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# R&D Collaboration between CERN and Industrial Companies: Organizational and Spatial Aspects

Paper

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# Abstract

The findings of fundamental research in fields like fusion research, space research or high energy physics stimulate innovation and technological progress in industry. Although R&D collaborations between companies already have been investigated in detail, R&D collaborations between companies and large-scale research centers are not well understood. This report is a part of a PhD study which aimed at providing answers to the question of how to best organise and manage R&D collaborations between industry and scientific centers. This research problem is analysed using CERN, the European Laboratory for Particle Physics, as a case study.

A conceptual framework is designed based on previous findings in Transaction Cost Economics, Strategic Management and the findings of related Empirical Studies. The conceptual framework captures the dynamics of R&D collaborations from conceptual design to managerial implementation: Besides the design of the collaboration format, one should pay particular attention to the selection of the collaboration partner, the negotiation of the collaboration agreement and the implementation of the collaboration. Based on the conceptual framework, general problems and success factors of innovative collaborations are identified.

The collected empirical evidence from 21 cases of R&D collaborations between the electronics and data communications industry and CERN is used to answer the research problem. The empirical data was gathered in personal interviews with company engineers and CERN engineers who were directly involved in the selected R&D collaborations.

The exploratory analysis leads to the identification of critical issues concerning the design of the collaboration format, the selection of the partner, the negotiation of the agreement and the implementation of the project. A deeper analysis of four R&D collaborations investigates how the collaboration partners organised the projects in order to ensure effective communication and common learning despite geographical separation.

Apart from developing a conceptual framework for analysing R&D collaborations, the contribution of this study to the theoretical debate is to add more nuance to observations in the current literature regarding factors resulting in successful collaborations. More specifically, the motivations for taking part in R&D collaborations and the differences between small and large companies are elaborated here in more detail. Second, the importance of informal networks and the role of trust in such undertakings can be demonstrated in a more differentiated way. Third, the link between specific communication patterns and the location of the collaboration partners is elaborated.

# I Introduction

The scale of scientific undertakings in fields like fusion research, space research and high-energy physics has grown very rapidly during the last 20 years. In Europe, this type of research has only been possible due to its international nature. However, due to economic austerity, European funding agencies have been encouraging such international research centers to share their technology development activities with industry in order to increase economic benefits.

Consequently, there has been a growing interest in universities and research laboratories on how to stimulate innovation and technological progress in industry. Over the last decade the economic benefits and spin-offs, resulting from interaction between large-scale research centers and industry have been investigated and reported upon (Lederman, 1984; Schmied, 1984; BETA, 1988a,b; Barbalat, 1994, Nordberg et al, 1996). Studies show that collaborating with large scientific facilities generates at least a three-fold economic utility for industry (Schmied, 1982). It is estimated that over 20% of the US Gross National Product now results from commercial technologies originally used in modern physics research (Lederman/Carrigan, 1987).

Since the 1980's R&D collaborations have proved to be an attractive way for companies to come up with new and better products and processes. Companies collaborate with other companies and research institutes in order to innovate products and processes.[1] Although collaborations between companies already have been investigated in detail (Contractor/Lorange, 1988; Harrigan, 1985a; Porter/Fuller, 1986), R&D collaborations between companies and research centers are not well understood. The large European fundamental research centers tend to lack a systematic approach to R&D collaborations with industry. Most of the current R&D collaborations originate at random and thus the hidden potential in this kind of activity is not fully exploited. The industrial and economic potentials embedded in basic research should be translated into routine procedures as part of general innovation processes in the economy (Hameri/Vuola, 1996: 538).

The present paper focuses on R&D collaborations between CERN, the European Laboratory for Particle Physics and its member states' industry. The research problem is how to best organise and manage R&D collaborations between industry and scientific centers like CERN. It can be further divided into the following questions:

[1]The relationship between private and public research is complementary (see Leyden/Link, 1991: 1673ff.), with the former traditionally concentrating on the short-term and applied, and the latter on the long-term and generic.

1) How should R&D collaborations be organised in order to minimise the difficulties that CERN and its industrial partners may encounter in co-operative efforts?

2) How should the collaboration partners be configurated from a spatial perspective, and how should they deal with physical distance?

3) What are the challenges facing R&D collaborations as they evolve over time, and how can they be managed?

In order to answer the research problem above a three-step process is employed. First, a conceptual framework is designed based on literature research in Transaction Cost Economics, Strategic Management and the findings of related Empirical Studies. Based on the conceptual framework, general problems and success factors for innovative collaborations are identified. The second step involves analysing a number of case studies of specific projects in detail. The critical issues in collaborations are identified as well as the related strategies to deal with these. The third and final step summarises the findings and gives a series of propositions describing the nature of optimal R&D collaborations.

The research method is dominantly empirical, using a logical inductive approach. Empirical case studies are used to answer the research problem which is formulated from previous findings in the research literature. A structured questionnaire is used to analyse the case studies.

The focus of this study is on the electronics and data communications industry participating in CERN R&D collaborations. These sectors are selected from several other high technology industries collaborating with CERN, because their share (in terms of number of projects) in the forthcoming design and construction of the world's largest particle accelerator, the Large Hadron Collider (LHC), and its particle detectors is by far the biggest. Excluded were civil engineering, mechanical engineering, electrical engineering, superconductivity and vacuum and low temperature technologies.

## II Background: CERN and its Interaction with Industry

CERN, the European Laboratory for Particle Physics, was founded in 1952 in Geneva, Switzerland as a joint European effort to provide research tools for physicists studying the smallest constituents of matter (Hentsch, 1991: 8). At that time, the smallest known particles were the nuclei of atoms and the related research was thus called nuclear physics.

At present, CERN has 19 member states and its annual budget in 1995 was about 950 million sFr. Its member states are Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Netherlands, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland and the United Kingdom. The membership contribution of each country is in the first approximation in proportion to its Net National Income. Israel, the Russian Federation, Turkey, Yugoslavia (status suspended after the UN embargo, June 1992), the European Commission and UNESCO have observer status. CERN has about 3000 staff members of which roughly 100 are dedicated to fundamental physics research only. The rest are either involved in the experiments and accelerators or provide infrastructure services (Hentsch, 1991: 27). In addition to the CERN staff, there are about 6000 active users on site from other physics laboratories and universities. Most of the users come from the member states but some 20% come from other countries (CERN, 1993b: 5).

In order to achieve its basic research mission, CERN designs, constructs and operates large-scale particle accelerators and detectors. The main components in an accelerator are the accelerating elements and, in a circular machine, the bending magnets. The particles are accelerated inside a vacuum. The vacuum system is surrounded by the accelerating elements and magnets. Finally, a control system is needed to operate the accelerator. Accelerators produce the necessary energies for particles to collide with each other or hit a given target. Detectors are used for detecting and studying the new particles generated by the collision. They surround the collision point. Their size is proportional to the collision energies of the particle accelerator (Kleinknecht, 1986: 56f.).

Designing and constructing a large-scale accelerator and detector system is a long-term process. In the case of CERN's next large accelerator, the LHC, the efforts started in the end of 1984 when the CERN Council passed a resolution stating its belief that the LHC was the right machine for the future of particle physics and of CERN. Two years later, the Council was presented with a full description of the project, including the expected experimental programme and cost estimates. After intensive discussions between the member states and the CERN management the LHC was approved by the 19 member states at the end of 1994. The machine is planned to be in operation at the full collision energy from 2005 onwards (CERN, 1996: 6ff.).

CERN basically interacts with industry in three different modes. They include informal information exchange, contract-based transactions and R&D collaborations.

## 1 Informal Information Exchange

Informal information exchange takes place for example in the form of industrial exhibitions on the CERN site, organised by CERN together with the member states on a regular basis. There, the companies have the chance to present their products and to get in contact with CERN engineers and physicists. Furthermore, CERN engineers visit companies, attend large industrial exhibitions and conduct market surveys on a regular basis. In all cases, the flow of information is rather informal and aims at scanning the market to find new suitable products, or, at keeping industry aware of CERN's needs, respectively.

## 2 Contract-based Transactions

At CERN, the dominant governance structure for acquiring technologies from industry is spot-market contracting. CERN's annual purchasing budget is about 350 million sFr, which approximately equals 35% of its budget, including all on-site technology domains and industrial support.

CERN deals with industry by means of standardised contracts, which reflect the financial rules of the organisation and follow well established purchasing rules and procedures. The purchasing policies of CERN are close to those of other public research organisations in Europe. The European Space Agency (ESA, 1980) and the European Synchrotron Radiation Facility (ESRF, 1988) select suppliers based on the lowest bidder and geographic quotas. The Joint European Torus (JET, 1991) and the European Union (CCE, 1989) select their bidders in a similar way to CERN. CERN aims at achieving a supply contract return coefficient of not lower than 0.8 for each and every member state (CERN, 1992: 3ff.; CERN, 1993a: 9). Consequently, CERN buys European on principle, except in those cases where European companies cannot meet technical requirements. Even then, preference is given to non-European products which can be assembled or finished by a European-based subsidiary (Hentsch, 1991: 25).

