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Competence-Based Evolution of Contractual R&D Relationships

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ABSTRACT

This research addresses the mutual evolution of competencies and inter-organisational relationships, by using a longitudinal case study approach.

The empirical phenomena that we investigate involve the professional research and development services offered by VTT Electronics, the contract research organisation. Within this context, we are interested in the relationships of one of the focal research groups of the organisation. Examples will be provided by the research and development of fault diagnosis systems, computers embedded in various kinds of electronic products designed for real-time condition monitoring.

The evolution of the research and development relationships in the field of fault diagnosis between VTT Electronics and its research partners and customers will be analysed from the late eighties to the present date. The analysis, mainly based on written case data, addresses both the basic characteristics of fault diagnosis competence and the effect of their changes on the relationships of the focal organisation.

Finally, some empirical, theoretical and managerial implications of our analysis will be presented.

PREFACE

This report has been written in collaboration by VTT Electronics and the University of Oulu. The main purpose was to lend a fresh perspective to the analysis of the relationships between VTT and its customers and research partners. A longitudinal case study approach was used to address the mutual evolution of competencies and relationships. The research and development of the so-called fault diagnosis systems was used as a case example.

The experiences gained from the research described in this report are encouraging. By comparing the technical, managerial and marketing-oriented viewpoints of the three authors, we came up with results that were, in our opinion, quite insightful. We are looking forward to continuing the study, in order to better understand and manage the competence-driven relationships of such contract research organisations as VTT.

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Oulu, April 9, 1998

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SYMBOLS AND ABBREVIATIONS

AAAI	American Association of Artificial Intelligence
AI	Artificial intelligence
ARA	Activity-resource-actor model
CBR	Case-based reasoning
CERN	European Laboratory for Particle Physics
GSM	Pan-European mobile telephone standard
ELE	VTT Electronics (1994 -) VTT Computer Technology Laboratory (1983 - 1993)
FIM	Finnish mark
IJCAI	International artificial intelligence conference
IMP	Industrial Marketing and Purchasing
IMS	Intelligent Manufacturing Systems
KE	Knowledge engineering
KEE	Knowledge Engineering Environment
R&D	Research and development
SPC	Statistical process control
Tekes	Technology Development Centre of Finland
TKK	Technical University of Helsinki
UIF	User interface
VR	Virtual reality
VTT	Technical Research Centre of Finland
WWW	World Wide Web

1 PURPOSE OF THE STUDY

Several theoretical and empirical studies have shown that collaboration with external partners provides a valuable means for industrial organisations to foster innovation and to improve the use of their resources. These studies have identified many kinds of potential collaboration partners, such as customers, suppliers and competitors, which are capable of contributing to the development and deployment of the resources of the focal organisation [Håkansson 1987, Hamel and Prahalad 1994, Gemunden and Ritter 1996, Eriksson and Keso 1997, Alajoutsijärvi and Tikkanen 1998].

Some studies have focused on the creation and evolution of a firm's resources through research and development (R&D) relationships [Gallon et al. 1995]. While some others have investigated the relationships in the services sector, e.g. [Halinen 1994], only a few authors have addressed the mutual resource and relationship evolution in independent research and development service organisations [Leppälä 1995]. Focusing on such an organisation, we are now introducing an integrative approach to competence-based evolution of R&D relationships.

Our research concerns VTT Electronics and its predecessor, VTT Computer Technology Laboratory (both later referred to as ELE). We will be reporting our observations of competence-based evolution and management of the ELE fault diagnosis relationships over a period of ten years, from the late eighties to the present date.

This kind of approach has been recommended in a recent technology management study [Reger and Schmoch 1996], for example. In contrast with a majority of the core competence literature that addresses competencies within a single company, we are studying inter-organisational relationships as a means of creating, managing and evolving competencies.

The first part of this report presents a review of some existing frameworks and concepts for the two relatively independent areas: organisational competencies and industrial relationships. The aim is to create a structural basis for bringing these two areas together. Then, the research methodology used in the study will be discussed. The case that we have studied, i.e. the contractual research and development of fault diagnosis systems, will be described by using a longitudinal approach. The framework that we have developed is then presented and used to analyse and explain the mutual evolution of the fault diagnosis competence and R&D relationships of the focal organisation. Finally, a few empirical, theoretical and managerial implications of the analysis results will be discussed.

2 COMPETENCE DEVELOPMENT IN INDUSTRIAL NETWORKS

In this chapter we will first discuss some approaches to understanding and analysing competencies, then the research on industrial relationships and networks will be dealt with, as well as a few examples of integrative approach. The two areas that we wish to link together in our research are addressed to some extent separately in this chapter, because the corresponding research communities are still rather far from each other. The few exceptions include, e.g. [Easton and Araujo 1996, Alajoutsijärvi and Tikkanen 1998, Rosenbröijer 1998]. We refer to [Reger and Schmoch 1996] as a recent, comprehensive study of research and development in general, and to [Leppälä 1995, Miettinen 1996] as studies of contractual R&D that involves VTT.

2.1 ELABORATING THE CONCEPT OF COMPETENCE

Since the publication of Prahalad's and Hamel's Harvard Business Review article "The Core Competence of the Corporation" [1990], the concept of competence has attracted a great deal of attention. The term heralds a revival of what has come to be known as the resource-based view in marketing [Pfeffer and Salancik 1978]. In the most general sense, competencies refer to organisationally embedded knowledge assets that can deliver differential values through a certain functionality for which a customer is willing to pay. According to Hamel and Prahalad, *competence* is “a bundle of skills and technologies rather than a single discrete skill or technology”. *Core competence* has to be something competitively unique, extendible and capable of creating customer-perceived value - Hamel and Prahalad simply characterise “core” as a synonym for “critical”, when speaking of competencies. Physical resources are not competencies, since competence is an aptitude. However, an aptitude for managing things may contribute to competence.

2.1.1 Characteristics of competence

Competence at a general level refers to knowledge and skills needed for choosing which tasks to perform, as well as why and how to perform the chosen task [Sanchez 1995]. The content of competence, i.e. the knowledge and skills related to a certain task, is thus important. In the context of R&D, *knowledge* can be interpreted as an understanding of the task to be accomplished [Numata 1996]. Functional and conceptual designs are crucial in R&D. The key points in conceptual design skills include allocation of product functions to subsystems and implementation technologies. Currently, in most cases the design process is event-driven, while from the viewpoint of knowledge formation, however, the process either deals with tacit or articulated knowledge, involving skills needed in the generation and verification of functional and conceptual design solutions.

A distinction can also be made between relationship-specific, portfolio-specific and generic competencies, which offers another interesting viewpoint on organisational interactions. Along a related dimension, individual, team-based, organisational and inter-organisational competencies can be identified [Eriksson and Ropo 1995]. For example, relationship-specific competencies can be created and exploited at the level of organisational teams, like in the fault diagnosis case discussed in this report.

Content

Core competence must achieve criticality by means of its utility and scarcity. It must include something that is experienced as being simultaneously useful and difficult to acquire from alternative sources [Boisot et al. 1995]. Yet, this is not the same thing as the narrowness of competence; wide capabilities may be rare and thus create a good basis for competence. The content of competence is typically divided into technological and managerial components. A more theoretical typology is presented by Sanchez [1995]. According to Sanchez there are three different kinds of competence content: *know-what*, *know-why*, and *know-how*.

The "know-what" content of competence can be defined as an ability to choose an important task from among a number of alternative, less important tasks. In a sense, "know-what" involves the strategic understanding of the purposes where "know-how" and "know-why" can be applied successfully. "Know-why" concerns the understanding of the principles that govern the functioning of a process related to a task. "Know-how", in turn, concerns the ability to change the current state of a system into a desirable direction, by carrying out the task. According to [Sanchez et al. 1996] competence is “an ability to sustain the coordinated deployment of assets in a way that helps a firm to achieve its goals. To be recognised as competence, a task on an asset must meet the three conditions of organisation, intention, and goal attainment.” Goals are thus sets of desired states of a firm’s system elements, operations, assets, management processes and strategic logic. [Håkansson and Snehota 1995] also point out that a company’s assets, especially its resources, are usually considered as given entities, but on a closer look it is the use of an entity that determines if it is a resource or not.

A resource can therefore be viewed as a relation between the provision and usage of some entity, rather than only the entity. Resources are both results of and conditions for some tasks, i.e. they are variable and not static. Resources can be changed in two ways, either by modifying their features (*resource transforming* tasks) or by changing the way or purpose for which they are used (*resource transfer* tasks). In other words, the two basic competence exploitation tasks involve resource transforming and resource transfer. According to [Hamel and Prahalad 1994] *resource allocation* has received too much attention in comparison with the task of *resource leverage*. The latter can be achieved in five ways: concentration of resources on strategic goals, efficient accumulation of resources, complementation of new types of resources to create higher-order value, conservation of resources, and recovering of resources by minimising the time between expenditure and payback.

Institutionalisation

Individual *capabilities* are attributed to individuals as traits or characteristics which result in efficient work performance. Examples for this predominantly psychological perspective will be provided by the studies of managers' leadership skills [Yukl 1994] and participation [Heller 1993]. Industrial relationships can be seen as processes where individuals act and react, as well as interpret and reinterpret each others' actions [Ford et al. 1986]. As a result, the participants learn the key issues concerning social behaviour, as well as the technological and managerial capabilities related to the interacting organisations and their contexts.

[Sanchez et al. 1996] views capabilities as “repeatable patterns of action in the use of assets to create, produce and/or offer products to a market.” A *skill* is “a special form of capability, with the connotation of a rather specific capability useful in a specialized situation or related to the use of a specialized asset”. Resources are assets that are available and useful in detecting and responding to market opportunities or threats. They include capabilities, but also other kinds of useful and available assets.

In addition to individual capabilities, there are collective knowledge and skills which are built and used in collaboration. In this research we regard these as competencies, rather than individual knowledge and skills. Competencies at the team level include capabilities for acquiring and enhancing certain expertise, producing significantly new expertise and increasing customer-perceived value [Mäenpää 1997]. Depending on the context, team-based competencies may involve informal interest groups, project teams and operational groups of the line organisation.

Firms can also be interpreted as having certain competencies at the organisational level [Prahalad and Hamel 1990, Boisot et al. 1995]. Furthermore, competence can also be identified at the level of inter-organisational networks (cf. [Henders 1992], pp. 143 - 157, networks with their "own-characteristics"). Individuals involved in a relationship within an inter-organisational network can be interpreted as forming quasi-organisations with their own specific capabilities [Alajoutsijärvi and Tikkanen 1998].

Mainstream management and marketing management literature emphasises generic “good management practices”, often presented as rather universal abstract capabilities that can be transferred across companies and industries. Theoretical studies (e.g. [Cooper and Kleinschmidt 1996, Leppälä 1995]) and practical surveys [SRI 1996] have been performed to identify good R&D practices, along the lines of the general management literature. The idea of *generic competence* works on the assumption that through the detection of general laws it is possible to apply abstractions for producing certain “effects” or forecasting the unfolding of events [Lilja et al. 1993]. As a critique to this view, the substantive approach is becoming increasingly important in management and marketing studies [Pettigrew and Whipp 1991, Eriksson and Ropo 1995, Alajoutsijärvi 1996]. *Substantial competence* refers to knowledge and skills created within relationships. Codification affects the possibilities of creating and exploiting substantial competence.

Codification

An important issue in understanding the concept of competence is the level of codification: competence, be it knowledge, skills or capabilities, may be *tacit* or *codified* [Boisot et al. 1995, Sanchez 1995]. Tacit or implicit knowledge is not articulated. It can usually be transmitted (the term "diffuse" is often used) only slowly in face-to-face situations and often only to a limited audience, under the conditions of trust and shared experience.

Codified knowledge, in contrast, can be transmitted much more rapidly and impersonally to larger audiences. By definition, generic competence is well-articulated, while tacitness is more typical of relationship-specific competence. Much of the current discussion of competencies advances the proposition that the tacit knowledge of a firm is more likely to be the source of a competitive advantage than its articulated knowledge. The reasoning on the basis of this notion goes as follows: if some knowledge is articulated, it can be understood by anyone and as a result can diffuse beyond the individuals and their organisations, which in turn leads to the loss of the competitive advantage. We do not take this view for granted (for barriers of diffusion see [Sanchez 1995]). On the contrary, we assume that in order to turn into core competence, skills and knowledge must be institutionalised [Hamel and Prahalad 1994, Alajoutsijärvi and Tikkanen 1998].

2.1.2 Competence evolution

According to [Hamel and Prahalad 1994], competition for competencies takes place at four levels: development and acquisition of constituent skills and technologies, synthesis of core competencies, maximisation of core product share, and maximisation of end product share. Synthesis of competencies requires harmonisation of various skills and technologies, in which "generalists, not just narrow specialists" are needed. A portfolio of competencies must be created and maintained for synthesis. A core product, or *a core platform* in the case of services, is most typically "an intermediate product somewhere between the core competence and the end-product".

Hamel and Prahalad claim that there are five key competence management tasks: identifying existing core competencies, establishing a core competence acquisition agenda, building core competencies, deploying core competencies, and protecting and defending core competence leadership. Their view of competencies is, however, that of a big corporate rather than a small organisational group, like that in this study.

According to [Sanchez et al. 1996] competencies must be *built* (qualitative changes of assets and capabilities dominate), *leveraged* (quantitative changes in assets and capabilities dominate) and *maintained*. [Sanchez and Thomas 1996] define competence building as "the process by which a firm creates its strategic options" and competence leveraging as the process by which the firm "exercises its existing strategic options".

From a managerial point of view, the knowledge of individuals must be linked and coordinated with other individuals within and between organisations [Sanchez 1995]. Thus, the building of competencies requires not only creating and possessing knowledge, but also having effective processes for deploying knowledge within and across the organisation boundaries.

To leverage the skills of individuals, an organisation must first be able to identify the strategically useful knowledge of its own members and that of other organisations. After identifying the relevant knowledge and skills available to the firm, managers must know how to transfer the central knowledge of the key individuals to other individuals, groups within the organisation or across several organisations.

Furthermore, managers must be able to manage the diffusion of knowledge, especially between organisations since diffusion may diminish the distinctiveness of the competencies of the organisation. According to [Sanchez 1995], the content of competence, i.e. know-what, know-how and know-why, can have different degrees of strategic significance in different contexts. Therefore, it may be reasonable for managers to diffuse only certain aspects of the content in terms of a specific relationship [Alajoutsijärvi and Tikkanen 1998].

2.2 UNDERSTANDING INTER-ORGANISATIONAL RELATIONSHIPS

Various conceptual frameworks and models have been suggested for describing organisational buyer-seller relationships. We will discuss the rapidly growing literature on such relationships to the extent that is relevant to our study. For a recent meta-theoretical review see [Möller 1994].

2.2.1 Elements of relationships and networks

The research on the processes related to relationship development has drawn heavily on the social exchange theory [Thibaut and Kelley 1959]. Researchers have highlighted buyers' and sellers' motivational investments in the relationship and their perception of the developing expectations, trust, satisfaction and commitment [Anderson and Narus 1984, 1990, Dwyer et al. 1987, Wilson and Mummalaneni 1986]. From our point of view, this research stream fails to involve the competence management perspective associated with the exchange, which we consider essential for the development of inter-organisational R&D relationships.

Another view of inter-organisational relationships is provided by the researchers examining the governance structures of dyadic relationships. Based primarily on transaction cost economics [Williamson 1985] and on the organisational dependence theory [Pfeffer and Salancik 1978], the researchers have shown how exchange conditions influence the nature of the exchange.

The continuum of changes in these conditions ranges from competition-dominated transactional exchange through co-operative exchange to the dominance of either party [Anderson and Coughlan 1987, Heide and George 1988]. While providing a contingency type understanding of dependence of the relationship, the governance structure research is rather static and the factors related to mutual interaction remain faceless macro forces.

Within the Industrial Marketing and Purchasing (IMP) group and based primarily on the resource inter-dependency notion, [Campbell 1985] and [Möller and Wilson 1988, 1995] have subscribed to the contingency of business relationships. They argue that the character or mode of a focal relationship depends on a complex set of variables, including product-related, actor-related, organisational and industry-related factors. Compared with the rather deterministic transaction cost analysis inspired work, these authors assume a more enacted view of the business environment incorporating experience-based differences in managerial perception and organisational learning. The most serious limitation of the contingency perspective is, however, its static character and its inability to highlight the business dyad beyond the dyad's type or state. Competencies are not addressed in this stream of research either. For example, [Halinen 1994] takes them for granted, when addressing the development of a dyad between an advertisement agency and its client.

