

THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Resource Combining across
Inter-organisational
Project Boundaries

FRIDA LIND

Division of Industrial Marketing
Department of Technology Management and Economics
Chalmers University of Technology
Göteborg, Sweden 2006

Resource Combining across Inter-organisational Project Boundaries
FRIDA LIND
ISBN 91-7291-757-1

© Frida Lind, 2006

Doktorsavhandlingar vid Chalmers tekniska högskola
Ny serie nr 2439
ISSN 0346-718X

Division of Industrial Marketing
Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Göteborg, Sweden
Telephone: +46 (0)31 – 772 1000

Chalmers Reproservice
Göteborg, Sweden 2006

Abstract

Resource Combining across Inter-organisational Project Boundaries

Frida Lind

Division of Industrial Marketing

Department of Technology Management and Economics

Chalmers University of Technology

This thesis focuses on the interplay between resource use and development that takes place in relation to inter-organisational research projects. Research and development efforts are characterised by resource combining in collaboration and networks among actors. One way of organising such efforts is inter-organisational projects. In the thesis, inter-organisational research projects are analysed in a network context.

The theoretical framework takes its starting point in the Industrial Network Approach. The notions of resource heterogeneity and embeddedness are taken as vital assumptions and points of departure for the analysis of resource combining in a network context. Empirically the thesis builds on an in-depth case study of an inter-organisational research project in the field of plant biotechnology. The project in focus consists of four project members: two companies and two university departments. This project has been studied between 2001 and 2004.

The case study illustrates how resource combining takes place across project boundaries. Thus, inter-organisational projects may not only use and develop resources internally in order to fulfil the project goals, but may also relate to research endeavours outside the project. “Project embeddedness” is discussed in terms of project members’ respective resource collections, including their access to project external resources. Five “patterns” are suggested for understanding how projects are linked to their contexts. It is argued that the mixture of these patterns sets the terms for how a project may cope with its context during a research process. Finally, the role of the project boundary is discussed in terms of two functions: separating and relating, both being of importance for resource combining across the project boundary. By extending the analysis beyond the project boundary, network effects can be observed, thus providing a wider scope of resource combining than what may be captured by focusing only on what takes place within projects.

Keywords: inter-organisational projects, research projects, resources, resource development, network contexts, network effects.

Acknowledgements

Five years have passed since I became a PhD student at the Division of Industrial Marketing, Chalmers University of Technology. Being a PhD student and writing a thesis have been both rewarding and enjoyable. The thesis has been written in a network context where several actors have contributed with resources that have been used and developed in relation to the thesis.

First and most warmly, I would like to thank my supervisors – my main supervisor Anna Dubois and Lars-Erik Gadde at the Division of Industrial Marketing, Chalmers University of Technology, and Ann-Charlott Pedersen, at the Department of Industrial Economics and Technology Management, Norwegian University of Science and Technology, who have formed the supervision committee. Thank you, Anna, for your guidance in the research process and your bright ideas, which have been a continuous source of inspiration! Thank you, Lars-Erik, for raising central questions in relation to the thesis and for providing it with structure! Thank you, Ann-Charlott, for being a valuable discussion partner and for your encouragement during the research process!

I also want to thank former and present colleagues at the Division of Industrial Marketing for creating a stimulating work environment and many nice lunches. Thank you, Jens Laage-Hellman, Kajsa Hulthén, Daniel Hjelmgren, Lennart Bångens, Peter Fredriksson, Fredrik Skarp, Viktoria Sundquist, Stefan Karlsson and Lars Bankvall. Thank you also, Yvonne Olausson, for your support! Moreover I would like to thank the neighbour division, Technology and Society, for sharing pleasant coffee breaks.

In addition, I am grateful to a number of researchers outside the division for commenting on research proposals, conference papers and thesis chapter drafts. Thank you, Elsebeth Holmen and Tim Torvatn, Department of Industrial Economics and Technology Management, Norwegian University of Science and Technology; Espen Gressetvold, Trondheim Business School; Alexandra Waluszewski, Department of Business Studies, Uppsala University; Håkan Håkansson, Department of Marketing, Norwegian School of Management; and Debbie Harrison, Department of Strategy and Logistics, Norwegian School of Management. Thank you also, Maureen McKelvey, Division of Industrial Dynamics, and Nina Modig, Division of Logistics and Transportation, Chalmers University of Technology.

I also want to thank Anna Kadefors, Division of Service Management, Chalmers University of Technology, for being the discussant at the final seminar in October 2005.

The thesis was made possible by financial support from several sources, for which I am very grateful. Initially a grant was received from Handelsbankens Forskningsstiftelser (Tore Browaldhs Stiftelse samt Jan Wallander och Tom Hedelius Stiftelse) and in the latter part funding was received from the Swedish Foundation for Strategic Research. Furthermore, grants have been received from the Royal Swedish Academy of Agriculture and Forestry, and Stiftelsen Wilhelm och Martina Lundgrens Vetenskapsfond 1. A travel grant was also awarded from the Chalmers University of Technology Foundation, which made a stay in Manchester possible.

My family and friends have provided great support during these years. Deep thanks to my parents, Ulla-Britt and Hans, for your encouragement and interest in the thesis! Thank you, Lovisa, my sister, for your support and help with the layout – thanks also to Tomas! Most warmly, I would like to thank my husband Ricard. Thank you, Ricard, for always believing in me and for your loving support; you are what matters most to me.

Thank you all!

Frida Lind
Göteborg, April 2006

Table of Content

1	INTRODUCTION.....	1
1.1	COMBINING OF RESOURCES.....	2
1.2	TECHNOLOGICAL DEVELOPMENT IN COLLABORATION	3
1.3	ORGANISING IN PROJECTS	4
1.4	AIM AND STRUCTURE OF THE THESIS.....	6
2	THEORETICAL FRAME OF REFERENCE.....	9
2.1	RESOURCE COMBINING	9
2.1.1	<i>Resource development</i>	<i>10</i>
2.1.2	<i>The interplay between resource combining, use and development.....</i>	<i>12</i>
2.2	CHARACTERISTICS OF PROJECTS	13
2.2.1	<i>Temporariness, uncertainty and goals.....</i>	<i>13</i>
2.2.2	<i>Projects and their environments.....</i>	<i>18</i>
2.2.3	<i>A project in time and space</i>	<i>23</i>
2.2.4	<i>Inter-organisational projects.....</i>	<i>25</i>
2.3	INDUSTRIAL NETWORK THEORY	30
2.3.1	<i>The network model.....</i>	<i>30</i>
2.3.2	<i>The resource dimension in focus</i>	<i>32</i>
2.3.3	<i>The role of interaction</i>	<i>35</i>
2.3.4	<i>Embeddedness and a network context</i>	<i>38</i>
2.4	RESOURCE COMBINING IN RELATION TO PROJECTS.....	42
2.4.1	<i>Resource use and development categories</i>	<i>42</i>
2.4.2	<i>The resource collections of a project.....</i>	<i>44</i>
2.4.3	<i>Project embeddedness</i>	<i>46</i>
2.4.4	<i>Dynamics of the project context.....</i>	<i>47</i>
2.5	RESEARCH ISSUES	48
3	METHOD	51
3.1	CASE STUDY RESEARCH	51
3.2	AN ABDUCTIVE APPROACH.....	54
3.2.1	<i>Systematic combining</i>	<i>54</i>
3.2.2	<i>Emergence of the framework and the case</i>	<i>56</i>
3.3	DATA COLLECTION	59
3.3.1	<i>Conducting interviews</i>	<i>59</i>
3.3.2	<i>Other sources of data.....</i>	<i>64</i>
3.4	TRUSTWORTHINESS.....	65
3.4.1	<i>Understanding of a “new” empirical field.....</i>	<i>65</i>
3.4.2	<i>Member checks</i>	<i>66</i>
3.4.3	<i>Saturation and triangulation</i>	<i>66</i>
3.4.4	<i>Continuous review and elucidation</i>	<i>68</i>
4	THE EMPIRICAL INQUIRY	71
4.1	THE WINTER OATS PROJECT.....	71
4.2	PROJECT BACKGROUND.....	73
4.2.1	<i>Oats – a small but healthy crop.....</i>	<i>73</i>
4.2.2	<i>Previous research efforts.....</i>	<i>75</i>
4.2.3	<i>Background to the goal formulation.....</i>	<i>77</i>

