R&D NETWORKS AS COMPLEX SYSTEM: THE CASE OF EUROPEAN NETWORKS

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ABSTRACT

The aim of this paper is to study the management of technological networks. It works from the basic axiom that networks are a complex reality presenting multiple aspects that need to be tackled from different theoretical approaches. The network, considered as a complex system, will be studied through the different subsystems making it up (structural, technological and management subsystem) analysing the different variables that underlie and delimit the management thereof. An empirical study will then be made of the networks set up for the development of technological projects in the framework of the European RTD programmes. The sample comprises 185 institutions taking an active part in said programmes, enabling a description to be made of the main features of the networks and the main challenges posed in the management of technological projects in the network.

KEYWORDS

Complex, System, Networks, Technology, Management, Structural, and Subsystem.

1. INTRODUCTION

Research and technology have been given a new boost in recent years. Basic technologies such as information and communication, material sciences and biotechnology have burst onto the economic and social scene and are now going from strength to strength.

The European Union (EU), quick to perceive this trend, has recognised the importance of joint collaboration and cooperation between European firms in activities with a high technological content (European Commission, 1995). Community policies are therefore propounding and supporting programmes of great strategic importance, both technological and commercial, in certain industrial sectors.

Since 1984 the Community has been implementing an autonomous research and technological development (RTD) policy by means of "framework programmes". The framework programme is the legal and organisational instrument for their development, laying down the main lines of work that qualify for EU financing (for further information, see http//europa.eu.int; or http//www.cordis.lu).

Table 1. Budget of Framework Programmes (Million ECU)

Programme	Years	Budget
1st F. P.	1984-87	3,750
2nd F.P.	1987-90	5,396
3rd F.P.	1990-94	8,825
4th F.P.	1994-98	13,215
5th F.P.	1998-02	14,960*
6th F.P.	2002-06	16,270*

* Million Euro

The aim is to make RTD activities more complementary with the union's other policies. The RTD projects involve several European countries –to foment transnational collaboration– several companies –to abide by competition laws– and, as far as possible, SMEs and universities –to stimulate technology transfer-. European cooperation is thus a sine qua non condition for obtaining financing from framework programmes. Projects submitted have to meet the following terms:

- That each team includes centres and/or companies from at least two community countries;

- That participants include at least one industry and a university or research centre and, lastly
- That working teams are as interdisciplinary as possible.

In short the European Union's technology policy encourages transnational network initiatives. Hence the importance and interest of analysing them, as they make up the basic structure for technological development and in fact a key part of business competitiveness.

2. THE COMPLEXITY OF TECHNOLOGICAL NETWORKS

R&D networks are usually defined as the union of two or more parties, institutions or individuals, who pursue a distinct assignment together (Balachandra and Friar, 1997; Aronson *et al*, 2001). The development of R&D projects implies the execution of activities that will create interactions in the dynamic process for the accomplishment of objectives. Laredo and Mustar (1996) also indicate that an organisational form is necessary for the development of the project; Teece (1992) and Ring and Van de Ven (1992) conclude that R&D networks are a form of business organisation.

The first stumbling block in studying technological networks is the lack o a single theoretical reference upon which to base their study, since these types of agreements and structures take in a host of different aspects and hence different approaches (for a review see Auster, 1994). Networks and alliances constitute a new "ubiquitous phenomenon" (Gulati, 1998) expressing a wide-ranging field that goes many different denominations: agreements, coalitions, consortia and networks, strategic alliances or associations.

From the above it can be deduced that the phenomenon of collaboration between economic agents, and more specifically in technological areas, is characterised by the ambiguity of the terminology, the multiple analytic approaches, the diversity of objectives, the multiple organisational forms, and so forth. These aspects mean that complexity is a particularity present in technological networks. In order to define principles for dealing with the above, it will be fundamental to take into account this aspect, and we will therefore proceed to describe the main factors, in our view, which make technological networks a complex phenomenon.

2.1. Technology as knowledge

New business management approaches consider technology as knowledge, in this sense technological knowledge is a resource and a capacity, which the organisation possesses. It is an intangible resource, which means without material form and not liable to be touched or noticed specifically and it is a capacity that companies or organisations possess, which enables them to generate output which may be seen by the market as differentials, thereby sustaining their competitive advantage.