The contracts are based on detailed technical specifications which are prepared by the technical divisions responsible. The contracts are often manufacturing-oriented and require limited designing and engineering effort on the part of the industrial partner. The level of precision in a specification depends on the available in-house expertise at CERN. Critical products, like accelerator or detector components, are usually specified in full detail. Products such as power electronics are on the other hand often specified in a more function-oriented way. In many cases, they rely on well established industrial standards. A typical classification of CERN contracts based on the level of supplier-perceived product uniqueness and the required engineering work is depicted in Figure 1.

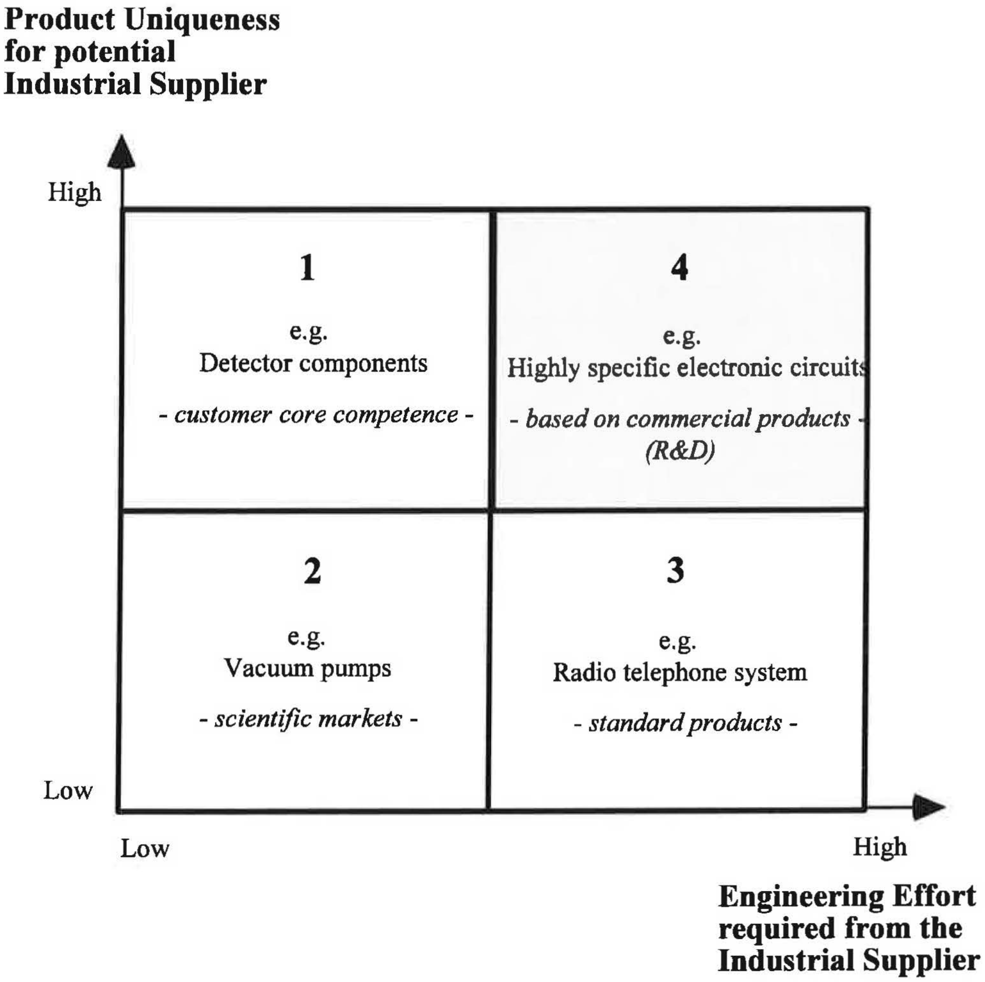


Figure 1: Interactions between CERN and Industry
(Source: Modified after Nordberg, 1994b: 8f.)

A low level of engineering effort required from the industrial supplier means that the level of CERN's technical involvement in the transaction is high. This is a reflection of the necessary development efforts in areas of CERN's core competences. CERN had already carried out the necessary research and development effort and had specified the product in detail. Consequently, there was no need for the supplier to undertake any engineering activities. Typically, this type of transaction took the form of a contract focused on production (see quadrant 1 and 2 in Figure 1). Conversely, the product in question may have been a well established product thus requiring limited technical involvement from

CERN (see quadrant 3 in Figure 1). In such cases, it was sufficient for the supplier to respond to a functional, more general specification (Nordberg, 1997: 141).

## 3 R&D Collaborations

When a major new project - like the LHC - is still in its design phase, several promising alternatives typically exist for overcoming major technological challenges. These solutions which are at the leading edge of contemporary technology require extensive, long-term R&D work in order to prove their suitability and reliability for their given purpose as well as to ensure their reproducibility on an industrial scale. In cases where the required product is CERN specific but where CERN has not yet gained sufficient know-how in-house, transactions with industry can no longer be based on contracts. There are several reasons for this. First, a detailed technical specification cannot yet be drafted for the required product. Secondly, the product is not yet available in industry even if it is based on existing industrial technologies. This is usually the situation when R&D collaborations are set up (see quadrant 4 in Figure 1). R&D collaborations represent a better solution to the need for fast access to knowledge that comes from sources of know-how that are not widely available (Powell, 1987: 77f.; Grabher, 1990: 16).

Despite the longer-term commitment made by both CERN and industry, only moderate financial contributions are made by the partners. CERN usually contributes in terms of providing manpower, manufacturing tools and testing equipment. Industrial partners frequently develop the required product in their own factories bearing a major part of the development costs themselves. During the last 10 years, more than 260 R&D collaborations have been signed with CERN, amounting to some 70 million sFr, excluding manpower costs.

Long-term R&D collaborations happen in high-technology areas linked to the development of instrumentation for particle physics, such as:

1) high-precision, ultra-fast electronics for registering beam collisions and for transferring large amounts of experimental data over very short periods,
2) powerful computer systems to analyse data centrally,
3) magnets,
4) superconductivity,
5) high-speed electronic data transmission networks between CERN and physics institutes in the member states and elsewhere (Hentsch, 1991: 49).

# III Conceptual Framework

The conceptual framework of this study portrays the process from planning to finishing R&D collaborations successfully. It consists of three components:

1) Transaction Cost Economics which discusses the link between transactions and organisational design.
2) Strategic Management Literature, discussing the design of hybrids, the selection of partners, the negotiation of agreements and the management of R&D collaborations.
3) Empirical Studies reporting factors influencing the successful implementation of collaborative projects.

## 1 Transaction Cost Economics

Increasing levels of transaction costs will shift the exchange relationship from market-based relations towards vertical integration depending on the extent of human, environmental and transaction-specific factors. Transaction cost economics argues that in the absence of asset specificity, market relations are the most efficient mode of governance. Instead, in the presence of bounded rationality (and possibly opportunism), high level of asset specificity and recurrent transactions, a unified governance structure is optimal (Williamson, 1975, 1985, 1986; Borys/Jemison, 1989; Medema, 1992; Pilling et al, 1994).

R&D-cooperation agreements, the core of this study, are neither arms-length nor purely internal relationships and can therefore be clearly assigned to hybrid modes of governance. As argued above, market relations are unsuited for the required high technology equipment because of the mixed or high level of asset specificity, bounded rationality and frequency. Internalisation is not possible due to institutional boundary conditions. Moreover it would not be efficient because the assets involved are neither single-purpose nor unique by nature.

Transaction Cost Economics has so far been a useful "tool" to identify hybrid modes of governance as the appropriate organisational form for the type of transactions discussed in this study. The theory provided some useful general insights on different types of transaction and alternative governance structures. However, it does not discuss in detail issues like purpose and nature of a project, partner configuration, interrelations between the magnitude of assets and power, as well as between frequency and location of partners. Therefore, the dynamics of partnerships in R&D cooperations cannot be analysed further in this context.

## 2 Strategic Management

In the Strategic Management literature collaborations and their strategic importance have been extensively studied since the early 1980s (Killing, 1983; Harrigan, 1985a; Porter/Fuller, 1986; Morris/Hergert, 1987; Contractor/Lorange, 1988; Hagedoorn, 1989; Foray, 1991). Although Transaction Cost Economics and Strategic Management share some common ground, they differ fundamentally in the objectives attributed to companies or organisations. Transaction Cost Economics states that companies should transact using the mode which minimises transaction costs. Strategic Management states that companies should transact using the mode which maximises profits through improving a companies competitive position with regard to their competitors (Porter, 1980; Harrigan, 1985b; Kogut, 1988; Buckley, 1990). Yet the two approaches should be treated as complements rather than as substitutes.