2.2.2 Evolution of relationships

A well-known conceptualisation of the evolution of industrial relationships is presented in [Ford et al. 1986]. In this classical article "How do companies interact" Ford and others argue that an inter-company relationship is basically ambiguous rather than clear cut. They propose four interrelated factors for characterising relationship changes: capability, mutuality, particularity and inconsistency. *Capability* describes the relationship between the interacting parties, be they organisations or individuals, in terms of what they can do for each other by using their resources. In the case of the monopoly of a supplier or a monopsonistic buyer, the relationship is based on a single capability by either party, while only one organisation has that capability. In perfect competition the relationship is also based on a single capability, but the capability is a commodity. If broader resources are required in relationships, they tend to move into a direction where differences between alternative actors are greater. This may lead to relationships based on broad resources and small differences between alternative actors, which is rather common in industrial networks.

Mutuality is a measure of the degree to which an organisation is prepared to give up its goals or intentions in order to increase its own ultimate well-being. This factor involves a trade-off between short-term opportunism and long-term gains. Mutuality can only be demonstrated over time and critical situations - the existence of conflicts presumes a certain level of mutuality. It is common for industrial organisations to have an overall idea of mutual interests, while simultaneously being in conflict over what should be their respective contributions towards the joint achievement.

Particularity characterises the relationship in terms of its direction and uniqueness. In extreme cases, where the relationship between the parties is unique and directed solely towards each other, there is a high degree of particularity.

Inconsistency refers to ambiguity or lack of clarity. The relationship may be inconsistent over time, or there may be inconsistency between different relationships of the same partners undertaken by different organisational units or persons. This concept focuses not only on relationships between parties with conflicting interests, but also between parties that have common interests. Inconsistency implies the opportunity for short-term expediency or changes in individual activities (cf. the *project cycle* in [Alajoutsijärvi 1996]), without changes in principal relationship policies (the *long cycle* in [Alajoutsijärvi 1996]). In this way, inconsistency captures the dynamic nature of relationships and characterises the activities of an organisation with respect to the other three factors.

2.3 RESOURCE-BASED VIEWS TO RELATIONSHIPS

The integration of the competence and relationship perspectives is perhaps most apparent in the studies that address the development and use of resources in business relationships, although such studies a still rather rare. [Easton and Araujo 1996] claim that “the possibilities for the use of a specific resource can never be fully specified”, but suggest that the ARA (activity-resource-actor) model [Håkansson and Snehota 1995] should be studied to be able to articulate what types of actors and resources exist and how their different configurations give rise to different relationship and network structures and processes. The ARA model serves as a starting point in our research. Since the model is one of the most widely used and discussed conceptual frameworks for industrial relationships, we only summarise its main characteristics here and refer to Chapter 5 for more details, where the model is used to describe the fault diagnosis related R&D relationships and resources of the case organisation.

According to Håkansson and Snehota, three layers of the “substance” of a business relationship can be identified by using the ARA model: *activities*, *resources* and *actors*. The effects of a relationship based on these three concepts are called functions. They can be identified for an individual firm, for a dyadic relationship and for a network of several actors. At the level of a firm, activity structures, resource collections and organisational structures can be formed. At the relationship level there are *activity links*, *resource ties* and *actor bonds*. Networks consist of *activity patterns*, *resource constellations* and *webs of actors*. From the viewpoint of a firm, the main problem is how to balance these functions to maintain relationships or networks. When the functions are put together at the three levels, an analytical framework consisting of activities, resources and actors vs. firms, relationships and networks will be formed (cf. Table 2, Chapter 5).

[Easton and Araujo 1996] propose several dimensions alias attributes to be studied for the resource layer: *existence* (creatability, depreacibility, durability), *evaluation* (valuation, evaluability, scarcity, positive or negative value), *relationships to actors* (controllability, accessibility, tradeability), and *relationships to other resources and activities* (integrity, versatility, complementarity, understandability). Easton and Araujo claim that the more difficult it is to access, own and control resources, the more individual firms must rely on exchange relationships and specialisation of resources and activities. The general product and process technologies used in the industry are, on the contrary, widely known and available: “they are described in technical journals in articles authored by leading technologists employed by competing firms as a form of promotion”.

[Elfring and Baven 1996] address the mutual evolution of resources and business relationships in knowledge-intensive services, such as engineering design and software development. The learning and capability development in the four evolution stages that they propose are characterised by external exposure (alliances, demanding clients), learning from clients, leverage of client relationship and development of internal organisational capabilities that they classify into functional and application capabilities. The former are the skills of the organisation related to its function, e.g. software engineering skills in a software house. The latter are needed for tailoring the functional capabilities to the needs of specific relationships. For example, a software house could need the knowledge concerning discrete parts production, if it is serving a car manufacturer.

At stage one, functional capability is used in house to serve a specific application. At stage two, the capability can be leveraged to several customers within an industry, and upgraded by learning from the different applications involved. Application expertise generated from completed projects is pooled. At stage three, this is not limited within the context of a single industry. At stage four, cross-marketing of combinations of different functional capabilities to different industries and applications can be done successfully. This process resembles the charter of many contract R&D organisations, such as VTT, in the sense that technological expertise is first created and then attempted to transfer to different kinds of industrial applications.

[Rosenbröijer 1998] takes the systems approach to capability development in industrial relationships and networks, based on resource usage tasks carried out by actors. Rosenbröijer considers resources as the basic elements of the capability of a firm, and points out that these are heterogeneous and dynamic, i.e. they change over time. The levels of firm (internal), relationship (external) and network (external), i.e. the three levels of the ARA model, are used by Rosenbröijer to analyse the development and integration of the focal firm’s capabilities, when interacting with other actors. Rosenbröijer defines competence as “a combination of knowledge and experience in combination with a special task”, whereas capability is the “ability and willingness to organise a mix of resources for productive activities, where resources are the basic elements to the activities in question”.

This means, according to Rosenbröijer, that there “are no total capability for a firm based on its whole resource collection”. This view is somewhat opposed to the core competence thinking, and it emphasises the one-of-a-kind alias relationship-specific capabilities. For the same reason Rosenbröijer sees that resource changes “might be unlimited”.

Rosenbröijer uses a typology based on financial, physical, organisational, human, technological and reputation resources. We have applied and extended this typology in our research, with an exception that individual knowledge is not included in organisational resources, but in the human resources. Moreover, we do not share Rosenbröijer’s assumption of resources from all the categories being equally important and becoming evenly mixed and integrated with other firms’ resources in relationships and networks.

At the network level Rosenbröijer makes a distinction between direct and indirect relationships. However, he claims that a situation where the focal firm makes the same resources available in the same way to several partners is “only theoretical” due to the unique division of labour between firms belonging to the same network. Speaking of contract research and development, this kind of situation is actually very common in so-called joint research projects and customer consortium projects.

Rosenbröijer also claims that relationship ends are “arbitrary and subjectively set by either researchers, managers, etc.” of the interacting parties. This is not true for contractual project-based R&D relationships, because the ending of a project is one of the most carefully planned and monitored aspects of a relationship.

2.4 PRELIMINARY CONCLUSIONS

The phenomena under study in the two research traditions forming the conceptual basis of this report, i.e. competence and network literature, are clearly interwoven, seen from the managerial point of view. The foci of the two approaches are reciprocal in managerial work. In summary, the development of inter-organisational relationships involves simultaneous identification and enhancement of competencies, and vice versa.

On the basis of what has been stated previously in this chapter, we will concentrate on the study of how competencies develop over time within the relationships of the focal organisation, i.e. in its *focal net*. The focal net is a part of a greater industrial network structure. Its main function is to capture all the network features that might have relevance to the focal organisation, from the chosen perspective. The boundaries of the focal net are defined and the whole net is perceived according to the views held within the organisation. Consequently, as the main unit of analysis the focal net reflects the strategic identity or position as seen by the focal organisation.

We will not yet construct any strictly categorised analytical model for describing and analysing the focal net of our case organisation. Yet, we will present a framework in Chapter 5, which is based on the ARA model [Håkansson and Snehota 1995] and which can be used, in practice, to make explicit and to evaluate the mutual evolution of the focal organisation's competencies and relationships. In this chapter, we have confined ourselves to a brief explication of the concepts that we wish to emphasise in the subsequent description and analysis of the case study.

The identification of the elements in the fault diagnosis R&D competence of the case organisation forms a basis for the definition of the relevant focal net, within which the competence has been made operational and has developed. The focal net engaged in the creation of customer-perceived value either directly or indirectly is modelled and studied by using the basic substance layers of the ARA model, actors, resources and activities.

Actor bonds and webs made explicit by the ARA model form a governance structure, in terms of which competence evolution can be analysed. Even more importantly, the resource dimension of the ARA model provides for an immediate link between the competence-based competition theory and the concepts of industrial relationships [cf. Easton and Araujo 1996, Rosenbröijer 1998, Alajoutsijärvi and Tikkanen 1998].

We will view the relationships of the contract research organisation through the development and exploitation of its competence, in this case the research and development of fault diagnosis systems. An opposed approach, i.e. analysis of focal organisation relationships where many different types of competencies can be used, has perhaps been more typical (cf. [Rosenbröijer 1998]) in the studies of industrial relationships.

A practical reason for the reversed approach can be seen in the fact that a contract research organisation can seldom afford to focus only on a single party when developing and making use of certain competencies. The charter of the case organisation of this research, for example, defines clearly that it must be able to serve the industry as a whole. The phrase *competence networking* that we will use in this report is also intended for emphasising the fact that an organisation competence changes, in practice, through its focal net, which in practice involves many different parties.

We will use the ARA model as a starting point for building an R&D *competence networking framework*. The framework that consists of several interrelated concepts is used to describe and explain the evolution of the fault diagnosis competence in the case organisation, as it has taken place within its relationships from the late eighties to the present date.

In order to better understand the elements of the fault diagnosis competence, we address a rather low aggregation level of actors, one research group of the focal organisation. Since our analysis is largely based on documentary data, we view external actors mostly at the level of firms and their typical employees, such as "automation engineers". Moreover, we will not analyse the evolution of the fault diagnosis competence of the external actors in detail, due to their relationship with the focal organisation.

3 RESEARCH METHODOLOGY AND DATA

The methodological choices in our study are guided by the purpose to increase the understanding of the mutual evolution of competencies and inter-organisational relationships. The longitudinal study [Halinen and Törnroos 1995] was chosen to cover the development of these phenomena over time. A perspective of several years is necessary for capturing the dynamics involved in industrial changes.

In this research we address a period of ten years, from the late eighties to the present date. This period covers most of the life time of the kinds of fault diagnosis systems that we are studying. It shows the rapid rate of technological changes, which has directly affected the evolution of the case organisation relationships and competence. Some of the most critical macro forces involved in the environment of the case organisation can also be pointed out.

One of the main aspects in our research methodology is its qualitative nature. A profound understanding of the development of industrial relationships and competencies involves examining and understanding them as they are or were in real life [Pettigrew 1987]. This suggests adopting a case study approach. Only a few longitudinal studies, such as Liljegren [1988], Lundgren [1991], Halinen [1994] and Alajoutsijärvi [1996], have been carried out on the development of inter-organisational relationships. Studies on competence development are even more exceptional [Eriksson and Keso 1997, Rosenbröijer 1998, Alajoutsijärvi and Tikkanen 1998].

Easton [1992], Cova and Mazet-Crespin [1996], and Tikkanen [1997] have discussed constructivist approaches to relationship and network studies. We wish to emphasise the relevance of this discussion by pointing out that competencies are constructed and evolved through activities carried out within relationships. Therefore, competencies are not fixed or given tasks on some pre-existing resources, but they are constantly being developed and managed as part of the evolving relationships of the organisation. Although we do not focus in this research on the problem of how to construct competencies, we show and analyse the evolution of the case organisation competence through certain R&D activities.

Access to a good case example is crucial in our approach. We argue that the R&D of fault diagnosis systems analysed in this report provides a good representation of both the kind of technical problems solved by contract research organisations and the types of relationships in which the problem solving processes take place. One of the most interesting aspects of the case example is that the creation of related competence within the focal net has indeed led to totally new relationships, which have further reshaped the competence. We attempt to identify, trace and analyse this evolution process from a competence-based viewpoint.

An important issue in a scientific case study is the access to data. We have used both public and corporate archives, as well as personal diaries of the key actors. Yet, it is difficult for a researcher to access tacit knowledge in a longitudinal study. For example, it is not straightforward to interpret notes made by individuals, while official documents usually describe only the final results and the most important management decisions. We are coping with tacitness by the fact that the first author of this report is an engineering research manager and an expert in contract research, the second author is an expert in business relationships and the third shows expertise in the systems to be studied. We do not claim that this is mandatory, but it has certainly helped us to better understand the complex phenomena that we are investigating.

According to [Miettinen 1993] the means of implementing source criticism in studies that involve innovations, such as joint R&D of systems that have never earlier been implemented, include the so-called “grey literature”, i.e. the use of different kinds of working reports in which the actors may have written down remarks that are polished away from more formal, scientific publications; articles in professional journals intended to be read not only by researchers, but also by practitioners and decision makers; popular presentation and marketing material by which the benefits of the innovation are described or the work is being motivated; newspaper and journal articles meant for a large audience; plans of action and annual reports that may, in particular, illustrate the views of decision makers; project plans and reports that illustrate the researchers’ motivations, although these may often be rationalised and tidied; records and personal notes made in meetings or on other occasions, by using personal notebooks; and notes on laboratory experiment that may describe the procedures being used and the problems and success encountered.

We have used all these kinds of written sources in this research, except laboratory experiment notes, as well as a limited number of interviews of the key informants. The research data has therefore been validated both by method and informant triangulation, i.e. by comparing the data acquired with the help of different methods and by cross-checking the data given by different informants [Miettinen 1993].

We have selected an augmented grand story approach to describe the case example. The grand story is a description of how the fault diagnosis competence emerged in the case organisation, in connection with the evolution of its external relationships. The story has been augmented by snapshots from the research data that illustrate, in particular, the often conflicting views and feelings of the participating actors, or occasionally of external individuals used to evaluate the results of certain relationships. Augmentation also provides insights into a more extensive integration of documentary data and interview results in the next phase of our research. The augmented texts have been selected both from public archives and from personal R&D diaries.

4 THE CASE OF FAULT DIAGNOSIS R&D

VTT Electronics, the case organisation of this study, offers *contractual R&D services* in the field of electronics. According to [Reger and Schmoch 1996], "research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications".

The R&D services of ELE cover a wide range of electronic technologies from microelectronics to computer software. The engineering skills mastered by the institute include, correspondingly, a variety of electronics and computer related techniques. In addition to electronics firms, ELE deals with companies that use electronics as a supporting product technology.

4.1 OVERVIEW OF VTT ELECTRONICS

Within ELE, we address research and development of the so-called *fault diagnosis systems* used in different kinds of electronic products to monitor and diagnose the condition of the controlled product and to help to recover from errors. Present fault diagnosis applications dealt with by ELE range from process control and machine automation to electronics assembly lines, moving vehicles and telecommunication networks. One of the main technologies used for implementing fault diagnosis systems at ELE has been *embedded software*, i.e. computer programs incorporated in dedicated hardware. The so-called *knowledge engineering techniques* have been used extensively by ELE in the development of fault diagnosis systems. Knowledge engineering is a special area of information systems and software engineering, focusing on such artificial intelligent (AI) computing techniques as logic programming, fuzzy and expert systems, neural networks and genetic algorithms. One of the ELE research groups specialises in knowledge engineering (KE).

This group, currently employing about twenty persons, is the focal actor in our case study. It has been responsible for R&D activities related to fault diagnosis systems since 1987. Most of the researchers of the KE group are university graduates in electronics and computer engineering. Almost all of the group's R&D activities are carried out as *projects*, which form a constant flow of relationships with ELE and its external parties. Many projects involve multiple actors whose competencies are integrated together and sometimes overlap, be they other research institutes, customer companies' own resources or other subcontractors. This situation differs from an inter-organisational relationship, where the seller is an expert service organisation, while the buyer does not have a similar capability (cf. an advertising agency and its client in [Halinen 1994]), and from a relationship where the seller develops and delivers dedicated technologies in which the buyer has decided to invest, but does not have the capability to develop these by itself [cf. a paper machine manufacturer and paper mills in [Alajoutsijärvi 1996]. On the other hand, ELE is not usually an expert in the customers' businesses.

