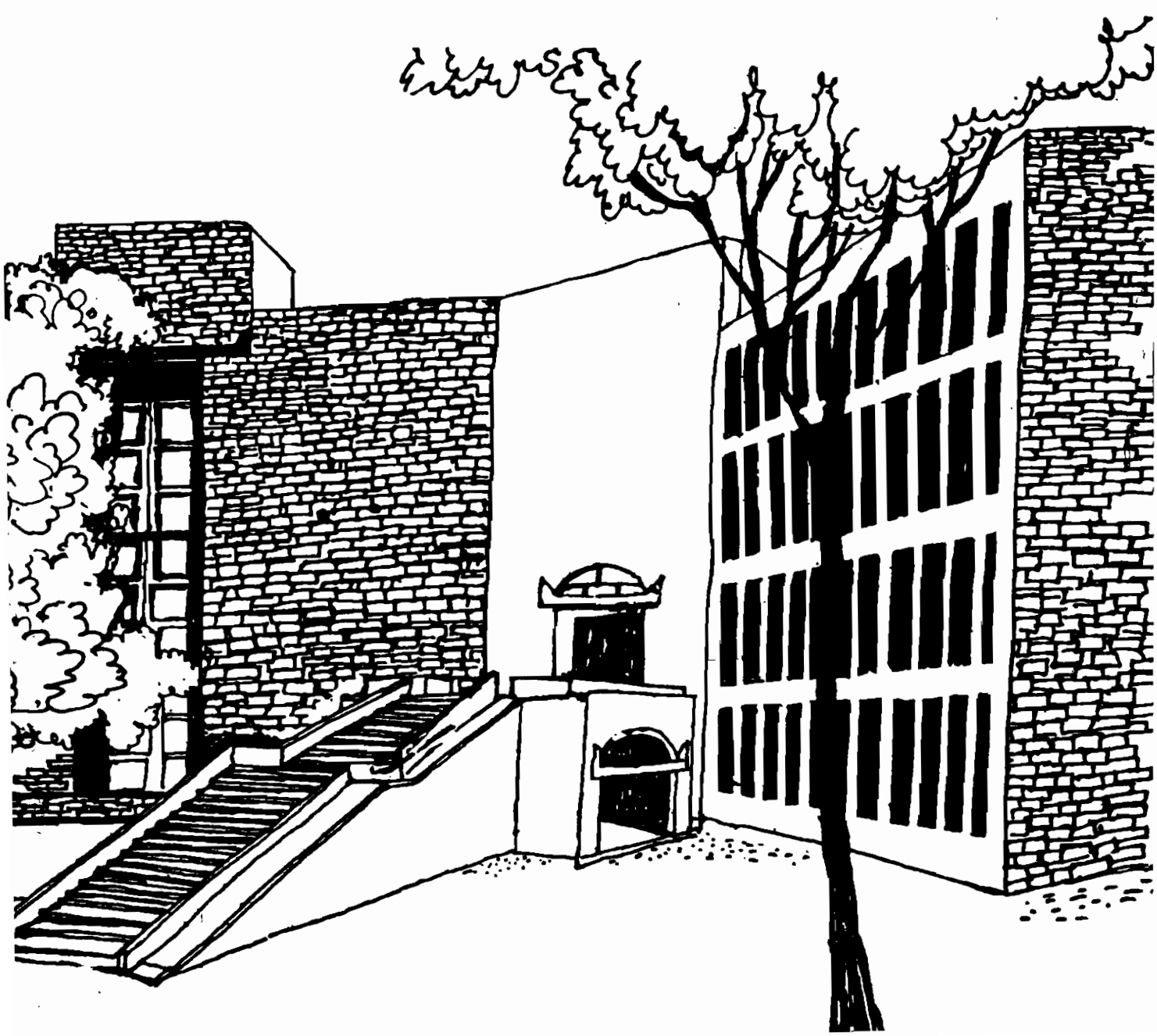
विद्याविनियोगाद्विकासः
IIM
AHMEDABAD

Working Paper



KNOWLEDGE BUILDING IN INDUSTRY - TECHNOLOGY INSTITUTION JOINT R&D PROJECTS: A PROCESS MODEL

BY

Ganesh N Prabhu
(FPM)

W P No. 1277
August 1995

INDIAN INSTITUTE OF MANAGEMENT
AHMEDABAD - 380 015
INDIA

Knowledge Building in Industry - Technology Institution Joint R&D Projects: A Process Model

by

Ganesh N. Prabhu

Indian Institute of Management at Ahmedabad, India.

To be presented at the
"R&D Management" Conference 1995 on
"Knowledge, Technology and Innovative Organizations"
at SSSUP, Pisa, Italy

September 20-22, 1995.

Address:

Ganesh N. Prabhu, Doctoral Student
D-1625, Indian Institute of Management
Vastrapur, Ahmedabad 380 015
INDIA

Ph: 91 - 79 - 407241 ext. 4516 (attn: Ganesh Prabhu D-1625)
Fax: 91 - 79 - 6427896 (attn: Ganesh Prabhu D-1625)

ACKNOWLEDGEMENTS:

The author is indebted to the forty joint R&D project participants and administrators in firms and technology institutions who freely discussed their projects and gave valuable insights. He expresses his gratitude to his thesis advisory committee - Prof. Mukund R. Dixit (Chair), Prof. Shekhar Chaudhuri and Prof. Deepti Bhatnagar of the Indian Institute of Management at Ahmedabad, India for their guidance in developing this study. The advice given by Mr. A.T. Kusre and Mr. Amitabh Kumar of the Industrial Credit and Investment Corporation of India and their support in gaining access to the organizations is gratefully acknowledged.

Knowledge Building in Industry - Technology Institution Joint R&D Projects: A Process Model

Abstract

Technology institutions (TIs) traditionally rely on industry for funding basic research, generating researchable problems and commercializing their R&D, while industrial firms traditionally rely on TIs for basic research and solutions to problems beyond their R&D capabilities. Intense firm - TI interactions in joint R&D projects also lead to both anticipated and unanticipated knowledge building and transfer across participating organizations which widen the scope of their technological and commercial activities. The type and scope of knowledge building depends on the mode of project process adopted.

Synthesizing from several indepth project case studies, this paper proposes a typological theory based model, which traces the process of knowledge building in three identified ideal types of effective project process in industry - TI joint R&D projects, labeled *Contracted Technology Development, Interactive Technology Transfer* and *Joint Technology Development*. These models can enable practitioners in understanding and initiating effective knowledge development processes in such projects.

INTRODUCTION

Technology institutions (TIs) (not-for-profit institutions, including universities, involved in technological research and development (R&D)) have traditionally relied on the industry for funding basic research, for generating researchable problems, as well as for the commercial application of the new technology they develop (Radosevich and Kassicieh, 1993). Industry has traditionally relied on TIs for basic research inputs, getting access to scientific frontiers, (Bonaccorsi and Piccaluga, 1994) and for solving technological problems which are beyond the capability of their internal R&D (Rosenberg and Nelson, 1993).