Technology, which is the resource, and technological knowledge are to be found, for example, both in a license or a patent acquired by an organisation, as well as in the people which make it up, and which through their work learn to improve the techniques used in productive processes or to incorporate greater added technological value into manufactured goods. This last point is called learning by using or learning by doing, in short learning by learning.

Technological knowledge may thus have an explicit character-the case of a patent or a license-or an implicit, tacit one-, in the case of generation by means of learning and experience (Hagedoorn, 1993). This last point may also be in the hands of an organisation member, in this case having an individual character, or be company knowledge possessed by the entire organisation. Additionally, we may consider knowledge as either general knowledge or specific knowledge, depending on its character and orientation.

Characteristics possessed by technology like the organisation's intangible resources and knowledge mean, in short, that its development-generation and transmission-is a complex phenomenon (Dosi and Orsenigo, 1985), in which environment factors have an influence (uncertainty, the dominant technological pattern, trends, and so on) as well as the characteristics of the agents involved (experience, size, technological culture, and so forth), that is, its capacity for development, transmission and appropriability, together with the actual characteristics of the good being transferred (the level of technological codification, its specific nature, and so forth) (see Dosi *et al*, 1990).

2.2. Interactions and structural heterogeneity in technological networks

The aim of technological networks is technological development, this being considered as a process ranging from generation to diffusion in the market. Since the eighties, with the explosion in international collaboration in this area, technological processes have ceased to be considered as sequential, integrated facts, being developed in networks where multiple interactions and a great diversity of participating agents are introduced, in what has been described as an interactive process, non sequential and non lineal (Rothwell, 1994). The network is not only made up of companies, but also involved are customers, suppliers, universities, public research centres, and so forth, which is partly derived from a complex interaction process between the different participants and in a great structural heterogeneity both through the diversity of organisation types and the different levels covered by the network (individuals, companies or company groupings, national innovation system, and so forth) as well through the environment in which they materialise -local, national or supranational-.

We should point out that the actual term interaction or relationship between organisations is in itself diffuse, a plurality of interpretations existing derived from diverse study and analytic approaches.

Generally, however, we can confine the content of the relationship between organisations to four elements (Johanson and Mattson, 1987):

1. A common orientation or predisposition to act jointly, whether it be exploiting and sharing a good (generating economies of scale) or making use of complementary aspects in the participating agents.
2. Dependency, deriving from different organisations acting together.
3. Implementation of the connecting link which, in some ways, is a form of uniting the interacting parts. These may present a series of characteristics which Aldrich (1979) limits to four: formalization, intensity, reciprocity and standardisation.
4. Investment made by the parties involved, which will determine the future commitment to the relationship and which normally materialises in people and time.

All these elements mean that relations between the agents are very complex when taking into account the great importance of these interactions in technological processes.

2.3. The presence of "conflicts of interests” in technological networks

A wide variety of institutions and organisations participate in the networks with multiple objectives and preferences, with differential information between themselves, with different capacities and decision-making criteria and, all of this in uncertain environments. Conflict in the technological network, understood as tension between two or more organisations arising from incompatibility of actual or desired reactions, is thus a constant threat. Situations of conflict sometimes arise from structural network aspects (Thomas, 1976), such as incompatible objectives, disagreement on decisions and contribution of resources (clear conflict); in others, they are related to attitudes and feelings amongst network members and are associated with disagreements about functions to be carried out and with expectations, perceptions and communication (underlying conflicts).

We could therefore consider relations between agents in technological networks to be a game of dynamic equilibrium, between co-operation and conflict, and which increases the level of management complexity due to the difficulty in predicting the behaviour of participating agents. The main characteristics defining complexity as an economic phenomenon are structural heterogeneity and functional interdependence (Koppel *et al*, 1991).

3. THEORETICAL APPROACH TO TECHNOLOGICAL NETWORKS

From the strategic management point of view, inter-company agreements[3] pose two analytical approaches: an external one bound up with the search for competitive advantage (as opposed to the classic concept of inter-company rivalry), which we will call *strategic alliance*; and an internal level, taking the form of strategic interdependencies that are generated between the members participating in the agreement, and these we will generically call *networks*.