Most of the representatives of ELE customers involved in the projects are themselves R&D experts in electronics. One of the results of this is that the customers' own employees may be partners and competitors as far as certain R&D tasks are concerned, although their context for carrying out R&D is different and their expertise is often more application-oriented than that of ELE. Yet, individual opinions and skills concerning the content of planned or delivered R&D services, as well as internal competition on resources both within ELE and within its customer, may strongly affect the evolution of a joint business relationship. This fact is our basic motivation for analysing "low-level" organisational and project groups, rather than the firm level. The following note made by an ELE research group manager during a customer visit, in which the results of two fault diagnosis projects were evaluated, illustrates the competence-related and competition-based conflicts that may arise in these relationships (customer meeting, 14.10.1994 K-e Oy):

> *V-o1 project: "Can this [fault diagnosis] method be used to predict future faults? [The project] did not succeed. No answer was gained". V-o2 project: "The same question is valid. We cannot continue based only on this idea. Other, competing ideas must also be tried. Is the approach too complex, does it apply to moving machines, is the model-based approach too 'complete'? Is the goal to solve problems or to develop academic theories?"*

Strategic research projects financed mostly by ELE itself are targeted to creating certain organisational competencies. These *"green"* projects include about 20% of the total project portfolio. Other projects are financed jointly by public funding bodies, ELE and its industrial partners. Their purpose is a further development and preliminary deployment of competencies. These *"blue"* projects comprise about 40% of the institute's project portfolio. The rest, the so-called *"red"* projects, are carried out for individual customer companies or sometimes for a consortium of several companies. The degree of industrial financing of the projects increases correspondingly, in green projects it may be half to one percent, whereas in blue projects it is typically twenty percent and in red projects a hundred percent. This kind of project portfolio is intended for supporting the "technology transfer" from research to industrial practice, as well as for reducing the risks involved in developing products based on new technologies, Figure 1. From the viewpoint of competence evolution, the "whats" of new technologies are assumed to develop towards "hows" and "whys" and individual knowledge and skills to organisational competencies at the same time.

In terms of the typology presented in [Alajoutsijärvi 1996], the portfolio includes many red projects for "technology-transferring" (existing competence is transferred to a single new relationship), green projects for "learning" (new competence is created in a network that is often based on existing relationships) and blue projects for "breakthroughs" (new competence is created or existing competence is extended in a new network). Some "routine" projects (existing competence is leveraged in an existing relationship) are also being carried out. In general, one of the basic problems in ELE is how to ensure the "right colour" of its R&D activities.

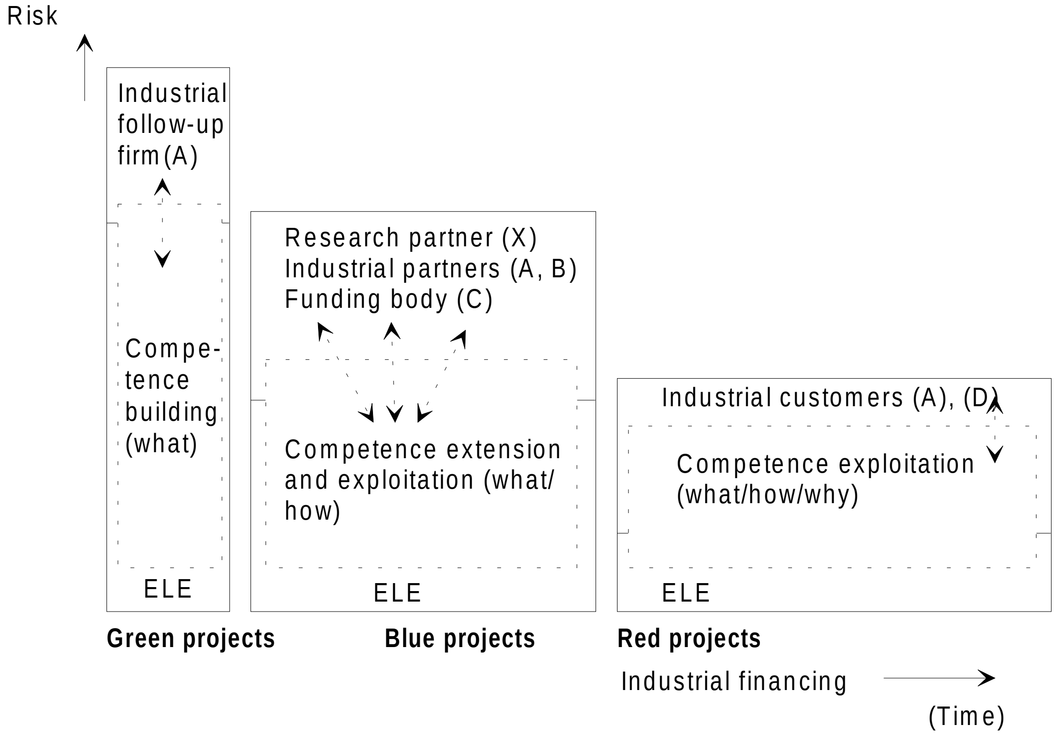

Figure 1. The intended project portfolio of VTT Electronics.

In practice the situation is, of course, much more complicated than what is shown in Figure 1. Yet, especially the different role of financial resources in the three compartments of the project portfolio directly affects the mutual evolution of relationships and competencies. Relationships are supposed to evolve from capability building (dyads in which individual companies participate by following and commenting projects in which ELE is creating some skills) via capability building and extension networks (several parties develop and exploit jointly the same capability) to competence leverage relationships (customers exploit the ELE competencies in dyads, by exchanging and integrating them into their own competencies). Occasionally, the latter may involve small networks of two to three customers that wish to exploit the same competence.

4.2 THE STORY OF THE FAULT DIAGNOSIS R&D

In the late eighties, a small KE research group of about five persons was established at ELE by extracting it from a larger software engineering research group. One of the main reasons for this reorganisation was the ongoing interest for "intelligent" knowledge-based systems. The interest was growing rapidly world wide.

The group was established by the ELE management mostly to support the launching of new research and development projects, financed by a newly established engineering R&D funding body Tekes and by individual industrial companies. Another important goal was to help a number of researchers to gain expertise in this new area. None of the original members of the group had much formal training or previous experience in knowledge engineering.

4.2.1 Late eighties - knowledge engineering research

Fault diagnosis was not included in the topics addressed by the KE research group it the beginning. In the late eighties, Tekes established a national AI research program, but ELE was not participating in the early “blue” fault diagnosis projects carried out as part of that program. The program involved the use of knowledge engineering techniques in a wide variety of applications. The R&D work of ELE in this program addressed *machine automation* applications.

Since AI techniques were being actively researched everywhere, also industry became interested in applying them. This interest was indicated by the fact that especially bigger companies were hiring knowledge engineering experts or were training their personnel on knowledge engineering techniques. In many cases the persons involved were, however, working in the research departments of the companies and not in actual product development departments. The industrial professionals who needed to know more about AI techniques were actively seeking for contacts with researchers. The initial relationships of the KE group started to emerge in the late eighties, involving thus quite a number of industrial professionals who were wishing to associate with researchers [Linnainmaa 1990]:

> *“In 1985 two [AI] research programmes were launched [in Finland] that focused on knowledge engineering. The main implementors of the programmes were the researchers of VTT and TKK [The Technical University of Helsinki], but also industry participated in the programmes in a considerable volume.”*

In connection with the AI research program ELE, together some other VTT institutes, universities and a few industrial organisations, invested in expensive development tools (extract from VTT’s letter to the Ministry for Financing, 1.8.1986):

> *“VTT plans to purchase 5 Symbolics machines [in total 1 809 349 FIM] and one Xerox AI workstation [160 000 FIM], plus 5 KEE software development environments, 4 of which will cost about 700 000 FIM”.*

The use of the *special tools* contributed to bringing the knowledge engineering experts of ELE and its customers closer to each other, thus making the relationships tighter. One of the ELE goals was to develop knowledge-based applications by using these tools, and then port the solutions to various kinds of target computers. This "embedding" of knowledge-based systems was thought to become a special capability for ELE, as ELE had been dealing with embedded target computers for many years. The approach was accepted also by the industrial sector, as it was believed that knowledge-based systems needed to be developed using specific techniques and tools, after which the developed solutions could be transferred into more conventional computers for usage. By the mid-nineties, however, most of the special tools had completely vanished as they had been replaced by general-purpose computers. The embedding problem had also disappeared. Investments in the special AI tools had become obsolete [Husso 1993]:

> *“At the beginning of the AI project companies, VTT and universities acquired plenty of AI tool related technologies. The tools important for carrying out the project were very expensive. These include, for example, Symbolics workstations. Investments in Symbolics machines were rather heavily criticised after the project - at present [1993] they are not much used any more.”*

A number of process and machine automation firms had taken part in the AI research program and had thus become interested in knowledge-based techniques. Yet, only few automation and control system professionals saw these techniques as a means of making their systems more "intelligent". Instead, they were facing such problems as how to cope with the data processed by the computers incorporated in modern, automated machines. Knowledge engineering techniques were proposed by ELE researchers as a means of solving the problems concerning data management and usage, by taking the practical requirements of machine automation applications into account (cf. [Kurki 1995], Chapter 2).

Most machine manufacturers had already got used to computer control in their products. Yet, features like intelligent data management and fault diagnosis were still considered rather distant problems by quite a number of manufacturers, who were wishing just to focus on computerising the basic control functions of their products. The interests of the Finnish machine manufacturers in knowledge-based product functions depended thus heavily on the technological maturity of their products. This has been pointed out in [Kurki 1995] and indicated, e.g. by the following notes taken from the diary of the manager of the KE research group.

(Meeting with Managing Director Seppo K. of N-t Oy, 12.11.1992):

> *“The basic equipment technology must be developed [first]. Fault diagnosis might be interesting [in the future].”*

(Meeting with Mika M. of L-o Oy, 3.6.1993):

> *“The basic control software should first be developed, and data acquisition, fault diagnosis only afterwards”.*

ELE managed, after all, to establish relationships with a few machine and process automation firms at the turn of the decade, and started to develop knowledge-based fault diagnosis features for their products. These firms had already developed quite sophisticated computer-based control systems, several commercial technologies to implement such systems were available, and - most importantly - the users of automated machines were increasingly interested in fault diagnosis (ELE’s annual report 1990):

> *“Autonomy of machines and devices has increased remarkably in recent years for several applications including process industry, data communication, and robotics. This brings new challenges for their diagnosis and maintenance. The expert system [developed by ELE in the VIDI project for Imatran Voima Oy] follows and interprets process status established by test parameters based on real-time fault diagnosis algorithms”.*

Another reason for the success of ELE in establishing “red” fault diagnosis projects without many preceding research activities might be the fact that some industrial partners of the early joint fault diagnosis research projects of the AI program were not at all satisfied with the results [Husso 1993]:

> *“None of the participating companies [of the AI research program] considered the developed knowledge-based software systems as economically important. One third believed that the systems developed in the subproject that they participated had no economic relevance at all. Over 70% of the industrial participants saw also the documents produced in the project as rather meaningless”.*

The KE group did not have too much experience in process and machine automation applications, while some other VTT institutes were more specialised in these fields of engineering. The technologies used to implement automation systems were also somewhat unknown to the ELE personnel. The only possibility was then to market the knowledge engineering techniques as a means of problem solving to machine manufacturers interested in fault diagnosis.

Thanks to the high tide of knowledge-based systems, this strategy proved a considerable success. Moreover, the KE research group had already recognised fault diagnosis as a potential area for using the knowledge engineering techniques in a small, self-funded (“green”) pre-study (Pekka Alasiuru’s report 1989):

> *“This report is based on a literature survey of the abstracts of 215 articles and conference papers. In addition, the most important conference proceedings [AAAI, IJCAI among others] from 1986 to 1988 have been evaluated, of which some 60 papers were selected. Moreover, the most recent research in the field has been analysed based on journal articles [Artificial Intelligence, AI Magazine among others]. Based on this material it can be said that diagnostic expert systems can be clearly classified as a distinct group of expert systems.”*

The ELE employees who had been involved in the early fault diagnosis projects could be characterised as *knowledge engineers*. The whole work was done by ELE personnel, if the customer did not have much knowledge engineering expertise. Related work reported in the literature at that time follows the same approach: individual knowledge engineers or small teams were creating intelligent systems for different kinds of applications.

The phrase "knowledge acquisition" was used by ELE to describe the capture of both explicit and tacit knowledge related to the development of fault diagnosis systems. Knowledge of the *application* and its modelling techniques (codified, for example, in automation and process modelling diagrams), as well as that of the computerised *implementation technologies* of automation systems, could be learnt by the ELE personnel as a part of each relationship and together with the customers’ knowledge engineers. The knowledge was, by definition, application and technology-specific.

The learning of that knowledge by, for example, application expert interviews and other knowledge acquisition methods was encouraged by the generally accepted philosophy of building knowledge-based systems. *Application experts*, such as process and automation engineers, were mostly not familiar with AI techniques and were thus not able to build and maintain knowledge-based systems on their own. This would also mean that the ELE knowledge engineering experts were quite easily able to join forces with industrial knowledge engineers, if the customer company had such personnel, as well as to exploit AI techniques and learn how to use them in automation applications.

ELE was aiming at combining knowledge engineering skills with application-specific knowledge. It started to develop its knowledge-based fault diagnosis capabilities especially for process and machine automation applications. A possible evolution of this state of matters, if the kinds of knowledge-based systems that were developed during the late eighties had really become an industrial practice, could have led to the customers' knowledge engineers becoming competitors for ELE. The promises of the early systems, however, failed by the mid-nineties - in many cases due to the lack of understanding of the real problems to solve. New directions needed to be taken both by ELE and industry.

4.2.2 Early nineties - addressing automation firms

An additional strength of ELE in the fault diagnosis projects was its capability for modelling computerised control systems, based on the years spent in specifying and designing embedded computer systems for various applications. Combining this with the knowledge engineering skills and with the accumulating experience of the customers' fault diagnosis problems clearly brought a fresh perspective to the fault diagnosis R&D.

Instead of building exotic knowledge-based models for fault diagnosis, *conventional computer system modelling techniques* could now be used. In other words, instead of using special knowledge-based models, "ordinary" engineering models of systems were used in fault diagnosis. The management of the special knowledge-based models had been complicated even for knowledge engineers, not to mention ordinary control system designers. The use of conventional computer system models in fault diagnosis thus greatly helped the application experts. Their responsibility with regard to the knowledge-based fault diagnosis features was moving towards their own engineering competence area [Kurki 1995]:

> *"Especially the need to develop additional complicated models [qualitative, causal, etc.] for fault diagnosis was a[n] undesirable feature. The contents of extra models are difficult to define due to the lack of available knowledge and knowledge inconsistencies between experts. The approach [to fault diagnosis taken by ELE] is strongly based on the use of existing models, such as the control system model and topological models".*

This meant, in practice, that the relations of the fault diagnosis researchers with the customers' application experts remained or became even more important. The relations with the customers' knowledge engineers became, accordingly, much less important than earlier. Therefore, the relationships to those customers who had employed knowledge engineers and with whom the initial fault diagnosis projects had been carried out would weaken. In some cases they vanished altogether, due to the rapid fall of industrial interest in AI techniques. The reason for the fall was that the techniques had not resulted in many practical industrial applications after the first three to four years. The fall was a global phenomenon. An additional accelerating reason for this development was the fact that the importance of the special tools that had been used to develop knowledge-based systems had disappeared.

As a net result, relations with industrial knowledge engineers were replaced by those with industrial application experts, including process engineers and control system designers. Moreover, ELE itself hired a few automation system professionals, who started participating in fault diagnosis projects. This helped ELE to establish relationships with such firms that considered the basic knowledge of automation systems and applications a prerequisite for co-operation.