The Strategic Management approach recognises the value and big attraction of collaborations and provides a meaningful typology of interorganisational arrangements. The need for different management approaches to different types of collaborations is underlined. The Strategic Management approach furthermore acknowledges the dynamics of R&D collaborations. That is, their evolutionary process needs to be considered and the problems and major challenges during the different stages of the collaboration process should be addressed. The design of a collaboration which reflects the spatial configuration of the partners and the distribution of power between the collaboration partners prepares the ground for the investigation of subsequent stages of the process. The Strategic Management literature discusses the difficulties and corresponding managerial measures linked to partner selection, agreement negotiations and implementation of collaborations. However, problems and challenges during different stages of the collaboration process are discussed on a fairly conceptual level only.

## 3 Empirical Studies on Collaborations

The predominant management practices, as well as more specific factors which affect the success of R&D collaborations, are explored in the light of individual empirical studies on collaborations. These studies are selected having in mind two specific reasons: first, their results represent a summary of the latest developments in research in this field; second, their methodology provides a close analogy to the one used in this study.

The above empirical studies provide a set of success factors for the design of collaborative R&D projects. Similarity of size and power, as well as coping with international differences when partners are located in different countries, are reported as critical factors. For the selection of the right partner, the presented studies identified success factors with regard to motivation and experience of potential partners. While negotiating the collaboration agreement, the definition of milestones is of particular importance. However, detailed regulation of the project implementation should be avoided in order to enhance flexibility. The empirical studies suggest that collaboration partners should be willing to adapt to changes in their partners' strategic objectives within their ability. This requires effective communication between the partners and internal communication with the management.

Figure 2 summarises the inter-relationships between the three components which form the conceptual framework. Starting from the static framework of Transaction Cost Economics which exclusively concentrates here on issues before the start of the project it continues with Strategic Management which investigates issues after the start of the project. In such a way, the dynamics of R&D collaborations are better captured, and then can be further elaborated by reviewing some selected Empirical Studies on Collaborations.

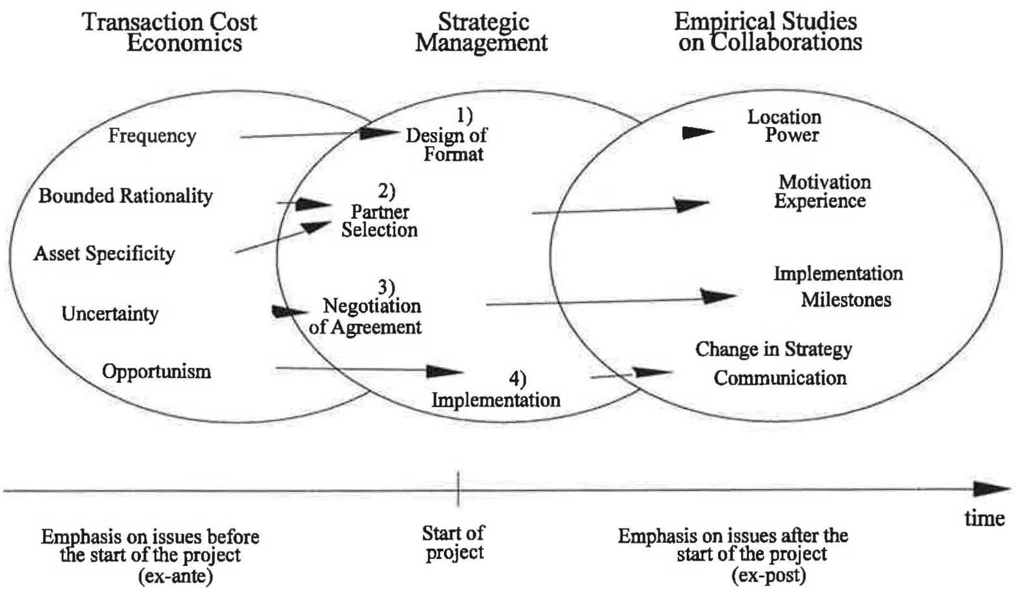


Figure 2: The Dynamics of R&D Collaborations from Conceptual Design to Managerial Implementation

The conceptual framework is developed for answering how to best organise and manage R&D collaborations between industry and scientific centers like CERN. Based on the conceptual framework, the author's propositions for identifying successful R&D collaborations are the following:

1) The development teams of the collaboration partners should be co-located in order to guarantee good communication and effective collaboration. Collaboration partners who are separated by physical distance should have intensive personal contact in the initial stage of the project followed by regular face-to-face contact to sustain the necessary level of confidence for communication via electronic media. The partners provide complementary inputs to the cooperative agreement and power should be symmetrical.
2) Industrial companies successfully take part in R&D collaborations with CERN more because of strategic reasons like gaining know-how, rather than because of short-term considerations like making profits or sharing cost and risk of R&D projects. Industrial collaboration partners need to have a critical mass in terms of in-house R&D capability in order to take part in and to benefit from R&D collaborations. Therefore, one will predominantly see medium-sized and large companies taking part in R&D collaborations with CERN.
3) Successful collaborations are implemented by partners who already know each other well from previous projects. The experience regarding partnerships in former collaborative efforts results in a high level of mutual trust which is reflected in the less frequent use of detailed collaboration agreements. Although the collaboration partners know each other very well, they have to be prepared for the risk of being confronted with unforeseen changes in strategies.

The propositions quoted above are used as guidelines while establishing the research methodology and carrying out the exploratory research phase.

## IV Methodology

The research design adopted in this study combines an exploratory and explanatory approach. Discussions with the author of a previous study on benefits and difficulties related to CERN contracts (Nordberg, 1994a) revealed that a sufficient number of collaboration projects for achieving statistical significant results would not be available. The number of relevant projects was expected to be smaller than 50 which is considered as the minimum size for a meaningful statistical analysis for a study of this nature. Consequently, the exploratory study aimed at identifying the pertinent success factors in a descriptive way. By describing the factors which are critical to the success of R&D collaborations a link is established between the conceptual framework, built in the previous chapter, and the explanatory study adopted to understand the collaboration process.

## 1 The Selection of Cases

The projects were selected from a database containing all the registered R&D collaborations between CERN and industrial companies and university institutes. The database was provided by the CERN Industry and Technology Liaison Office (ITLO). The listing contains more than 200 projects from six different technology domains present at CERN. It provides basic information like a short description of the project, the collaborating company or institute, contact person(s), status of the project and reference number of relevant documents.

As a result, 30% of the projects fitted the definition of a R&D collaboration presented in Chapter II. The described selection process is summarised in Figure 3 below.

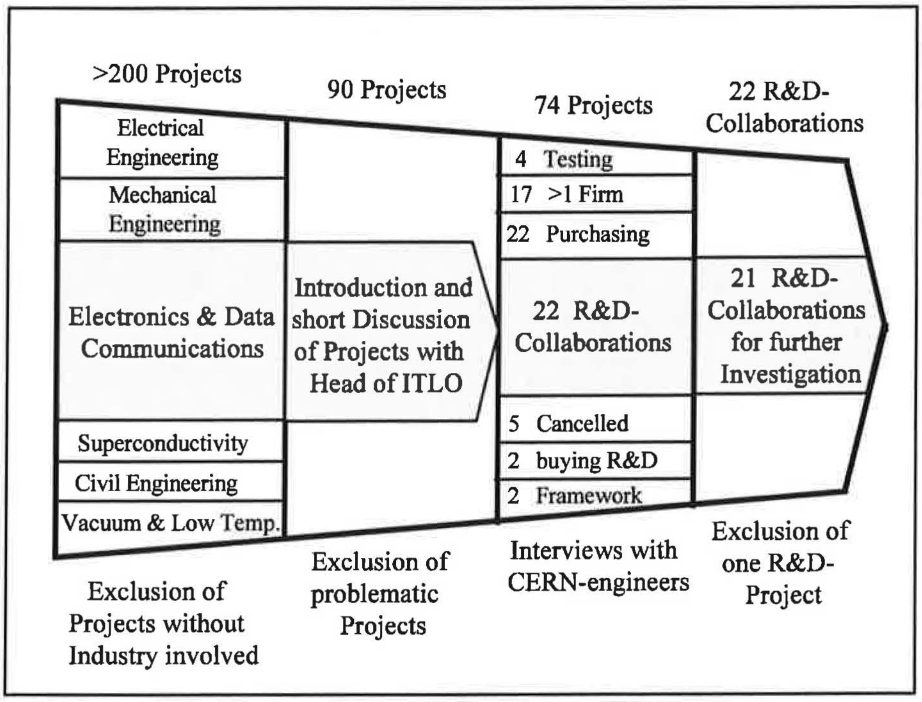


Figure 3: The Selection of Cases for further Investigation

## 2 The Data Gathering Process

The interviews with the CERN engineers who are responsible for the selected projects had more than one purpose:

1) The selection of the final number of collaborations had highest priority, as described in the previous chapter.
2) Additional factors could be identified like specific difficulties which were not yet covered in the questionnaire. In such a way, one could refine and finalise the draft questionnaire.

