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Measuring the efficiency of inventive activities along inventive projects in R&D

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Abstract

Measuring the efficiency of inventive design is the first research step to determine the key indicators of inventive efficiency. Detecting measurement objects, parameters, and the impacts factors that involve with inventive design processes provides us toward founding an effective measurement. The article looks for the appropriate zone across organizational processes for measuring inventive efficiency and mapping criteria. It aims to clear the principal criteria of measuring inventive efficiency, and demonstrates the necessity of a pertinent selection for entry factors to define indicators. This research is fed by an inquiry of about 100 French companies with their R&Ds.

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Keywords: inventive design efficicnecy, inventive design performance, inventive activity, TRIZ, inventive project, R&D;

1. Introduction

A design process can be represented as a network of design activities [3]. Duffy et al. 2003, with the assumption that design activities can be abstracted at the knowledge level, defined generic design activities in the term of changing knowledge due to activity [17]. Thereby, technical specifications and patents constitute the first choices media of technological information that can transform into the products by development and manufacturing [14]. Hubka and Eder 1996, described design as a rational cognitive activity that can be decomposed into smaller steps, stages and/or phases [5] [17]. They have defined a hierarchical model of design activities, which consists of different levels such as design operation, basic operations, elementary activities, and elementary operations. Furthermore, Schumpeter 1911, described invention as the creation of new technology while by commercial success becomes innovation [17]. Indeed, an invention is an idea or a concept to have a new or improved device, product, process or system [3] [16]. All of these conclude that inventive activities compose the earliest stages of innovation process including inventive problem-

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solving for proposing new product/process by creation or/and improvement. These stages (green box in figure 1) are known as the fuzzy front-end phase with the highest impact on the whole innovation process, its inputs and outputs [Fig. 1]. Although the fuzzy front-end phase is the least-well-structured part of the innovation process [4], successful treatment of its activities in the chain of innovation process increases innovative results qualitatively and quantitatively.

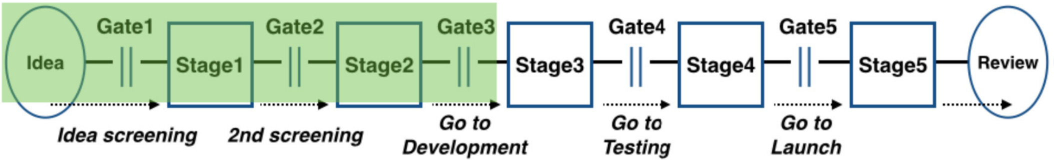

Fig. 1. The fuzzy front-end phase along inventive projects has the highest impact on the whole innovation process.

Between different hierarchical layers of an R&D department including innovative projects, processes, activities and acts, in this research with the aim of characterizing efficient treatment of inventive activities, we investigated on the projects level [Fig. 2]. We consider an inventive activity as the smallest process unit. So a set of them realizes particular processes. Indeed, companies define, equip and apply particular processes in order to manage activities, and extract the maximum benefit from resources. The project level, at a higher layer, includes particular processes to achieve project goals. Accordingly, measuring the efficiency of inventive projects provides a comprehensive efficiency of included processes and activities. This can be considered as the main gage pointer for studying inventive efficiency of R&Ds [Fig. 2].

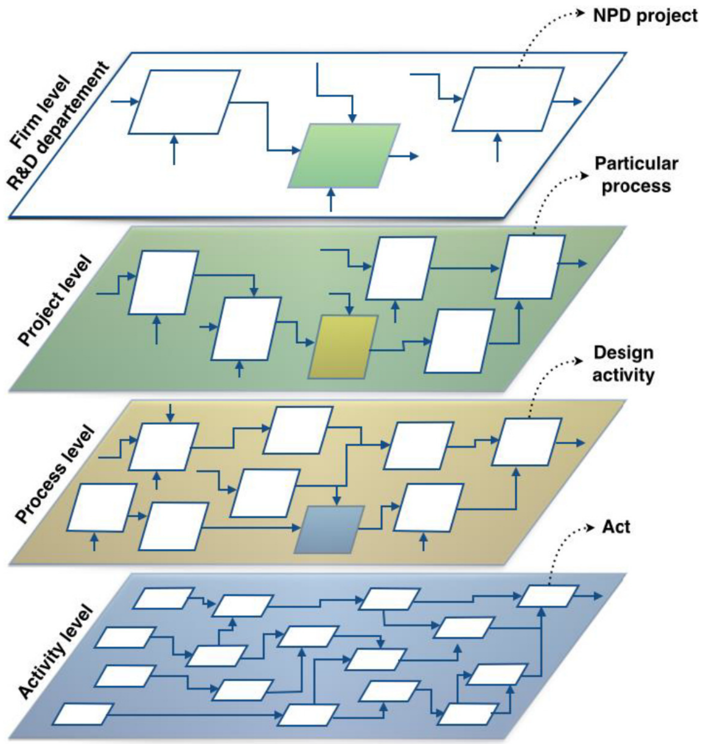

Fig. 2. Hierarchical levels for managing inventive activities in innovative projects

This paper aims to clear and map out the fundamental criteria of measuring inventive efficiency, and demonstrates the necessity of having an appropriate data-base with measuring effectiveness within a measurement system.