Lower labour expenses and a better knowledge of AI techniques had favoured relationships between universities and industry during the early days of the AI research program. By the mid-nineties the combined computer system development, knowledge engineering and R&D project management skills of ELE appeared to be more important to industry, since fault diagnosis systems needed to be implemented as parts of commercial industrial products and not only as research prototypes (a note from the KE group manager’s diary during a visit at T-k Oy, 12.2.1993):

> *“Diagnostics emerged during the winter. [ELE has] good knowledge of the technological development. Demonstration [of the results of the DIMS project] were given with a very good feedback. The following step: discussions on product development during the autumn with the customer, implementation in 1994”.*

One of the key results of this period, seen from the ELE perspective, was the laying of foundation for the understanding of the whole fault diagnosis problem solving chain, i.e. of the tasks required for developing practical fault diagnosis systems. Moreover, as the role of ELE in this *problem solving process* become clearer, it was easier for both the ELE knowledge engineers and the application experts of its customers to see what resources and skills each party brought into the process. Earlier, the roles of ELE and industrial knowledge engineers had actually been overlapping and sometimes competitive. The new situation resembles the one described in [Miettinen 1996], who analyses the so-called innovation network of a new physical process - biotechnical pulp bleaching - with which a similar problem solving process and several actors in different roles are associated. A remarkable difference in the fault diagnosis case is, however, that ELE’s relationships involved contractual product development (“red”) rather than pre-competitive joint (“blue”) research activities.

4.2.3 Mid-nineties - the fault diagnosis platform

After several contractual fault diagnosis projects had been carried out for automation companies, it was found out that the basic problem solving process and its results, the *diagnosis functions*, were rather similar. The process and functions were studied by a researcher, who had managed many of the fault diagnosis projects and later became the head of the KE research group. Data acquisition, fault detection, fault localisation, fault explanation and fault recovery functions were identified. The problem solving process was streamlined and the functions gradually evolved towards *a fault diagnosis platform*. Parts of this platform existed physically, as software modules that could be ported to different implementation technologies. At first the platform existed merely in the form of marketing overhead slides of the KE research group. The usage and control system models of the customers' applications needed to be designed anew in the fault diagnosis projects, as well as the system implemented by using technologies favoured by particular customers. However, ELE could reuse both the problem solving process and the fault diagnosis functions, as shown in Figure 2.

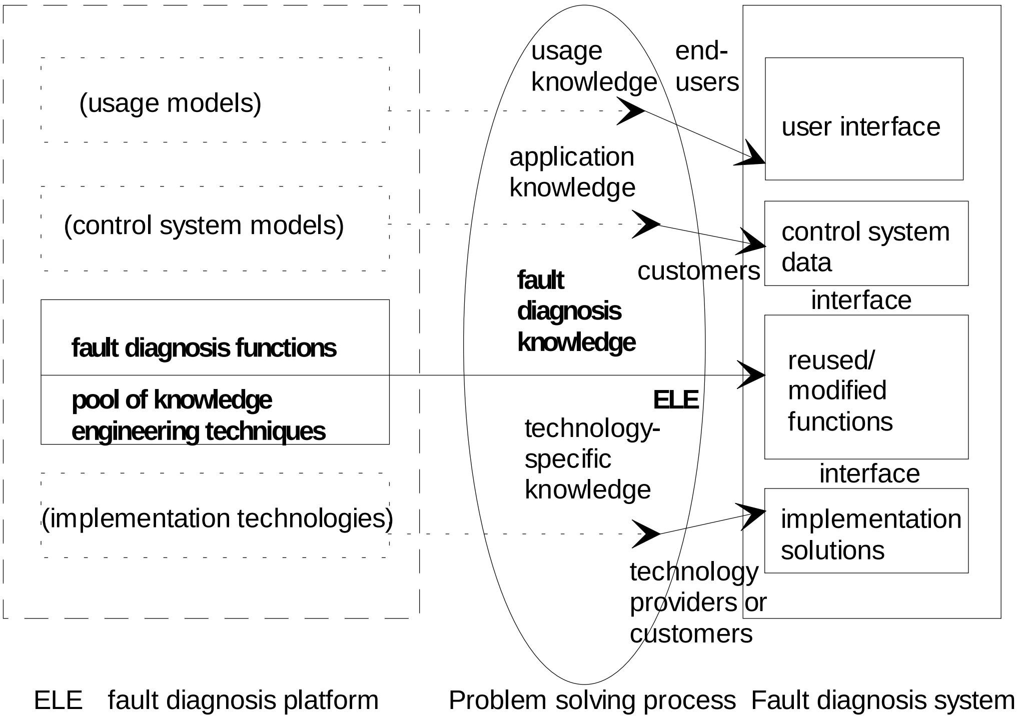

Figure 2. Utilisation of the fault diagnosis platform.

The platform was successfully utilised in contractual R&D projects, also from the viewpoint of financial results (ELE's result report 1994):

> *"The industry has been very interested in [fault] diagnosis expertise, at the beginning of 1995 the volume of contractual projects in this area is over 2 million FIM."*

Fault diagnosis systems were built in the mid-nineties also by several other institutes of VTT (the annual report of VTT 1996):

> *Real-time fault diagnostics for building automation: "Real-time fault diagnostic methods have been developed by VTT Building Technology in several co-operation projects with domestic industry and in an International Energy Agency's Annex 25 project. In practice, fault diagnostic methods have to be integrated into the software of the automation system".*
>
> *Fault diagnostics bring new features to building automation systems and add a new dimension to their marketing. "Automatic location of power grid faults: VTT Energy, ABB Transmit Oy, and Pohjois-Karjalan Sähkö Oy have together developed a system that determines automatically the location of faults in the mains supply, disconnects the section of grid affected by the fault, and engages back-up power supplies. The system has been developed as part of the Edison research programme of electric distribution".*
>
> *Remote support for process operators: "A remote support system developed in collaboration between VTT Automation and Ahlstrom Machinery ... supports fault diagnostics as well as planning and realisation of maintenance operations. The remote support system has been developed in an international project belonging to the Intelligent Manufacturing Systems (IMS) research programme."*

These projects emphasised, however, diagnosis functions of much lower-level, such as real-time data acquisition. The functions were often closely integrated with some new implementation technologies and developed in joint ("blue") research projects. Apparently, the projects did not follow any general fault diagnosis problem solving process.

ELE, having been dealing with practical fault diagnosis problems already for several years, aimed at technology-independent solutions instead. The fault diagnosis problem solving process and the platform could be reused in an increasing number of contractual projects. The KE research group maintained and extended the existing customer base by indicating that ELE was offering a comprehensive process and some reusable resources for solving fault diagnosis problems. The customers appreciated the strategy of combining their own application expertise with the ELE fault diagnosis and computer system modelling skills (the annual report of ELE 1995):

> *"In VTT Electronics we have discovered a valuable partner. The ideas on the diagnostics of embedded machine controls match well with our needs for paper winders", says Jari Paanasalo, the product development manager [of Valmet Oy]. "Together we can implement demanding algorithms, which we could not do if we acted alone. We also gain a wider perspective on diagnostics and control systems".*

By the late nineties, ELE had become quite competent in solving practical fault diagnosis problems in the domain of automation applications. It had rather wide capabilities and an established process to solve such problems. Its role in the problem solving process was clearer than the role of some other parties interested in fault diagnosis. In particular, the role of the application experts of some other VTT institutes dealing with fault diagnosis overlapped with the roles of industrial engineering professionals.

4.2.4 Late nineties - new applications

After the fault diagnosis problem solving process and the platform had been used in several contractual R&D projects, it was realised that apart from automation there might be many other application areas in which fault diagnosis was needed. One of the application areas that was studied, mainly because of its growing business volume, was telecommunications. It seemed that the acquisition, monitoring and analysis of alarm data in *telecommunication networks* was a fault diagnosis problem, for which the existing problem solving process and the platform functions could be used.

However, both this application and the technologies used to implement network devices were different from those of automation applications. Although ELE had rather close contacts with some telecommunication network equipment manufacturers, there were others with whom it had practically no contacts. Moreover, there were no relationships with the end-users of network equipment, i.e. telecommunication operators.

This posed problems in gaining the necessary knowledge of the new application domain, especially since telecommunication networks are complex assemblies of interrelated equipment and systems. Although an automated machine, for example, is a multi-technology system, it is usually one product sold by a single company and designed by a rather small team of engineering and application experts. The development of a telecommunication network may, on the contrary, involve hundreds of different engineering professionals, as well as many distinct companies, business units and subcontractors. Several different operators, i.e. customers of the equipment manufacturers, may also be involved in the development.

Within this new context ELE decided to address a new knowledge engineering technique, *case-based reasoning* (CBR). A practical reason for this decision was the fact that the first fault diagnosis project involving telecommunication networks belonged to a new national ("blue") research program on intelligent systems. Yet, as it was economically feasible for ELE, the project was organised as a ("red") contractual consortium project, so that the consortium of three different business units of the same company acquired financing from Tekes to cover part of their contractual R&D expenses.

The work was carried out by ELE, since it had originally marketed the topic to these companies by using its problem solving skills and the fault diagnosis platform as a reference. It had also prepared the project proposal. Since the case-based reasoning technique was new to ELE, a new knowledge engineering expert was recruited for the project to gain expertise in the technique. Investments were also made in an expensive knowledge engineering tool, different from the one used several years ago.

The overall situation looked very promising, with regard to the utilisation and extension of the ELE fault diagnosis skills (ELE annual report 1995):

> *“Failure situations into automatic control. Considerable competitive advantage can be achieved by incorporating diagnostic systems into products. VTT Electronics is developing knowledge-based techniques for failure diagnostics in GSM networks with Nokia Telecommunications Oy. The diagnostic system is based on models of the GSM network. An alternative [case-based] reasoning method, based on stored information of failure situations, helps to match the current problem with a previous one”.*

However, the new context resulted in difficulties. “Red” R&D activities did not succeed as smoothly as they had succeeded in automation applications. The network equipment manufacturers that had established a consortium to co-operate with ELE could not name any single person, who would be familiar with the application as a whole. Moreover, there were no single models of the network available, not even clear ideas on how the network should be modelled. Operators were not involved in the project, and it appeared that the equipment manufacturers' knowledge of the end-users' needs could not be easily transferred to ELE.

The actual efforts of the project focused largely on selecting appropriate means for network modelling. The benefits of the fault diagnosis problem solving process and the platform functions could not be shown, not even the benefits of integrating the CBR technique and application knowledge for fault diagnosis. The project result was delivered within the planned schedule and budget, but it was just a demonstration system with no interfaces to the real network equipment. All this together with some managerial problems in carrying out the project caused a conflict that almost led to an interruption of the work. From the ELE point of view this might have resulted in losing this application domain for several years. The ELE personnel for project and line management went through the reasons for the difficulties in an internal quality review meeting (Tilhi project’s final review, 15.4.1997):

> *Factors that decreased efficiency: “The difficulty of acquiring domain knowledge was underestimated in the application of the [case-based reasoning] CBR technique”.*
>
> *Estimated risks and their realisation: “Little [application] domain expertise, also overestimated in the customer side. The end users’ views would have been needed in the implementation of the CBR prototype. [The customer company] could not organise e.g. a visit to some telecommunication operator”.*
>
> *Experiences and improvement suggestions: “The project was research-oriented, new solutions were sought for the customer’s problems; for this reason it might have been better to carry out the project as a [“blue”] research contract rather than as a [“red”] development contract.”*

We point out, however, that in this phase ELE was successfully carrying out considerable fault diagnosis projects for both machine and process automation customers (the annual report of ELE 1996):

> *"Rautaruukki has thorough expertise on the [steel manufacturing] process and its problems, while the strength of VTT Electronics lies in fault diagnostics and embedded software design. In an extensive three-year project, VTT Electronics takes care of the development on an expert system that will integrate diagnostic information. The fault-diagnostic system of the hot-strip rolling mill will be ready at the end of 1997. The total budget of the project is FIM 8 million, from which the share of VTT Electronics' projects is FIM 2 million. Further development and commercialisation of the results may make them available to other steel manufacturers too".*

Some of these projects were the same kinds of large consortia as the network diagnosis project, in which several different factory sites and research partners were involved, as well as public funding bodies. Some new KE techniques were applied also in these projects and the same expensive knowledge engineering tool was utilised to some extent. A remarkable difference was, however, that many of the ELE employees involved in these projects had already gained experience of automation applications, whereas none of the persons involved in the network diagnosis project had much telecommunication engineering expertise. Moreover, several basic functions of the fault diagnosis platform and the whole problem solving process could be reused in these automation-related projects. Table 1 summarises the main developments in fault diagnosis R&D at ELE from 1986 to 1997.

Table 1. Evolution of fault diagnosis competence and relationships in ELE.

Period	**Competence**	**Activities**	**Partners**	**Focal net**
1986-88	AI techniques	Internal R&D	-	(informal)
1989-91	Knowledge engineers, AI tools, embedded system skills	Blue and red projects: development of system prototypes	Process and machine automation firms	R&D projects, interaction of knowledge engineering experts
1992-94	Diagnosis functions, automation application and system modelling skills	Red and blue projects: development of diagnosis functions for automation applications	Machine automation firms, R&D partners, funding bodies	R&D projects, interaction of diagnosis and automation experts
1995-97	Platform, KE techniques, problem solving process	Green, blue, red projects: development and use of the platform	Automation and telecom firms, funding bodies	R&D projects, interaction of diagnosis and application experts (and end-users)

5 R&D COMPETENCE DEVELOPMENT IN A FOCAL NET

Our R&D *competence networking framework* consists of two layers. One of the layers used to explain the basic elements of contractual R&D is called the *"substance"* layer [cf. Håkansson and Snehota 1995]. The other layer, called the *"management"* layer, describes the evolution of the elements of the substance layer over time.

5.1 SUBSTANCE LAYER OF THE FRAMEWORK

The substance layer of the R&D competence networking framework is based on the ARA model, Table 2. It describes the activities carried out to develop and exploit R&D resources together with external parties.

Table 2. The substance layer of the framework.

FOCAL NET/ SUBSTANCE	**FIRM**	**RELATION-SHIPS**	**NETWORKS**
COMPETENCIES			
Activities	*Activity structures:* Internal pre-study on fault diagnosis based on the literature	*Activity links:* Contractual development project between ELE and a customer company	*Activity patterns:* Joint research project in a national research program
Resources	*Resource collections:* Use of embedded systems modelling techniques and tools in the development of fault diagnosis systems	*Resource ties:* Development of fault diagnosis functions for a machine automation system manufactured by a customer company	*Resource constellations:* Joint knowledge acquisition session of ELE, the knowledge engineers and application experts of the company involved
ACTORS			
Parties	*Organisational structures:* Internal quality review board	*Actor bonds:* Project management group	*Actor webs:* Joint project team of ELE and its research partners

We are presenting a typology of fault diagnosis competence by extending and reformulating the resource typology given in [Rosenbröijer 1998], and by associating it with a typology of R&D activities. The firm, relationship and network levels form the *focal net* dimension of the substance layer [Håkansson and Snehota 1995, Rosenbröijer 1998].

At the substance layer, we are interested in what *types of elements* there are, what their main characteristics (alias *attributes* [Easton and Araujo 1996]) are, and how they relate to each other. We use typologies to define classes and types of elements and values to define their attributes. The existence of certain types of elements and the values of their attributes depend on time, which must also be made explicit. [Rosenbröijer 1998] uses a resource typology based on financial, physical, organisational, human, technological and reputation resources. To explain and analyse the fault diagnosis case, we modify and extend this typology and associate it with the typologies of R&D activities, actors and relationships. The typologies are by no means comprehensive, but sufficient enough to explain the main concepts of the fault diagnosis case. The classes, types and attributes of the typologies form a hierarchy, which is critical for ensuring the usability of the framework.

Figure 3 that shows the main elements of the typologies and their interrelations is drawn as an entity-relationship diagram, in order to show how the elements relate to each other. The figure is thus to be read in the direction of the labelled relationship arrows. For example, an “actor” element “acts on” elements of the type “resource”.