4.3	THE FOUR PROJECT MEMBERS	79
4.3.1	<i>The Swedish Farmers Supply and Crop Marketing Association</i>	79
4.3.2	<i>Svalöf Weibull</i>	81
4.3.3	<i>The Department of Cell and Molecular biology</i>	82
4.3.4	<i>The Department of Computer science</i>	83
4.4	RESEARCH ACTIVITIES IN THE PROJECT	85
4.4.1	<i>Research phase 1: Preparations for sequencing</i>	85
4.4.2	<i>Research phase 2: Sequencing</i>	87
4.4.3	<i>Research phase 3: EST-data analysis</i>	95
4.4.4	<i>Research phase 4: Preparations for microarray analysis</i>	112
4.5	THE CURRENT SITUATION.....	116
5	CATEGORIES OF RESOURCE USE AND DEVELOPMENT	119
5.1	IDENTIFYING RESOURCES AND ACTIVITIES	119
5.1.1	<i>Research phase 1: Preparations for sequencing</i>	120
5.1.2	<i>Research phase 2: Sequencing</i>	122
5.1.3	<i>Research phase 3: EST-data analysis</i>	122
5.1.4	<i>Research phase 4: Preparations for microarray analysis</i>	126
5.2	THE RESOURCE USE AND DEVELOPMENT CATEGORIES	128
5.2.1	<i>Resources developed and used within the project</i>	128
5.2.2	<i>Resources developed outside and used within the project</i>	129
5.2.3	<i>Resources developed within and used outside the project</i>	131
5.2.4	<i>Resources developed prior to and used during the project</i>	132
5.2.5	<i>Resources developed during and used after the project</i>	133
5.2.6	<i>The resource categories of the winter oats project</i>	133
6	RESOURCE COMBINING WITHIN THE PROJECT	137
6.1	COMBINING OF RESOURCES TOWARDS THE PROJECT GOALS	137
6.1.1	<i>The project goals</i>	138
6.1.2	<i>Resource combining towards the overall goal of the project</i>	139
6.1.3	<i>Resource combining towards the specific goal of the project</i>	140
6.2	PROCESSES IN INTER-ORGANISATIONAL RESEARCH PROJECTS.....	150
6.2.1	<i>Changes in the resource collections</i>	150
6.2.2	<i>Interaction and learning</i>	153
6.2.3	<i>Search and discovery</i>	154
6.2.4	<i>Functions and dynamics of the project goals</i>	155
6.3	SUMMARY	157
7	RESOURCE COMBINING ACROSS THE PROJECT BOUNDARY	159
7.1	COMBINING OF RESOURCES OUTSIDE THE PROJECT	159
7.1.1	<i>The project's contribution to other research activities</i>	160
7.1.2	<i>Potential contribution back to the project</i>	164
7.2	THE NETWORK CONTEXT OF A PROJECT.....	165
7.2.1	<i>Resource collections and discoveries</i>	166
7.2.2	<i>Project embeddedness and the project members</i>	167
7.2.3	<i>Patterns in a project's links to the context</i>	172
7.2.4	<i>The evolving project context</i>	183
7.3	SUMMARY	185
8	THE ROLE OF THE PROJECT BOUNDARY.....	187
8.1	FUNCTIONS OF THE PROJECT BOUNDARY.....	187
8.1.1	<i>Separating and relating</i>	187
8.1.2	<i>Identity and difference</i>	189

8.2	PERSPECTIVES ON PROJECT BOUNDARIES	191
8.2.1	<i>The multiple boundaries of a project</i>	192
8.2.2	<i>The context's effects on the project</i>	194
8.2.3	<i>Network effects across project boundaries</i>	195
9	REFERENCES.....	199

List of Figures

Figure 2.1:	A temporary organisation limited in time.	14
Figure 2.2:	A project in its environment (Gilbert 1983, p. 84).....	19
Figure 2.3:	Framework for interior process dynamics of a project (Engwall, 2003, p. 805).	24
Figure 2.4:	An inter-organisational project.	25
Figure 2.5:	A construction project in its context (Dubois and Gadde 2000, p. 212).	29
Figure 2.6:	The network model (Håkansson, 1987, p. 17).	31
Figure 2.7:	Factors determining the interaction in a particular episode (Jahre et al., 2006, p. 52).	36
Figure 2.8:	The time context of a project.	40
Figure 2.9:	The organisational context of a project.....	41
Figure 2.10:	Resource use and development categories in relation to a project.	43
Figure 2.11:	The resource collections of an inter-organisational project.	45
Figure 2.12:	Project embeddedness with regard to activities and resources.	47
Figure 3.1:	Systematic combining (Dubois and Gadde, 2002, p. 555).....	55
Figure 4.1:	The winter oats project and the four project members.....	72
Figure 4.2:	The project members and their initial interests.....	79
Figure 4.3:	The project members involved in the first research phase.....	87
Figure 4.4:	The clustering process from raw data to processed data (adapted from the MWG Biotech webpage ²⁶).	91
Figure 4.5:	The process of assembling ESTs into genes (adapted from the MWG Biotech webpage).	91
Figure 4.6:	The four types of oats sent to the sequencing firm.	92
Figure 4.7:	Project members and external organisations involved during sequencing.....	95
Figure 4.8:	Four steps in EST-data analysis towards identifying cold-adaptation genes in oats.	96
Figure 4.9:	Pie diagram of oats classifications developed in the winter oats project ³⁴	105
Figure 4.10:	Project members involved during the EST-data analysis.	106
Figure 4.11:	The project members using the EST data outside the project.....	111
Figure 4.12:	Project members involved in the preparations for microarray analysis.....	114
Figure 4.13:	Project members involved in another uses of the EST data during the preparations for microarray analysis.....	116
Figure 5.1:	Overview of the four research phases of the winter oats project (2001-2004).....	119