By conducting the interviews with the CERN engineers detailed information was obtained about the project history, about the collaboration agreement and the difficulties encountered in the course of the project. A categorisation of successful and unsuccessful projects could not be done, because from CERN's point of view all investigated projects had been successful. Due to the lack of detailed information about the benefits of the industrial partners, unsuccessful collaborations could not be identified at this stage in the empirical investigation.

When interviewing engineers from the industrial collaboration partners the interviewee was invited to introduce his company, its products and services, finally focusing on the collaboration with CERN in general and on the specific R&D collaboration in particular. Interviews were not taped as this would have in some cases reduced the level of openness and confidence, thereby possibly preventing certain statements. The author and interviewee went through the questionnaire, with the author making all the notes and, in most cases, filling in the questionnaire following the interviewee's oral answers. In any case, results were carefully transcribed immediately after each interview, thus indicating specific details to be clarified by phone and possible further questions to be asked in coming interviews. Between July and October 1996 interviews with 24 company engineers took place in six European countries. In four cases, the interviews took place at CERN. In one case, the questionnaire could not be completed in the course of the interview. It was finished by the interviewee and then sent back to the author.

## 3 Data Analysis

Combining quantitative with qualitative evidence is of special importance in the present study. Quantitative evidence can indicate relationships which may not be salient to the researcher. Due to the limited number of collaborations one could not apply rigorous statistical tests. Therefore, the strength and consistency of relationships had to be judged within and across cases (Eisenhardt, 1989: 543f.).

Once all the data asked for in the questionnaires had been collected, it was entered into a data base and processed by using, whenever possible, standard program libraries for statistical analysis. The statistical analysis was limited to descriptive statistics, focusing on the frequencies of specific indicators. In parallel, a so-called sequence analysis was used, which emphasised intimate familiarity with each case as a separate entity. In such a way, patterns for each case emerged separately before attempts were made to generalise patterns between cases (Ibid.: 540).

Next, similarities and differences between projects involving large companies were carefully investigated, as "the juxtaposition of seemingly similar cases by a researcher looking for differences can break simplistic frames" (Ibid.: 541). The emergent relationships were verified with the evidence in each selected case. This verification was similar to that in traditional hypothesis testing research. The key difference was that each hypothesis was examined for each case, not for all the cases simultaneously. The underlying logic was treating a series of cases as a series of experiments with the empirical data of each case being compared with the emergent frame (Yin, 1988: 38).

The next step of this iterative process was to compare the emergent frame with the evidence from projects involving small companies. By searching for similarities in projects with different partners with regard to their size, one could reveal important patterns of within-group similarity and across-group differences[2]. At this point, the qualitative data were particularly useful to understand why, or why not, emergent relationships held (Eisenhardt, 1989: 542).

Given the risk of collecting such a staggering volume of rich data, one may feel tempted to build a theory which tries to capture everything, being rich in detail, but lacking the simplicity of an overall perspective (Ibid.: 547). By linking qualitative discoveries from the interviews to the identified critical factors, which are based on the developed conceptual framework, only the most important factors are examined and described in detail. The final product from within-case and cross-case analysis will be propositions about success factors in the organisation and management of R&D collaborations. Due to the fact that the hypotheses-building process was so intimately tied with actual, empirical evidence, the likelihood of producing propositions which closely reflect reality is high.

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[2]Alternatively, one could also juxtapose successful and unsuccessful projects. However, in the course of conducting the interviews it quickly emerged that the vast majority of the collaborations were perceived as successful projects by the companies. The perception of success was directly linked to the companies' expectations. Hence, if gaining experience with a certain technology was expected, projects could be perceived as successful, even if they did not lead to the completion of a specific prototype. Consequently, the selection of categories according to the size of companies was preferred.

# V Analysis and Results

The quantitative evidence of the four groups of variables, as identified in Chapter III, are reported below. The discussion of the variables follows the order in the conceptual framework (see Figure 2).

## 1 Design of Collaboration Format

Based on the findings in the reviewed literature (Killing, 1983; Håkanson, 1993; Hameri/Nihtilä, 1995; Williamson, 1985; Pilling et al, 1994) one expects to see that the development teams of the collaboration's partners are co-located in order to guarantee good communication and effective collaboration. Furthermore, the research literature suggests that in successful collaborations the partners provide complementary input to the cooperation agreement and that power is symmetrical. Thus, the conceptual framework leads to the following design variables, which are investigated below:
1) Location
2) Power.

**Location:**
The industrial collaboration partners under investigation were located in six different European countries: the United Kingdom, France, Germany, Italy, Norway and Switzerland.

The results of the literature review suggested that because of recurrent transactions in the course of a collaboration (Williamson, 1975, 1985, 1986; Borys/Jemison, 1989; Medema, 1992; Pilling et al, 1994) the collaboration partners should be co-located when implementing the project (Allen, 1977; Handy, 1995; Hameri/Nihtilä, 1995). However, in almost two-thirds of the investigated projects, the collaboration partners were not co-located for the entire duration of the project. The partners established mechanisms in order to communicate effectively and to facilitate a common learning process (Kogut/Zander, 1992; Choi/Lee, 1996) despite geographical distances. Consistent with De Meyer's (1991) findings, one could observe more frequent face-to-face meetings at the start of projects.

**Power:**

The power relationship in the collaboration was assessed by the extent to which the companies could influence the structure of the collaboration agreement. In the case of a symmetrical power relationship (Storper/Harrison, 1991), it was assumed that both parties could influence the agreement to the same degree and negotiate the conditions of the collaboration project in a shared fashion. In the case for a dominant partner it was expected that the dependent party had to accept, more or less, the conditions proposed by the dominant partner.

Figure 4 summarises the power relationships in the investigated R&D collaborations showing the extent to which companies could influence the structure of the collaboration agreement.

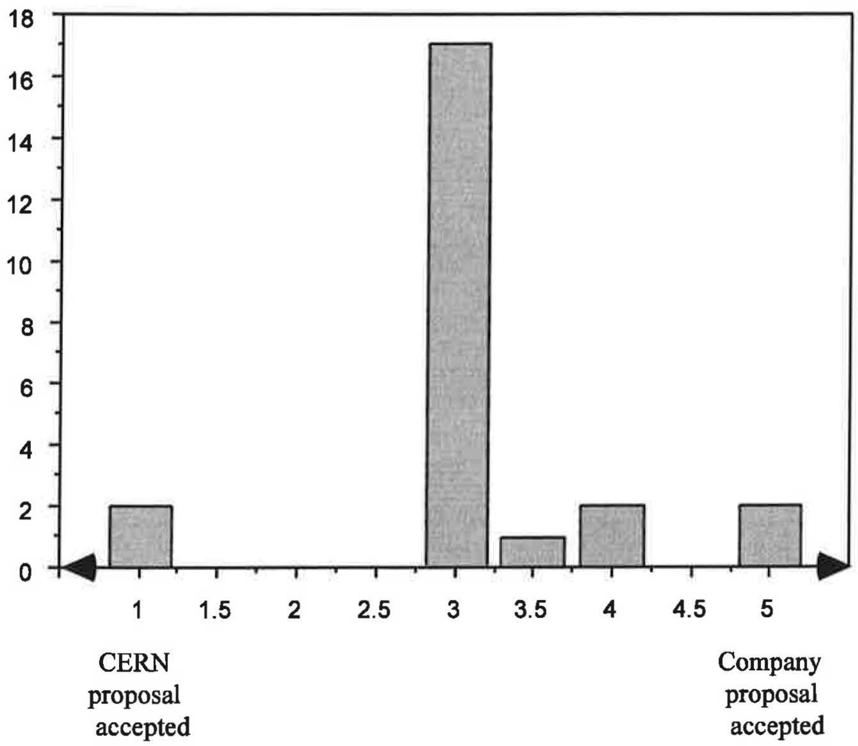


Figure 4: Power Relationships in R&D Collaborations[3]

Figure 4 shows that in the majority of cases, power is either well-balanced (value of 3 on the 5-point Likert-scale) or the industrial partner is in a position to determine the conditions of the collaboration agreement. Only with very small companies could CERN dominate the industrial partner with regard to the collaboration agreement. Although CERN is a large-scale research center, the annual R&D budgets of CERN groups

[3]The horizontal axis gives the 5-point Likert scale from "CERN proposal accepted" to "Company proposal accepted" and the vertical axis the corresponding number of companies.

involved in collaborations are considerably smaller than the R&D budgets of the collaborating teams of large companies. In some cases CERN, because of its limited resources, may be dependent on a large industrial partner. If, in such cases, the complementary assets provided by CERN are not of strategic importance to the firm, dependency is not mutual. The company is in a position to dominate the project and to determine the conditions set out in the collaboration agreement (see the five large companies with values from 3.5 to 5 on the 5-point Likert-scale in Figure 4).