2. Inventive design efficiency (nID)

Efficiency is the ratio of useful work performed to the total resources expended [13]. Duffy et al. 2005, described efficiency in design as the quotient of dividing the material gain (M+) by resourced used (R) within an activity [9] [Fig. 3].

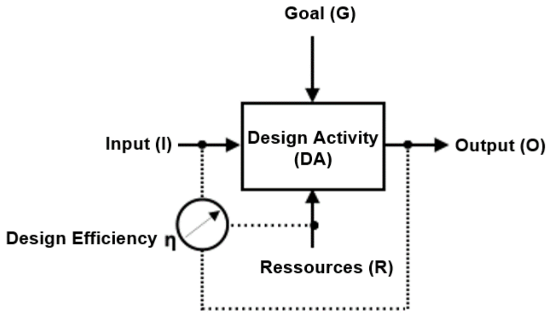

Fig. 3. Classical definition of design efficiency [9]

In inventive design, at the project level, the efficiency is seen as a metric of relationship (ratio) between inventive outputs, at knowledge level, and the resources used in fuzzy front-end phase (FFE). The comprehension of inventive output as material gain and the resources used within FFE are the main challenges of this paper.

2.1. Knowledge gain (Kn+) as the material gain (M+)

An innovation process is a learning process [11]. Moreover, since design is a proceeding of knowledge [8], all the activities during design process deal with knowledge processing. Indeed, knowledge as the main object for changing comes to help to generate new output. In inventive design, the material gain means to possess technological evolution, and appears by product, process. Measuring technological evolution in output qualitatively is not evident. Technology is defined as the application of scientific knowledge for practical purpose [13], and measuring technological evolution needs to measure the changes emerged through applied knowledge on proposed solution. Although new solutions can be presented in different forms such as sketch, patent, prototype, industrial product, and maybe innovation along a new product development project, the principles of evolution are same. In this regard, technological evolutions or the knowledge gain (Kn+), by inventive design projects, can be measured qualitatively as well as quantitatively. Because technological evolution comes from the changes occurring in inherited characteristics over new generated technology and so its measurement should be done by some comparisons between new generations and the ancient ones. It means that inventive measurement is based on comparison of new solutions, at the output, with existing solutions, at the input [7].

Measuring technological evolution is not in the scope of this paper, but what is certain is that the value of new outputs (quantitative measurement) is determined by detecting the distance of evolution (qualitative measurement). Table 1 represents KnQi+ as the qualitative, and KnQn+ as the quantitative scale of technological evolution.

Table 1. Knowledge gain (Kn^+) along innovative projects

Value of Knowledge gain	Sign	Description
Qualitative	Kn^+_{Ql}	Value of technological changes (qualitatively value)
Quantitative	Kn^+_{Qn}	Number of inventive output (unit) (quantitative value)
Total	$Kn^+ = Kn^+_{Qn} \, . \, Kn^+_{Ql}$	Value of Knowledge gain

2.2. Resource used (R)

The fuzzy front-end phase of innovation projects as the specific process to generate inventive outputs needs specific resources. It's evident that any resource used in any hierarchical level such as material, tools, creative mind, creative methods, creative organization, creative environments, creative teams, creative management, training methods, can be summarized in time and cost. More than 70 percentage of participants in our inquiry differentiated inventive design from routine ones by time, cost and human-resource. Moreover the combinations these criteria such as man-hour and man-hour cost are taken into account in this work [Table 2]. Indeed, the man-hour and the man-hour cost are taken into account as the complementary criteria to avoid the missing of minding value in the measurement.

Table 2. The principal criteria and their units of measuring resources used

Criteria of measuring resource used (R)	Sign	Unit of criteria
Cost	c	Euro
Time	t	Hour
Human Resource	hr	Brain
Man-Hour	mh	Man-Hours
Man-Hour Cost	mhc	Euro

2.3. Efficiency of inventive design

By measuring the knowledge gain (Kn+) and the resources used during a design process, the calculation of efficiency is possible. Measuring the knowledge gain in 2 forms (qualitatively and quantitatively), and implementing them with 5 criteria of measuring resources used, give ten rates of efficiency value. According to the criteria of resources used, measuring the efficiency can be categorized in frequency, worth and creativity of human-resource [Table 3]. In all the case, resources used are limited to fuzzy front-end phase (FFE), and knowledge gain is verified after the fuzzy front-end phase [Fig. 1].