Moving further from these traditional interactions, where TIs have found it unviable to maintain the infrastructure and manpower for manufacturing activities, such as building either prototypes or final products internally, they have subcontracted these to the industry. Similarly industrial firms which have their own internal R&D facilities, but either lack or find it unviable to maintain the highly qualified manpower or expensive equipment required for some types of R&D activities, have subcontracted these to TIs (Bonaccorsi and Piccaluga, 1994). In this manner both firms and TIs are able to expand the scope and range of their activities without increasing their infrastructural investment.

External sourcing of technology enables firms to specialize (Wittaker and Bower, 1994) and gives them access to new patents (Bailetti and Callahan, 1993), specific expertise, risk sharing, ease of exit (Bower, 1993) and facilitates organizational learning (Dodgson, 1993). Industry - TI relationships have been found to develop along six distinct ways through: (a) personal informal relationships, (b) personal formal relationships, (c) third party

intervention, (d) formal targeted agreements, (e) formal non-targeted agreements and (f) creation of focussed structures (Bonaccorsi and Piccaluga, 1994).

Joint R&D projects, which fall under formal targeted agreements, represent an intense form of relationship between firms and TIs. A joint R&D project arises when the firm approaches the TI with a technological problem (and the TI accepts it) for which (a) the TI has no ready transferable solution or access to such a solution and (b) the TI and firm both have complementary expertise and capabilities required to solve the problem. The joint R&D project involves simultaneous or sequential R&D work by both the TI and the firm working either independently (reporting progress to each other) or together. TI - firm joint R&D have been found to be initiated by structural conditions, institutional characteristics and personal motivations (Lopez-Martinez et.al., 1994). Success factors are a shared language and culture (Mansfield, 1991), awareness of mutual interdependence (Laage-Hellman, 1987), long relationships and physical proximity (Mansfield, 1991).

Though the apriori requirements with which the firm and TI agree to a joint R&D project are important, such projects can also lead to unanticipated benefits for the participating organizations which do not enter into apriori cost-benefit analyses. Though initiated as time bound project based interactions, they may lead to long term relationships and agreements if the project interaction is fruitful. One of the ways in which such interaction can be fruitful is when it leads to partially anticipated, but largely unanticipated knowledge building in, and knowledge transfer across, the participating organizations. This knowledge generation (Nonaka, 1994) and assimilation is important, as it improves each organization's capabilities to handle new and more complex activities, and broadens their scope to innovate. It may therefore impact both the firm and the TI in their immediate and future technological and commercial activities.

While such knowledge generation often takes place in a serendipitous manner, project participants and administrators can modify structural conditions and initiate processes that facilitate the process of knowledge creation and transfer. Therefore, apart from the content of the apriori requirements with which the firm and TI agree to a joint R&D project, it is important to understand the process of knowledge building such projects. This understanding is crucial to the development of informed policy and practice in this field.

It is to this end that this paper is addressed. The paper is in three parts. The first part explains the choice of the case study research methodology, describes its implementation and the nature of data collected. The second part proposes a typological theory (Doty and Glick, 1994) of the process in firm - TI joint R&D projects by drawing from and synthesizing several indepth project case studies of such projects. Three ideal types of project process in firm - TI joint R&D projects are described and modeled. In the third part, a model of the process of knowledge building within each ideal type is developed. These models trace the web of interlinked project processes which result in knowledge building in the joint R&D projects, and indicate their anticipated or actual impact on firm and TI activities.

METHODOLOGY

Inter-organizational studies (see Alter and Hage, 1993; Borys and Jemison, 1989; Bresser and Harl, 1986; Oliver, 1990; Ring and Van de Ven, 1992 for structuring reviews) have concentrated on antecedent conditions (Huxham, 1993), structure (Ring and Van de Ven,

1992) and cost-benefit analysis (Wood and Gray, 1991). The focus of these studies "has been on the strategy and reasons for entering a collaboration, rather than its management" (Bailetti and Callahan, 1993, p. 131). Literature stresses the importance of process in inter-organizational relationships (Ring and Van de Ven, 1994; Thomas and Trevino, 1993) but process studies of multi-organizational activity are rare (Zajac and Olsen, 1993).

Grounded case studies (Glaser and Strauss, 1967; Yin, 1984) are an appropriate (Parkhe, 1993) and valid (Smith, 1989; Tsoukas, 1989) methodology to fill this gap. The existing literature also emphasizes the need for more case study based process studies in strategic management (Chakravarthy and Doz, 1992; Jemison and Sitkin, 1986; Lyles, 1990; Schendel, 1992a, 1992b; Van de Ven, 1992), organization studies (Daft and Levin, 1993) and technology (Itami and Numagami, 1992).

Method

In this research the firm - TI joint R&D project was taken as the fundamental unit of analysis. Qualitative process studies of multiple cases was the methodology used. The case studies (Yin, 1984) traced the life of the project from conception to completion. The longitudinal processual approach (Burgelman, 1983) was adopted. Indepth semi-structured and open ended interviews were used to collect data from key project participants in both participating organizations, and supplemented by observations, records and reports (Yin, 1984). The broad approach was in the "holistic" tradition (Chakravarthy & Doz, 1992) of strategy process research in attempting "to track simultaneously over time, multiple contextual factors, strategies, decision processes, administrative systems and outcomes" while focusing on a "narrow strategic problem" (p.8). This approach has not been adopted for research in multi-organizational contexts, but is recommended (Parkhe, 1993). The study followed Eisenhardt's (1989) framework for the process of building theory using case study research.

The focus of the case studies was on understanding why and how the projects evolved technologically and interactionally, how they were managed, and the ways in which the participating organizations and persons added value to the project and to each other. The interviews covered the developmental history of the project, each organization's apriori interest and evaluation of its costs and benefits, and the change in these over the project duration. Other topics covered were the governance structure, characteristics of the project and technology which affected project implementation, and the nature of interaction during implementation. Participants were also asked to describe and evaluate their learning from the project and its likely impact on their organizations, in both technical and managerial spheres.

Research Site and Choice of Cases

The Industrial Credit and Investment Corporation of India Limited (ICICI), an Indian developmental financial institution initiated the Sponsored Research and Development (SPREAD) Programme in 1991. This is a unique programme in the developing country context in requiring formal cooperation between an firm and a TI as a condition for R&D project financing. By providing low cost loans to over fiftyfive firms so far, which are returnable conditional to project success, the ICICI has taken part of the project risk and acted as a catalyst for the joint activity. The programme provides a unique and important research site.

Twelve SPREAD programme supported dyadic joint R&D projects, undertaken by six firms with seven TIs, were studied. The projects were selected to reflect variety of

technologies, industrial sectors, types of R&D, firms and TIs. Both single location (firm and TI located in one city) and multilocation (firm and TI located in different cities) cases were covered, as proximity is an important variable affecting project process (Mansfield, 1991). A variety of cases were chosen in an effort to develop richer theory (Eisenhardt, 1989). Apart from completed projects, ongoing projects were studied in order to facilitate real time observation of stages of project development. Forty interviews were taken in multiple rounds spread over a period of nine months in 1994-1995.