For the purposes of this paper we define networks as the set of cooperation agreements[4] reached between different independent organisations (companies, the government, universities or other types of institutions) to carry out a communal technological project.

Technological networks, the object of our study here, represent a very significant part of the whole set of cooperation phenomena[5] (Hagedoorn, 1993). Technology as the object of inter-company cooperation has been studied by many authors (Nueno and Oosterveld, 1988; Kandel and Durand, 1990; Dussauge *et al.*, 1988; Porter, 1985; Dussauge and Garrette, 1991). Le Moigne (1990) and Moles (1990) sum up the purposes of cooperation by dividing it into three

[3] There are five types of relationships between firms, all conveniently beginning with the letter "c": conflict, competition, coexistence, cooperation and collusion (Easton *et al.*, 1992).
[4] Here we are using the concept of cooperation as a synonym of collaboration, though when we later turn to the study of strategic interdependencies between agents, we will deal with the term from the point of view of cooperative games.
[5] For the historical precedents see Johnson (1971), Stopford and Wells (1972) or Leroy and Maroise (1979).

groups: technological, strategic and structural; whereby the objective is seen to be a juggling act between this set of purposes and all the possible intermediate configurations.

As for the reasons justifying the need to study technological networks, the following are the most noteworthy:

- The importance of technological knowledge in company competitiveness (Peteraf, 1990; Grant, 1991;Porter, 1985; Prahalad and Hamel, 1990; Kay, 1995);
- The paramount role played by technology in the international sphere, a phenomenon called by some authors *technoglobalism* (Dunning, 1993);
- The need to cut down the high transaction costs associated with the transfer of technological knowledge (Arrow, 1962; Atkinsons and Stiglitz, 1969; Williamson, 1975; Teece, 1981; Kay, 1995)

To understand the management of technological networks that have arisen in the framework of community RTD programmes, the analysis, in our opinion, has to take in the following questions:

a) Structural aspects: in terms of the kind of members involved in the projects, their number, characteristics, etc.

b) Technological aspects: in terms of the type of products generated, the activities carried out, the stages into which the process is divided, interrelations, etc.

c) Organisational aspects: in terms of network management, hierarchical structure, the definition of objectives, etc.

d) Strategic aspects: in terms of the possible competitive advantages deriving from participation in technological projects, with the type of resources sought in the cooperation, etc.

e) Interrelationships between partners: in terms of how the network is set up between them, what their contributions are, how the benefits are shared out, etc.

We can therefore pinpoint four theoretical approaches for tackling the host of aspects involved in the study of technological networks and, in general, in the analysis of cooperation between organisations , see table 2. In sum, technological networks have a markedly multidisciplinary character and embrace different approaches and dimensions that all need to be taken on board in our study, otherwise our account could end up partial and biased.