Figure 5.2: The resources used and developed during preparations for sequencing.....	120
Figure 5.3: The resources used and developed during sequencing.....	122
Figure 5.4: The resources used and developed during the EST data analysis.....	123
Figure 5.5: The resources used and developed during preparations for microarray analysis.....	127
Figure 5.6: The resource use and development categories of the winter oats project.....	134
Figure 6.1: The project goals of the winter oats project.....	138
Figure 6.2: Combining of B ₂ and B ₃ towards the overall goal of the project.....	139
Figure 6.3: Combining B ₂ and B ₃ – development of A ₂	141
Figure 6.4: Combining A ₂ and B ₄ – development of A ₃	142
Figure 6.5: Combining A ₃ , B ₅ and B ₆ – development of A ₄	143
Figure 6.6: Combining B ₁ , A ₄ and A ₅ – development of A ₄ and A ₅	145
Figure 6.7: Combining A ₄ , A ₅ , B ₇ and B ₈ – development of A ₆	146
Figure 6.8: Combining A ₆ , A ₄ , B ₉ and B ₁₀ – development of A ₇	148
Figure 6.9: Combining B ₁₁ , A ₇ and A ₁ – towards fulfilling the specific goal.....	149
Figure 7.1: Combining of C ₂ and other resources in a new application.....	161
Figure 7.2: Combining of C ₃ and other resources in a new collaborative effort.....	162
Figure 7.3: Combining of C ₄ and other resources in an existing programme.....	163
Figure 7.4: Project embeddedness with regard to activities and resources.....	168
Figure 7.5: Unidirectional pattern of resources into the project.....	173
Figure 7.6: Unidirectional pattern of resources out of the project.....	175
Figure 7.7: Interactive pattern of resources out of the project.....	176
Figure 7.8: Interactive pattern of resources into the project.....	178
Figure 7.9: The pattern of isolation.....	179
Figure 7.10: Isolation and embeddedness of projects in theory and practice.....	183

List of Tables

Table 3.1: Orientation interviews in the field of bioinformatics.....	62
Table 3.2: Interviews related to the winter oats project.....	63
Table 4.1: Results delivered by the sequencing firm.....	94
Table 5.1: The resource use and development categories of the winter oats project.....	135

1 Introduction

This thesis deals with how resources are developed and used in relation to an inter-organisational research project. The empirical context in which resource use and development are explored is a joint research project concentrating on oats. The goal of this project is to develop winter oats, that is, oats which can be sowed in the autumn, survive the winter and be harvested in the spring.

Four organisations take part in the project. First, a co-operative, where the majority of the members are farmers, is one of the members of the project. The co-operative's development division has an interest in improving certain characteristics of oats, in this case the crop's frost tolerance. The second member of the project is an international plant-breeding and seed group, specialising in developing new varieties and producing seed for customers in cold climate areas. The rationale for this firm to be involved in the project is that the firm has not been able to breed oats that survive the winters, in spite of several attempts.

In addition, two research groups are involved, representing two university departments. One of them focuses among other things on research on plant structures and functions. The other focuses on developing methods and algorithms for structuring and handling huge amounts of data. The data focused on in this project consist of nucleotide sequence information in which the key to frost resistance, a first step towards developing winter oats, is expected to be found.

The firm and the co-operative involved in the project represent future users of the results of the project, while the two research organisations aim for knowledge development in their respective areas. The research project as such, the four project members, some external actors and their joint activities are in focus for the empirical inquiry of this thesis.

The overall research focus in this thesis concerns resource use and development – especially how resource use and development are connected with how actors in different ways combine and recombine resources. In line with other studies, for example Jahre et al. (2006), the phenomenon of resource combining is chosen as a way to analyse resource use and development. The winter oats project, introduced briefly above, is used as an arena to analyse resource combining.

Below, resource combining is in focus in section 1.1, which leads to section 1.2 concentrating on technological development in collaboration. This is followed by section 1.3 which concerns organising in projects, and section 1.4 in which the aim and structure of the thesis are presented.

1.1 Combining of resources

In this study, projects are used as an arena for analysing resource combining, as mentioned above. The members of a project may represent different kinds of resources that may be useful in a project. While a project member can use some of the resources single-handedly, most of the resources of a research project must be combined in order to fulfil the project goals.

In addition, resources may be needed from actors external to the project. This means that there are not only the resources of the different project members that may be combined in a project, but also resources external to the project. The combining of resources, internal and external, appears to be necessary in order to create desirable results from an inter-organisational research project. Resource combining is thereby regarded as an important aspect of inter-organisational research projects.

The combining of resources is connected with making use of already existing resources. Use is thus an aspect related to resource combining. Resource combining is also related to the creation of new resources. Hence, resource combining is related not only to the use of existing resources but also to the development of new resources.

Research projects, in focus for this study, are often characterised by uncertainty, regarding what to be developed as well as how to develop it. Which resources are needed and how they are to be combined may thus be unclear. New combinations of resources often originate from interaction between actors (Håkansson and Snehota, 1995), e.g. between providers and users or among the members of an inter-organisational project. Resource combining based on interaction can yield innovative results – i.e. novel ideas, new solutions, or unique adaptations or improvements.

Recently, several researchers have studied resource development taking place in interaction among various actors within industrial networks (cf. Holmen, 2001; Wedin, 2001; Håkansson and Waluszewski, 2002; Baraldi, 2003; Forbord, 2003; von Corswant, 2003; Gressetvold, 2004; Hjelmgren, 2005). In particular, these studies focus on the empirical settings of interactive product development, process development, and the development and use of new

technologies. The way resources are combined in inter-organisational research projects is thus related to previous studies of technological development, which is discussed in the next section.

1.2 Technological development in collaboration

The importance of collaboration among organisations, including firms, research organisations and other organisations, in technological development has been emphasised in numerous studies. In the “border zone” between different organisations, the conditions for development and innovations seem to be fruitful (Laage-Hellman, 1989; Håkansson, 1990; Powell and Smith-Doerr, 2000). Håkansson and Eriksson (1993, p. 30) explain the innovative conditions found in the interfaces between different organisations:

New knowledge often develops in the interface between different knowledge areas and, furthermore, the meeting of different actors can in itself have an energizing effect on the development process.

Several studies have focused on interactive development processes, for example between suppliers and customers or users (e.g. Rosenberg, 1982; Dwyer et al., 1987; Lundvall, 1988; von Hippel, 1988). Several authors suggest that close interactive buyer-supplier relationships may result in innovative effects, in terms of combining highly specialised resources of the companies involved (Håkansson and Eriksson, 1993; Bidault et al., 1998; Gruner and Homburg, 2000; Wynstra and Pierick, 2000; Nordberg et al., 2003).

Hence, inter-organisational collaboration among different types of actors is important for the development of new products and knowledge. The interfaces between organisations can be described as the ground for research and development activities. However, research and development activities are performed not only in single collaborative relationships but also in networks of companies (DeBresson and Amesse, 1991). Furthermore, according to Powell et al. (1996, p. 119):

A network serves as a locus of innovation because it provides timely access to knowledge and resources that are otherwise unavailable, while also testing internal expertise and learning capabilities.

Both firms and universities perform development and research activities, as separate entities and in collaboration (Rosenberg and Nelson, 1994). Interaction

between the academic world and the industry is argued to be a breeding ground for innovation, in which the role of the universities has been discussed extensively from a policy perspective (cf. Jacobsson, 2002).

Collaboration is argued to be especially evident in sectors with intensive research and development (R&D) (Hagedoorn, 1995). One R&D-intensive sector, in focus for this study, is the biotechnology sector. The biotechnology sector is characterised by collaborative scientific and product development processes (McKelvey et al., 2004; Oliver, 2004).

In a general notion, development processes are seldom linear (Kline and Rosenberg, 1986). It lies in the nature of discovering new things that it is impossible to know in advance what will come out of the process. According to Powell et al. (1996, p. 142): “*Science does not follow an orderly path; it has a nasty habit of spiraling off into multiple, uncharted directions*”. In addition, other authors have pointed to the fact that it can never be completely known beforehand how the development process will turn out (Lundvall, 1988; Tidd et al., 2001; Håkansson and Waluszewski, 2002). Nevertheless, in order to perform technological development activities, they need to be planned, organised and managed somehow. Project organisations are one way to organise development activities.