A TYPOLOGY OF TI - FIRM JOINT R&D PROJECTS

Drawing from and synthesizing the case studies, a typological theory (Doty and Glick, 1994) of the process in firm - TI joint R&D projects is proposed. Three ideal types of project process in firm - TI joint R&D projects, labeled *Contracted Technology Development, Interactive Technology Transfer* and *Joint Technology Development* are described. The ideal type descriptions are complex and holistic theories (Doty and Glick, 1994) representing modes of effective project process in firm - TI joint R&D projects.

Contracted Technology Development

A Contracted Technology Development (CTD) project is defined as one where (a) the firm contracts out the basic part of an R&D project to a TI which implements it independently, (b) if the TI succeeds, the firm takes a technology transfer of the basic product or process in a one time intensive interaction and (c) the firm subsequently works independently on the applied part of the R&D project. For a CTD project implementation process to be feasible, the project technology should allow for a clear, independent and temporally sequential division of work between the TI and the firm. The technology should be transferable from TI to firm in a one time intensive interaction. For it to be viable, the TI and firm should both have clearly superior expertise and capability, as well as cost advantage, in handling their respective parts of the project, compared to the other. The firm receives readymade basic technology rapidly, and at a lower cost than if it had developed it on its own.

The firm identifies a project with a clearly definable end result, but either does not have the resources, or cannot spare the resources required for implementing the basic research part of the project. Alternatively the firm, facing high competitive pressure, wants to get results as rapidly as possible, and therefore cannot spare the time to experiment and learn on its own while doing basic research for the project. The firm therefore contracts the basic research part of the project to a TI which has greater expertise and experience in work of that nature, and therefore can execute the project faster and more economically. If success rates in basic research are low, the firm may opt to improve its chances of having sufficient successful projects, by expanding its portfolio of concurrent projects through contracting out basic research for a large number of them to TIs, and taking technology transfers of successful ones.

The firm keeps track of the quality of work and areas of interest of the TIs through their publications, presentations at conferences, and news items in the general and industry specific media. Past employees of TIs working in the firm also keep in touch with their earlier colleague network (Kriener and Schultz, 1993). The firm therefore has a fair idea of

which TI to approach for their project. When approached, the TI accepts the project if it broadly falls within their current or future areas of research, and if it can contribute to their knowledge and experience. The TI may have the required expensive equipment that the firm lacks, finds unviable to purchase, and is not available elsewhere. In such cases, considering their charter, the TI may feel obliged to accept the project. The TI sees these projects as a means to keep in touch with the industry, earn revenue, train students or junior scientists and advance their work.

The projects do not represent major breakthroughs in technology, but involve incremental and often repetitive refinement of known technology. However, the projects are not just application of known technology, and the end results are patentable new technology. The project work is clearly divided between the firm and the TI. The TI exclusively does the basic product or process development (laboratory scale) till technical feasibility is reached. The firm then exclusively works on developing the product or process to the commercial scale, including making changes required to make the it viable.

During the project phase at the TI, the firm supports the TI in accessing inputs from outside sources, which the TI may find difficult to procure speedily. It also monitors progress at the TI by seeking reports at each stage. Once the TI successfully completes its part of the project, the firm sends a set of people to the TI for a short period, for technology transfer. These people are selected from those who will work further on the applied part of the project, for making the product or process suitable for commercial scale production. They are knowledgeable enough to absorb the technology rapidly and make all possible enquiries required for subsequent work at the firm. The technology transfer is primarily of the product or process technical information, rather than the tacit knowledge gained by the TI project participants. Seen apriori this disadvantage in such a project implementation mode, is traded off against the speed of implementation that the TI can give.

The firm then works independently in its own laboratories on developing the product or process for viable commercial scale production. This may involve changes in raw material and process parameters to suit available materials and customer requirements. The end product or process may therefore be substantially different from the one given by the TI. This also allows the firm to maintain secrecy of the technology till it is patented and launched.

The CTD project is characterized by medium level personal and organizational interest in the project at both the firm and the TI. The project is of commercial rather than strategic importance, and often one of a stream of projects being undertaken by the firm. Both organization's CEOs provide only administrative support, while the next level takes the initiation and coordination role. The TI - firm link is primarily contractual.

Evaluation of the TI by the firm is based on their evaluation of the TI project head's knowledge base, their ability to keep the project technology confidential, the speed of implementation of the project and success rates. The firm is positive about giving the TI future contracts, if these meet their expectations. Evaluation of the firm by the TI is based on their clarity in communicating their requirements and expectations, timely and appropriate support in accessing inputs from outside sources, and ease of technology transfer due to adequate knowledge among firm personnel. The TI is positive about accepting future contracts from the firm, if these meet their expectations. Figure 1 depicts the CTD project process.

(Figure 1 about here)

Interactive Technology Transfer

An Interactive Technology Transfer (ITT) project is defined as one (a) which involves the use of some skills, technology and equipment which is not available with the firm inhouse but is available with the TI, (b) the firm wishes to acquire these skills, technology and equipment, both for the project and for future work, (c) the firm contracts the TI for assistance on a consulting basis for teaching these skills and acquiring the technology and equipment, through regular intensive interaction, while implementing the project. The contract may also call for use of TI equipment till the firm acquires the same. For an ITT project implementation process to be feasible, the project technology should be transferable from TI to firm during the intensive project interaction. For it to be viable, the TI should have clearly superior expertise and capability in teaching the required skills and in guiding the firm, compared to the firm learning these on their own, through trial and error.

The firm identifies a project with a clearly definable end result, but does not have some of the skills, technology and equipment required for implementing it. The technology required for implementing the project is a level above that known to the firm. For its future growth it is essential for the firm to learn this technology to implement future projects, but it perceives difficulty in learning the technology on its own. Alternatively the firm, facing high competitive pressure, wants to get the first project involving the new technology implemented as early as possible and therefore cannot spare the time to experiment and learn the technology on its own before implementing the project. The firm therefore contacts a suitable TI in its vicinity, which has these skills, technology and equipment, to assist it during project implementation in a consulting capacity. The project is initiated as a consequence of a history of casual to intensive interaction between the TI and the firm, for a variety of reasons -conferences, student training, testing of equipment, consultancy and earlier projects. As TI and firm are located in the same city, this long interaction is both facilitated and sustained. The TI and firm personnel have professional respect for, and friendly personal relations with, each other.

Once the project idea is put forward by the firm, the TI evaluates it in terms of its own benefits. The project is seen as one of a series of interactions with the firm. It is examined primarily in terms of its usefulness for training their students or junior scientists, and as a learning opportunity. The TI accepts the project if it broadly falls within their current or future areas of research, and if the work has some unique and challenging components. For the TI the work does not involve a major technological leap, but is largely an application of known technology to a real industrial problem. Therefore much of the work is of customized, non-patentable nature. The TI sees the project as an opportunity to apply and demonstrate their knowledge in industrial practice, earn revenue, and to some extent advance work in their areas of interest. The TI also sees the project as important in terms of supporting the industrial firm in upgrading its their skills, while simultaneously developing a new product.