Table 2 Theoretical approaches to study the networks

***Transaction Cost Theory*:** Networks, and more specifically cooperation agreements, are seen from this viewpoint as an intermediate form of coordinating and executing activities, midway between the market (invisible hand) and the business organisation (visible hand) (Arrow, 1969; Williamson, 1975, 1985,1999). This intermediate form of coordination is envisaged as continuum of multiple possibilities between both extremes (market and company), the particular position within this continuum depending on the characteristics of the transaction (Hennart, 1988; Kogut, 1988). These characteristics refer to the uncertainty of the transaction, its specificity and the interrelation frequency needed to bring it about. The most efficient structure will be that which manages to minimise the transaction costs (Imai and Itami, 1984; Walker and Weber, 1984). ***Strategic Management*:** From the management viewpoint cooperation comes across as an atypical form of inter-company relation. Cooperation as a strategic option strives to find a competitive advantage that can generally be considered to stem from economies of scale (Porter, 1980; Harrigan, 1985; Kogut, 1988), or the sharing of complementary goods and activities by the companies making up the agreement (Joffre and Koenig, 1984; Hennart, 1988; Roberts and Mizouchi, 1989; Dussauge and Garrette, 1991). From this approach the critical points are the choice of the alliance and partners, plus questions to do with the management, development and control thereof. Aspects such as trust, commitment to the coordination of activities and relationships of a social character are therefore the keys to a strategic alliance (Gulati, 1998). ***Organisation Theory*:** From the viewpoint of the organisation, company networks, set up by the signing of cooperation agreements between diverse organisations, are a response to the contingencies of the economic environment (Child, 1972; Hannah and Freeman, 1977; Aldrich, 1979; Lawrence, 1981). This form of organisation is an adaptive structure to the new demands of the latter, mainly flexibility and globalisation (Galbraith, 1973; Astley and Fombrun, 1983). Small firms, intrinsically more flexible and fleetfooted in adapting to the ever-changing complexities of the new environment, respond to the challenges of trading in a global market by setting up agreements with other firms, forming veritable inter-company networks (Jarillo, 1986). Major companies, for their part, global in their very conception, seek greater flexibility and adaptation capacity through the breaking down of their hierarchical structure, setting up strategic units or autonomous business units that form nodes of veritable intra-company networks (Handy, 1988).Both types of actions, occurring simultaneously in time, tend to blur the distinction between one company and another, due to the existence of multiple interrelationships based on cooperation agreements. ***Game Theory*:** Game theory, from an instrumental point of view, provides the principles upon which the cooperation agreement is to be based – ex-ante principles – and determines the efficient solutions of the cooperative game (Shapley, 1969; Aumman, 1976). The ex–ante principles involve such aspects as the number of partners and the quality of the partners who are going to participate (group rationality principle) and the particular interest taken in an agreement by an individual agent (individual rationality principle). They also help to determine such questions as working efficiency and stability through an analysis of the contributions of the partners and the share-out of benefits. Game theory thus offers both a quantitative and qualitative analysis framework for achieving efficiency and stability of the cooperation agreement (Moulin, 1995).

3. NETWORK MANAGEMENT FROM A SYSTEMIC APPROACH

Along these lines, therefore, we can analyse technological networks from a systemic perspective whereby networks are conceived as complex organisational forms responding to a behavioural scheme, endowed with control mechanisms and adapted to the environment (Bertalanffy, 1956). This approach accepts the construction of logic to analyse and explain the problems of network management. In this way we can: move closer to the complex reality of the technological collaboration phenomenon; break down the system complexity into simpler subsystems, in which we can tackle analysis from already theorised study approaches.

We will therefore define R&D networks as a complex socio-technical system in interaction with their environment, thus allowing us to define a series of interdependent subsystems related with their management, their technological and strategic aspects, and finally with their structural outlook. In the framework that follows we will discuss these subsystems and we will generate the hypotheses for the analysis.

3.1. Subsystem of management or governance structure

The recognition of organizational structures in R&D alliances is an initial condition frequently mentioned in collaborative R&D literature. Ring and Van de Ven (1994) and Teece (1992) affirm that R&D networks are a form of business organization although a great dispersion on how to approach to the different governance structures of R&D networks exists (Branstetter and Sakakibara, 2002). Gulati (1998) defines the governance structure as the formal contractual structures used to organize the partnership in strategic alliances. Williamson (2002) for his part, points out that the objective of governance structure is to infuse order in a relation where potential conflict can arise, and where opportunities to make common gains exist. This author illustrates that three types of attributes to describe a mode of governance exists: (a) incentive intensity; (b) administrative controls and (c) the legal rules regime.

There are two different approaches to the governance structures of R&D alliances (transaction costs and social capital) which are explained by the double character of technology as objective of alliance. On the one hand technology is an economic good susceptible to transaction and, on the other, technology entails information and knowledge. This double character originate the diverse explanatory variables and to the lack of unanimity between them. Nevertheless, the substantial support for the analysis derived from both transaction costs and social capital approaches suggests that one and the other can explain governance structures in R&D alliances.

In the transaction cost approach the explanatory variables for governance structures are specificity and appropriating (Willianson, 2002). Then, the objectives of governance structures are minimising transaction costs and opportunist behaviour, turns them into hierarchy and appropriation costs. From this point of view the more specificity of alliance results in more hierarchyzed forms of governance and the higher appropriating of technology tends to create safeguards mechanisms. Similarly Imai and Itami (1984) consider alliances as hybrid forms of organisation between the market and the firm.