1.3 Organising in projects

Projects appear to be an increasingly common form of organising. The number of persons involved in project activities is growing and the interest in project organising is increasing as well (Lundin and Midler, 1998; Lundin and Hartman, 2000; Morris and Pinto, 2004). In some industries, projects constitute the main organising form, for example in the construction industry. These sectors, where the main part of the activities is organised in projects, are sometimes referred to as “project-based sectors” and some firms may be characterised as “project-based” (Hobday, 2000). Some authors even talk about a “projectified society” (e.g. Lundin and Söderholm, 1998; Sahlin-Andersson and Söderholm, 2002), which refers to projects pervading the society at various levels.

There are many different types of projects; the number of people involved, the budget, the time, and the fields that projects are used in may vary considerably. Some projects involve scientists from several parts of the world, having budgets of several millions and tailor-made instruments, and spanning over several years. There are also examples of projects involving only one person, who works with the project task during a short time period.

Söderlund (2005) suggests a classification of three different types of projects: first, “business” projects, which are projects that take place in industries where solutions between suppliers and customers are delivered in terms of completed projects, such as construction of new buildings or engineering of roads. Second, “development” projects are projects where the ambition is to develop something new, such as technologies, products, knowledge or processes. Third, “change” projects are projects aiming at accomplishing organisational changes.

In this thesis, the focus is on development projects, i.e. projects aiming at creating something new. Characteristics of development projects are e.g. that they build on integration of knowledge across disciplines and technical solutions (Söderlund, 2005). In the development of new products, processes and knowledge, projects appear to be an important and common form of organising (cf. Engwall, 1995). Companies, universities and research institutes usually organise their research activities and new product development efforts in projects. In particular, inter-organisational projects seem to be an appropriate form of organising for collaboration and networks in research and development (Powell et al., 1996).

A typical focus within the project literature has been on the project as a “lonely phenomenon” (Engwall, 2003). With few exceptions, projects have been studied as isolated entities. One reason may be that some authors have made recommendations that, in order to manage a project successfully; the project should be conducted autonomously with a powerful project manager (e.g. Eisenhardt and Tabirizi, 1995). Others recommend that projects should have loose couplings to their environment in order to allow focus (Lundin and Söderholm, 1995; Hobday, 2000).

In contrast, Sahlin-Andersson and Söderholm (2002) argue that a broader view of projects is needed to further the understanding of how to organise and manage projects. There is a need to go “beyond project management” and understand projects as part of a wider context. Especially for research and development projects, there is a high mutual dependence with the project environment in terms of exchange of resources, information and knowledge (Bengtsson and Ericsson, 2002).

Hence, there seems to be a need for taking a broader perspective on projects and in particular for research and development projects. Not only should the people working in projects benefit from an increased understanding of how projects operate in a context, but also other stakeholders such as the parent organisations may see advantages in a better understanding of how a project interplays with its context. In addition to the benefits from a managerial

perspective, there is a need for conceptualising the context of a project from an academic point of view (cf. Sydow et al., 2004).

In conclusion, several authors argue that projects need to be studied in a context. In this study, accordingly, projects are studied in a context. In particular, inter-organisational research projects are in focus of this study. An inter-organisational project may be, for example, a joint effort between firms, such as suppliers and customers, or university departments working together in a project. Another example, which will be discussed at length in the empirical inquiry of the thesis, is situations wherein firms and university departments are engaged in joint research projects.

Specifically, this thesis focuses on resource combining in resource use and development in the arena of an inter-organisational research project. Hence, the focus is on the resource combining taking place in relation to an inter-organisational research project. By focusing on how resources are combined in inter-organisational research projects, two things may be accomplished. The understanding of resource use and development may be furthered. In addition, it may contribute to expanding the understanding of projects in their contexts and inter-organisational aspects of projects.

1.4 Aim and structure of the thesis

With the background in section 1.1 – 1.3, the aim of the thesis is the following:

The aim of the thesis is to develop an understanding of resource combining in inter-organisational research projects in their contexts.

The structure of the thesis is as follows. Chapter 2 contains the theoretical frame of reference, which presents the theory that underlies the thesis. The chapter consists of four main parts: resource combining, characteristics of projects and project environments, industrial networks, and resource combining in relation to projects. The frame of reference also concludes with the formulation of four research issues.

Chapter 3 includes a discussion of the method that has been used throughout the research process of the thesis. The method chapter describes aspects of using a case study method, such as systematic combining of theory and the empirical material and some methodological issues concerned.

Chapter 4 presents the empirical inquiry of the inter-organisational research project active in the field of plant biotechnology. The chapter starts with a

description of the project members and the project background. This is followed by a description of the four research phases that the project has gone through during 2001 and 2004.

Chapter 5 contains the analysis of the empirical material based on the frame of reference, presented in Chapter 2. In this chapter, the case study is analysed with regard to different categories of resource use and development.

Chapters 6 and 7 analyse the case with regard to how resources are combined within and across the project boundary. Chapter 6 explores how resources are combined towards the project goals and discusses internal processes of a project. Chapter 7 focuses on how resources are combined across the project boundary and therein relates to other research activities in the context. This discussion concerns projects in their contexts in terms of project embeddedness, patterns describing projects' links to their contexts and an evolving context.

In the final chapter of the thesis, Chapter 8, the role of the project boundary is discussed. In this concluding chapter, the functions and effects of project boundaries are explored.

2 Theoretical frame of reference

This chapter presents the theoretical frame of reference of the thesis and four research issues. In order to fulfil the aim of this thesis, analysing resource combining in the setting of inter-organisational research projects in a context, the theoretical framework is built on five related parts.

The first part introduces the phenomenon of interest: the combining of resources. This first part also presents previous studies related to this one. See section 2.1.

The second part concerns projects, which are the empirical arena in which resource use and development are explored. This part (section 2.2) highlights some project characteristics and how projects have been studied in their environments.

The third part focuses on industrial network theory, the theoretical ground of this thesis. This part (section 2.3) introduces the network model and concepts crucial for analysing resources.

The fourth part discusses resource combining in relation to projects seen as embedded in a network context. This part also presents the research issues of the thesis. See section 2.4.

In the fifth part of the frame of reference, section 2.5, the research issues are presented again to provide an overview.

2.1 Resource combining

The aim of this thesis concerns analysing resource combining in inter-organisational research projects in a context. In order to analyse the process of resource combining, earlier studies of development in industrial networks form a vital background. Below, studies of resource development are outlined, followed by a subsection where resource combining, use and development are discussed and related to each other.

2.1.1 RESOURCE DEVELOPMENT

Several studies have investigated technological development and the connections with interaction processes (see Håkansson, 1987; 1989; Laage-Hellman, 1989; Walusewski, 1990; Lundgren, 1991). Based on these empirical studies, five characteristics of technological development are identified (Håkansson et al., 1993). First, technological development is a continuous process, which consists of improvements, ruptures, turn-arounds and changes. It implies that the process of technological development seldom (or never) can be controlled and organised by one actor.

Second, technological development is a process that includes tensions. They may be tensions between the existing and the new, or between different actors with different purposes with a development process, which points to the importance of synchronisation.

Third, not all solutions tried in a process of technological development become realised. At times, a certain solution may be re-used again at a later stage in time; however, such is not always the case. This also emphasises the difficulties in deciding whether something is to be regarded as successful or not.

Fourth, a certain technological development process is closely related to other ongoing processes in the environment. Actors in technological development therefore currently need to engage in political processes in order to influence others in a certain direction.

Fifth, outcomes of technological development processes, e.g. a new solution, depend not only on the solution but also on external factors. For example, other actors may facilitate or hinder the use of a certain solution.

