two clusters is the *Project IDentifier* (PID). It does not mean that *means* have nothing to do with the quality of *results*; we must look at more detailed and goal-oriented supervised BNs for investigating fine contextual truths. But it means that finally, the major driver to the quality of *results* is embedded in the genes of the project initial statement itself.

Moreover *results* are disconnected and show relationships only with the *kind of reviewer* (RV2) and PID variable. *Means* variables are also isolated and have only major correlations with PID and *team features* variables, respectively S7 (*Number of committed students*) and S4 (*Presence rate at tutorial sessions*); which is finally a virtuous finding.

7 TESTING SOME HYPOTHESES BY SUPERVISED LEARNINGS

So as to confront some findings of the literature review as well as hypothesis concerning the foundations of RID, some of the questions/hypothesis that we have further explored in building finer supervised BNs are:

- What is the importance and impact of the problem setting phase which is well developed and specific to RID process?
- Are the different project types differently correlated with requirements in *means* and *results*?
- Is there a relationship between the type of the project and the capacity to innovate?
- Which are the *means* that have the major impact on the overall innovation *results*?

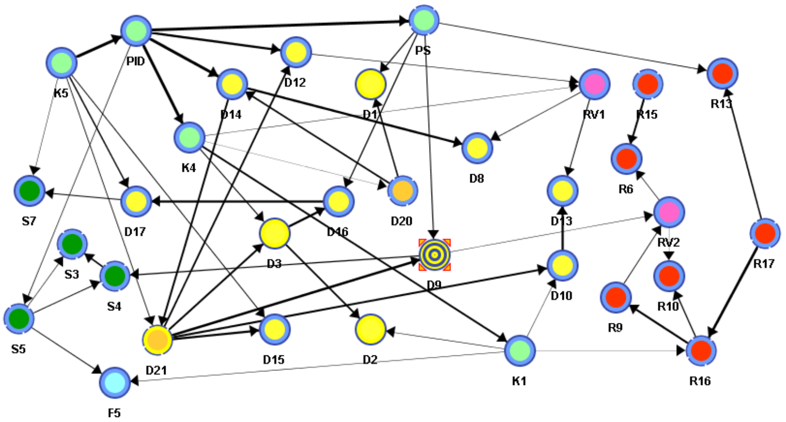

Figure 3. Semi-supervised network on D9

In total, 12 supervised networks have been performed and analyzed, in optimizing the learning algorithm for the best prediction accuracy of a targeted variable to explain. Within each Bayesian Network several more detailed analyses are performed: global inference analysis (strength of correlation), dendograms, occurrence matrices and distribution analysis for several parameters (an average of 4-5 analyses for each network is performed). Finally, 240 analyses have been performed and analyzed. We only comment hereafter a few of them.

When exploring the importance of different means in problem solving phase, we have observed an interesting behavior and correlation between variable D9 and the global success D21. It must be underlined here that D9 *mean* variable: *organization of creativity* is not only the successful achievement of brainstorming workshops, it is also the crystallization of the ideas condensed in knowledge books and identified innovation leads, defined in view to the definition of the global project context and present usage contexts (see Figure 3). Also, the semi-supervised network on D9 in Figure 3, asides from showing an interesting correlation complexity, shows also the impact of the project typology variables (PID, K4, PS, K1 and K5) on the quality of *organization of creativity* D9 but also on the *overall quality of problem setting* D21. Moreover, D21 is directly impacted by the *means* at the very beginning of the RID process, notably *proper definition of the ideal needs*, *identification of stakeholders* and *adequate definition of the present usage context* (D1, D2 and D3).