Table 3. The partial rates of efficiency (Pη) in inventive design

Knowledge Gain (Kn^+)	Value of knowledge gain – quantitative Kn^+_{Qn}	Value of knowledge gain – qualitative Kn^+_{Ql}	**Value of knowledge gain – complete** Kn^+
Resource Used (R)	***Quantitative Partial efficiency***	***Qualitative Partial efficiency***	***Efficiency of inventive design process***
		Frequency of inventive process	
Time (*t*)	$P\eta_1 = Kn^+_{Qn}/t$	$P\eta_2 = Kn^+_{Ql}/t$	$\eta_t\ ID = Kn^+/t$
		Worth of inventive process	
Cost (*c*)	$P\eta_3 = Kn^+_{Qn}/c$	$P\eta_4 = Kn^+_{Ql}/c$	$\eta_c\ ID = Kn^+/c$
		Creativity of inventive process	
Human-Resource (*hr*)	$P\eta_5 = Kn^+_{Qn}/hr$	$P\eta_6 = Kn^+_{Ql}/hr$	$\eta_{hr}\ ID = Kn^+/hr$
		man-hour creativity in inventive process	
Man-Hour (*mh*)	$P\eta_7 = Kn^+_{Qn}/mh$	$P\eta_8 = Kn^+_{Ql}/mh$	$\eta_{mh}\ ID = Kn^+/mh$
		creativity worth in inventive process	
Man-Hour Cost (*mhc*)	$P\eta_9 = Kn^+_{Qn}/mhc$	$P\eta_{10} = Kn^+_{Ql}/mhc$	$\eta_{mhc}\ ID = Kn^+/mhc$

2.3.1. Pertinency and its influences on efficiency

Andreasen et al. 1998, confirmed that the considerable efforts are done to ensure using of right resources at the right time, to carry out the right activities for the right reasons to give the right results [2]. Gilbert 1980, presented the concept of pertinence in the notion of performance in innovation [10]. Analyzing the imposed condition by the entries of an innovation process helps to define and represent significant indicators of inventive efficiency. The efficiency of inventive design can be affected by the nature or/and the behaviour of resources, goals, and inputs. So, using the pertinent ones is determinative for inventive efficiency. For example, outfitting the fuzzy front-end phase via the scientific design methods that involve with input knowledge, human-resources, and goals for facilitating the resolution of inventive problems [18] can emerge positive influence on the efficiency. This is confirmed by our inquiry, when 71 percentage of participants admitted that. Likewise, the inquiry confirmed the influence of operational rules for the creative teams.

Concerning projects' goals, the generation of new technology through inventive design process has a direct relation with technological domain and administrative targets. Both of them can exert a strong effect at the output. In this case, for clarifying the effects, we have defined the coefficients to balance the efficiency of generation [Table 4]. Accordingly, the administrative coefficients (p_1, p_2, p_3) according to the administrative targets are:

- Artifact generation (physical) with attain market presentation *(p1)*
- Process generation (physical) with attain market presentation *(p2)*
- Knowledge generation (documental) with attain scientific publication *(p3)*

In the other hand, the projects take technological coefficients (ii. $_n$) in accordance with their technological domains. Table 4 represents administrative and technological coefficients as to the difficulty of generation as 'generation value coefficients' (GVC) for balancing imposed conditions. Determining value of coefficients is the next step of our research.

Table 4. Levelling inventive generation difficulty according to the technological domains and the administrative targets Inventive design project

		Inventive design project		
	Administrative project targets	Generation of artifacts	Generation of processes	Publication of knowledge
General Value Coefficient (GVC)	Administrative (α)	α_1	α_2	α_3
	Technological (τ)	τ_k ; $k \in T$; T={technological domains}		

Another example is absorption rate at the output that has great influence on the efficiency. The absorption rate depends on the characteristics of the FFE's outputs which can be defined by the next stages of design process or/and the markets. 'Feasibility', 'ideality', 'usefulness' are some of these characteristics [9] [7]. Recognizing the importance of each one and considering them along technological evolution help us to increase the absorption and consequently efficiency.

By presenting the concept of pertinency and some example, it can be concluded that detecting those key parameters that have influence on the numerator (Knowledge gain (Kn+)) and the denominator (Resources used (R)) is indispensable to achieve a helpful indicators of inventive efficiency.

2.4. Case study:

Research and development department of an electrical company has launched an inventive project namely INNAP to offer a new AC adaptor (convector) in its target-market. Project team has found two functional problems as the opportunity of developing new products and so the project's goal is based on the elimination of them. The project has been done in 87 days with 38 experts and a budget of 78,750.0 Euros so that the FFE phase was involved 15 days with 11 experts and spends 22,300.0 Euros. The number of propositions at each stage along the process [Fig. 1] is summarized in Table 5.