Since it has the required equipment and expertise that the firm lacks, the TI may, considering its charter, feel obliged to accept the project. It is also possible that it feels obliged to support a local, small, resource poor firm, which has no alternative source for technical support. It may be interested in training firms so that technology spreads and they can manage such projects on their own in future. The TI may also see the firm's plant as an experimental base to try out new design ideas and modifications, which are beneficial to the firm and are within the limits of the firm's proposed project, usually as a peripheral benefit.

The initial part of the project is carried out by the TI for demonstrating the technology to the firm. Since this requires very little original work for the TI, a major part of it is delegated to their students or junior scientists. The overall guidance, consulting and training is provided by the senior scientists. The TI assists the firm in their negotiations for getting project financing and for purchase of equipment. This is required as the firm enters a new and unfamiliar technology area. As the TI has experience in setting up their own laboratory in that specialized field, it is familiar with the requirements and can support and advice the firm in planning and developing its own laboratory.

The ITT project is characterized by a medium level of personal and organizational interest by the firm. The project is of strategic importance to the firm but not of critical importance. The firm CEO is actively involved in supporting the project, but initiative and interest in the project emerge from the next level - the R&D or production functional head. The TI - firm link is primarily relational and to a lesser extent contractual. Though the firm and TI have a long history of interaction, there is a tacit understanding that the firm would not repeatedly approach the TI with the same problem, but would learn during the course of the project to solve the problem on its own in future. Continuous future interaction is expected by both TI and firm. The future interaction is expected to be on new problem areas which the firm has not brought to the TI before.

Evaluation of the TI by the firm is based on their evaluation of the knowledge base of the TI project participants, the quality and ease of interaction with them, and their ability to teach the new technology in an interesting and effective manner, apart from effectiveness in implementing their part of the project. The firm is positive about interacting with the TI in future if these meet their expectations. Evaluation of the firm by the TI is based on their clarity in communicating their requirements and expectations, their interest and ability to absorb the new technology and the ease of interacting with them. The TI is positive about accepting future contracts from the firm, if these meet their expectations.
Figure 2 depicts the ITT project process.

(Figure 2 about here)

Joint Technology Development

A Joint Technology Development (JTD) project is defined as one which (a) involves developing a product or process along with the creation of new technology, or significant leap in the present technology, (b) requires the use of complementary knowledge, skills and equipment available with both the TI and the firm, (c) the firm contracts the TI for jointly developing new technology by pooling their complementary capabilities. The contract is open ended, allowing for expansion and changes in plans, as new knowledge created during the project leads to new technology development avenues. For an JTD project implementation process to be feasible, the TI and firm should have clearly complementary expertise and capabilities, which cannot be acquired by the other. For it to be viable, the apriori perceived benefits of the new technology being developed, should far outweigh the investment and perceived high risk associated with it.

The firm identifies persistent problems with using present technology in their product or process, and seeks to incorporate new technology to solve these problems. Alternatively, it finds its present technology obsolete, and requires new technology for competitive advantage. The technology required involves a major technological leap for the firm, which

the firm finds itself unable to take on its own - lacking the skills, technology and equipment required to do so. For its future growth it is essential for the firm to create new technology for future projects. The firm therefore seeks a TI, its first choice being one in its immediate vicinity (same city), to collaborate with it for developing new technology. The initial contact is usually with a TI scientist personally known to the firm CEO, emerging from a previous consultancy assignment.

The TI scientist when approached with the project idea, accepts it for a variety of reasons, starting with the friendly obligation, but more due to the inherent interest and excitement generated by the creative and developmental nature of the project, which has unique features and great potential for the scientist's and TI's research interest and programme. The project is seen as providing the TI scientist the scope to learn, add to the TI's resources, do something unique at the cutting edge of technology in the field, have potential of being published, and most importantly be personally and academically exciting. This interest and excitement spurs the scientist to act as an initiator and coordinator, in getting other TI scientists with the required complementary expertise interested in the project. They too get interested in the project for the same or similar reasons and are incorporated in the project.

At the TI, the work is divided among the TI scientists based on their expertise areas but they have a number of meetings throughout the project to coordinate and support each other. This is essential where parameters of each subproject are interdependent with parameters of other subprojects. At the firm, a coordinator is designated who coordinates various subgroups working on individual subprojects. The work may involve members of the firm's project team personnel working at the TI's premises and vice-versa. Even when they work separately, they communicate their work to each other as often as required, so that each knows intimately what the other is doing. Meetings are highly frequent and intense, usually of long duration, characterized by a high degree of openness, and equal acceptance of failure and success.

There is high reliance on trust and enthusiasm to carry forward and control the project, in the face of high risk and uncertainty. Both the TI and the firm go far beyond their initially written contractual agreements in their effort to do their best for the project. There is high personal rapport between the firm CEO and the TI coordinator which, emerging from earlier interactions, is sustained and developed during the course of the project. The JTD project is characterized by high personal and organizational interest by the firm. The project is of strategic and critical importance to the firm. This leads to a high degree of interest and initiative from the firm's CEO to initiate, lead and directly manage the project. Other project participants are also highly enthusiastic about the project, as they see considerable scope in it to learn new skills, as well as benefit from being involved in a project that is at the *cutting edge* of technology. The TI - firm link is primarily relational.

The scope of the project often expands as new avenues emerge with generation of new knowledge. These opportunities are either immediately seized by the project team, or kept in mind for future work if resources required are not currently available. At the successful conclusion of the project, the firm is usually willing to work on future collaborations with the TI, and often proposes subsequent projects. The TI is also positive about collaborating with the firm, and either accepts these new projects or wishes it had the time and resources to take up such projects. In either case the TI is positive about working with the firm in future.

Evaluation of the TI by the firm, is based on their evaluation of the knowledge base of the TI project participants, the quality and ease of interaction with them, their ability to understand the complex technological problem faced by the firm and develop new technology suitable for the firm's special requirements, apart from effectiveness in jointly implementing the project. The firm is positive about collaborating with the TI in future if these meet their expectations. Evaluation of the firm by the TI, is based on their clarity in communicating their requirements and expectations, their interest, their ability to contribute in a complementary manner to the new technology development effort, their openness and understanding in accepting failure as a part of success in the R&D process, and the ease of interaction with them. The TI is positive about collaborating with the firm in future, if these meet their expectations. Figure 3 depicts the JTD project process.

(Figure 3 about here)

KNOWLEDGE BUILDING IN TI - FIRM JOINT R&D PROJECTS

Knowledge building processes in each of the three ideal types of project process are described. In each ideal type, these occur in different ways with different consequences for the firm and TI.