As demonstrated above, the size of the industrial partner may affect the symmetry of the power relationship. Companies were assigned to the following four categories[4]: up to 15 employees, up to 100 employees, more than 100 employees, more than 500 employees. Figure 5 shows the number of companies in each category:

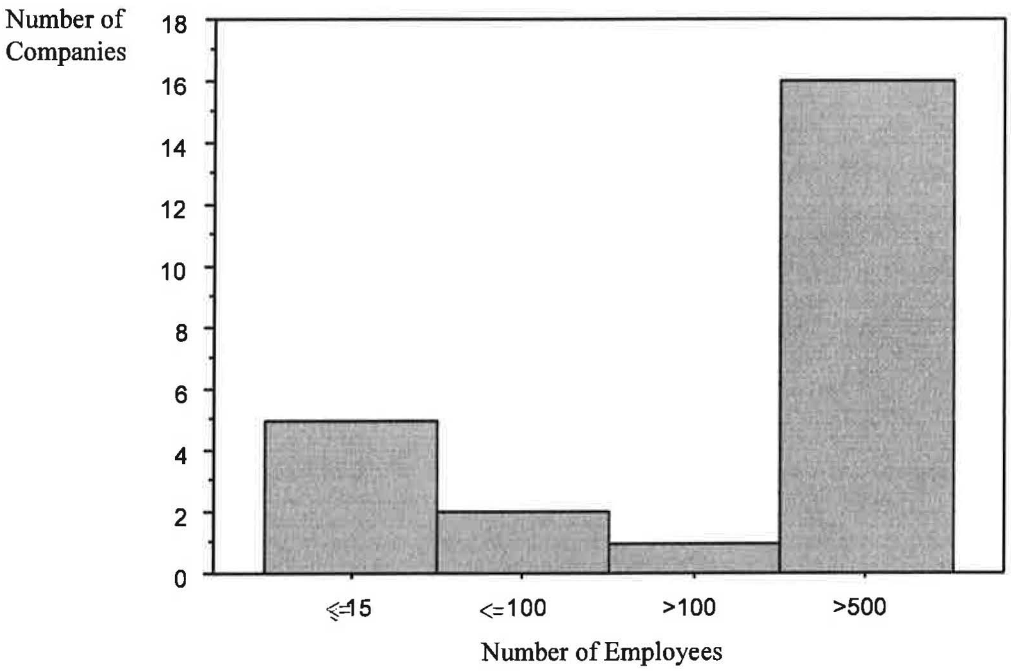


Figure 5: The Size of the Industrial Collaboration Partners

From Figure 5 a clear pattern can be observed in the distribution of the selected collaborating companies. First, predominantly large companies take part in R&D collaborations with CERN. Second, very small companies with less than 15 employees

[4]In the literature, standardised classifications of company size do not exist. The present categorisation of companies was based on the classification used in publications of the European Commission (EC, 1994) and BETA (1995), where small and medium-sized firms are defined as firms which have less than 500 employees. Aiginger/Tichy (1985) defined companies which have less than 100 employees as small, and companies which have up to 500 employees as medium-sized. No classifications for very small companies exist. As a consequence, this study made its own classifications. Companies were classified as very small businesses if they had up to 15 employees.

make up another group of collaboration partners. This result corresponds to the findings of Smith et al. (1991: 459) who studied inter-firm collaboration for innovation in the electronics, instrumentation and electrical sector. They found that, in these sectors, innovation was becoming more important at both ends of the firm-size spectrum. That is to say, for very small and very large firms. While large companies may set the operational environment for small firms, small companies were generally very flexible, were able to respond quickly to changing needs and had technological expertise in very specific niches.

Small companies are often faced with the critical mass problem; due to financial constraints they are not able to take part in such R&D collaborations. One way to overcome the financial restrictions is to enter a collaboration together with a large partner on which the small firm can catch a "piggy-back" (Smith et al, 1991: 463). Two out of the five small companies introduced above entered the R&D collaboration with CERN in such a way.

Consistent with previous research (Ouchi/Kremen Bolton, 1988; Teubal et al, 1991; Hagedoorn/Schakenraad, 1994), it would indeed appear that the collaboration scheme is for the most part limited to large companies due to the considerable financial burden. This is also reflected in the distribution of companies in the present study, where three times as many large companies take part as small ones.

## 2 Selection of the Collaboration Partner

The literature (Harrigan, 1988; Hagedoorn/Schakenraad, 1990; Wissema/Euser, 1991; Kleinknecht/Reijnen, 1992; Lutz, 1993) suggests that certain key dimensions have to be assessed when selecting a collaboration partner. The key dimensions are the partner's motivation, previous experience with collaborative efforts, and the cost of the collaboration compared to the company's other R&D efforts. The findings of previous research suggest that industrial companies successfully take part in R&D collaborations with CERN because of strategic reasons like gaining know-how, but not because of short-term considerations like making profits or sharing the cost and risks of R&D projects. Thus, the partner variables, following from the conceptual framework, were:

1) Motivation,
2) Experience

**Motivation:**

The motivation for taking part in R&D collaborations with CERN were measured using a 5-point Likert scale. On the scale, 1 meant "of no importance" and 5 "of very high importance" to the industrial partner. Figure 6 presents the mean values for the reported motivations. The vertical axis gives the mean value of each motivation and the T-line the corresponding standard error.

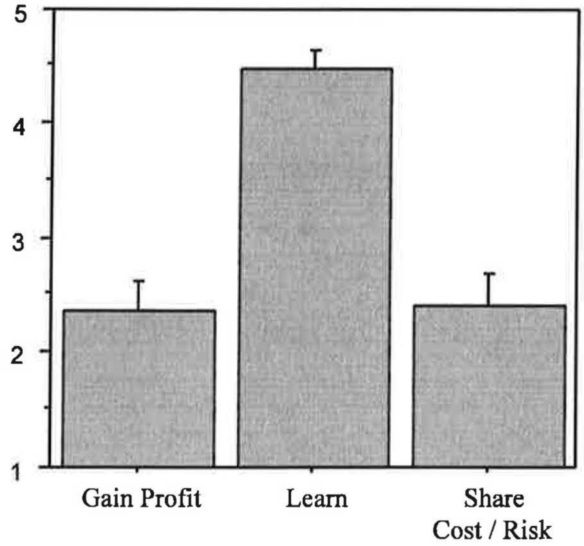


Figure 6: Motivations for Collaborating with CERN

From Figure 6 it is observed that learning and gaining know-how is the prominent motivation for taking part in R&D collaborations with CERN. Learning and gaining know-how was of high importance for 21 out of 24 companies (at least a value of 4 on the 5-point Likert scale).

Here, learning can refer to the understanding of a new technology at a level where research is still required, or it can be linked to gaining a better comprehension of customer requirements for a prototype in the development phase (Nueno/Oosterveld, 1988; Zagnoli/Cardini, 1994), as put by one of the interviewed company engineers:

> *"We would gain first-hand experience with customer requirements rather than just talk about customer requirements."*

Although gaining profit is, in the long-run, important for all industrial companies, it appeared to be less important than learning as a motivation for taking part in R&D collaborations with CERN. In the majority of investigated projects the companies did not expect to make considerable profit as a direct result of the R&D collaboration itself. Instead, the companies intended to make profits from products based on the know-how gained from the projects. The limited possibility of gaining direct financial profit was due to the nature of collaborations in contrast to market contracts. In contrast, companies attaching much importance to direct profit would obviously expect to sell their R&D-

capability to CERN. This is often not feasible for the CERN groups because of tight budgetary constraints.

Sharing the cost and risk of R&D is also an important motivation for collaboration, but it is far less important than learning. This finding corroborates the findings of previous research (Hagedoorn/Schakenraad, 1990; Kleinknecht/Reijnen, 1992), suggesting that sharing costs and risks do not play an important role as driving forces for international R&D cooperation. In several projects in the present study sharing costs and risks was of no importance at all, because the companies alone wanted to be in charge of the final product. Consequently, they were concerned about being able to implement every single step of the industrialisation of the prototype independently of CERN. Thus, companies tended to cover all the development cost, as illustrated by one of the interviewed company engineers:

> *"There is no rebates in R&D-costs ... if you want to have an industrialised product, your company must be prepared to continue alone. ... you have to bear the full cost."*

In other words, the companies did their development work jointly with CERN, but they relied for example on their own, well-known subcontractors when it came to the designing of the layout and the manufacturing of electronic boards. Even when designing the layout in collaboration with CERN would have been a less expensive solution, these companies preferred using their own subcontractors in order to remain independent of CERN.

Furthermore, sharing costs and risks was not important to some companies, because they were prepared to carry the cost of the R&D undertaking alone in any case. However, collaborating with CERN enabled the company to accelerate the development process, and reduce the research-to-production time. In addition, the interviewees were asked about their expectations concerning the result of the R&D collaboration:

At first glance, the expectations are divided more or less equally between new products and acquired knowledge. However, the picture changes completely if the expectations are classified based on the size of the companies. The expectation of pure learning and gaining know-how is a phenomenon which was only observed in large companies. The smaller companies were exclusively interested in products as the end-result of the collaboration project. This observation provides further corroboration from the similar findings of Smith et al (1991) on different expectations as regards the results of collaborations dependent of company size.