Table 5. The number of outputs at the gate of each stages of INNAP project

Functional problem (*fp*)	Ideas (*sf1*)	Concepts specification (*sf2*)	Developed specification (*sf3*)	Prototype (*sf4*)	Industrial product (*sf5*)	Innovation (*sf6*)
2 (*fp*1, *fp*2)	8 ($\iota_{1...8}$)	5 ($\iota_2, \iota_4, \iota_6, \iota_7, \iota_8$)	4 ($\iota_4, \iota_6, \iota_7, \iota_8$)	4 ($\iota_4, \iota_6, \iota_7, \iota_8$)	3 ($\iota_4, \iota_6, \iota_8$)	2 (ι_4, ι_8)

To obtain the qualitative amount of knowledge gain (Kn_{QI}^+), we rely on five levels of invention (as a good alternative for Kn_{QI}^+ [Table 6]) by Altshuler [1] (Table 6).

Table 6. Altshuler's five invention levels as an alternative solution for grading technological evolution of ideas (TED)

Level of invention	Problem analysis	Solving methodology	Generated solutions in INNAP
1	Don't consider contradictions	Routine solution (non-inventive solution)	-
2	Consider contradictions	Provided solution through the same technology	$\iota_1, \iota_3, \iota_5, \iota_8$
3	Consider contradictions	Provided solution through a different technology	$\iota_2, \iota_4, \iota_6$
4	Consider contradictions	Provided solution through a different science	ι_7
5	Consider contradictions	Provided solution through a new discovery	-

So the results are gathered in Table7 as the table of inventive efficiency [Table 7].

Table 7. Inventive efficiency of INNAP project

Knowledge Gain (Kn^+)	Value of knowledge gain – quantitative Kn^+_{Qn}	Value of knowledge gain – qualitative Kn^+_{Ql}	**Value of knowledge gain – complete** Kn^+
Resource Used (R)	***Quantitative Partial efficiency***	***Qualitative Partial efficiency***	***Efficiency of inventive design process***
Time (*t*)	$P\eta_1=2/105=$1.9%	$P\eta_2=5/105=$4.8%	Frequency of inventive process $\eta_t\ ID=$4.8%
Cost (*c*)	$P\eta_3=2/22300=$0.009%	$P\eta_4=5/22300=$0.02%	Worth of inventive process $\eta_c\ ID=$0.02%
Human-Resource (*hr*)	$P\eta_5=2/11=$18.9%	$P\eta_6=5/11=$45.4%	Creativity of inventive process $\eta_{hr}\ ID=$45.4%
Man-Hour (*mh*)	$P\eta_7=2/1155=$0.8%	$P\eta_8=5/1155=$0.4%	man-hour creativity in inventive process $\eta_{mh}\ ID=$0.4%
Man-Hour Cost (*mhc*)	$P\eta_9=2/19.3=$10.4%	$P\eta_{10}=5/19.3=$25.9%	creativity worth in inventive process $\eta_{mhc}\ ID=$25.9%

For standardizing the efficiency measurement and compare the efficiency of different projects with different technological domain and administrative targets, we have considered 'generation value coefficients' (GVC) of technology (τ) and also administration (a) in the calculation. Here, it is assumed that the GVC of electrical domain is 0.67 and the administrative GVC for producing artifact as projects' target is 0.80. So we have the balanced rate in Table 8:

Table 8. Partial efficiency after giving effect of technological and administrative GVCs, $\tau_{electrical}=0.67$, $\alpha_{artifact}=0.80$

Efficiency: **Kn^+**	**Frequency**	**Worth**	**Creativity**	**man-hour creativity**	**creativity worth**
Kn^+_{Qn}	1%	0.004%	10.13%	0.43%	5.57%
Kn^+	2.57%	0.01%	24.33%	0.21%	13.88%

3. Conclusion

The efficiency of inventive design is one of the main wings of characterizing design performance, which should be considered with the other elements of effectiveness measurement. In this paper, the appropriate zone of measuring inventive efficiency across hierarchal organizations was presented. We have also clarified knowledge gain as the material gain in inventive design and its nature as technological evolution that must be considered inventive measurement. Estimating the distance of technological evolution helps us to measure the value of inventive efficiency. For resources used, the principal criteria of measuring was presented and different types of inventive efficiency were summarized [Table 3]. Furthermore, the influence of Pertinency on efficiency and the involvement of different elements with design process has been discussed and introduced as the main subjects for defining inventive indicators. Overall this paper is a clarification of measuring inventive efficiency.

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