Contracted Technology Development

In a CTD project, the basic R&D part of the product or process is carried out independently and entirely by the TI. Once the firm communicates its expectations, personal TI - firm interaction during this phase is low and limited to reports about success or failure at each stage. The frequency of communication is low, as frequent interaction is unnecessary or irrelevant. Interaction is even lower when the firm and TI are in different cities. Little or no technology transfer takes place during this phase. As the projects involve incremental and repetitive refinement of known technology, the task is given to students or junior scientists, for whom the work has largely experiential value, and as a consequence their interest level may drop over time, once experience is gained and the work becomes repetitive. For the senior scientist or project head who guide them, learning is primarily of the "what worked and what did not work - and why?" nature, derived from the large number of experiments conducted by the students or junior scientists. In this phase, knowledge building is entirely within the TI, embodied in their experience. This experience has utility in their further research programme in the same or similar areas.

Once the basic R&D is successfully completed, the TI project team gives a demonstration of their developed product or process to the firm project team, who also take trials if required. During this short period of demonstration and trial, intensive interaction takes place between TI and firm project teams. The firm project team asks several questions to learn about the technical development process - specially about experiments which failed, so that avenues already explored by the TI are not repeated by the firm. The scope and quantum of technology transfer is largely dependent on the ability of the firm personnel to ask relevant questions, and absorb knowledge during this short period. The technology transfer is however limited in scope. A large part of the tacit experiential knowledge and expertise developed by the TI during their phase of the project is not transferred. It is also

possible that this tacit knowledge is unnecessary for the firm and therefore not sought actively. At the firm, the project team works on scale up and commercialization of the basic product or process, and gains experience and knowledge for similar future projects. Figure 4 depicts the knowledge building process in CTD projects.

(Figure 4 about here)

Interactive Technology Transfer

In an ITT project the firm's major objective is to learn a new technology while implementing the project. Interaction is of high frequency and intensity for project related matters, as well as for informal or formal training being imparted by the TI to the firm. Though parts of the project work are conducted separately at the firm and the TI, each consults the other at every stage throughout the project, as their further work depends on the work completed by the other. Over time, as training proceeds, the firm does most of the work on its own under the TI's guidance. The technology and knowledge transfer in an ITT project is embodied in the frequent formal and informal interaction and technology demonstrations which occur throughout the project duration, during visits to each other's premises. A major part of the this technology transfer is from the TI to the firm, though the TI does learn a little from the firm - specially in the practical and commercial aspects of applying technology in practice.

The learning in an ITT project is of two types. For the students or junior scientists from the TI, the learning is in developing practical skills and applying theory to practice in an actual industrial problem. This also leads to their gaining confidence in the usefulness of their course work knowledge. For the firm, the learning is of advanced techniques useful to their industry, while applying them to a practical problem. They also gain practical experience during the joint purchase and use of new equipment required for setting up their laboratory for using the new technology. Figure 5 depicts the knowledge building process in ITT projects.

(Figure 5 about here)

Joint Technology Development

In a JTD project, the attempt by both the firm and TI, is to create new technology, as the present technology is inadequate to solve the firm's technological problem. The work is in the realm of both pure and applied R&D, both happening simultaneously. There is close and frequent interaction between the organizations. Since for both, the problem is unique, and each have complementary knowledge and expertise, this interaction is instrumental in teaching what they know to each other. There is interactive creation of the new technology, with joint and almost equal learning for both TI and firm participants, as they work together and learn together.

While the objective of the JTD project is clearly to move to a new technological level, there is apriori no clearly definable end result. The firm is open about exploring new technology avenues, as they emerge during the course of project implementation, if they are within its investment ability and risk bearing capacity. The TI is also willing to explore such new avenues, as their interest grows with the expanding scope of the project, within their constraints of time and resources.

The project results in capability development by both the TI and the firm. Apart from developing the new product or process, both gain substantial tacit learning through the project, which is seen by both TI and firm participants to have benefits in future. Participants also discover unanticipated benefits from the project. The firm finds itself thinking in previously unexplored ways, resulting in new projects incorporating the new technology. The interaction also exposes the firm to the latest technical literature in the field, which may lead it to rethink on technology related decisions in other areas entirely unconnected with the project. There may be an overall technological upgradation as the new technology and skills diffuse throughout the firm. The TI scientists discover new unexplored practical and theoretical problems for future research, which are at the *cutting edge* of technology in the field. These can become topics for graduate and doctoral research under their guidance, using the firm as a research base. Figure 6 depicts the knowledge building process in JTD projects.

(Figure 6 about here)

CONCLUSIONS

This paper contributes a mapping of the process of knowledge building in TI - firm joint R&D projects. This is useful in understanding how factors at the individual, organizational and interorganizational level combine to facilitate knowledge creation in each type of joint R&D project. The process models also provide insights aiding understanding and decision making by firms, TIs and policy makers in initiating, executing and sustaining a progressive programme of such projects.

REFERENCES

Alter, C. and Hage J. (1993) *Organizations Working Together*, Newbury Park, California: Sage.

Bailetti, A.J. and Callahan J.R. (1993) "The coordination structure of international collaborative technology arrangements", *R&D Management*, vol. 23, no. 2, 129-146.

Bonaccorsi A. and Piccaluga A. (1994) "A theoretical framework for the evaluation of university - industry relations", *R&D Management*, vol. 24, no. 3, 229-247.

Borys, B. and Jemison D.B. (1989) "Hybrid arrangements as strategic alliances: theoretical issues in organizational combinations", *Academy of Management Review*, vol. 14, no. 2, 234-249.

Bresser, R.K. and Harl J.E. (1986) "Collective strategy: vice or virtue?", *Academy of Management Review*, vol. 11, 408-427.

Burgelman, R.A. (1983) "A process model of internal corporate venturing in the diversified major firm", *Administrative Science Quarterly*, vol. 28, 223-244.

Chakravarthy, B.S. and Doz Y. (1992) "Strategy process research: focussing on corporate self renewal", *Strategic Management Journal*, vol. 13, Summer Special Issue, 5-14.

Daft, R.L. and Levin A.Y. (1993) "Where are the theories for the new organizational forms? an editorial essay", *Organization Science*, vol. 4, no. 4, 1-6.

Dodgson, M. (1993) "Learning, trust and technological collaboration", *Human Relations*, vol. 46, no. 1, 77-95.

Doty D. H. and Glick W. H. (1994) "Typologies as a unique form of theory building: towards an improved understanding and modeling" *Academy of Management Review*, vol. 19, no. 2, 230-251.

Eisenhardt, K.M. (1989) "Building theories from case study research", *Academy of Management Review*, vol. 14, 532-550.

Glaser, B. and Strauss A. (1967) *The Discovery of Grounded Theory: Strategies for Qualitative Research*, London: Wiedenfeld & Nicholson.

Huxham, C. (1993) "Pursuing collaborative advantage", *Journal of the Operational Research Society*, vol. 44, no. 6, 599-611.