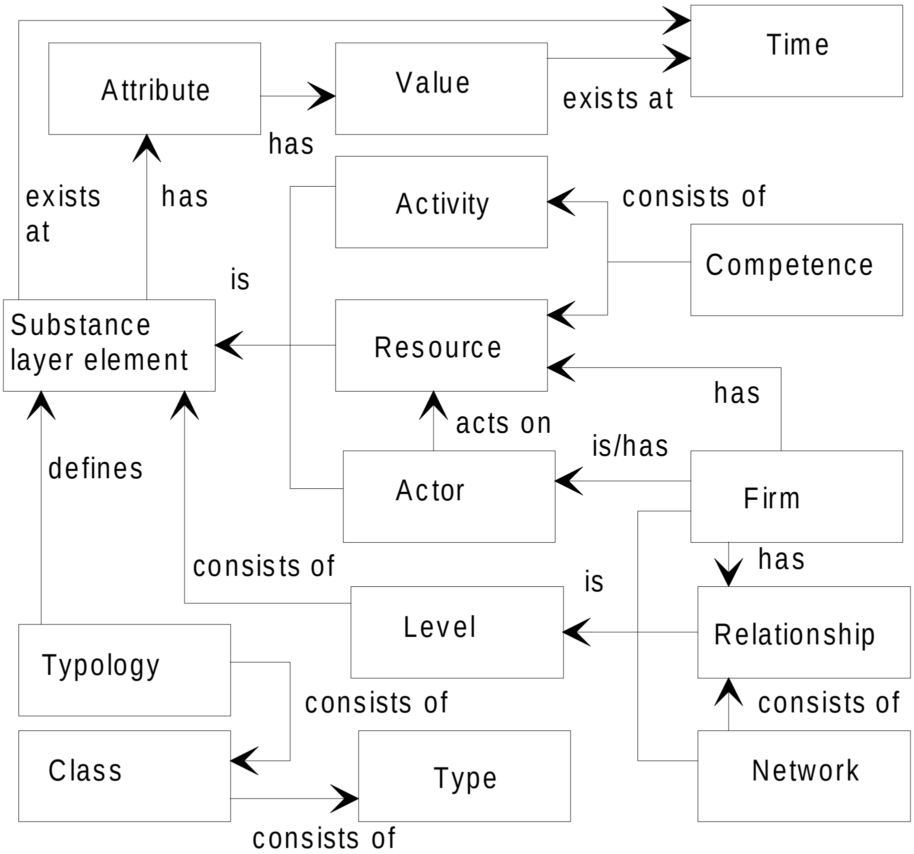

Figure 3. Relations between the elements of the substance layer.

Table 3. Typology of R&D competence elements.

ELEMENTS	**Classes**	**Types**	**Attributes**
COMPETENCIES			
Resource			Relations, Time
	Human	Expertise	Application, Function, Technique, Technology, Maturity, Value
	Technological	R&D service	Application, Function, Technique, Technology, Maturity, Value
	Physical	Product	Application, Function, Technique, Technology, Maturity, Value
		Document	Task, Existence, Value
		Tool	Task, Existence, Value
	Temporal	Calendar time	Time
		Time-table	Schedule
		Effort	Volume
	Financial	Expense	Value, Task, Actor
		Income	Value, Task, Actor
	Organisational	Management system	Type
	Reputation	Professional reputation	Reputation
Activity			Relations, Time Tasks, Value
	Human	Learning, Doing, Management, Evaluation	
	Technological	Tracking, Acquisition, Planning, Use, Transfer, Integration, Evaluation	
	Physical	Tracking, Acquisition, Use, Transfer, Integration, Evaluation	
	Temporal	Planning, Use, Evaluation	
	Financial	Planning, Use, Evaluation	
	Organisational	Project management	
	Reputation	Professional appearance	

The classes of resources and activities shown in Table 3 are the same, so as to provide a basis for analysing the fault diagnosis competence. Referring to the three basic dimensions of competence discussed above, i.e. content, institutionalisation and codification, we focus on how the content of tacit human knowledge develops to institutionalised technological competencies, within the organisation's relationships to external actors. We thus address financial, organisational and reputation resources only to a limited extent in this research. An additional reason for this choice is that the grand story that we use to describe the fault diagnosis case focuses on the technological and physical resources of ELE.

The actual R&D service is the main type of technological resource utilised in R&D relationships; at the level of individuals the possession of some expert skills is required to carry out such services. Physical resources are in this report simply thought to be either products, documents or development tools. Temporal resources are missing from the typology used in [Rosenbröijer 1998], although they are crucial in project-based R&D activities. The basic types of temporal resources planned for and controlled in projects, such as schedules, efforts and calendar time, are therefore included in Table 3. Project management is one of the most important organisational resources of ELE, and professional reputation is a resource that is used, e.g. when initiating relationships. Financial resources are almost always exchanged in contractual R&D that involves external parties.

Activities are needed for acquiring different types of resources, planning for, carrying out, evaluating and utilising the results of the actual R&D work, supporting individuals in developing and extending their expertise, taking care of project management, planning and controlling of financial matters, following general technical developments and acting as a member of the professional R&D community. The class level resource and activity attributes shown in Table 3 define relations between different element classes, as well as time. Some of the basic types of relations were shown in Figure 3. The attributes of certain types of activities, i.e. the characteristics of the R&D work, are not addressed in this research except the "Task" attribute that makes explicit the fact that most activities consist of smaller tasks. The main reason for omitting activity attributes is that we use the framework to analyse the fault diagnosis case at the grand story level, and we have not yet addressed the level of projects, where the characteristics of individual R&D tasks can be analysed in detail (cf. [Leppälä 1995]).

The attributes of different types of resources are shown in Table 3. This representation facilitates the study of the main characteristics of the fault diagnosis competence and their changes. We focus on analysing the technical competence, i.e. the content of the R&D services of the focal organisation. The content of the technical competence is characterised at the institutionalisation levels of individuals and organisational actors, by using the following four hierarchical dimensions: the *application* domain (and products) involved, (the problem solving process and) the *functions* accomplished by the product, the engineering *techniques* (and the methods) on which the functions are based, and the *technologies* (and components) used to realise the product, Figure 4.

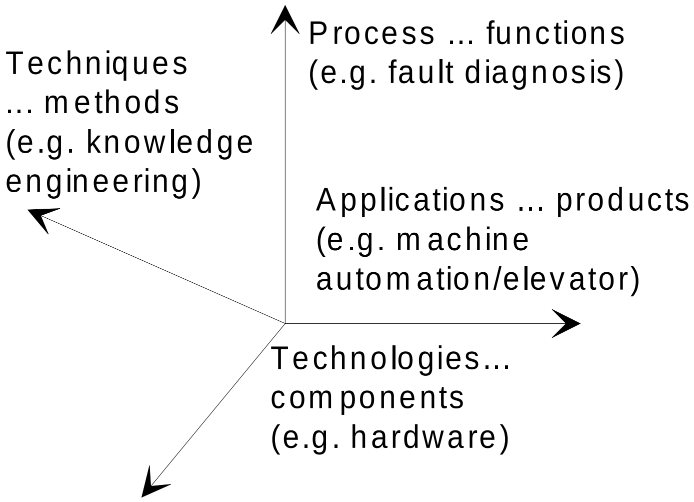

Figure 4. The four dimensions of the content of a technical competence.

The four dimensions become intertwined in the physical products resulting from R&D activities, and therefore they must also be defined for the physical resources of the product type. The “Maturity” attribute is used to describe the codification of all these resource types. For physical resources of the types “Document” and “Tool”, the attribute “Existence” is defined instead, because in this research we are not interested in their form of appearance but only in their existence (cf. [Easton and Araujo 1996]). In the fault diagnosis case, the functional dimension includes the problem solving process and the diagnosis functions. The applications range from machine automation to telecommunication, involving different types of products, such as elevators, rock drilling machines and GSM network equipment. Several knowledge and system engineering techniques and methods were used, and various kinds of technologies and components were applied in their implementation.

[Elfring and Baven 1996] separate functional capabilities from application capabilities, which fits with two of the dimensions shown in Figure 4. [Abell 1980] uses three of the four dimensions, i.e. applications, functions and technologies, as a means of structuring markets - or vice versa, as a means of choosing the competitive focus for a firm. However, both authors miss the “techniques” dimension, which was the original starting point of the fault diagnosis R&D activities of ELE. The four dimensions can be used to analyse how implicit individual skills change to explicit organisational competence, which may ultimately appear in such a tangible form as the ELE fault diagnosis platform or a fault diagnosis system of the paper winder of a paper machine. The competence may be evaluated in any point of this evolution. The “Value” attribute is therefore defined for expertise, R&D service and product types of resources (cf. the “evaluation” attribute in [Easton and Araujo 1996]).

The actors are typed in Table 4 according to their level of aggregation that spans from individuals to industries. Industrial segments are webs of organisations active in a certain application domain, such as machine automation and telecommunication. At the firm level, research institutes, universities, public funding bodies, government authorities and companies are typical roles of firms involved in R&D.

Tool vendors are special types of companies. The organisational units include management and functional groups, such as the KE research group. Temporal organisational groups are also defined, in the fault diagnosis case there are temporary project teams and quality assurance teams. Individual persons involved in research and development activities can be characterised either as managers, R&D persons or end users.

Table 4. Typology of the actors of the substance layer.

ELEMENTS	**Classes**	**Types**	**Attributes**
ACTORS			
Party			Name, Time, Relations
	Industry	Industrial segment	Application, Characteristics
	Organisation	Firm	Role
	Organisational unit	Organisational group, Temporal group	Firm, Role
	Individual	R&D person, Manager, User	Firm
RELATIONSHIPS			
Industrial relationship			Name, Actors, Time, Relations, Capability, Mutuality, Particularity, Inconsistency
	Internal	Own R&D	Volume
	Transaction	Meeting	
	Relationship	Contractual R&D	Volume, Type, State
	Network	Joint R&D	Volume, Type, State
	Environment	R&D community	Macro forces

The focal net consists of the actual R&D relationships. In addition to the firm, relationship and network levels of the focal net there are single transactions, events that take place in a short period of time, compared with longer-term relationships. Different kinds of meetings are typical transactions in contractual R&D. Many of them are embedded in relationships, e.g. project management meetings. Other transactions also take place, such as purchasing of a system development tool. Relationships can be characterised by the four variables proposed in [Ford et al. 1986], in addition to the attributes “volume” (e.g., the financial value, size in man-years), “type” (e.g., “green”, “blue” and “red”) and “state” (e.g., competitive, cooperative, dominating, dominated [Alajoutsijärvi 1996]).

5.2 FAULT DIAGNOSIS COMPETENCE AND RELATIONSHIPS

We will now use the framework to model the elements of the fault diagnosis competence and relationships, before focusing on their evolution over time. Since we have already made these elements explicit in the augmented grand story, we will only clarify their organisation according to the framework, rather than repeat the whole story. Tables 5 to 9 illustrate the resources and activities involved in the fault diagnosis case, Table 10 shows the actors and Table 11 the relationships. The “Relations”, “Time” and “Value” attributes are not discussed, because the evolution of the fault diagnosis relationships and competence will be analysed in the next section.

The elements shown in the tables were extracted from the fault diagnosis story. Certain classes and types of elements were first identified, followed by an attempt to determine the values of the resource, actor and relationship attributes. Although this kind of an analysis is trivial and used here only to illustrate the framework, it also ensures that the framework fits with the reality, i.e. we do not suggest concepts that cannot be identified from the case study. And vice versa, a practical approach to developing a conceptual framework for R&D competence networking would involve carrying out analyses of several cases, starting from grand stories and continuing into the details of individual relationships, actors and resources.

The human resources shown in Table 5 involves expertise, either as knowledge or as skills. The values of the four attributes of competence, i.e. applications, functions, techniques and technologies, can be easily identified for the expertise of the individuals involved in the fault diagnosis case. The functional dimension may not be as obvious as the others, but actually some of the actors can be recognised as experts in certain fault diagnosis functions, such as fault recovery. In more general terms, the ELE researchers can be claimed to possess functional skills in fault diagnosis, i.e. knowledge of the fault diagnosis problem solving process as a whole. Knowledge acquisition and embedding are some examples of their functional skills in the late eighties and early nineties, while more comprehensive problem solving process skills would play a central role later. In the mid-nineties, there was an obvious lack of knowledge of telecommunication applications.

At the level of individuals, the learning related to certain resources is a key activity. Learning can be based on formal training or, more importantly, on the actual R&D work. The combination of skills, such as knowledge engineering and computer system modelling skills, is also important. This corresponds to the central role of capability integration pointed out in [Rosenbröijer 1998].

There is no description of a systematic evaluation of the individual fault diagnosis expertise in the grand story, but it has been illustrated in some of the augmentations of the story. Technological resources and activities are the key elements in the fault diagnosis case, since the core exchange items of the relationships were R&D services based on technological resources.

Services must be planned and the content of the service must be designed and delivered. For service planning, some general information must often be acquired first, e.g. through a literature survey and by gaining some understanding of the customer's application.

Table 5. Examples of human and technological resources and activities.

Resource types	**Attribute values**
Expertise	Maturity (knowledge, skill) Technique (knowledge engineering, process engineering, control engineering, embedded system modelling, telecommunication engineering) Function (knowledge acquisition, embedding, embedded control, fault diagnosis) Application (automation) Technology (expert systems, embedded systems)
R&D service	Technique (logic programming, system modelling method, fuzzy logic, case-based reasoning) Function (data acquisition, fault detection, fault localisation, fault explanation, fault recovery) Technology (rule-based expert systems, knowledge bases, embedded software and hardware, electronics) Application (process automation, machine automation, telecommunications) Maturity (customer-specific service, platform)
Activity types	**Attribute values**
Learning, Doing, Management, Evaluation	Tasks (training, skill combination, R&D, customer feedback)
Tracking, Acquisition	Tasks (pre-study, literature survey) Task (acquire knowledge, interview experts)
Planning, Use	Tasks (prepare a project proposal, establish a relationship, launch a project, meet customers)
Transfer, Integration, Evaluation	Tasks (specify, design, implement and "embed" systems, improve systems, build and maintain knowledge-based systems, extend and modify knowledge representations, model computerised control systems, specify and design embedded systems, tailor existing system solutions)

The physical resources acquired, developed and exchanged in the fault diagnosis case include fault diagnosis systems, documents and system development tools, see Table 6.

Certain resources were acquired, such as tools, and others implemented. The physical fault diagnosis systems that were implemented can be characterised according to the same four dimensions as expertise and R&D services, while the maturity of the product is connected with its commercialisation. AI, embedded system and control system development tools were acquired and utilised, in addition to generally available and documented information. No special tools were developed by the focal actors themselves, the tools were provided by external tool vendors.

Table 6. Examples of physical resources and activities.

Resource types	Attribute values
Product	Application (cf. R&D services) Function (cf. R&D services) Technique (cf. R&D services) Technology (fault diagnosis system, knowledge base, software module, hardware component, process modelling diagram, control system model, topological model, fault diagnosis platform) Maturity (research prototype, commercial product)
Document	Existence (conference paper, journal, annual report, overhead slide)
Tool	Task (embedded system, control system, expert system development) Existence (commercial tool)
Activity types	**Attribute values**
Tracking, Acquisition, Use, Transfer, Integration, Evaluation	Tasks (cf. R&D services)

Organisational and reputation resources and the related activities are illustrated in Table 7. The organisational project management resources of ELE were exploited in fault diagnosis R&D through the institute’s project management system.

The professional reputation resources are difficult to estimate, and they depend heavily on the actual content of the results of R&D activities. However, the KE group could be identified as an expert in solving fault diagnosis problems of automation systems since the mid-nineties. The professional appearance of the fault diagnosis researchers included participation in joint national research programs, conducting doctoral studies and publishing professional reports, papers and articles.

Table 7. Examples of organisational and reputation resources and activities.

Resource types	**Attribute values**
Project management	Type (ELE’s project management system)
Professional reputation	Reputation (expert in fault diagnosis problem solving for automation applications)
Activity types	**Attribute values**
Project management	Tasks (project management, project review meeting)
Professional appearance	Tasks (participation in research programs, doctoral studies, publishing)

Temporal resources were also needed in fault diagnosis projects, as illustrated in Table 8.

Table 8. Temporal resources and activities in the fault diagnosis case.

Resource types	**Attribute values**
Calendar time	Time (months, years)
Time-table	Schedule (start date, end date)
Effort	Volume (person-years)
Activity types	**Attribute values**
Planning, Use, Evaluation	Tasks (...)