These empirical studies have formed the background to regarding relationships as crucial for technological development and in turn viewing relationships as resources. In addition, they illustrate that resources, such as technologies or solutions, are related to each other. Other resources facilitate the use and development of a certain resource. As a result, resource development in interaction has been investigated in several studies.

The empirical studies reviewed above can thus be seen as a background to focusing on resource development in interaction. According to Håkansson and Waluszewski (2002, p. 14):

Interaction forms development, but is at the same time a part of it. Thus, understanding development involves understanding interaction with which it is so closely intertwined.

Håkansson and Waluszewski (2002) suggest a model for analysing resource development based on four resource entities: two physical in character (products and facilities) and two organisational in character (business relationships and business units). This model is able to capture interaction among the resources, argued to be of importance for understanding resource development. In focusing on resource development in interaction, the interfaces among resources become a central concern. Changes of the resource interfaces have been used as a way to approach resource development (Baraldi, 2003; Hjelmgren, 2005; Jahre et al., 2006). Furthermore, when a resource interacts with other resources, it is given some specific characteristics (Håkansson and Waluszewski, 2002). These characteristics of resources are referred to as features and imprints.

The model of four resource entities for resource development has been used in several different empirical areas and for understanding theoretical aspects of resource development in interaction. The model was developed on the basis of the empirical context of IKEA and the pulp and paper industry, in particular the technological development processes of making paper more environmentally friendly. This study revealed that, for example, some of the actors that became vital in the process were far from central when the process started.

Hence, the model was developed through a study of technological development. There are also other examples of studies of resource development based on this model from the context of technological development. One such example is the analysis of the electricity demands in a network context, which pinpoints how all the four resource entities are needed to explore technological development in an industrial setting (Wedin, 2001). Another example from the setting of technological development concerns the empirical context of the development of electronic chips for user-specific applications (so-called ASICs) (Gressetvold, 2004).

In addition, resource development has been studied in other contexts besides technological development. Supply networks, and the relationships among firms and their suppliers, have been analysed in terms of resource development (Gadde and Håkansson, 2001). Interfaces among resources and the change of interfaces have been explored in the area of logistics (Jahre et al., 2006).

Hence, resource development has been studied in several different empirical contexts and with different foci theoretically related to the development of

resources. Resource development and the use and combining of resources are discussed in the next section.

2.1.2 THE INTERPLAY BETWEEN RESOURCE COMBINING, USE AND DEVELOPMENT

Resource development is related to both the use and combining of resources. The interplay between resource development and resource use has been approached in terms of the view that, while the use of resources is changed, this is considered as resource development (Håkansson and Snehota, 1995; Holmen, 2001). The development and use of resources can occur simultaneously. If a resource or the use of a resource is changed during use, it means that the resource is developed during use. However, resource use and resource development can also be separate processes. A resource may be developed first and used later, or the opposite. Nonetheless, use and development as separate or intertwined processes, use and development influence each other.

The interplay between resource development and resource combining has been investigated by, for example, Skarp (2006). In his study the product development activities of a steel supplier are analysed in terms of combining and recombining of resources. Owing to the small scale of the operations of this supplier, product development is undertaken in two steps. To achieve manufacturing economics, the output of the steel plant is a standardised product. Since potential customers have different requirements on the features of the product, a second step is needed in the development process, where the standardised product is adapted to the context of each customer. In this step, the 'final' product's features are developed through the product's combining with other resources. Some of these resources reside within the customer and supplier firms while others are located in the outside network.

The interplay between resource use and resource combining was the basic issue in a Norwegian study of logistics (Jahre et al., 2006). Contrary to common approaches to logistics, this study departed from the assumption that logistics resources not only impose costs, but also generate value. The value-generation potential of these resources is determined by their use. It is shown in the case studies that, by combining and recombining logistics resources, actors affect the use of resources and thus their value. The authors present a model of 'resourcing' where the use and value of particular logistics resources are related to the actors' systematic combining of resources. Also in this study, resource combining across company boundaries was crucial for the efficient use of logistics resources. In these combining efforts, interaction in business relationships proved to be most important.

In this section the interplay between resource use, development and combining has been explored. In the next section, project organisations – the arena for studying resource combining – are in focus with emphasis on some characteristics of importance for resource combining.

2.2 Characteristics of projects

In this section, projects are the phenomena under scrutiny and some characteristics of projects and their environment are presented. The first section concerns characteristics of projects, emphasising three aspects: (1) projects as temporary, (2) uncertainty in relation to projects and (3) the role of the project goals.

The second section describes projects and their environments. Models describing the environment as consisting of various parts of an organisational context are outlined. In addition, a framework is presented where a project is seen as part of both a time context and an organisational context.

The third section deals with inter-organisational projects and their peculiarities. Inter-organisational projects are argued to be more complex because the project members might have diverse goals with taking part in a project and they might to different degrees take part in other activities besides a certain project. Finally, inter-organisational projects are seen as part of networks.

2.2.1 TEMPORARINESS, UNCERTAINTY AND GOALS

There is a rich variety of projects organised in different fields, such as engineering, construction and public health services. The number of people involved, the budget and the time period of projects may vary greatly as the field in the project is organised.

Therefore, it is difficult to articulate a generic definition of what a project is. Engwall (1998) refers to the problem of making a distinction between project and non-project activities as a (non-reachable) goal of an exact language. Hence, there seem to be no easy answers to what a project is. According to Sahlin-Andersson and Söderholm (2002), a project cannot be distinguished from other forms of organising by one simple criterion, such as technical content or formal structure. Nevertheless, time and project goals stand out as central characteristics of projects in relation to understanding resource use and development. In addition, uncertainty appears to be characteristic, especially for research projects. These three characteristics are described below.

Projects as temporary organisations

A project can be seen as a temporary organisation. Lundin and Söderholm (1995) suggest a theory of the temporary organisation centred on action. Four concepts are used for defining the action-based temporary organisation: time, task, team and transition. The task concerns what is to be accomplished by the temporary organisation, which often motivates the creation of a project. The task is not always completed but may nevertheless be said to represent a main motivation of the organisation. Team means that a temporary organisation is designed by and around people. The relationships between the individuals of the team, and between the team and the environment, are argued to become central for a temporary organisation. The transition concerns the focus on progression because something is to be changed, based on the temporary organisation. Transition is also related to action at the centre of the definition of temporary organisations, which often are set up to accomplish action of some kind.

Time is a most fundamental aspect of a temporary organisation (Lundin and Söderholm, 1995). Temporary organisations are limited in time, and it is often known already from the start when and that a project is planned to end; see Figure 2.1. Projects have a start and a planned ending date. Due to the temporary character, there have been events before the project, and there will be other events after the project is finished in time. Projects can thus be described as finite organisations with a start date and a planned ending date.

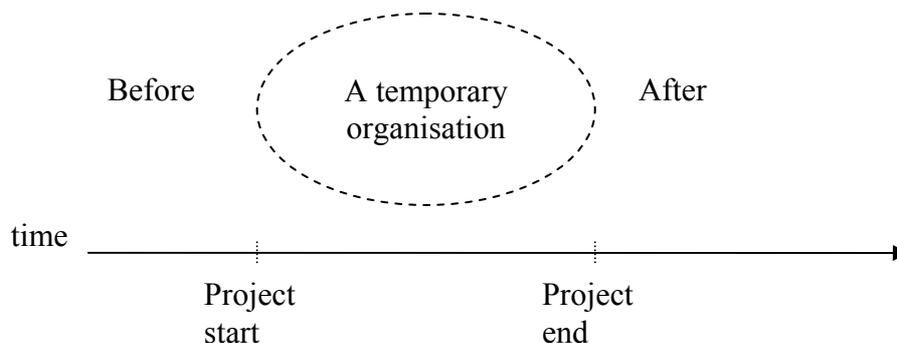


Figure 2.1: A temporary organisation limited in time.