From the "social capital" approach information and knowledge are the key variables to determine the governance structure of R&D networks. From this initial view other authors suggest that alliances are social networks with a series of interrelated nodes (that comprises agents and individuals) which allow us to define the networks as structures of ties (Powell *et al*, 1996; Gulati, 1998). These networks of contacts between actors can be an important information source for participants. Then, the ties (or the relations between agents) and the information into network acquire great importance to define governance structures. Granovetter (1985) defines the strength of ties based on a combination of amount of time, emotional intensity, intimacy (mutual confidence) and reciprocal services between the partners of alliance.

Thus, there are alliances that "exploit" information cope with alliances that "explore" information which results in different forms of governance (Rowley *et al*, 2000). The first one constitutes highly cohesion alliances (strong ties) with a small number of partners whose objective is the development of products (through the knowledge) to obtain competitive advantages. On the contrary, the alliances to explore information have a great number of partners and low cohesion (sparse) being its objective to obtain technology information. Therefore:

Proposition1: There will be a management subsystem in R&D networks whose objective will be the governance of them. In this subsystem, the key variables will be the hierarchy and the formalization of relations between partners.

3.2. Technological subsystem

Extent research into the objectives of R&D networks has been developed (Hagedoorn, 1993). Select research has focused on the context of the externalisation of technological activities. One stream of studies has looked at the tangibility of technological activities (Trott, 1998) and explains externalisation when activities are less tangible (e.g. basic research that requires high level of specific knowledge); on the contrary, internalisation processes are recommended when these activities consist on product development, diffusion or technology transfer. Other studies rely on transaction costs to explain the externalisation of activities (Robertson and Gatignon, 1998) and try to determine which technological activities might be in the market and which might be developed through collaborative joint projects. The accepted principle is the risk reduction as much for the accomplishment of great projects as in the case of new markets entrance or market uncertainty. Another issue identifies the activities associated with incremental and radical innovations to determine their degree of externalisation (see for example Khanna, 1998).

In order to achieve established objectives in joint R&D projects, it is necessary to develop a number of activities which can be grouped in stages which shape technological processes (Chiesa and Manzini, 1998). Technological processes have firstly focused on the context of linear and sequential process (Rothwell, 1994). The research has explored, in the development of different stages, non-sequential and non-linear processes as well as the multiple links as attributes of technological processes. Together with these features, Coombs et al. (2001) point out that technological processes are distributed processes among all agents involved.

From this angle we will try to study the technological process and technological aspects within the network: the type of technology developed, the type of products generated, the stages into which the process is divided, the type of partners, the interrelations and so forth. Therefore:

Proposition 2: There will be a technological subsystem in R&D networks whose finality will be to develop a technological process being its key variable the kind of project to accomplish, also the degree and type of interaction between projects.

3.3. Structural subsystem

Networks are made up by a series of organisations (universities, public research centres, companies, the government, consulting firms, and so forth) that constitute the nodes thereof, bonded by a series of links of interrelationship and interdependence. In this sense, R&D networks as voluntary cooperation agreements between two or more firms, as points out Gulati (1998), require of a suitable structure being the objectives to solve conflicts (Lorange and Roos, 1992), to coordinate common works (Geringer and Herbert, 1989) and to distribute results (Ring and Vand de Ven, 1992).

From this point of view Game Theory, provides the principles upon which the cooperation agreement is to be based – ex-ante principles – and determines the efficient solutions of the cooperative game. The ex–ante principles involve such aspects as the number of partners and the quality of the partners who are going to participate (group rationality principle) and the particular interest taken in an agreement by an individual agent (individual rationality principle). They also help to determine such questions as working efficiency and stability through an analysis of the contributions of the partners and the share-out of benefits. Game theory thus offers both a quantitative and qualitative analysis framework for achieving efficiency and stability of the cooperation agreement (Moulin, 1995). Therefore:

Proposition 3: There will be structural subsystems in R&D networks whose finality will be optimize the network structure being their key variables the degree of interrelation between members and the existence of common objectives.