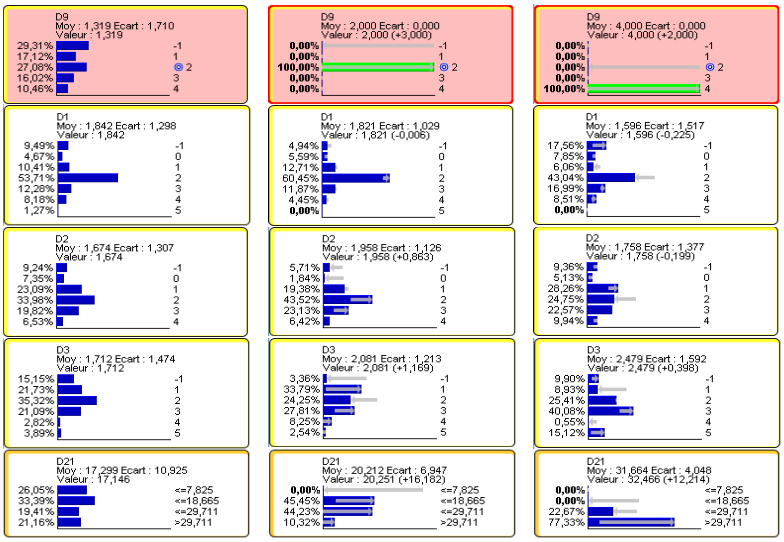

Figure 4. Distributions and correlations between intensity of brainstorming task and overall quality of the problem solving phase

It can be finely observed in Figure 4 through the three successive distributions of variable modalities (in columns) while hypothesizing a first simulation with D9 with an *average* quality (second column of Figure 5) and a second simulation with D9 with a *very good* quality (third column). The changes propagation in distributions underlines that the overall quality of organization of creativity D9 and consequently of the overall problem setting D21 are more likely to happen if radical investigations (D1, D2 and D3) have occurred in the early stages of RID process, while being correctly done.

8 QUALITY OF BAYESIAN MODELS

Finally we have estimated the quality of the unsupervised and the supervised learning processes. To do so, the unsupervised BN has been assessed through the observation and the comparison of the two log-likelihood, for the training and the testing sets respectively. The ratio between those two values provides us an estimation of the precision of the model. Indeed, the more these values are close, the higher the reliability. In the paper, the two indexes (training value=77.18 test value= 79.09) are close enough to ensure a high reliability, consequently our model fits for both training and test sets.

To evaluate the precision of supervised BNs, we have observed the GINI index. This coefficient provides a precision level of prediction. It measures the ratio between the number of correct predictions and the total number of predictions. This index is comprised in range [0;1]. The more it is close to 1 and the more the model is precise. Regarding the BN commented in Figure 4 related to targeted D9 variable, the GINI ratio is equal to 0.827. This score also reflects a good precision of our model.

9 CONCLUSION: REVISING OR REINFORCING OUR BELIEFS

In the present research study, we have tried to check some findings or claims of previous papers, but also to extend them with contextual variables (such as the *project type*), as well as to address the importance of the RID problem setting onto the overall quality and *results* of the innovative project. Some of the conclusions of these analysis are:

- The analysis has confirmed globally the correlation between means and overall quality (see [34; 24; 1; 28-31]). Nevertheless, we found that Bayesian Networks have helped us to explore these correlations more in details. Moreover, it has been found that the problem setting phase and the radical exploration in this phase have an important impact on the overall quality of problem solving as well as innovation. The importance of the usage definition and correct contextual positioning of the project seems important for the overall results.
- It has also been observed that the *project type* variables have an impact on the RID process and therefore motivates the flexibility in defining different design *means* and the overall organization of the RID process. A meta design of the design process itself must be thought of.
- Previous experience in design projects seems determining when it comes to the evaluation of innovation projects like it happens in company conditions (decisions made by top managers with a limited understanding of *means* and *results* in a limited time). We have clearly highlighted a discrepancy in evaluation between the senior and junior designers. To make short, we have measured that more proofs are required by senior jury members to be convinced of an actual innovation or value creation within a design project. It made us conscious that an important perspective to explore are the discrepancies between the perceived values of an innovative project by top managers (here, jury members) and the actual values that have been generated, as suggested by Figure 5.

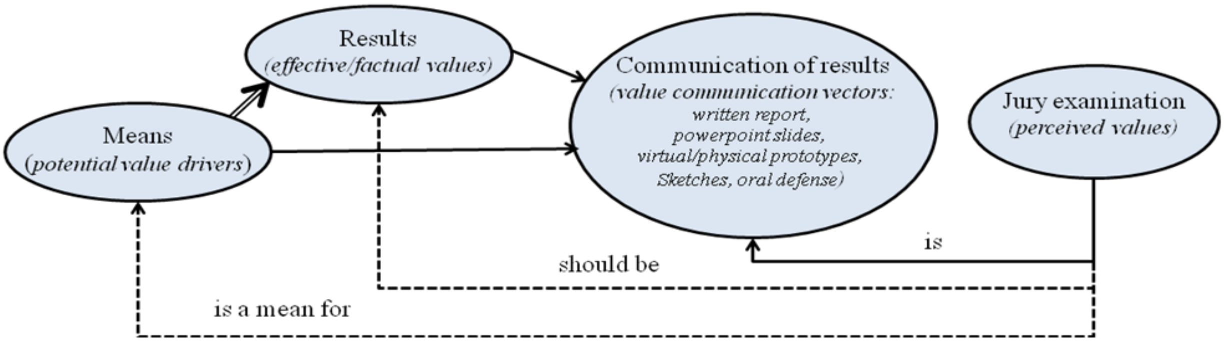

Figure 5: Difficulty of objectively assessing actual values of an innovative project