The expenses involved in the fault diagnosis case, as shown in Table 9, include the costs of R&D projects and tool investments. Three main sources of income were used to cover the expenses: ELE itself, Tekes and industrial companies. The financing of the activities depended on the types of the projects. Investments included purchasing special tools for the needs of certain projects.

Table 9. Examples of financial resources and activities.

Resource types	**Attribute values**
Expense	Value (cost), Actor (ELE), Task (R&D, investment)
Income	Value (financing), Actor (Tekes, industry, ELE), Task (...)
Activity types	**Attribute values**
Planning, Use, Evaluation	Tasks (...)

Resources on activities are carried out by actors, so that different types of relationships can take place. The actors and relationships related to the fault diagnosis case are illustrated in Tables 10 and 11, correspondingly. It is quite uncomplicated to identify the main actors in the fault diagnosis story, and the main relationships that took place in the form of distinct projects can also easily be pointed out.

Table 10. Actors identified in the fault diagnosis case.

Actor types	**Attribute values**
Industrial segment	Application (telecommunication, network operating, automation), Characteristics (automated)
Firm	Name (VTT Electronics, VTT Automation, VTT Energy, VTT Building Technology), Role (research institute) Name (Tekes), Role (public funding body) Name (Ministry for Financing), Role (authority) Name (TKK), Role (university) Name (T-k Oy, K-e Oy, N-t Oy, Rautaruukki Oy, Imatran Voima Oy, Valmet Oy, L-o Oy, Nokia T-s Oy) Role (possible customer, customer, partner, competitor) Name (Symbolics vendor), Role (tool vendor)
Organisational group	Firm (ELE), Name (KE research group), Role (R&D) Firm (company), Role (product development, research)
Temporal group	Name (Tilhi), Firm (ELE) Role (project, quality assurance)
R&D person	Firm (ELE, company, VTT research institute), Role (automation designer, control system designer, process designer, knowledge engineer, project manager)
Manager	Firm (ELE, company), Role (managing director, KE research group head)
User	Role (user of a machine, network operator)

Table 11. Examples of relationships identified in the fault diagnosis case.

Relationship types	**Attribute values**
Meeting	Type (project management, quality assurance, marketing)
Contractual R&D	Type (dyadic project), State (cooperative, competitive, dominating, dominated)
Joint R&D	Type (multi-party project, R&D program), State (cooperative, competitive, dominating, dominated)
R&D community	Macro forces (interest in AI)

5.3 MANAGEMENT LAYER OF THE FRAMEWORK

The management layer of the framework makes explicit how and why the elements of the substance layer change over time. The substance layer is based on two dimensions: *substance elements* consisting of resources, activities and actors, and the *focal net* expressed at the internal firm and the external relationship and networks levels. At the management layer we try to answer the question of how the *evolution of competencies*, purposeful activities carried out by actors to develop and use resources, affects the *external relationships* of the focal organisation.

5.3.1 Changes of the focal net

We will address changes in project-based relationships rather than in individual transactions. The basic types of changes that may occur in project relationships are rather simple: *starting and ending of a relationship or a network, changing of a relationship to a network, and vice versa*. Although in principle each type of project relationship may change into any other type, the strategic goal of a contract research institute is first to extend its internal self-funded activities to joint R&D projects, and then to specialise them on several different contractual relationships, or if possible, to expand them to contractual networks. Shortcuts to contractual R&D from internal activities are possible, although risky, whereas reverse changes are more seldom.

The finishing of internal R&D activities without any continuing external relationships is usually considered as a failure, whereas the possible negative effects of the ending a relationship or dissolving a network depend on the financial and technical resources involved. A project relationship may continue, sometimes for several years, with regular intermediate evaluations. Changes of R&D relationships are illustrated in Figure 5.

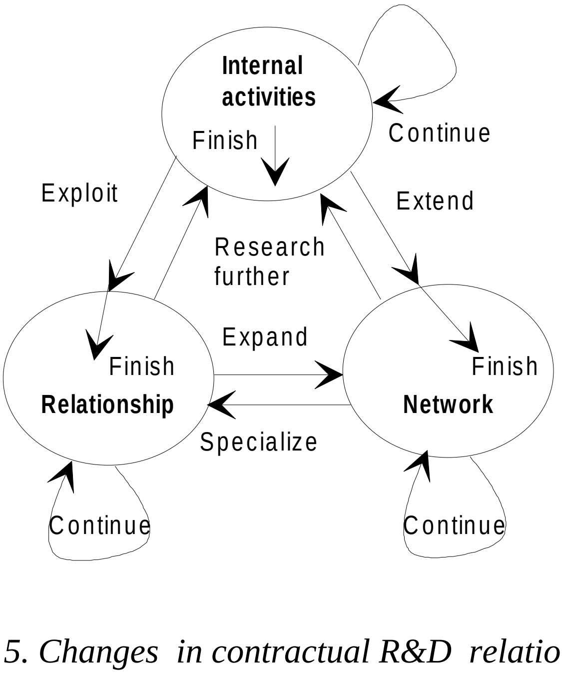

Figure 5. Changes in contractual R&D relationships.

The changes are affected by the macro forces of the environment (cf. [Alajoutsijärvi 1996]). At the substance layer of the R&D networking framework such macro forces are simply expressed as an attribute of the community in which contractual R&D is being carried out. The changing characteristics of industries, such as their readiness to use certain technologies, produce other kinds of macro forces that affect project relationships.

5.3.2 Changes within relationships

Since relationships involve external actors, one of the main relationship management processes is the *control of resource exchange and sharing* between the participating actors. In contractual R&D the source of financial resources is usually explicitly defined, whereas the ownership of technical resources may be a much more controversial issue.

In the case of ELE, the portfolio of green, blue and red projects based on different sources of financial resources affects the ownership of technical resources acquired or developed in connection with R&D activities. Changes between and within the firm, relationship and network levels must therefore be analysed in terms of the three types of projects, see Table 12. For example, networks may exist both as joint customer consortium (“red”) projects and joint research (“blue”) projects, while the different source of financial resources make the networks completely different as far as the participating actors and the ownership of technical resources are concerned.

Table 12. Changes within R&D relationships.

Type of relationship	**Relationship change**	**Source of financial resources**	**Ownership of technical resources**
Own R&D: green project	Internal: No changes	Focal organisation	Focal organisation
Joint R&D: G. Green project B. Blue project Contractual R&D: C. Red project	Network colour change: G. to B. or C. B. to G. or C. C. to B. or G.	Focal organisation & external parties Funding body, R&D parties External parties	Focal organisation R&D parties External parties
Joint R&D: G. Green project B. Blue project Contractual R&D: C. Red project	Relationship colour change: G. to B. or C. B. to G. or C. C. to B. or G.	Focal organisation & external party Funding body, R&D parties External party	Focal organisation R&D parties External party

The ownership of technical resources acquired, developed and exchanged in relationships is important, because it affects the future resource usage possibilities of the participating organisations, i.e. it constraints the management of the changes shown in Figure 5. If the technical resources are owned by an external party, the focal actor must rely on the institutionalisation and codification of the skills of its employees involved in the project. If the ownership is equally shared, there is a possibility for competing offerings of the same resources in the future. If the ownership is unevenly shared, competition is likely to emerge more slowly between the partners. If the focal actor owns the resources, it can develop them further internally, as well as use them in any external relationships in the future.

These phenomena will affect the state of the focal organisation relationships in a complex manner over time. We will use the four relationship attributes based on [Ford et al. 1986], i.e. capability, mutuality, particularity and inconsistency, to identify processes by which the values of the attributes and thereby the states of the relationship can be managed. Table 13 shows how the attributes affect each other, with examples of the corresponding characteristics of the substance layer elements.

Table 13. Interrelationships between relationship attributes.

Attributes	Particularity	Inconsistency
Capability	[1] Example: specialisation in a certain customer application	[2] Example: only a few persons possess knowledge of a technology important to many customers
Mutuality	[3] Example: a contractual consortium concerning a certain technology or technique	[4] Example: inexperience in the development of a customer's application

Based on these interrelationships between the relationship attributes, four processes to manage the change of relationships can be identified (cf. [Alajoutsijärvi and Tikkanen 1998]):

- Balancing the particularity of resources (capability vs. particularity)
- Assuring the desired level of capability (capability vs. inconsistency)
- Balancing the mutuality of activities (mutuality vs. particularity)
- Assuring the desired level of mutuality (mutuality vs. inconsistency).

"Balancing of the particularity of resources" concerns the question about the extent to which the focal organisation should tailor its resources towards relationships with particular parties. The particularity of the organisation resources has long-term strategic implications because of the possible non-transferability of investments made in certain relationships. Highly relationship-specific resources, e.g. skills serving only one customer, may prove hazardous in the long run.

Very general resources, such as generic scientific knowledge, may, on the other hand, not facilitate establishing and maintaining specific relationships, especially in the case of participants that are or become experienced in the subject matter themselves.

Because of the risks involved in the lack or excess of particularity, organisations must be concerned about the extent to which the mutuality of their activities is related to the particularity of their resources. We call the corresponding managerial process the *"balancing of the mutuality of activities"*. For example, if the level of mutuality within a particular contractual R&D consortium is perceived as high, the participating organisations may decide to make expensive relationship-specific investments or hire persons experienced in a specific common technique, to facilitate the co-operation.

The management of inconsistencies involves *"assuring the desired level of capability"* and *"assuring the desired level of mutuality"*. Having a desired level of capability concerns, for example, the development of skills among those individuals in the organisation involved in certain relationships. Seen from the customer's perspective, there may be not enough personnel with the necessary skills available in the organisation, or the skills may vary over time. It is wise for a contract research organisation to have full resource allocation rights for it relationships, so as to be able to manage capabilities as an institution. On the other hand, customers may like to be served by people who they know personally (cf. [Halinen 1994]).

The fourth management process, assuring the desired level of mutuality, is concerned with the training of the interacting persons. For example, inexperienced persons may be allocated to projects in which the use of application-specific knowledge plays a central role.

Table 14 summarises the relationship dimension of the management layer.

Table 14. The management layer of the framework: relationships.

FOCAL NET	**FIRM**	**RELATION-SHIP**	**NETWORK**
CHANGES IN RELATIONSHIPS			
Internal activity	Finish, Continue	Exploit	Extend
Relationship	Research further	Continue, Finish, Change colour	Expand
Network	Research further	Specialise	Continue, Finish, Change colour
Outer context	Observe and react to the macro forces		
RELATIONSHIP MANAGEMENT PROCESSES			
Balance particularity	Manage particularity of the resources		
Assure capability	Manage consistency of the resources		
Balance mutuality	Manage mutuality of the activities		
Assure mutuality	Manage consistency of the activities		

5.3.3 Competence evolution

One of the main goals of this study is to analyse how the evolution of competencies affects the external relationships of an organisation. In the previous section we discussed the kinds of changes that can take place in the relationships of a contract research organisation and the processes that can be used to manage the changes. We modelled both the changes and their management processes as part of the management layer of the R&D competence networking framework. We will now discuss how to deal with the changes in competencies.

As indicated in Table 14, the changes in relationships and competencies can be related to each other via the four management processes, by which the desired level of particularity (relationship-specificity vs. generality) of the organisation resources and mutuality (tailoring vs. generality) of its activities are set and maintained. Particularity of a resource depends on codification, so that implicit resources are usually relationship-specific and explicitly coded resources more general. Mutuality of an activity depends on the institutionalisation of the resource on which the activity is performed. Personal tasks are usually more mutually oriented than high-level organisational activities or macro forces. The content of a resource affects its capability, but the effects of the content on particularity and mutuality depend on the *life cycle of the resource*. Figure 6 illustrates the mutually evolving dimensions of the “competence space” and the “relationship space”.

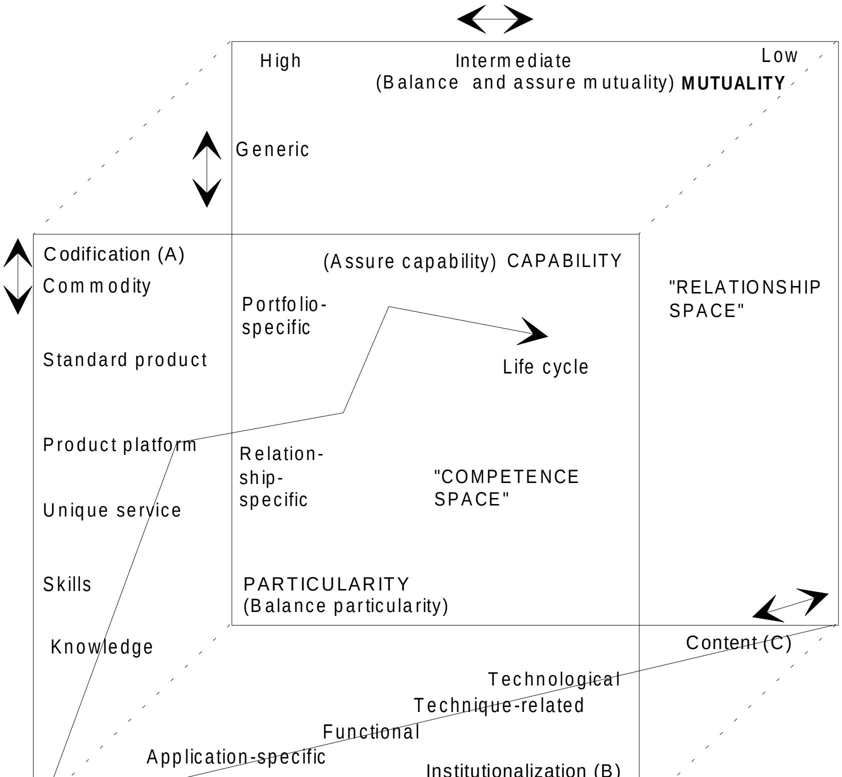

Figure 6. Mutual evolution of competencies and relationships.

One could claim that e.g. generic engineering techniques are less particular for a certain relationship than some application-specific knowledge. This is, however, not necessarily the case. For example, the initial fault diagnosis relationships of ELE were highly particular, while still based on a mutual interest of highly generic knowledge engineering techniques. The techniques dominated the ELE fault diagnosis related resources at the end of the eighties. High particularity of the resources presupposed the use of these techniques, and high mutuality meant seeking of contacts with industrial knowledge engineers, rather than with application experts or end users.

We will borrow the concept *dominant design* [Uusitalo 1995] for defining the life cycle of the content of a resource. According to Uusitalo, evolution of industrial designs includes the following phases: era of incremental change, discontinuity, era of ferment, era of substitution, threshold of substitution, era of design competence and dominant design. A simplified life cycle of the content of a resource thus consists of incremental changes, discontinuity, substitution, competence and dominance. These phases must be defined for each of the four dimensions of the content, Table 15.

Table 15. Life-cycle phases of the content of a resource.

Life-cycle phase	**Applications**	**Functions**	**Techniques**	**Technologies**
Incremental changes	New types of products	New product features	Improved techniques	More efficient technologies
Discontinuity	Ageing products	Obsolete product features	Unused techniques	Old-fashioned technologies
Substitution	Substitute products	Replaced product features	New, better techniques	Newly developed technologies
Competition	Different product versions	Custom product features	Alternative techniques	Alternative technologies
Dominance	One product concept	Standard product features	Common techniques	Common core technologies

An organisation is at some point of time in a certain life cycle phase with regard to any of the four dimensions. It may seek relationships with other parties to help maintaining or changing the life-cycle phase of a specific dimension. Its goals concerning the preservation or change of a life-cycle phase affect the particularity of the resources that it wishes to exchange and the mutuality of the activities that it is willing to perform as a part of the relationship. Moreover, codification and institutionalisation of a resource should fit with the life cycle. For example, if the organisation wants to exploit a common core technology, it must have access to explicitly codified information of that technology.

Competencies develop through activities that change the content, codification and institutionalisation of resources. The management of changes of resources can divided into five distinct processes (cf. [Boisot 1986, 1994]): problem-solving, diffusion, absorption, scanning and life-cycle management.

Problem-solving refers to the process of codifying and giving a structure to tacit knowledge possessed by specific actors (direction A in Figure 6). However, this kind of codification always sheds tacit knowledge, as the transmitters consciously or unconsciously know more than they can ever say. *Diffusion*, in turn, refers to the sharing of insights or institutionalisation of knowledge within a larger community of actors (direction B in Figure 6). The diffusion of well-codified and abstract information to a large community is technically less problematic than diffusion of data which is implicit and relationship-specific.