Again, this phenomenon may be linked to the critical mass problem: for small companies the cost of taking part in a R&D collaboration were very large compared to their available resources. They had to come up with marketable products as soon as possible in order to get a return on their investments. For small companies, problems arose when CERN was already satisfied with a solution which did not involve the full development of the product or prototype, but for which the small company still needed CERN's expertise.

However, only large companies could afford to learn without having an immediate application for the gained know-how. For the large companies the R&D collaboration was often only one out of several other projects in the same field. In such a way, the companies could use different technologies or technological approaches from one collaboration to sort out problems in another. If, in the course of the project, it turned out that the company was not going to take the route followed by the collaboration, this insight alone could justify investment in the project. At least, such a situation was not problematic for large companies because their contribution to the project was rather small compared to their overall R&D investment.

Figure 7 below presents for each category of size (in terms of the number of employees) companies' reported expectations. The vertical axis gives the number of companies in each size category.

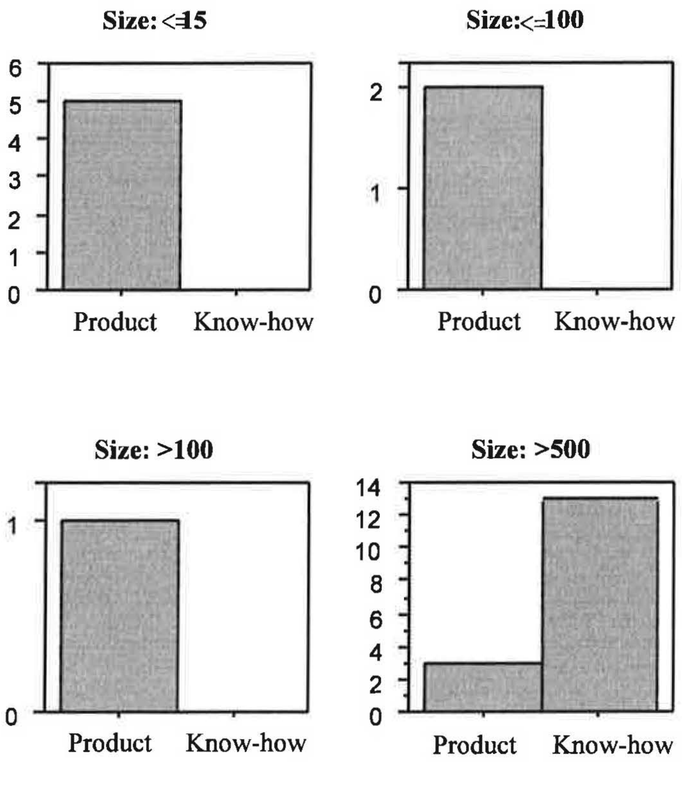


Figure 7: Expectations from the Result of the Collaboration

**Experience:**

Twenty-one out of the 24 industrial partners were already experienced in doing business with CERN. In 15 cases the firms had taken part in R&D collaborations before, whereas in two cases business with CERN had been limited to market contracts. In four cases the companies had only informal contacts with CERN before taking part in the R&D collaboration in question. Even the companies which did not have any experience with CERN, had experience in collaborations with other research organisations in the same field. The remaining three companies already had experience with other international research organisations or with national high-energy physics institutes in their home countries.

The classification above refers to the experience of the companies' groups or divisions taking part in the collaboration. Some large companies had been involved in more than one project.

In sum, almost all investigated companies had many years' experience in R&D collaborations with CERN or other research centers. Companies without collaboration experience had at least informal contacts with CERN or had done business with CERN through purchasing contracts. Therefore, it appeared that all companies were acquainted with CERN's specific requirements. This confirms the findings of Smith's (1991) study about innovation in collaborations of large and small firms. Smith et al found that the existence of informal, personal contacts among the scientific and engineering elite of the companies was a key success factor in the establishment of collaborative links.

Based on the collected evidence there seem to be four types of differences which divided companies and research centers. These differences explain some areas of conflict which can arise in the course of collaborative projects. However, the differences only pose major problems if the partners are not prepared to deal with them. The first three differences which were reported by the respondents (Time Horizon, Driving Motivation and Dealing with Knowledge) are frequently discussed in the research literature (see for example Goldhor/Lund, 1983; Stankiewicz, 1986; Leyden/Link, 1991; Rosenberg, 1990; Tödtling-Schönhofer/Tödtling, 1993; Hameri, 1996). However, for the fourth aspect there seems to be no indication in the research literature:

According to several respondents from industry, difficulties due to a different assessment of the effort necessary to perform specific tasks were critical because of different reliability requirements. Both companies and research centers needed reliable products or equipment, respectively. The difference was that in research centers such as CERN the equipment was almost exclusively utilised by experts under laboratory conditions, so, whenever a problem arose it could most likely be solved either by the user himself or by an on-site expert. In contrast, products for commercial markets had to meet higher demands on reliability. Companies had to make sure that the products operated without any problem while being used by non-expert customers. As a consequence, companies generally estimated that more time needed to be spent, in comparison to research centers, on finding highly reliable solutions to a problem. Furthermore, for companies the testing of the prototype was usually more extensive in order to meet industry's reliability standards.

## 3 Negotiation of the Collaboration Agreement

The research findings of the strategic management literature and empirical studies on collaborations (Ouchi/Kremen Bolton, 1988; Forrest, 1992; Håkanson, 1993; Shaughnessy, 1995) suggest that the definition of the partners' duties, the definition of ways to resolve conflicts, and set milestones should be basic elements of R&D agreements. Furthermore, it is expected that the experience regarding prior partnerships between the organisations results in a high level of mutual trust, which is then reflected in the less frequent use of detailed collaboration agreements. Consequently, the regulation of the following elements in the collaboration agreements is investigated below:

1) Implementation
2) Milestones.

**Implementation:**

While reviewing the R&D projects for further information it turned out that a written agreement was not available for every project. In 16 out of 21 collaborations the agreements were completed and signed before the start of the collaboration project. In three projects the agreements were signed as late as three months after the start of the project, and in two cases the engineers could not remember when the signing of the agreement took place. In sum, one can say that at least six projects were solely based on trust which was demonstrated either by the renunciation of written agreements or by the fact that one could start the work on the project prior to having all the documents signed. However, the partners did not necessarily trust each other with regard to the non-disclosure of information. Thus, trust appears to be multidimensional. While the collaboration partners trust inter alia each others technological capability, they do not trust, in the long-term, confidentiality of information. This observation suggests a notion of trust which is fundamentally different from its unidimensional concept in the research literature (Thorelli, 1986; Zaheer/Venkatram, 1995).

The respondents were asked to indicate whether, in hindsight, they would want to change any specific items of the collaboration agreement concerning the implementation of the project. Two-thirds indicated that the structure of the agreements had been satisfactory. In four cases, the engineers stated that they would like to change the regulation of intellectual property rights and non-disclosure arrangements.

Furthermore, three respondents indicated that they would change the regulation of the partners' duties if they were to negotiate the agreement once again. The companies had signed agreements which defined the responsibilities of the parties in very general terms only. Consequently, they faced difficulties, especially at specific milestones and at the end of the collaboration project. The difficulties at the end of the collaboration concerned, above all, the continuation of joint development work to a stage from where the industrial partner would be able to carry on the work alone. In line with the findings of Smith et al (1991) this issue appeared to be specially critical for small companies.

In two cases disagreement about each partners' responsibilities led to prolonged discussions and serious conflicts. Here, the engineers indicated that they would stipulate ways of resolving conflicts in future agreements.

In addition, the respondents were asked to indicate on a 5-point Likert scale if they had to deal with difficulties due to a lack of management involvement during the implementation of the project. However, several company engineers did not perceive a lack of management involvement as a potential source of difficulties, but instead the involvement of management. Seventeen out of 24 company engineers perceived no difficulties due to the involvement of management. In cases where this was reported as a problem, it was not necessarily linked to the daily business of the project's implementation but to changes in strategies of the company which could put the continuation of the collaboration at risk. However, in one case, where the involvement of the management was linked to a lack of management support, the collaboration was reported to have encountered a big difficulty. These observations confirm the findings of previous research (Devlin/Bleackley, 1988; Sherman, 1992; Håkanson, 1993) which emphasised the importance of both top management support for the project and a relatively high degree of autonomy for the project management.

**Milestones:**

In 12 projects two different ways of defining milestones were observed. First, in two projects, the partners regulated each others activities by either listing the activities for every year of the planned duration of the project or by fixing the dates by when the partners had to complete specific tasks. Second, the partners did not specify tasks or deliverables but agreed to review the progress on a regular basis. The periodic progress reviews took place every two, three or six months. However, in all the projects, the definition of milestones was not linked to any sanctions should one partner not fulfil his task in time.