Temporary organisations are often discussed in relation to, and sometimes in contrast to, permanent organisations. According to Sahlin-Andersson and Söderholm (2002, p. 20):

Projects are the primary example of a temporary setting, whereas a traditional and hierarchical functional organisation is the most obvious example of a permanent setting.

The temporary aspect is thus a distinguishing character in comparison to permanent organisations, e.g. companies, which normally are planned to exist for an indefinite period. However, there are examples of temporary organisations or projects lasting longer than permanent organisations. Permanent and temporary organisations have both similarities and differences, which are made use of as a basis for forming a theory of action and learning (Ekstedt et al., 1999). Furthermore, the relationships between the temporary and the permanent are suggested as subtle and multi-layered (Sahlin-Andersson and Söderholm, 2002).

According to Lundin and Söderholm (1995), it becomes natural to think in terms of subsequent phases when time is limited. Hence, for temporary organisations time is not only limited but also linear in terms of passing through a number of phases, referred to as “time-as-a-sequence” or “time-as-phases”. However, in practice the phases are described as overlapping (ibid.) and uncertainty causes difficulties in relation to different phases (Lindkvist and Söderlund, 2002).

Uncertainty, search and discovery

Uncertainty is defined as a state not known or definite, and may refer to a present situation or the future (Gressetvold, 2004). According to Karlsen (1998), most projects experience environments that are complex and dynamic, and therefore result in uncertainty. According to Lundin and Söderholm (1995, p. 452) “*Any project, regardless of the general conditions, is subject to negotiation and is perceived as being uncertain and equivocal.*” Environmental uncertainty of projects is also discussed as “contextual uncertainty” (Christensen and Kreiner, 1997) and it is argued that the uncertainty cannot be reduced enough on the basis of the project goals.

In particular, research and development projects appear to be characterised by uncertainty. It lies in the nature of processes aiming to explain the unknown that it cannot be completely known beforehand what is to come out of such efforts (Powell et al., 1996; Håkansson and Waluszewski, 2002). Uncertainty is thus characteristic for research projects.

Both search and discovery concern exploring the unknown. According to Håkansson and Snehota (1995, p. 141 referring to Kirzner 1992) “*discovery is defined as finding the unexpected, while search is looking for something already identified*”. It means that discoveries contain elements of surprise in

finding the unexpected, while search can be related to searching for known characteristics of a resource or a certain resource. Furthermore, discoveries cannot be deliberately searched for since one does not and cannot know that anything exists to be discovered (Kirzner, 1992).

In research projects, the degree of uncertainty may be high regarding both search and discovery. Lindkvist and Söderlund (2002, p. 284) express the uncertainty regarding search thus:

...while “what” to achieve is typically rather well specified, it is very much up to the team to find out “how” to accomplish this, during the project execution phase.

Hence, there may be uncertainty concerning what resources to combine in order to fulfil the objective of a research activity. One way to reduce uncertainty regarding “how” is through iteration or “trial-and-error” processes (ibid.). Furthermore, Lindkvist and Söderlund (2002) argue that projects, with a well-specified project goal, can be seen as a way of dealing with uncertainty regarding “how”.

In addition, a research project may entail uncertainty regarding potential discoveries which are not at all possible to plan or predict, but need to be pursued and identified by the project members. Despite the uncertainty, the goals of a research project provide direction and function as starting points for resource use and development.

The role of project goals

The task is suggested as one of the concepts in the theory of a temporary organisation, and is also related to the issue of project goals. According to Engwall (2002, p. 263) “*the goal is the core element of every project’s existence*”. Hence, project goals are important elements of projects. However, formulating and working towards project goals are not straightforward. The role of the project goals has been discussed in terms of e.g. difficulties in formulating them in advance and ambiguity (ibid.).

Christensen and Kreiner (1997) argue that project goals seldom can be formulated completely at the start of a project due to uncertainty in terms of limited knowledge, information and an “incomplete world”. Project goals need to be refined and this is often done during a project. According to Christensen and Kreiner (1997) a main function of the project goals is to *motivate* the project members to engage in creating useful, meaningful and relevant results from the project. In addition, Engwall (2002) proposed that a primary function of project goals is to create a project start.

Commonly the results of a project are not what the project was set out to accomplish. However, projects not reaching their goals are not necessarily unproductive projects. It may be that the outcomes are better than what was planned (Lindkvist and Söderlund, 2002). There is also a learning ingredient in the process of formulating project goals. It is not until project execution that project goals become real and filled with meaning. During planning, project goals are rather abstract and difficult to grasp (Engwall, 2002).

There are several different kinds of goals for a project, related to different functions. Visions are described as more long-term and overall, while operationalised goals are broken down and continuously refined during the project. “Latent project goals” are described as a combination of visions and the operationalised goals (Christensen and Kreiner, 1997). In the latent goals, both an overall vision formulated at the project start and the continuously refined project goals become merged.

Although project goals may be difficult to formulate at the project start and therefore are seldom fulfilled in their original version, they play important roles for projects. According to Engwall (2002, p. 275):

The project goals provide direction. It focuses on a preferred state in the future. It redirects attention from other issues to problems and solutions related to the project.

Another role that project goals play is to stimulate the outcomes from a project. When the goals are set high, the results of the project members’ achievements may, according to Christensen and Kreiner (1997), become higher than if the goals were set lower. In accordance with these high project goals, the drawbacks of not fulfilling them need to be limited. Hence, by setting extremely high project goals, more or less impossible to pursue, the results of a project may be more advanced.

To conclude, the role of time as limited and sequential, the issue of uncertainty, and project goals as providing direction for the project are identified as three characteristics of projects of importance for resource combining in inter-organisational research projects.

In the next section, projects are discussed in their environments. Studying projects as embedded in their environment is in accordance with the aim of the thesis. Hence, it will be interesting to look at how other researchers have conceptualised and studied projects in their environments.

2.2.2 PROJECTS AND THEIR ENVIRONMENTS

The need for studying projects with consideration to how they relate to their contexts or environments has been emphasised by several authors (Gilbert, 1983; Kreiner, 1995; Löwendahl, 1995; Christensen and Kreiner, 1997; Blomquist and Packendorff, 1998; Karlsen, 1998; Engwall, 2003; Engwall et al., 2003; Sydow et al., 2004; Maaninen-Olsson, 2004). Lundin and Steinhórsson (2003) also suggest contextualisation of projects or temporal organisations as central, and Söderlund (2004) concludes in his review article that closer attention should be paid to the relationships between projects and their environments. In relation to projects developing new products, processes or knowledge, projects are often dependent on information, resources and knowledge outside the project, and the firm organising the effort (Bengtsson and Ericsson, 2002). This implies that the environment is vital for research projects, as this thesis concerns.

A main argument for why projects should be considered as embedded in their environments is that projects are temporary organisations. Sydow et al. (2004) argue that projects as temporary systems are likely to be embedded in more permanent contexts on various levels. It is important to acknowledge this contextual embeddedness of the temporary in the permanent, since projects use resources, routines and rules from the permanent structures. Placing a project in an organisational or corporate context indicates a willingness to acknowledge that “*projects are embedded in wider structures and processes*” (Sahlin-Andersson and Söderholm 2002, p. 18). Projects’ embeddedness in the societal context may be seen as a way of understanding how projects contribute to organisational and societal changes.