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REFERENCES

[1] Shah J.J., Kulkarni S.V., Vargas-Hernandez N., "Evaluation of Idea Generation Methods for Conceptual Design: Effectiveness Metrics and Design of Experiments", Journal of Mechanical Design, vol. 122(4), 2000. 377-385.

[2] Wheelwright S.C., Clark K.B., "Revolutionizing Product Development", Free Press, 1992.

[3] Motte D., Bjärnemo R., Yannou B., "On the interaction between the engineering design and development process models - Part I: Elaborate Elaborations on the generally accepted process models", Proceedings of ICoRD: 3rd International Conference on Research into Design, January 10-12, Bangalore, India, 2011.

[4] Motte D., Bjärnemo R., Yannou B., "On the interaction between the engineering design and the development process models - Part II: Shortcomings and limitations", Proceedings of ICoRD: 3rd International Conference on Research into Design, January 10-12, Bangalore, India, 2011.

[5] Motte D., Yannou B., Bjärnemo R., "The specificities of radical innovation", Proceedings of ICoRD: 3rd International Conference on Research into Design, January 10-12, Bangalore, India, 2011.

[6] Kim C.W., Mauborgne R., "Blue ocean strategy - How to create uncontested market space and make the competition irrelevant", Harvard Business School press, Boston, USA/MA, 2005.

[7] Rianantsoa N., Yannou B., Redon R., "Concept-to-value: Method and tool for value creation in conceptual design", Proceedings of IDETC/DAC: ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conferences / Design Automation Conference, August 15-18, Montreal, Canada, 2010.

[8] Rianantsoa N., Yannou B., Redon R., "Dynamics of definition and evaluation of value creation strategies and design concepts", Proceedings of IDMME Virtual Concept, October 20-22, Bordeaux, France, 2010.

[9] Aurisicchio M., Bracewell R., "Engineering design by integrated diagrams", Proceedings of ICED, Stanford University, 2009.

[10] Bracewell R., Wallace K., Moss M., Knott D., "Capturing design rationale", Computer-Aided Design, vol. 41, 2009. 173-186.

[11] Aurisicchio M., Gourtovaia M., Bracewell R., Wallace K., "How to evaluate reading and interpretation of differently structured engineering design rationales", Artificial Intelligence for Engineering Design, Analysis and Manufacturing, vol. 22, 2008. 345-358.

[12] Hatchuel A., Weil B., "A new approach of innovative design: an introduction to C-K theory", in 14th International Conference on Engineering Design - ICED'03, 2003.

[13] Boujut J.F., Blanco E., "Intermediary Objects as a Means to Foster Cooperation in Engineering Design", Journal of CSCW, vol. 12(2), 2003.

[14] Jeantet A., "Les objets intermédiaires de la conception", Sociologie du travail, vol. 3/98, 1998. 291-316.

[15] Thompson S.C., Paredis C., "An Introduction to Rational Design Theory", Proceedings of IDETC/DTM: ASME International Design Engineering Technical Conferences & Computers and