*Absorptio*n denotes the process of applying the codified knowledge to different situations in a "learning by doing" or "learning by using" fashion (reversed direction A in Figure 6). For example, the use of an existing fault diagnosis platform in a new relationship is likely to involve exploitation of the codified functional diagnosis knowledge in the context of new technologies and applications, as indicated in Figure 2.

Scanning refers to the identification of the threats and opportunities that exist but are hidden in some data (reversed direction B in Figure 6). Scanning transforms such data into unique or idiosyncratic insights that come into the possession of groups or individuals. Scanning may be rapid when the data is well codified and abstract, but very slow and random when the data is implicit and relationship-specific. For example, identification and understanding of even the most critical environmental macro forces hidden in large amounts of incongruous information is all but straightforward.

The management of the life cycle of a resource involves choosing on which dimensions of the content to focus (cf. [Abell 1980]) and how to affect or make use of the life-cycle phase of the focal dimensions (direction C in Figure 6). An organisation may, for example, focus on one or more of the dimensions and take care of the other dimensions through its external relationships. Depending on the scope of the resources being dealt with, it may need to manage the content of several interrelated resources, so that they are combined for the strategic goals of the organisation. If the combination involves the resources of any external parties, absorption and diffusion of the content of the own resources must be controlled.

A contract research organisation may possess knowledge of hundreds of different techniques and technologies, deal with tens of different applications and focus on several functional problem areas. When establishing and maintaining its relationships, the organisation should be able to judge and manage the life cycle of at least the most critical resources that it will develop or exploit in specific relationships.

Since we consider competencies as combinations of resources and activities, the management layer of the R&D competence networking framework should also address the changes of activities. One of the most important means of managing R&D activities performed on human, technological and physical resources in a contract research organisation is a project management system, which we have modelled as an organisational resource at the substance layer of the framework. Other management activities involve, e.g. planning and co-ordinating the R&D activities of such organisational units as research groups.

Yet, we neither address the management of individual projects in this study, nor the management of the focal organisational group. For this reason, we take an indirect view on the management of changes in R&D activities, through the kinds of changes in resources discussed above and summarised in Table 16. If, for example, the codification of a resource is increased by the problem-solving process, the R&D activities of the organisation should change from individual learning to group-related transfer and combination of explicit technological skills.

Resource combinations, for which [Rosenbröijer 1998] proposes special connector functions, are an inseparable part of contract research and development activities, which we have modelled at the substance layer of the R&D competence networking framework. The content, codification and institutionalisation of a resource affect its integration. In terms of Figure 6 the problem is how to combine the evolution of the resources developed or possessed by the different participants of a focal net in a desired way. Since several participants may focus on similar resources, the combination may not be just a straightforward integration of mutually complementary skills and products.

Table 16. Management layer of the framework: resources.

Resource characteristics	**Management processes**	**Changes**
Firm		
Content	Life-cycle management	Dimension changes: application, function, technique, technology Life-cycle phase changes: incremental changes, discontinuity, substitution, competence, dominance
Codification	Problem-solving Absorption	Maturity increases Maturity decreases
Institutionalisation	Diffusion Scanning	Context of actors increases Context of actors decreases
Focal net		
Resource ties and resource constellations	Combine Control absorption Control diffusion	Resource combinations change Relationship-specificity changes Mutuality changes

5.4 EVOLUTION OF THE FAULT DIAGNOSIS RELATIONSHIPS

When analysing the archives of the focal organisation, we found only one document including an explicit analysis of the changes in fault diagnosis resources and relationships. Figure 7 shows a part of this document. It illustrates how ELE was viewing the past and possible future evolution of its fault diagnosis projects and resources in spring 1993. The former are indicated by the names of the projects (e.g. “CORTEX”) and the interacting parties (e.g. “CERN”), the latter include different technologies (“expert systems”), knowledge engineering techniques (“rule-based techniques”) and applications (“energy management”).

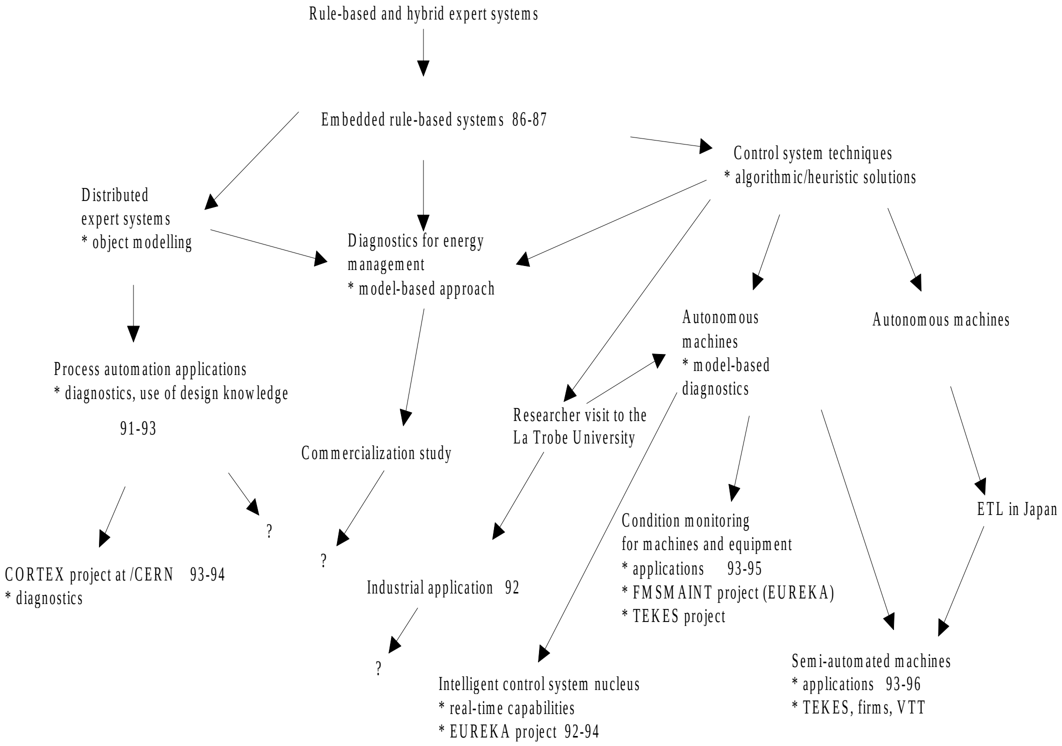

Figure 7. Illustration of the evolution of fault diagnosis R&D in ELE.

A much more detailed analysis of the evolution of the fault diagnosis R&D activities and competence is possible by means of the management layer of the R&D competence networking framework. We will carry out the analysis from the viewpoint of relationships, using changes in the fault diagnosis competence of the institute to explain the evolution.

Figure 8 summarises the changes that took place in the fault diagnosis R&D activities during the past ten years, by showing the competencies, relationships and actors that were involved. The figure is an abstraction of the changes of the substance layer elements presented earlier, shown over time. Relations between the elements are in this case depicted for illustration by dashed arrows. The finishing of a relation is indicated by an arrow that ends with a cross-line. Critical changes and change management processes will be discussed at the end of this section, by using the concepts of the management layer of the R&D competence networking framework.

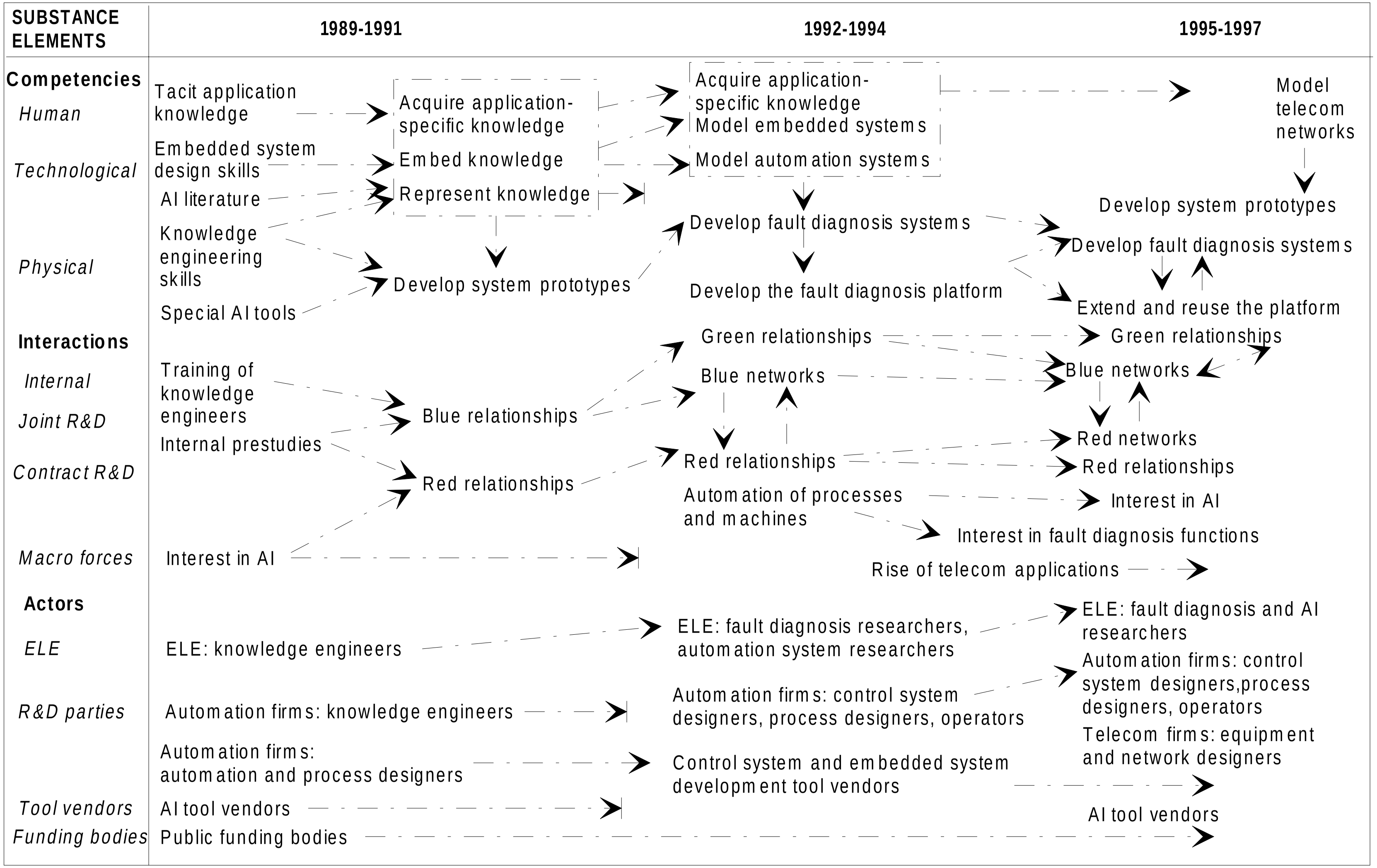

Figure 8. Competence-based evolution of fault diagnosis relationships.

1989 - 1991

Fault diagnosis was regarded at ELE as one possible problem area where generic knowledge engineering techniques could be deployed. A lot of the related knowledge was explicitly coded and generic. The relationships established with the knowledge engineers of process and machine automation companies resulted in the combination of this knowledge with the formerly tacit application knowledge ("expertise"). The relationships were established for the acquisition of application knowledge and for the joint deployment of knowledge engineering skills, rather than for the deployment of fault diagnosis knowledge. The ELE personnel were neither closely associated with the customers' automation engineers nor with the end users, machine operators. The knowledge of the implementation technologies of automation systems was not of any great importance, while AI expert system technologies, including special development tools, were emphasised instead. The KE techniques and technologies were believed to win the competence of future information systems, i.e. to become the dominant computing paradigm of the nineties.

The initial skills of ELE in the fault diagnosis of automation applications was thus built *in* relationships. Skill creation *for* relationships included mainly studying different generic KE techniques. The financial importance of the fault diagnosis projects, in terms of their volume, was rather modest. The R&D investments of ELE were also modest, basically literature surveys for scanning new generic knowledge. As far as ELE was concerned, the relationships featured a high degree of mutuality and particularity at the same time (cf. cell 3 in Table 13). ELE aimed at assuring a certain level of capability in generic KE techniques and some special AI technologies.

1992 - 1994

In terms of Table 13, relationships stayed in cell 3, the degree of mutuality and particularity of the ELE relationships remained high. However, its capability moved towards a wider engineering area in which the generic KE techniques were used for supporting rather than dominating purposes in R&D. Its competence in fault diagnosis had clearly emerged into team-based knowledge.

The increasing number of distinct projects meant that ELE was still busily absorbing its skills, but had not yet reached the problem solving level of explicit competence management. However, the combination of skills in automation applications, computer system modelling and KE techniques, all used together to build industrial fault diagnosis systems, indicated the first signs of portfolio-specific competence. This rather wide combination of skills may also have created a barrier towards competitors, at least towards the customers themselves and the universities, concerning the exploitation of the fault diagnosis knowledge that was made explicit.

Many project relationships with industrial knowledge engineers ended. The special AI tools used in establishing and carrying out some of the earlier projects became obsolete as consequence of the technological discontinuity, and were substituted by control system development tools.

At this point ELE had already made explicit some knowledge of automation applications, diagnosis functions and implementation technologies, which can be considered as portfolio-specific diagnosis knowledge. This knowledge started to dominate subsequent relationships and further competence building. Skills in generic KE techniques became combined with skills in computer system modelling techniques. The need of “embedding” skills vanished together with the special AI tools used to develop prototypes of knowledge-based systems.

The role of public funding bodies was rather distant in the relationships, yet important. They did finance a few joint R&D projects, but were not deeply involved otherwise, e.g. by co-ordinating research programs. This left room for ELE to simultaneously carry out fully contractual development projects with the same automation firms that were involved in joint R&D activities, so that the industrial exploitation of the results was accelerated. Some of the physical items that were exchanged can already be called fault diagnosis systems, as opposed to fault diagnosis features of automation systems.

The emerging portfolio-specific fault diagnosis competence helped ELE in extending its relationships, which in turn paved a road for competence building for relationships and increased the financial importance of the fault diagnosis projects. The first considerable internally funded green fault diagnosis projects were launched. The KE research group reached a dominating state in certain relationships, through a series of several successful problem solving projects. By 1994, ELE can be said to have started moving away from cell 3 of Table 13. It had not only rather wide capabilities for solving fault diagnosis problems, but also a distinct profile compared with some other parties that had become interested in the same area.

1995 - 1997

The fault diagnosis platform emerged gradually, and was documented by an individual person involved in several different fault diagnosis relationships. The problem solving based on platform normalisation, extension and management became important, in addition to the absorption of the fault diagnosis competence in specific relationships. The core fault diagnosis competence was made explicit through a set of functions, in order to separate the platform from specific automation applications and their implementation technologies. A pool of generic knowledge engineering techniques was used to support these functions. The pool could be updated on the basis of the emergence of the life cycle of KE techniques. For example, there was a rapid increase of interest in fuzzy logic during the early nineties, and the technique was incorporated into the pool. Case-based reasoning and neural network techniques followed a similar pattern later.

Generic computer system modelling techniques helped to link fault diagnosis functions to applications and implementation technologies. End users became involved in some projects where operator-assisted fault explanation and recovery features were developed. This resulted in an increasing emphasis on user interfaces and usage support technologies.

The financial importance of the fault diagnosis projects still increased, as these had become a backbone of the contractual R&D activities of the KE research group. A few competitors participated in some projects, as well as members of other ELE research groups. The latter were mostly experts in certain embedded systems implementation technologies, such as digital signal processing solutions used in real-time data acquisition. However, the functional fault diagnosis problem solving competence did not diffuse outside, but remained within the KE research group.