The planned completion of the collaboration project appeared to constitute an important milestone. Some of the selected projects only took half a year, whereas others went on for five years until they were finished. However, the majority of companies investigated (15 companies) completed their projects within two years. On average, the project duration was 2.2 years, as indicated by the peak of the curve in Figure 8. An engineer from a large company stated that

> *"... experience in collaborations with CERN has shown that projects should not be too long ... the longer the projects, the less successful they are."*

According to the engineers' experience the optimal length of a project is about two years for following reasons:

1) if the project takes longer, one would have to deal with changes in CERN personnel due to fixed-term contracts of employment, and
2) in the computing sector one has to have paybacks within three years.

The project duration of the R&D collaborations investigated is presented in Figure 8. The horizontal axis gives the duration of R&D collaborations in years and the vertical axis the corresponding number of companies involved in the projects. The curve shows the normal distribution.

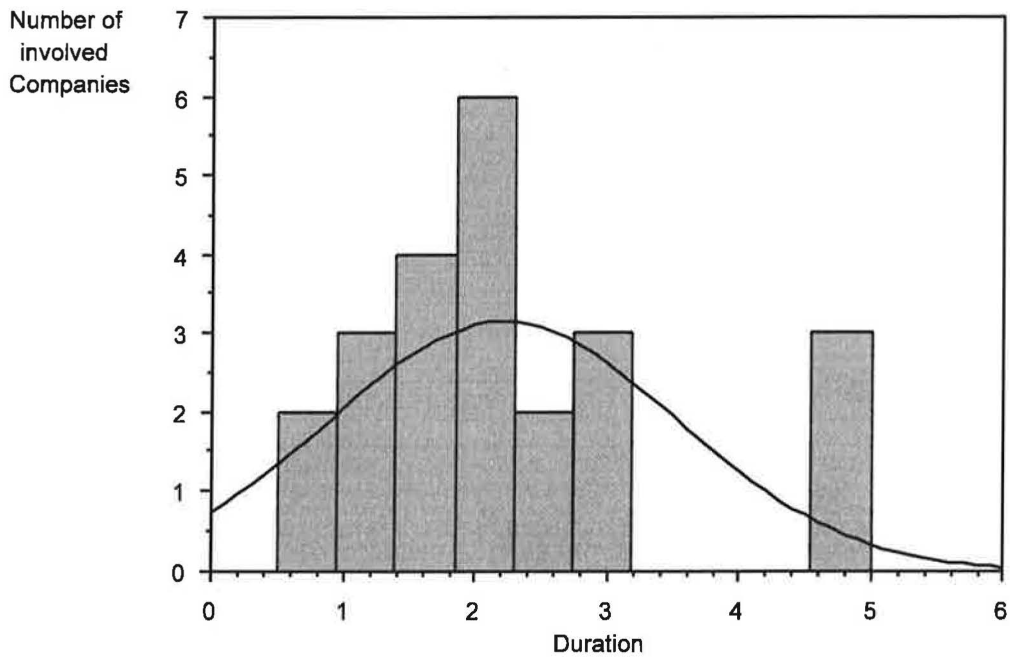


Figure 8: The Duration of the Investigated R&D Collaborations in Years.

The majority of the collaborations were finished within two years. In the short-term projects, development work was dominant and there was basically no research involved. The short project duration can be explained by the following observations:

1) The collaborations did not cover the entire development work necessary for reaching the production phase. Companies had already started the development work for a specific product when entering the collaboration with CERN. In some cases, a prototype was already available. In other projects the companies continued with further development after the collaboration finished.
2) In joint projects where companies were mainly interested in gaining know-how was the collaboration also only part of the companies' entire development work for specific products.
3) The task to be performed in some joint R&D projects was very limited and could be fulfilled within the stipulated short period of time.

Although the product life cycle in the electronics industry is often less than two years, one would have expected a longer duration for the R&D projects investigated, based on the findings in the reserach literature (Nueno/Oosterveld, 1988; Pilling et al, 1994). In six cases, in the present study, the project duration was three to five years. By checking both the duration of the project and the required R&D effort, as perceived by the respondent, one could find a correlation between these two factors. In effect, three projects took considerably longer than the average because there was more research work involved. Two project engineers stated that they overran the scheduled end of the projects by one or two years, because of the unexpected high proportion of research work to be done. In one project the company had to perform extensive research in order to understand the manufacturing process of a highly specific alloy. In the other case, the company reentered a market from which it had withdrawn several years before. Consequently, research was dominant in that project, because the company had to start from scratch.

## 4 Implementation of the Collaboration

The literature suggested that in order to ensure successful implementation of R&D collaborations, it is very important that all partners identify and agree on how to co-ordinate and adapt their activities. According to several empirical studies on collaborations (Håkanson/Lorange, 1991; Farr/Fischer, 1992; Forrest, 1992; Lorange, 1992; Mohr/Spekman, 1994) the most critical factors at the implementation stage are the risk of being confronted with unforeseen changes in strategies from the collaboration partners, the continuous support of top management and the establishment of effective information channels and mechanisms to facilitate communication. Accordingly, the following implementation variables are investigated below:

1) Changes in Strategy,
2) Communication.

**Changes in Strategy:**
The respondents from the companies were asked to indicate whether they had encountered difficulties due to changes in partners' strategies. In four cases, engineers stated that they had to stop the collaboration either before the scheduled end of the project or they had not continued the project to its next planned phase. However, the reported difficulties were due to changes in the company's strategy and not to changes in CERN's strategy.

In one case the project was planned to be implemented in two phases. The second phase was subject to mutual agreement after installation and consequent review of phase one. The project was stopped after phase one, because of the following reason, described by the company's engineer:

> *"We were pushing a technology where we did not have a marketable product. ... Furthermore, we came to the conclusion that the product would be too expensive."*

In another project the company decided, after two years of joint work, not to follow the specific product line which was the basis of the R&D collaboration with CERN. In contrast to the previous project, the termination of the collaboration was not at all expected by CERN.

**Communication:**
The respondents were asked to indicate on a 5-point Likert scale the perceived difficulties in communication due to possible geographical distance. Three respondents perceived geographical separation as a big hindrance to efficient communication, at least in certain stages of the project. However, in one of the three cases the difficulties were limited to communication between the local subsidiary which was directly involved in the collaboration, and the company's consulting engineers in the US head office. The same internal difficulties were reported in three of four other projects, where the respondents perceived geographical separation as a difficulty, but not as a big one.[5]

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[5]Value of 3 on the 5-point Likert scale.

Seventeen interviewees reported no difficulties related to physical distance. In eight of these projects, the partners were almost co-located. In the remaining nine collaborations, the partners felt that geographical separation did not influence efficient communication in any way.

The emphasis on specific means of communication had changed in the course of all collaborations, except in the eight projects above where the partners were co-located. The respondents reported that

1) They had more regular meetings early on,
2) They first had meetings and then communicated solely via e-mail, and
3) Face-to-face meetings only took place during important phases of the project.

Towards the end of the collaborations one could also observe a change in the way the partners communicated with each other. In cases where the partners had decided to stop the project after completing the first phase of the collaboration (as discussed in the above section, dealing with "changes in strategy"), the partners had meetings less often than before. In all other cases the partners intensified their contacts when the product moved from the design to the integration phase. While the empirical evidence of the present study suggests two "peaks" in the intensity of face-to-face communication (see Figure 9) - one at the beginning of the project, and one at the end - previous research literature (Forrest, 1992; Bronder, 1993) does mainly concentrate on the initial stage of the process. In the beginning, intensive face-to-face contact needs to take place in order to develop mutual trust and to get the project started.

Figure 9 depicts, schematically, the communication structure implemented in order to achieve common learning despite geographical distance. The vertical axis gives the frequency of face-to-face communication.

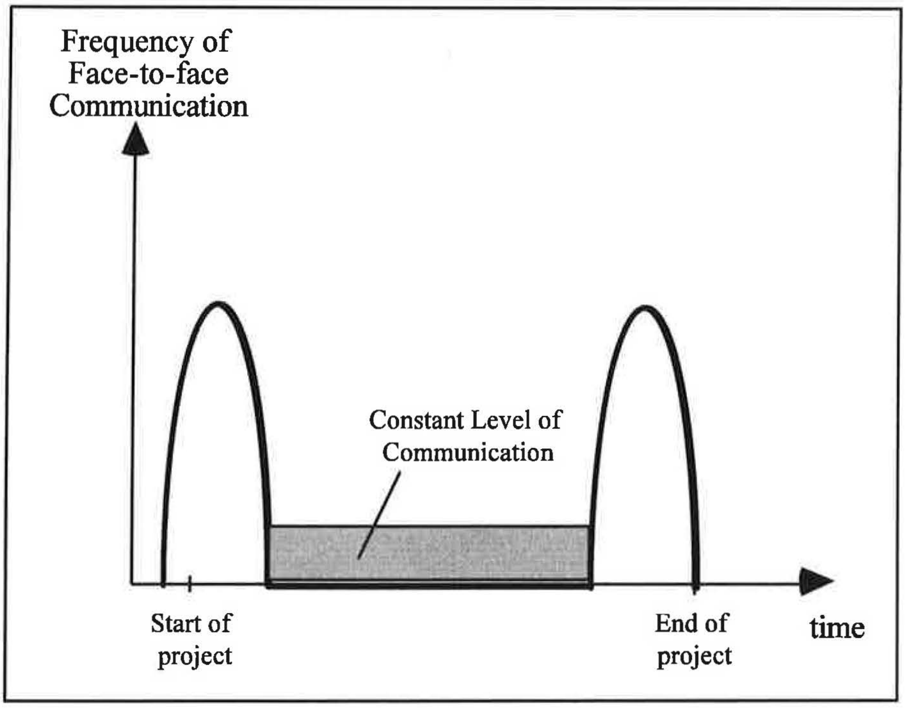



Figure 9: The Communication Structure in R&D Collaborations with CERN

## 5 Analysis of Selected Cases

By investigating selected projects the aim is to understand how the above identified factors are implemented and possibly interlinked. First, similarities and differences between two projects involving large companies with more than 500 employees are investigated. The emergent frame will then be compared with the evidence from two collaborations involving only small companies. Four selected R&D collaborations are analysed to see how the collaboration partners

1) Organised the projects to ensure effective communication and common learning despite geographical separation,
2) Established and held contact to CERN,
3) Established mechanisms to avoid disclosure of know-how.