Information in Engineering Conferences / Design Theory and Methodology Conference, August 15-18, Montreal, Canada, 2010.
[16] Yannou B., Chen W., Wang J., Hoyle C., Drayer M., Rianantsoa N., Alizon F., Mathieu J.-P., "Usage Coverage Model For Choice Modeling: Principles", Proceedings of IDETC/DAC: ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conferences / Design Automation Conference, August 30 - September 02, San Diego, CA, 2009.
[17] Yannou B., Wang J., Yvars P.-A., "Computation of the usage contexts coverage of a jigsaw with CSP techniques", Proceedings of IDETC/DAC: ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conferences / Design Automation Conference, August 15-18, Montreal, Canada, 2010.
[18] Pahl B., Beitz W., "Engineering Design: A Systematic Approach", Springer, Technology & Industrial Arts, ISBN 3540199179, 1996
[19] Ulrich K.T., Eppinger S.D., "Product Design and Development", McGraw-Hill, New York, 1995.
[20] Cross N., "Engineering Design Methods - Strategies for product design", John Wiley & Sons, Chichester, 1994.
[21] Liu Y.C., Bligh T., "Towards and 'ideal' approach for concept generation", Design Studies, vol. 24(4), 2003. 341-355.
[22] Pugh S., "Total Design: Integrated methods for successful product engineers", Addison Wesley, New-York, 1990.
[23] Jones E., Stanton N.A., Harrison D., "Applying structured methods to Ecoinnovation. An evaluation of the Product Ideas Tree diagram", Design Studies, vol. 22(6), 2001. 519-542.
[24] Shah J., Vargas-Hernandez N., "Metrics for measuring ideation effectiveness", Design Studies, vol. 24(2), 2003. 111-134.
[25] Astebro T., "Key Success Factors for Technological Enterpreneurs' R&D Projects", IEEE Transactions on Engineering Management, vol. 51(3), 2004. 314-321.
[26] Millier P., "Marketing The Unknown: Developing Market Strategies For Technical Innovations", John Wiley&sons, New-York, 1999.
[27] Dong A., Hill A.W., Agogino A., "A Document Analysis Method for Characterizing Design Team Performance", Journal of Mechanical Design, vol. 126, 2004. 378-385.
[28] Yang M., "An examination of prototyping and design outcome", Proceedings of ASME Design Engineering Technical Conferences, Salt Lake City, USA, 2004.
[29] Yang M., "Observations on concept generation and sketching in engineering design", Research in Engineering Design, vol. 20(1), 2009. 1-11.
[30] Yang M., Cham J., "An Analysis of Sketching Skill and Its Role in Early Stage Engineering Design", Journal of Mechanical Design, vol. 129, 2007.
[31] Yang M.C., "Concept generation and sketching: Correlations with design outcome", Proceedings of DETC-DTM: ASME Design Engineering Technical Conferences - Design Theories and Methodologies, September 2-6, Chicago, Illinois, USA, 2003.
[32] Roozenburgh N.F., Eekels J., "Product Design: Fundamentals and Methods", John Wiley & Sons, Chichester, 1995.
[33] Fricke G., "Successful individual approaches in engineering design", Research in Engineering Design, vol. 8, 1996. 151-156.
[34] Mabogunje A., Leifer L., "Measuring the Mechanical Engineering Design Process", Proceedings of 26th Annual Frontiers in Education Conference on Technology-Based Re-Engineering Engineering Education, Salt Lake City, USA, 1996.
[35] Yang M.C., Wood W.H., Cutkosky R., "Design information retrieval: a thesauri-based approach for reuse of informal design information", Engineering with Computers, vol. 21, 2005. 177-192.
[36] Kulkarni S., "Idea Generation Techniques-a critical survey", Arizona State University, 1998.
[37] VanGundy A.B., "(2nd Ed.) Techniques of Structured Problem Solving", Van Nostrand Reinhold, New York, 1988.
[38] Ben Ahmed W., Yannou B., "A bayesian learning of probabilistic relations between perceptual attributes and technical characteristics of car dashboards to construct a perceptual evaluation model", International Journal of Product Development, special Issue on “Engineering Emotional Design (EED) and Kansei Engineering (KE)”, vol. 7(1-2), 2009. 47-72, DOI: 10.1504/IJPD.2009.022276.

[39] Cai Z., Sun S., Si S., Yannou B., "Identifying product failure rate based on a conditional Bayesian network classifier", Expert systems with applications, vol. to appear, 2010.
[40] Jensen F.V., "An Introduction to Bayesian Networks", UCL Press, London, 1996.
[41] Huang C., Dawiche A., "Inference in Belief Networks: A Procedural Guide", International Journal of Approximate Reasoning, vol. 15, 1996. 225-263.
[42] Jouffe L., Munteanu P., "New Search Strategies for Learning Bayesian Networks", Proceedings of Tenth International Symposium on Applied Stochastic Models, Data Analysis, Compiègne, France, 2001.
[43] Bouckaert R.R., "Probabilistic network construction using the minimum description length principle", Lecture notes in computer science, vol., 1993. 41-41.
[44] Lam W., Bacchus F., "Learning bayesian belief networks: An approach based on the MDL principle", Computational Intelligence, vol. 10, 1994. 269–293.