Table 3: The R&D Networks as Complex Systems

Subsystem	**Variables**	
	Input	**Output**
Management	➢ **Formalization** ➢ **Planning** ➢ **Decision**	➢ **Degree of hierarchy** ➢ **Degree of structure**
Structural	➢ **Objectives** ➢ **Frequency** ➢ **Coordination**	➢ **Degree of common objectives** ➢ **Degree of interaction between partners**
Technological	➢ **Activities** ➢ **Steps** ➢ **Products** ➢ **Contacts**	➢ **Typology of projects** ➢ **Degree of interaction between projects** ➢ **Degree of sequentially of projects** ➢ **Degree of opening of projects**

4. A CASE OF APPLICATION: THE EUROPEAN R&D PROJECTS

4.1. Research design

The chosen time frame was networks in operation from 1994 to 2002 (from the 4^{rd} to 5^{th} RTD Framework Programmes). The selected sample had a population of 202 institutions. The need of a representative sample (with experience and high participation in European technological projects), urged us to chose a set of institutions at a European level, the UETPs (University Enterprise Technology Partnership) under the aegis of the COMETT Programme (Community European Technology Training Program). These make up a very dynamic set of specialised institutions with great professional experience in running European projects. The Commett Program was set up in July 1986 by the European Commission. To summarise, the objectives of the program were: to give a European dimension to cooperation between universities and enterprises for innovation training and application of new technologies. Its is important to point out that the members of the network not only participated in and managed the Commet Program but that this also had strong interrelations with other community programs, mainly of R+D

After trying out the questionnaire on five institutions that met the requirements, the definitive questionnaire was then sent to the whole set, 185 valid replies being obtained (a return rate of 91.6%). The sample error was 6.45%, with a confidence interval of 95.5% for $p= q= 0,5$. The questionnaire comprised 208 variables, structured into 35 questions. Questions could be open or closed the latter being either dichotomous or based on a Likert scale.

4.2. Results.

Following subsections show the results from the study. Table 4 presents a set of descriptive data from European R&D networks such as scientific areas, geographic distribution and typology of networks. Afterwards we analyse the main characteristics of the three subsystems marked: management, technological and structural subsystem.

Table 4. Descriptive data from the sample

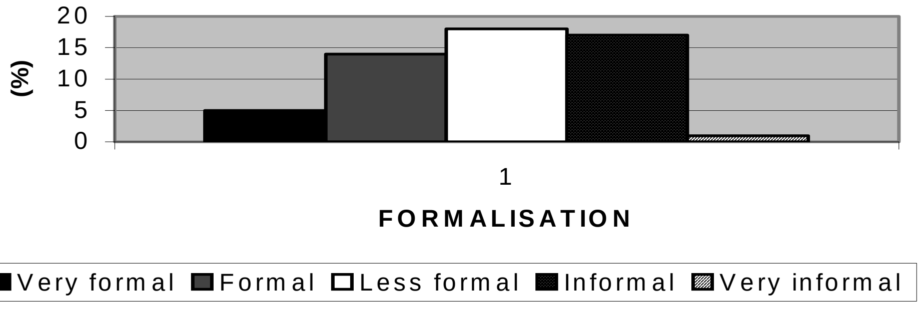
Main scientific areas		
Areas of activity	(%) of response	
Information Technologies	53	
Telematics	32	
Communication Technologies	27	
Industrial and Material Technologies	65	
Standards, Measurements and Testing	14	
Environment and climate	41	
Marine sciences and Technologies	7	
Biotechnology	4	
Biomedicine and Health	5	
Agriculture and Fisheries	26	
Non nuclear energy	1	
Nuclear fission safety	0	
Controlled thermonuclear Fusion	0	
Transport	12	
Targeted socio-economic research	48	
Distribution of replies by country		
EU and EFTA Country	(%)	
Austria	2	
Belgium	2	
Denmark	2	
Finland	3	
France	15	
Germany	13	
Greece	3	
Ireland	3	
Italy	11	
Netherlands	3	
Norway	2	
Portugal	7	
Spain	15	
Sweden	3	
Switzerland	1	
U.K.	15	
Typology of networks		
Kind of partner	Median	Mode
Universities	5	5
Industrial Partner	4	5
Consultants	3	4
Research Institutes	4	5
Industrial Liaison Units	4	4
Number of partners		
3 to 4	4	4
5 to 7	4	5
8 to 10	3	4
More to 10	3	5
Number of countries		
2 to 3	4	4
4 to 6	4	4
7 to 10	3	4
More to 10	3	1