The planning of the first telecommunication network diagnosis project was based on the idea of specialising the existing competence for a new application domain. From a relationship perspective, ELE wished to exploit its existing competence for the needs of new customers that were already co-operating to develop network equipment. The customers of these parties, i.e. telecommunication operators, were not involved, but that had been the case in a number of earlier ELE fault diagnosis projects. A funding body was involved indirectly, by financing the participating customers. In the context of this project, the mutuality and particularity of ELE were rather low and the inconsistency high, because of the lack of knowledge of the new application. The knowledge appeared to be highly tacit and problems arose even concerning the notations through which it was planned to be made explicit, not to mention the content itself. The knowledge of the CBR technique, on the other hand, was generic and available through literature and supported by certain development tools.

Yet, it seems that too many things were changing at the same time. In the first telecommunication network diagnosis project not only the application, generic KE techniques and system implementation technologies were changed, but also the resources and actors involved in the project. It was difficult to model the complex application, and the types of system models produced for automation applications were not feasible. The customers were questioning the importance of the case-based reasoning technique. Furthermore, the ELE researchers were not familiar with the technique, and thus had to spend a lot of time acquiring the generic knowledge related to it.

Although ELE had been aiming at an incremental change in fault diagnosis competence, it fell back into an early substitution state - fighting against the presently dominant GSM network management solutions. The intended management of competence building in this context was mostly knowledge scanning, done on an individual basis. It proved very difficult to carry this out for the knowledge of the complex application domain. Moreover, although codified knowledge of the CBR technique was available, its combination with the application knowledge did not succeed too well.

6 CONCLUSIONS

We have studied the mutual evolution of R&D relationships and competence of a contract research organisation, with a focus on how relationships develop as a consequence of the changing competence. The problem is reciprocal, because competence will not, in practice, evolve without changes in relationships. A layered framework was presented above to illustrate the main elements of competencies and relationships, as well as their evolution. The substance layer of the framework is based on the ARA model, according to which competencies are viewed as activities performed by actors on certain resources. The management layer of the framework describes how relationships and competencies evolve over time.

The framework was used to model and analyse the fault diagnosis case. During the construction of the framework and the analysis of the case, we identified a number of empirical, theoretical and managerial issues concerning the framework and its further development. These will now be discussed, in addition to the problem of modelling and analysing *contexts*, which we have not yet addressed in the study.

6.1 EMPIRICAL FINDINGS

The analysis of the fault diagnosis case was mostly based on a grand story put together by the authors and commented by a few key informants. The story was augmented with a number of texts to illustrate aspects related to individual actors, relationships and competence elements. This kind of augmented story was quite a good starting point for creating the R&D competence networking framework. It resembles the real life in the sense that the organisation’s collective understanding of the past, the grand story, forms a backbone for a large number of distinct episodes.

We have mostly used documentary data in the augmented grand story, but we believe that this data forms a good basis for subsequent interviews, in which individual experiences can be captured. However, it is necessary to analyse further documents related to certain relationships, especially to R&D projects, in order to make use of the experiences. Otherwise some parts of the R&D competence networking framework will not be utilised to their full capacity. For example, the use of financial resources can be tracked reliably only at the level of distinct projects and investment activities.

Several life cycle phases, a few years each, could be identified in the case story. The first and the most recent phases were strongly affected by a similar kind of a macro force, the interest in KE techniques. In between, the focal organisation focused on applying its fault diagnosis knowledge and skills mainly to industrial automation systems. One of the macro forces that helped to extend and expand relationships in this phase was the increasing automation of processes and machines.

The fault diagnosis platform, an explicitly codified piece of the focal organisation R&D competence, resulted from carrying out the fault diagnosis problem solving process in several subsequent R&D projects. The emergence of telecommunication applications in the late nineties seemed to offer an excellent opportunity for expanding ELE relationships by reusing the core fault diagnosis competence. The difficulties that were encountered in this new domain were mostly due to the lack of application-specific knowledge.

The actual content of the fault diagnosis R&D work has directly affected the relationships of ELE. Generic knowledge engineering techniques, fault diagnosis functions, implementation technologies and various product applications have together shaped the fault diagnosis competence. The overall evolution has proceeded from techniques via understanding the core functions and the whole problems solving process to new applications. Different technologies have been used as implementation means in each phase. The focus on generic KE techniques was useful especially in the first phase, but corrupted rather rapidly because of the common availability of the techniques. At the beginning, the knowledge engineering skills of ELE depended largely on special resources, but these resources lost their importance in a very short period of time. Focusing on fault diagnosis functions and the problem solving process as a whole helped ELE to stay in the automation domain, if not yet entering new application domains.

The fault diagnosis platform is not a product itself, but a product concept resulting from the problem solving process carried out in several different relationships. The core functions must be constantly extended, keeping in mind that new applications require extensive modelling efforts. New implementation technologies must be used in almost all new applications, in addition to scanning new generic techniques for their possible utilisation. It is striking that both in the earlier and in the more recent relationships the introduction of new generic techniques has caused problems. Technology, as a means of implementing fault diagnosis functions, has not been unimportant, but has not played any central role either. This is certainly one of the most interesting empirical findings in this research, although it does not mean that technological skills are unnecessary in fault diagnosis R&D.

Only a few elements have completely vanished from the fault diagnosis substance of ELE. The institute is, for example, still successfully dealing with automation system applications, using several generic KE techniques and implementing fault diagnosis functions by using many kinds of technologies. However, the view of ELE of the relative importance of the substance elements has changed dramatically. This has considerably affected the fault diagnosis R&D relationships of ELE during the past ten years. Empirically, it is interesting to point out that the ideal project portfolio shown in Figure 1, from green to red relationships via blue networks, is not obvious at all in the case data. For example, almost no self-funded fault diagnosis research projects were carried out in the late eighties, and the fault diagnosis platform emerged largely as a spin-off of the fully contractual R&D activities in the early nineties.

6.2 THEORETICAL CONTRIBUTIONS

The main theoretical contribution of this study is the R&D competence networking framework. Although earlier studies, such as [Leppälä 1995], have addressed contract research organisations, there is still a distinct lack of longitudinal analyses. Although these are more common in the field of industrial marketing, they still fail to address the role of competencies in emerging relationships in depth. Even [Rosenbröijer 1998] that investigates the problem remains at a rather abstract typology level with regard to capabilities. Moreover, he takes the conventional approach by focusing on certain relationships of the focal organisation, rather than on certain competencies. The reversed approach that we have taken, the analysis of the relationships of the focal organisation concerning a specific competence, is more strongly oriented towards the basic strategy of a contract research organisation, the goal of which is to create, maintain and extend relationships for its competencies. The number of such competencies is almost invariably smaller than the number of the R&D relationships of the organisation, because of the need to transfer new technical expertise to industry as a whole.

Although the substance layer of the R&D competence networking framework is based on the ARA model, it contributes to the model by including a detailed conceptualisation of the R&D resource dimension. Although the resource typology that we are suggesting is mostly based on an earlier work, we have revised and extended that work and associated it with the concepts of actors and relationships. In particular, the four-dimensional model of the content of resources - applications, functions, techniques and technologies - proved to be useful for explaining the fault diagnosis competence of the focal organisation. This model, based on [Abell 1980], is neither specific to the fault diagnosis case nor to contractual R&D. The dimension of generic techniques not included in Abell’s original market model was crucial in the fault diagnosis case. [Elfring and Baven 1996], for their part, miss three of the four dimensions.

The substance layer of the framework is, after all, yet another extension of a well-known relationship model. Although it is interesting as such at least for the needs of a better understanding of contract research and development, the main contribution of the framework is its management layer. Using [Ford et al. 1986] as a starting point, we identified a number of possible changes in relationships and four processes to manage the changes. Earlier research has addressed changes of relationships and networks, as well as investigated their reasons and results. Yet, for example, the fact that the change of the colour of a relationship is crucial in contract R&D cannot be explained by means of the earlier relationship models.

Although the typologies of the substance layer of the framework are hierarchical, there is a need to develop a much more elaborated hierarchy, in order to focus on truly critical elements of relationships and competencies. Too flat a categorisation of the large number of concepts involved in real-life relationships makes the analysis difficult, not to speak of practical competence and relationship management tasks.

The life cycle concepts, used for industries in [Uusitalo 1995], were applied to the four dimensions of the content of competence. Problem solving and absorption processes were defined for codification, diffusion and scanning processes for institutionalisation. Control of absorption and diffusion affects the particularity and mutuality of competence, correspondingly.

As opposed to [Rosenbröijer 1998], who addresses capability combination as a distinct function, we consider competence integration based on resource combination as an inseparable part of contract R&D. The content, codification and institutionalisation of the competence affect its integration, as shown by the fault diagnosis example.

6.3 MANAGERIAL IMPLICATIONS

One of the basic problems of a contract research organisation is to know how to use its knowledge and skills in a “correct” way that helps to open up and manage the position of the organisation in a complex portfolio of projects. Competencies should be actively developed and exploited, but the dangers of *core rigidities* should be avoided [Leonard-Barton 1992]. The same applies to the particularity and mutuality of the organisation relationships.

The fault diagnosis case indicates that the development and exploitation of the focal organisation’s relationships and competence was a highly concurrent process. There was no clear distinction between the development and exploitation phases, as opposed to the view of e.g. [Sanchez and Thomas 1996]. On the contrary, it seems that although the project portfolio of the focal organisation is intended to separate competence building *for* relationships from competence leveraging *in* relationships, such truly important changes in competencies as the emergence of the fault diagnosis problem solving process and platform resulted from highly simultaneous competence exploitation and development activities.

Concurrent management of competencies and relationships is thus needed. The managers of a contract research organisation should be able to identify target states and paths in the space of current and new competencies and relationships (cf. Figure 6) in a meaningful way, as illustrated in Figure 9. Intuitively, the upper left “mass-customisation” corner of Figure 9, in which the organisation takes an advantage of its existing competencies, while simultaneously being active in the development of new competencies, is a good target state. Reaching that state depends on both how it and its customers view and develop their relationships and how their competencies match and evolve together.

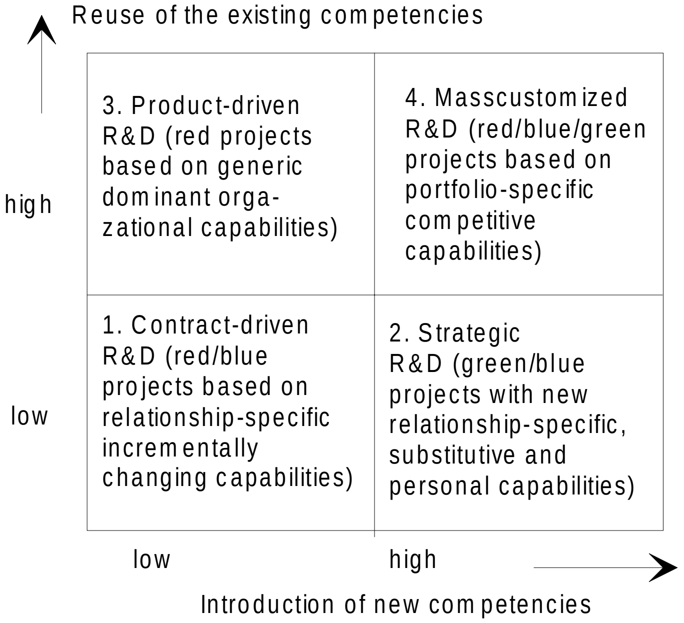

Figure 9. Competence-based management of contractual R&D.

Since the evolution of the four dimensions of the competence content is crucial for the development of relationships, the use of the management layer processes by which desired changes of competence can be controlled should be analysed in more detail. The processes can be expected to result in an increased “maturity” of R&D, for example as follows (cf. [Elfring and Baven 1996]):

- in an early phase of the contractual R&D, the competence is based on knowledge of radically new or incrementally improved technologies, or on the understanding of some generic techniques not yet fully applied to solve certain problems or not yet implemented as commercial technologies, whereas

- in the more “mature” phases R&D services are based on product platforms resulting from the understanding of the functional problem solving process, i.e. reuse of core functions, use of certain generic techniques, development or use of appropriate implementation technologies, and understanding of the customers’ applications and end-users’ to a sufficient degree.

This would mean that the increase in the maturity of R&D builds on the top of technologies and generic techniques, but focuses on functional skills and processes needed to solve certain problems for the current key customers, by means of actively investigating possible new applications for those skills. In this process, technologies and generic techniques are used more as a means of ensuring technical ways that are flexible enough for solving problems than as R&D competencies as such.

In terms of [Gallon et al. 1995] techniques and technologies could thus be called *primary capabilities*, whereas *critical capabilities* would be the ones used to develop and exploit reusable solutions for the problems on which the R&D organisation wishes to focus. The knowledge of the customers' applications and end-user needs would be either critical or primary, depending on the importance of a specific customer account.

In order to manage change paths in practice, the organisation would need to carry out its strategic and operational planning based on a vision, in which new elements could be incorporated into the content of its competencies, so as to be able to affect the emerging relationships. Table 17 illustrates such planning, by showing some possible new elements of ELE fault diagnosis R&D competence.

Table 17. Planning for the evolution of the maturity of R&D.

Fault diagnosis competence	**New applications**	**New functions**	**New techniques**	**New technologies**
1998 - 1999	Electronics assembly lines	Data mining, optimisation	Neural networks, SPC, genetic algorithms	Assembly automation, neural network environments, data bases
2000 - 2001	Intelligent electronic appliances	Explanation, visualisation	Usability engineering, multimedia engineering	Embedded UIFs, VR, WWW, data networks

In addition to *planning for R&D maturity*, it should be known how to *evaluate the maturity* the competencies and relationships of a contract research organisation. Maturity assessments have become an industrial practice in some fields, e.g. software industry and they have also been analysed from the viewpoint of R&D (see, for example, [Miller 1995]).

However, the existing maturity assessment models focus on the quality of the internal activities of the organisation rather than on the evolution of its resources as parts of the external relationships. For this reason they are generic, rather than substantial models that would take the changing context of the organisation into account. Such approaches as [Lewis and Gregory 1996] could perhaps be used as a better starting point for developing a substantial, context-sensitive R&D maturity assessment framework.

6.4 TOWARDS CONTEXTUAL UNDERSTANDING OF COMPETENCE DEVELOPMENT

There is a general acceptance of the importance of contexts for understanding firms and business relationships [Lundgren 1992, Håkansson and Snehota 1995, Halinen and Törnroos 1995, Alajoutsijärvi and Eriksson 1998]. Yet, the principles of contextual analysis have not been thoroughly studied in industrial marketing and competence literature. In this research we have used the ARA model to make explicit a specific context of contractual R&D, while not analysing R&D contexts more thoroughly. In general, only a few studies have addressed contexts as a means of understanding the behaviour of industrial organisations and their relationships [Anderson and Narus 1994, Halinen 1994, Alajoutsijärvi 1996, Rosenbröijer 1998].

Contexts are central in the process-based approaches to industrial management [Pettigrew 1985, 1987, 1989 and 1992, Pettigrew and Whipp 1991, Pettigrew et al. 1989 and 1992]. In these approaches, contexts usually describe a broader area of connectedness or embeddedness, compared to a business network surrounding a firm. [Pettigrew and Whipp 1991] and [Pettigrew 1987] describe contexts to be composed of economic, social and political forces and developments (called the external or *outer context*) and a company’s resources, capabilities, culture and politics (called the internal or *inner context*). Yet, the authors do not provide any extensive discussion of what the inner context is, which is pointed out in [Alajoutsijärvi and Eriksson 1998].

In this regard, the results of the fault diagnosis case study discussed in this report could be used as a starting point for making explicit real-life inner and outer contexts of R&D, and for analysing how the two are interrelated in practice.

Although the current industrial marketing research does not emphasise the relevance of the inner context as explicitly as it emphasises the outer context, some aspects of the inner context can be found in the existing relationship models. Notions of situational features of individuals, the social system and the atmosphere of the original IMP group’s relationship model can certainly be seen as elements of the inner context. Other relationship models are provided in [Möller and Wilson 1995, Halinen 1994], for example. The basic problem with all these models, from our viewpoint, is that they are trying to make an a priori definition of what the relevant inner and outer contexts are.

Furthermore, their definition of the inner context is rather narrow - the complexity of the context is often used as an excuse, which leaves little room for case-specific variations [Alajoutsijärvi and Eriksson 1998]. Concerning the few in-depth analyses of outer contexts, several macro forces are identified in [Alajoutsijärvi 1996] that affect certain industrial relationships. [Halinen 1994] proposes “general social, political and technological forces” for such variables in an outer context of professional service relationships.

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