In both collaborations with large companies (Collaboration A and B), the partners had to deal with a geographical distance of several hundred kilometers between the development teams. The collaboration partners were located in different European countries and worked on their own premises. Intense face-to-face communication could be observed in both cases in the beginning and towards the end of the collaboration project. In contrast to collaborations A and B above, both small companies were located close to CERN. In project C the company was situated in Geneva, and in project D the company was located in the Geneva region - about one hour from CERN by train or car. Although the collaboration partners were almost co-located, one could observe practically the same communication pattern as in the projects with large and distant collaboration partners.

In all four selected projects the partners had long-standing experience in collaborations with CERN. Both large companies had implemented mechanisms to detect interesting inventions and technologies at CERN and to establish contacts with the relevant development teams inside the company (see Table 1). In contrast to the collaborations with large companies, following interesting activities at CERN was less formal with the small partners and not linked to using specific persons or teams. Both small ompanies usually detected interesting projects via their personal reationships with the CERN teams with whom they had had many years of collaboration experience.

Despite the fact that in collaboration A and B the partners signed non-disclosure agreements, the companies were aware that condfidentiality would not be maintained forever. The companies viewed a possible leakage of information - although not deliberately disclosed - as the price of collaboration. In other words, the collaboration partners had developed high levels of trust in the course of long-standing relationships, but obviously the companies did not fully trust CERN when it came to the disclosure of critical information. In both collaborations with small companies the strong personal links between the engineers from the CERN teams and the engineers from the company's design team facilitated the waiving of non-discosure agreements.

The similarities and differences across the selected collaborations are summarised in Table 1 below.

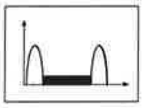
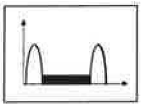
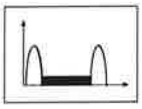
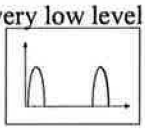
| | Large Companies | | Small Companies | |
|---|---|---|---|---|
| **Parameters** | Collaboration A | Collaboration B | Collaboration C | Collaboration D |
| **1) Design** | | | | |
| Location | distant | distant | Geneva | Geneva area |
| Mechanism to deal with distance | PhD student, company covers all travel cost | bi-monthly meetings | meet whenever necessary | avoid too many contacts |
| **2) Partner** | | | | |
| Experience with CERN | long-standing | long-standing | long-standing, since start-up | long-standing, since start-up |
| Contact to CERN | liaison officer | team at CERN | strong personal links | strong personal links |
| **3) Negotiation** | | | | |
| Non-Disclosure Agreement | duration: 2 years;<br>- before: disclosure only without company confidential info<br>company expects info leakage | duration: 2 years after termination;<br>- before: disclosure only when company agrees<br>company expects info leakage | strong personal links;<br>disclosure puts continuation of long-standing partnership at risk | strong personal links;<br>know-how protected through short life-cycle |
| **4) Implementation** | | | | |
| Communication | intensive in beginning and end, meetings whenever necessary<br> | intensive in beginning and end, bimonthly meetings<br> | intensive in beginning and end, meetings whenever necessary<br> | intensive in beginning and end, rest: reduce communication to very low level<br> |

Table 1: Similarities and Differences across the investigated Collaborations

# VI Conclusions

## 1 Main Findings

The exploratory analysis led to the following findings:

1) The R&D collaborations were individual transactions in an envelope of long-term partnerships. The partners knew each other from previous joint R&D projects and they remained in informal contact with each other after project completion. One can observe bilateral transactions within a network of more potential partners. However, the network was dynamic because the structure changes from project to project and CERN was not always the "hub".

2) However, most of the individual collaboration projects were short-term in nature. The project duration was on average 2.2 years.

3) The industrial collaboration partners were dominantly large multinational companies. The second major group of collaboration partners were small companies with less than 15 employees. The industrial collaboration partners were spread Europe-wide.[6] In contrast to initial expectations, the project teams were not necessarily co-located throughout the entire duration of the project.

4) Learning and gaining know-how was the prominent motivation for taking part in R&D collaborations with CERN. However, there were different expectations hoped from the results of the R&D collaborations, depending on the size of the company. Pure learning and gaining know-how was expected by large companies. Smaller companies were exclusively interested in products with commercial potential.

5) The collaborations were based on high levels of trust between CERN engineers and company engineers. In several cases, it emerged that either a written agreement was not available or the agreement was not signed until up to three months after the start of the project. Respondents stated that a written collaboration agreement was often not required by the collaborating team but rather, by the company lawyers.

6) Furthermore, one could observe a low level of direct financial contribution. Although the number of engineers directly involved in the project was also low, one had to

[6]Notwithstanding, the distribution of collaboration partners is, in the investigated projects, strongly biased towards Switzerland (with 13 out of 24 companies based in Switzerland). However, this is at least partly the result of making the first informal contacts with the Swiss subsidiaries of the multinational companies involved. Even if the development team involved came from some other country in Europe, the project would then be counted as Swiss. Nevertheless, one can in general observe a bias towards France and Switzerland, known as the "host-country effect" (CERN, 1992: 15).

conclude, on the basis of the respondents' statements, that considerable resources in terms of manpower and money were often provided inside the company.

7) In general, project managers did not experience difficulties resulting from lack of management support. However, in several projects difficulties were reported due to changes in strategy and difficulties with non-disclosure agreements.

## 2 Practical Implications for Collaboration Management

Although the present study has only investigated R&D collaborations with companies in the electronics and data communications industry, the findings suggest a number of implications for the management of collaborations which may also be valid for other industrial sectors:

1) R&D collaborations start from informal contacts between the collaboration partners. For example, if a company wants to collaborate with CERN it first has to enter the informal network, either by establishing gatekeeping engineers on the CERN site or by developing strong personal links with specific CERN groups. To achieve this, the industrial exhibitions at CERN could be used as a starting point.

2) Before joining a R&D collaboration, companies should find other possible applications and markets for the product or technology which is intended to be jointly developed with the research partner such as CERN. Hence, R&D collaborations should not be exclusively based on the expectation of getting follow-up contracts.

3) The full support of senior management is of vital importance for the successful completion of R&D collaborations which may fall outside a firm's current corporate strategy, but have the potential to be included in future strategic development. Thus, both collaboration partners have to make sure of getting the "green light" from their upper-level management before starting the collaboration project.

4) When implementing a collaboration one has to take the different organisational cultures into consideration. In the case of CERN, companies must be aware of CERN's open communication policy resulting in possible problems linked to long-term confidentiality of information. Consequently, before entering a collaboration, project companies should weigh up if possible benefits from the project would outweigh the risk of disclosing confidential information. If the company comes to the conclusion that their know-how is of high strategic importance and cannot be disclosed under any circumstances then it is better not to start the collaboration.

5) By reducing the number of engineers directly involved to the minimum, one also reduces the complexity of the project and the management of the collaboration becomes much easier. However, the critical know-how should not be "accumulated" in one person alone, otherwise the overall success of the project may become subject to the individual commitment of a single person.
6) For small companies, problems can arise when a research partner such as CERN is already satisfied with an incomplete solution, for example not getting involved in the full development of the product or prototype, but for which the small company is nevertheless dependent on CERN's expertise. Consequently, small companies have to make sure at the start of the project that the collaboration partner commits himself to continue the collaboration up to an agreed completion point.

7) The partners should implement a very critical review of the progress 1 to 1.5 years into the collaboration project. In case one of the initial viewpoints had drastically changed since the beginning of the project, the partners would have to consider seriously either appropriate managerial measures or the termination of the collaboration.

8) By keeping the length of the project short, the risk of unexpected changes in a partner's strategy is reduced.

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