- **Management Subsystem**

The management subsystem analyses the organisational structure and the decision-making systems, moreover the information systems that flesh the network. Related with this management subsystem (see table 5), the technological networks analysed are founded on a simple consensus-based structure with a certain ad hoc character, similar to the adhocratic structures proposed by Mintzberg (1979). The results of the study show that organisational structure created for running the network is very simple. Coordination is generally taken on by the network promoter, whose capacity of decision-taking and supervision is very limited, being subject it to the consensus of partners. There isn't a marked hierarchical structure, where lateral links serve as the main mechanism for coordination between partners. Liaison between partners is therefore usually frequent and informal. Summarising the above, we can say that network management is based on a priori planning determined by the programme requirements. The searching for consensus is a constant feature, above all in important decisions, which are taken in meetings attended by all partners.

Table 5. Degree of hierarchy and structure

Decisions to define objectives and to solve problems		
Agents	*Less important (%)*	*More important (%)*
The opinion of coordinator	12	88
The opinion of partners	7	93
The opinion of EU institutions	26	74
Criteria to planning the project		
Criterion	*Median*	*Mode*
Technological knowledge	4	4
Equal distribution	5	5
"Ad hoc" decision	4	4
Planning "a priori" of projects	4	5
Formalisation of relations between partners		



- **Technological subsystem**

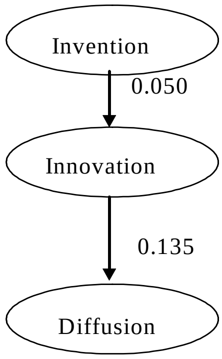
The technological subsystem, which studies not only the type of research carried out by the network but also the diverse results obtained. This technological subsystem reveals three different technological projects: innovation, diffusion and invention. The development of each kind of project implies to establish contacts outside the project as is shown in table 6.

Table 6. Tipology of projects and opening degree

Type of technological project		
Type	*Median*	*Mode*
Invention	2	2
Innovation	4	4
Diffusion	3	4
Contacts and sources of information outside the project		
Contacts	*Median*	*Mode*
Customers	3	2.5
Suppliers	3	4
Competitors	2	1.4
Research institutes / Universities	4	3
Trade fairs	3	3
Conferences and workshops	4	4
Scientific and technical literature	4	4
Results of public R&D programs	4	4
Standard legislation	3	3
Professional organization	3	4

In this subsystem, we can analyse the interrelation between the threee different projects through a structural model that shows these relations. Results from table 7 show that a low interrelation between the projects exists. Furthermore, to the weak interrelation between projects we can add the non-linearity and non-progressiveness as a characteristic of interrelation (see table 8). It allows us to consider the independence between projects and the non-sequentially linking invention-innovation-diffusion.

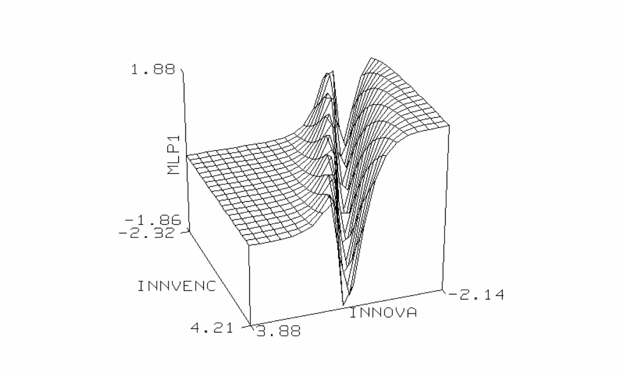
Table 7: Interaction between projects: Structural modelling



Chi-square=224 (d.f.= 69); p=0.097; GFI= 0.880; AGFI= 0.832; CFI= 0.957; RMR= 0.012 and RMSEA= 0.021

Table 8. Linearity and sequentiality degree between projects. Simulation: Multilayer perception (MLP) neural network

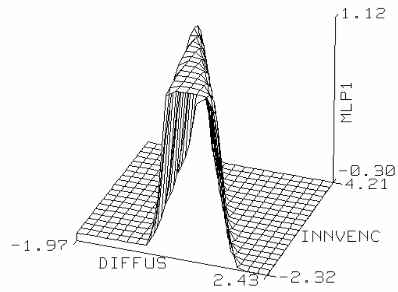
Dynamic simulation between Invention and Innovation projects



RMS Error = 0.9118765; Percent correct = 70.31%. Input: Invention and Innovation; Target: Diffusion.