Itami, H. and Numagami T. (1992) "Dynamic interaction between strategy and technology", *Strategic Management Journal*, vol. 13, 119-135.

Jemison, D.B. and Sitkin S.B. (1986) "Corporate acquisitions: a process perspective", *Academy of Management Review*, vol. 11, 145-163.

Kriener, K and Schultz M. (1993) "Informal collaboration in R&D. the formation of networks across organizations", *Organization Studies*, vol. 14, no. 2, 189-209.

Laage-Hellman, J. (1987) "Process innovation through technical cooperation" in Hakansson H (ed.) *Industrial Technological Development*, London: Routledge.

Lopez-Martinez, R.E., Medellin E., Scanlon A.P. and Solleiro J.L. (1994) "Motivations and obstacles to university - industry cooperation (UIC): a Mexican case", *R&D Management*, vol. 24, no. 1, 17-31.

Lyles, M.A. (1990) "An agenda for strategic management in the 90's", *Journal of Management Studies*, vol. 28, no. 6, November, 503-515.

Mansfield, E. (1991) "Academic research and industrial innovation", *Research Policy*, vol 19, no. 237-249.

Nonaka I. (1994) "A dynamic theory of organizational knowledge generation", *Organization Science*, vol. 5, no. 1, February, 14-37.

Oliver, C. (1990) "Determinants of interorganizational relationships· integration and future directions", *Academy of Management Review*, vol. 15, no. 2, 241-265.

Parithe, A. (1993) "Messy research, methodological predispositions and theory development in international joint ventures" *Academy of Management Review*, vol. 18, no. 2, 227-268.

Radosevich, R. and Kassicieh S. (1993) "Strategic challenges and proposed responses to competitiveness through public sector technology", *California Management Review*, Summer, 33-50.

Ring, P.S. and Van de Ven A.H. (1992) "Structuring cooperative relationships between organizations", *Strategic Management Journal*, vol. 13, 483-498.

Ring, P.S. and Van de Ven A.H. (1994) "Developmental processes of cooperative interorganizational relationships", *Academy of Management Review*, vol. 19, no. 1, 90-118.

Rosenberg, N. and Nelson R.R. (1994) "American universities and technical advance in industry", *Research Policy*, vol. 23, 323-348.

Schendel, D. (1992a) "Introduction to the summer 1992 special issue on strategy process research", *Strategic Management Journal*, vol. 13, Summer, 1-4.

Schendel, D. (1992b) "Introduction to the winter 1992 special issue: fundamental themes in strategy process research" *Strategic Management Journal*, vol. 13, Winter, 1-3.

Smith, N.C. (1989) "The case study: a vital yet misunderstood research method for management" in Mansfield R. (Ed.) *Frontiers of Management Research and Practice*, London: Routledge, 50-64.

Thomas, J.B. and Trevino L.K. (1993) "Information processing in strategic alliance building: a multiple case approach", *Journal of Management Studies*, vol. 30, no. 5, 779-814.

Tsoukas, H. (1989) "The validity of idiographic research explanations", *Academy of Management Review*, vol. 14, 551-561.

Van de Ven, A.H. (1992) "Suggestions for studying strategy process: a research note", *Strategic Management Journal*, vol. 13, Summer, 169-188.

Wittaker E. and Bower D.J. (1994) "A shift to external alliances for product development in the pharmaceutical industry", *R&D Management*, vol. 24, no. 3, 249-260.

Wood, D.J. and Gray B. (1991) "Towards a comprehensive theory of collaboration", *Journal of Applied Behavioral Science*, vol. 27, no. 2, 139-162.

Yin, R.K. (1984) *Case Study Research: Design and Methods*, Beverly Hills, California: Sage.

Zajac, E.J. and Olsen, C.P. (1993) "From transaction cost to transactional value analysis: implications for the study of interorganizational strategies", *Journal of Management Studies*, vol. 30, no. 1, 131-145.