One effect of viewing projects as embedded in their environments concerns the project goals, discussed above. While a project is embedded, the project goals are likely also to be embedded in a context. Hence, the project goals are formulated as part of a wider context. Furthermore, projects as characterised by uncertainty are also part of an environment. Staber (2004) argues that organisations cannot protect themselves from the uncertainty of the environments. Instead, projects need to absorb external uncertainty to survive.

Concluding from the above, inter-organisational research projects are to be studied in a context. In the next section, different ways of conceptualising the project environment are discussed.

Project environments on several levels

Some authors propose models of the project environment that consist of several levels. Some models build on two levels, while some models suggested build on more than two.

Gilbert (1983) defines the project as part of an immediate and an outer project environment, as illustrated in Figure 2.2. The immediate environment consists of clients, other internal departments of the parent organisation, subcontractors and external contractors. In addition, the immediate environment consists of the local community, national government and its agencies. The outer environment represents the international economic and political environment in which the project exists.

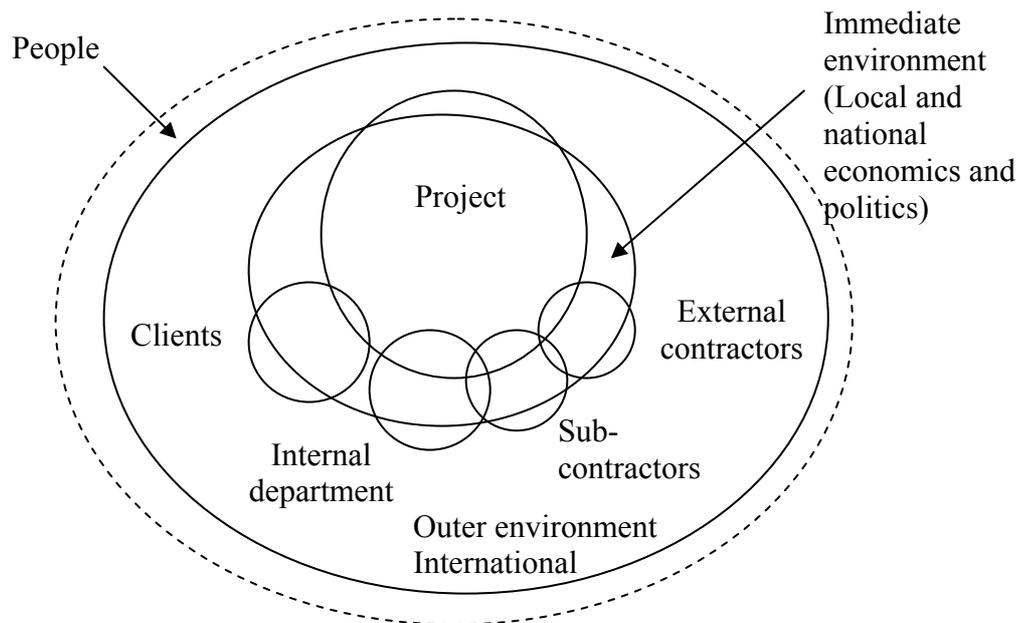


Figure 2.2: A project in its environment (Gilbert 1983, p. 84).

According to Gilbert (1983, p. 84), “...the [project] environment consists of people inside as well as outside the project; individuals and groups with their own opinions and motivation”. It is thus emphasised that there are people both within the project and in the environment. All people involved in a project need to be aware of what is going on in a project and why. Gilbert (1983) also stresses the issue of uncertainty for projects in terms of the environment being complex and changing. Hence, by having project members that know what goes on in the project and why, the project members can interpret requirements better, adapt to changes and be alert to unacceptable trends.

Karlsen (1998) makes a similar categorisation of project environments in terms of (1) a task environment and (2) a general environment. Karlsen (1998) refers to organisation theory and Thompson (1967), who made a distinction between task environment and residual environment in relation to organisations. In the project’s task environment, actors are included that have a direct influence on the project, such as actors that provide the project with resources and those that expect results from a project. The following groups can, according to Karlsen

(1998), be categorised as the task environment of a project: customers, suppliers, public, finance and insurance, control and certificate authorities, users, consultants, press and media, basis organisations, and interest groups.

Furthermore, Karlsen and Pedersen (1998) stress that the suppliers of a project are important actors of the project environment to be taken into account. The supply of goods and services is often a source of uncertainty in projects. Working more closely with the suppliers may thus reduce some of the uncertainty caused by the environment (*ibid.*).

The general environment of a project consists of the following aspects (Karlsen, 1998): technological factors, e.g. access to technology, physical factors such as climate or buildings, economic, labour market, political, environmental and cultural factors.

Sydow et al. (2004, p. 1478) suggest a model of the environment of a project that builds on four levels, which they argue should be considered when analysing project-based organisations. The four levels are the organisational unit, the entire organisation, the network level and the field level. First, the organisational-unit level refers to what department or division the project is carried out at. It matters a lot what kind of unit the project is embedded in. Second, the level of the entire organisation is likely to be an important context of projects. It will have an impact whether a project is part of an organisation that almost manages all its activities as projects or whether projects are seen as exceptions. One important aspect, from both the organisation's and the project's perspective, is the coupling and the decoupling of a project. A close coupling between the project and the organisation may result in learning between the two. Third, the level of networks: there may be different types of networks, e.g. strategic networks, that provide an important context to projects. For example, in some industries inter-organisational networking is more common than in others. Fourth, the level of organisational fields might be strong in some industries. For instance, clusters may provide a context for some projects.

Above, models for analysing the project environment have been outlined, which propose different levels of the context. Another vital part of projects' environments is the parent organisation, which is discussed below.

The parent organisation

Many projects have at least one parent organisation, that is, the organisational unit, department, or division that administrates and runs the project. Often a project manager reports to the parent organisation and, in turn, the parent organisation provides the project with resources. Both the parent organisation

and the relationship between the project and the parent organisation are important parts of a project's environment.

The nature of the relationship between a project and its parent organisation(s) is referred to by Löwendahl (1995) as "the degree of project embeddedness". Based on a case study of the winter Olympics game in Lillehammer, Löwendahl (1995) concludes that the lack of a parent organisation, referred to as a "none degree of embeddedness", provides special challenges for project management. A project without a parent organisation has a high degree of freedom regarding, for example, defining tasks, recruiting people and organising the work. On the other hand, the drawbacks are lack of routines, procedures and standards. In addition, the credibility of being part of a parent organisation is missing.

Organisations often run and initiate several projects in parallel, or over time. Organisations running several projects drawing on the same resource pool are referred to as "multi-project environments". Eskerod (1998) focuses on multi-project settings and analyses how the organisational units which run their activities in projects, mainly product development departments, handle resource allocation issues. It is concluded that the human resource allocation is seen as a negotiation process among the different actors of a company. In "traditional" project management theory, resource allocation is seen as a scheduling task. However, a negotiation process is a better way of understanding human allocation processes (*ibid.*). In a similar vein, it has been argued that competition and battles for resources among projects are common characteristics of a multi-project environment (*cf.* Eskerod, 1996; Engwall and Jerbrant, 2003).

There is not only competition among projects in a multi-project setting, but also opportunity for learning between projects. The need for learning between projects has been highlighted by Björkegren (1999), in a study of knowledge transfer among projects and the organisation in which they are performed. Björkegren (1999) expands the project as a unit of analysis in time to include other projects and the parent organisation. Furthermore, obstacles to knowledge transfer between projects have also been pinpointed (Lindkvist, 2001).