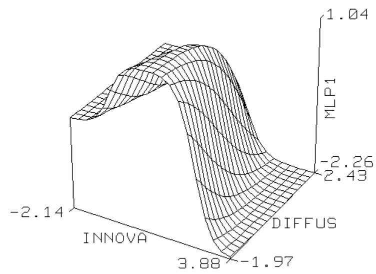
Simulation activation function: Hidden layer (Tahn) and output layer (linear).

Dynamic simulation between Diffusion and Invention projects



RMS Error = 0.948445; Percent correct = 57.35%. Input: Diffusion and Invention; Target: Innovation.
Simulation activation function: Hidden layer (Tahn) and output layer (linear).

Dynamic simulation between Innovation and Diffusion projects



RMS Error = 0.835745; Percent correct = 73.25%. Input: Innovation and Diffusion; Target: Invention.
Simulation activation function: Hidden layer (Tahn) and output layer (linear).

- **Structural subsystem**

The structural subsystem, which takes into account the kind of participating organisations and the relations and interactions set up between the agents involved in technology processes. Related with this structural subsystem, we can affirm that there is a low coincidence of objectives, despite the existence of a common incentive (see table 10). The network therefore could be defined as a coalition of institutions. This situation might lead to conflicts of interests between partners, both in the contribution (resources) and in the sharing out of results. The networks analysed in the sample do not correspond strictly speaking to cooperation networks but rather to coalitions of institutions.

Table 9. Common objectives and interaction degree between partners

Reason to participate in R&D projects		
Reasons	*Median*	*Mode*
Institution's objectives	4	4
Regional needs	3	4
Financial possibilities	4	5
Common objectives of network	2	3
Technological exchange	3	3
Others	3	3
How are organized the activities?		
Activities	*Median*	*Mode*
Each partner independently	4	5
In team with our partner	3	2
Others	2	3
Frequency of contacts		

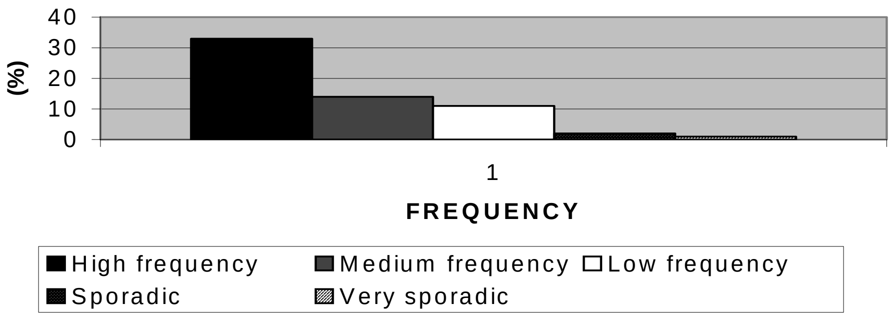


Table 10: Characteristic of European R&D networks

- *Technological networks are based on a simple hierarchy-free structure, decisions being taken by consensus with frequent informal liaison of a horizontal character.*

- *Technological projects are carried out in the network, with multiple interactions both internal and external and involving the participation of diverse agents, presenting neither a linear nor sequential character.*

- *The networks analysed in the sample do not correspond strictly speaking to cooperation networks but rather to coalitions of institutions.*

6. GENERALISATIONS AND IMPLICATIONS

Conclusions refer to the methodological sphere, the most important factor here being the consideration of networks as a multidisciplinary and complex phenomenon. In our opinion, therefore, it should be tackled from a general viewpoint, from which to generate a methodology for its study and management.

The proposed methodology would take three subsystems for the analysis:

- The structural subsystem, taking in both the kind of organisations that participate and the relations and interactions set up between the agents involved in technological process.
- The management subsystem takes in the analysis of the organisational structure and of the decision-making systems, furthermore the control and information systems that flesh out the network.
- The technological subsystem, taking in the analysis not only the types of research carried out through the network but also the diverse results obtained.

We believe that this methodology could serve as the starting point for the analysis of efficiency in the development of technological processes in networks. This analysis would be an extremely useful tool for organisations, weighing up the pros and cons of carrying out cooperative projects with other companies.

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