***

Figure 1 : Process Model of CTD TI - Firm Joint R&D Projects

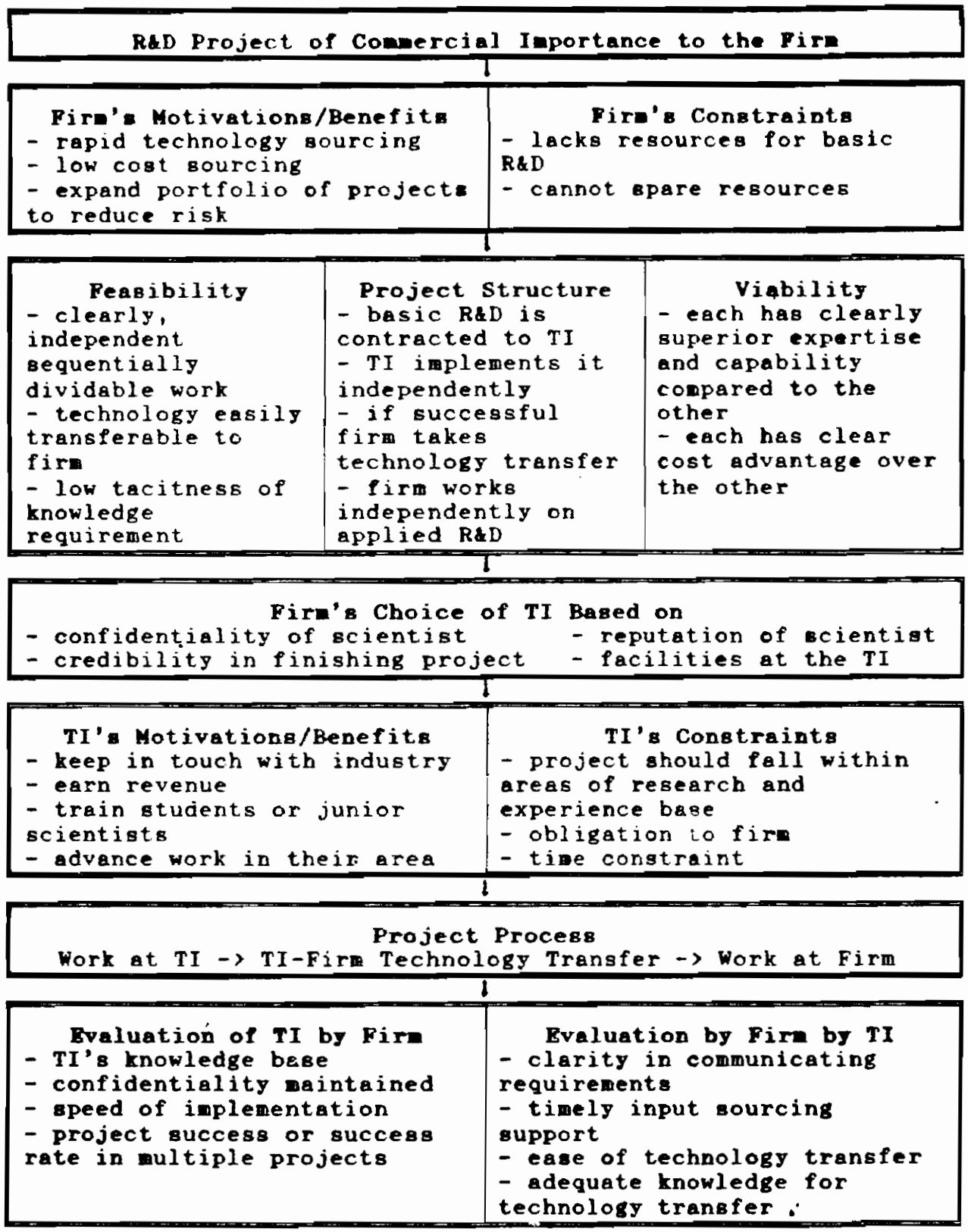


Figure 2 : Process Model of ITT TI - Firm Joint R&D Projects

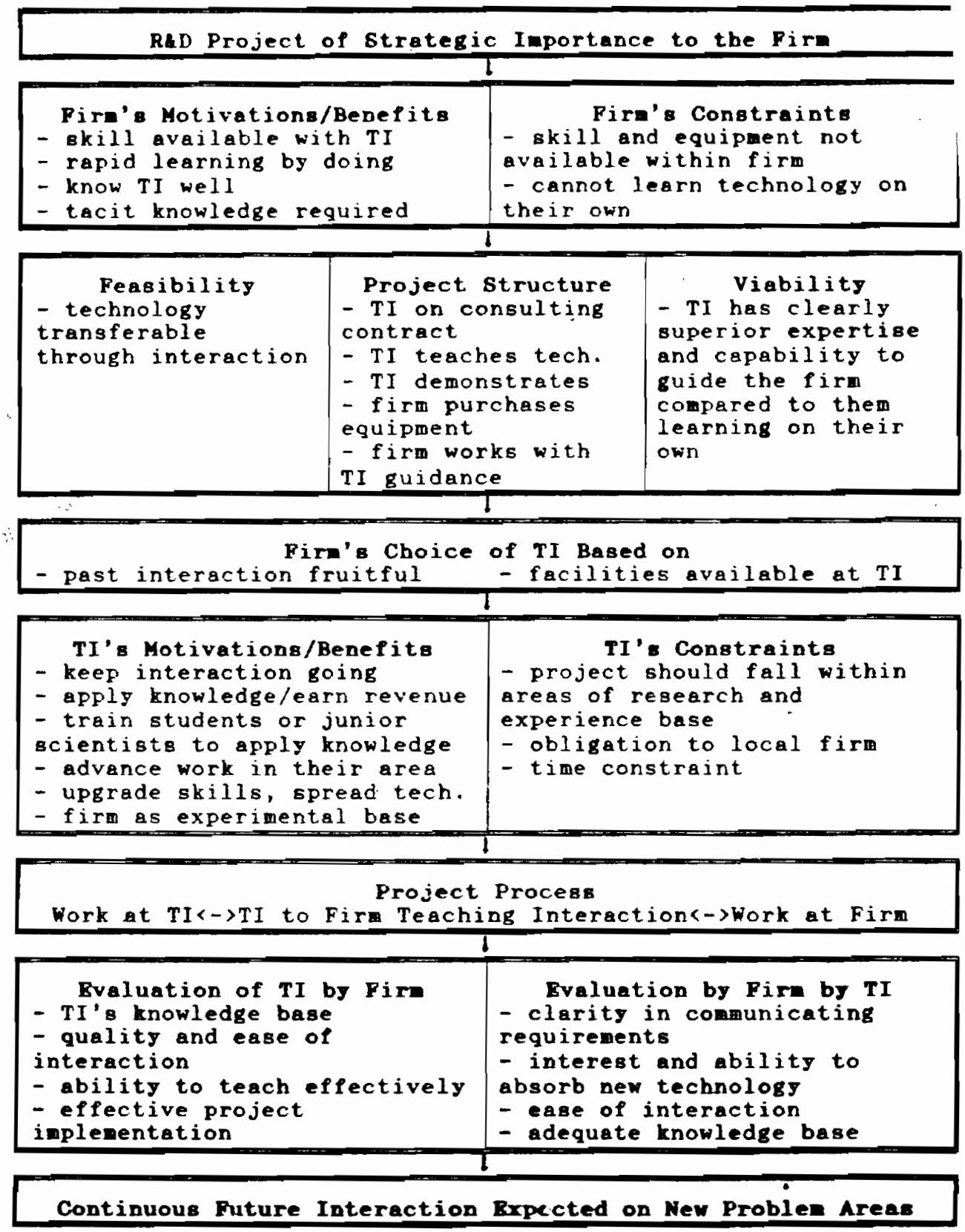


Figure 3 : Process Model of JTD TI - Firm Joint R&D Projects

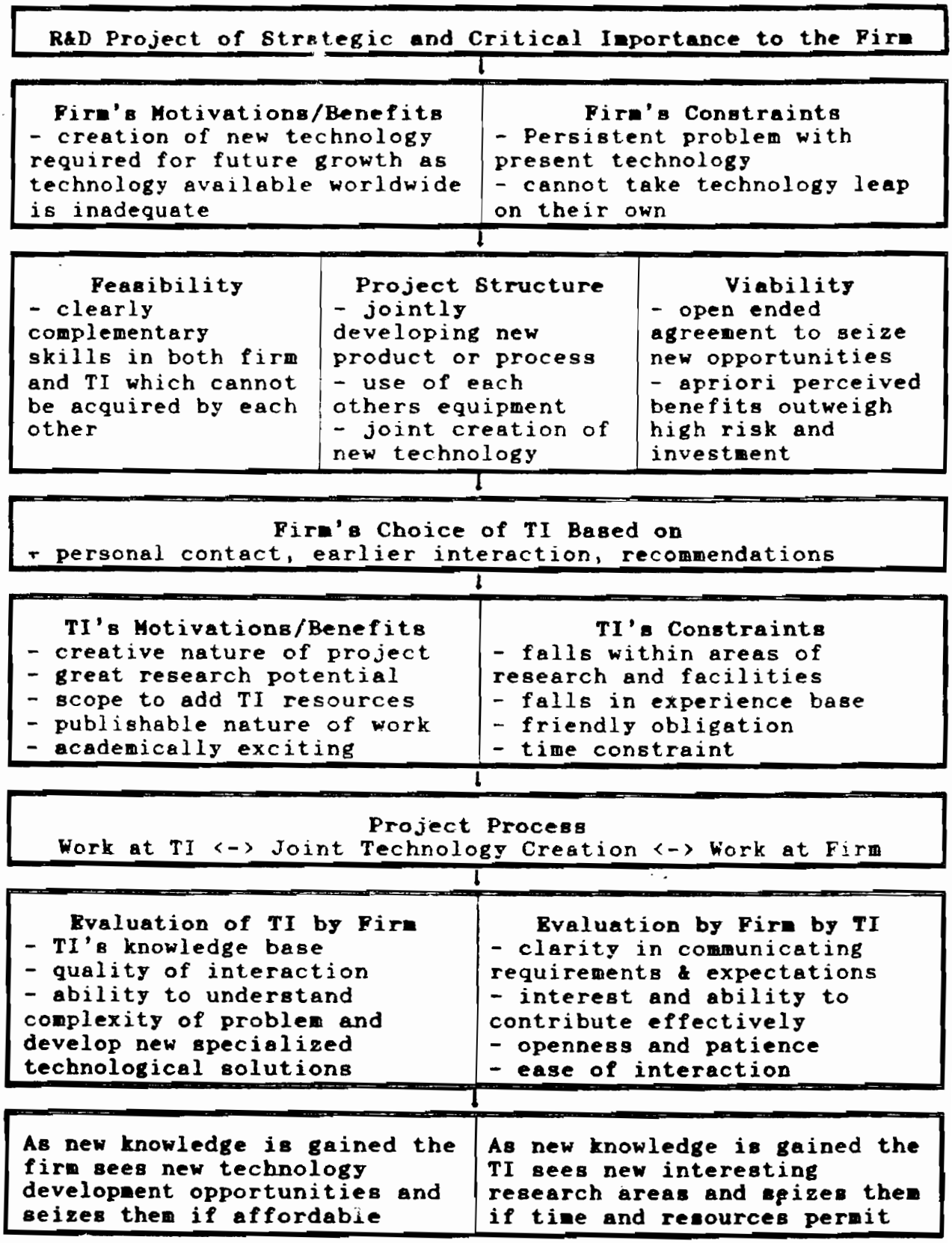


Figure 4 : Knowledge Building in CTD TI - Firm Joint R&D Projects

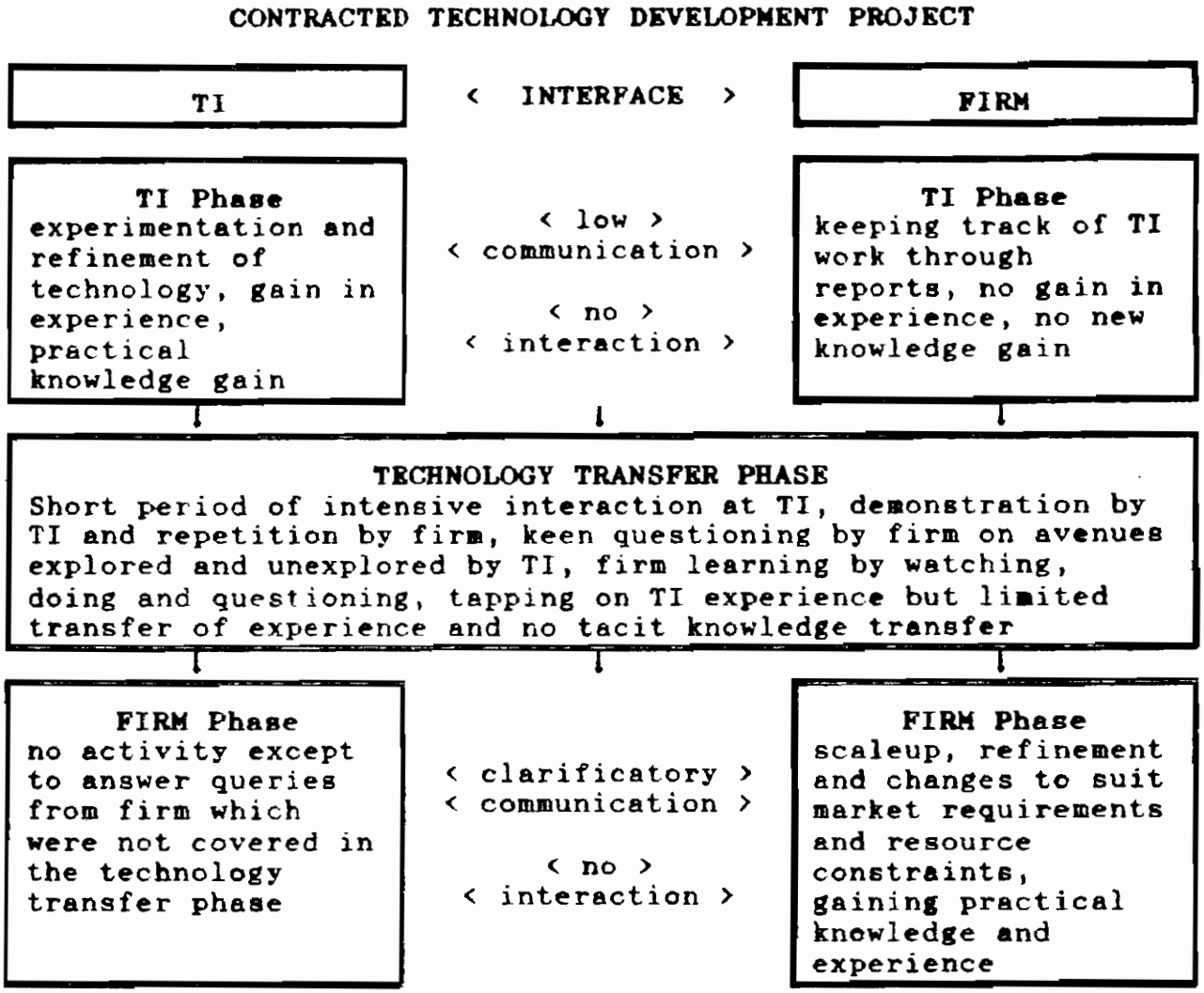


Figure 5 : Knowledge Building in ITT TI - Firm Joint R&D Projects

INTERACTIVE TECHNOLOGY TRANSFER PROJECT

TI	< INTERFACE >	FIRM
At TI high interaction between scientists within TI, learning from each other, from teaching, applying knowledge to practice, practical and commercial aspects, gain in experience	**TOGETHER** high interaction, high frequency of communication, training formal and informal, new technology demonstration at TI or firm, jointly setting up the new laboratory at firm	**At FIRM** learning by instruction and by doing, learning to apply advanced technology to industrial practice, learning about new equipment while purchasing them and setting up own laboratory

Figure 6 : Knowledge Building in JTD TI - Firm Joint R&D Projects

JOINT TECHNOLOGY DEVELOPMENT PROJECT

TI	< INTERFACE >	FIRM
At TI new knowledge, new experience, tacit learning, new technology for immediate and future application, capability and facility development, exposure to practice	**TOGETHER** high interaction, high frequency of communication, teaching each other complementary past knowledge, creating new knowledge together, working together, learning together, equal learning for both	**At FIRM** new knowledge, new experience, tacit learning, new technology for immediate and future application, capability and facility development, exposure to literature
↓	↓	↓
technological upgradation, new research areas to explore emerge	willingnes to explore new opportunit[illegible]	technological upgradation, new ways of thinking and applying new knowledge emerge