So far, different models of the project environment have been presented. However, the project environment may also change during a project, which is related to the discussion above about uncertainty as a characteristic of projects. Below, project environments are discussed as drifting.

Drifting project environments

According to Christensen and Kreiner (1997), the surrounding world of companies and projects is changing and “incomplete”. The incomplete world has an impact on the conditions of a project, for example in terms of the goal formulation, which was argued to be difficult or impossible to pursue in a comprehensive manner in the beginning of a project. Hence, the context of a project is characterised by dynamics.

Thus, most companies’ and projects’ reality is argued to involve drifting environments (Kreiner, 1995, p 338) and “*a drift manifests itself relative to the projected environmental conditions, on the premise of which the project was originally designed and planned*”. Hence, a drift manifests itself relative to the conditions at the outset of a project. The environment is coloured by uncertainty, in terms of fast and unpredictable drifts or changes. The changes may concern market, technology and qualifications, values and attitudes among co-workers. The consequences of a certain action are a result of an interaction process between the project and its environment, and consequently are difficult to predict. The project reacts and positions itself in relation to its environment and vice versa. It is complicated to predict the outcomes of such interactive processes due to the uncertainty regarding other actors’ reactions.

Staber (2004) identifies “boundary-spanning networking” in the area of web design, a sector characterised by technical skills that quickly go out of date, uncertain employment, and project workers concerned about getting access to and maintaining the latest information about the market. According to Staber (2004), the project workers are involved in boundary-spanning activities that seem to build on personal networks to create opportunities for learning and obtaining new knowledge in an uncertain environment.

Others also discuss external networking by project members. Kreiner and Schultz (1993) suggest, based on a study of the Danish biotech sector, that networking seems to be vital for getting access to the latest information on the research frontier. Kreiner and Schultz (1993) concluded that information sharing through informal networking was one important factor for getting access to the latest research and being up to date with the biotech community. In other words, gossiping was concluded to be a crucial way of getting access to information and therein being part of a drifting environment. The Danish biotech sector was concluded to be a “barter economy” characterised by the fact that researchers in the industry and academia exchanged favours and services with limited monetary exchange. That is, they helped each other out by e.g. doing experiments. On some occasions, the informal networking between the university and the industry was developed into collaboration and formalised

projects. Hence, the informal networking as a way of acting in a drifting environment may be seen as a first step towards building collaborative efforts.

To conclude, models for analysing the project environment have been outlined, and the project environment is described as drifting. However, recapitulating one of the characteristics of projects discussed above, projects were described as temporary in character, i.e. they are limited in time. This means that an appropriate way of understanding the environments of projects is in terms of time and an organisational context.

2.2.3 A PROJECT IN TIME AND SPACE

Engwall (2003) defines the context of a project to have two dimensions: “time” and “space”. The time context and the organisational context are supplementary ways of expanding the context of a project.

Extending the scope around a project in these two dimensions has implications for research about projects and emphasises aspects to be regarded as characteristics of projects. By extending the time frame, important events explaining the occurrence of some events in a project may be included; for example, there may have been similar projects taking place just before the project in focus, or the project manager may have been involved in another project previously and therefore may get support based on previous achievements. In addition, ideas of how the output of a project may be used can influence the project. One implication of such extension of the time frame lies in including the “*input* in a project in the analysis” (Engwall, 2003, p. 803, emphasis in original). It means taking the resources available at the project start, e.g. personal experience from previous projects and existing technological solutions, into account. A second implication lies in analysing the *output* of a project, for example in terms of ideas of how the results of a project are planned to be used after the project is completed.

By extending the organisational scope of a project beyond the individual project, the activities in a project can be analysed in relation to other project and non-project activities that are ongoing simultaneously. In addition, the project activities may be analysed in relation to the parent organisation and the institutional¹ structures of an organisational environment (Engwall, 2003). Thus, a third implication for research is how a project is dependent on the progress of other simultaneous projects in the environment, e.g. in terms of technical problems in another project causing delay. A fourth implication lies in studying the project in relation to the parent organisation, specifically the

¹ The institutional environment includes factors such the norms and values of the environment (Powell and DiMaggio, 1991).

role and the function connecting the project and the parent organisation. For example, the timing of a project in relation to the parent organisation's other activities may be decisive. The fifth implication concerns how the project fits with the norms and values of the environment. For instance, if a project fits well into the surrounding norms it may facilitate the project execution.

These five implications of seeing a project as part of the context in both time and space are summarised in a framework (ibid., pp. 804-5); see Figure 2.3. The framework thus points to central characteristics of projects, seen in the context of time and space.

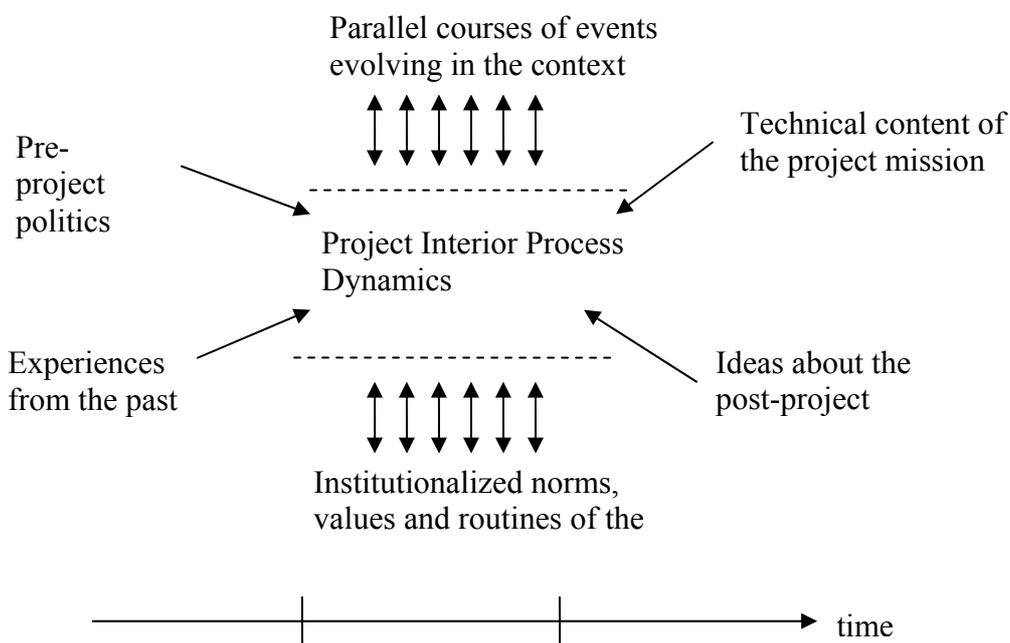


Figure 2.3: Framework for interior process dynamics of a project (Engwall, 2003, p. 805).

The framework emphasises the importance of events occurring outside the project and parent organisation in the factor “Parallel courses of events evolving in the context”. In this factor, the parallel activities and simultaneous projects of the parent organisation are included, as mentioned above, but also other projects and non-project activities taking place outside the parent organisation.

Extending the time frame is done by going backwards in time and including the history. In the framework, this is done in the dimensions “pre-project politics” and “experiences from the past”. The time frame is also expanded forward to include events taking place after the project closure, in terms of the dimensions “technical content of the project mission” and “ideas of the post-project”.

future”. Both these dimensions, regarding extension of the time frame forward, influence the project interior dynamics due to the plans.

The institutional factors are emphasised in the dimension “institutionalized norms, values and routines of the context”. This factor surrounding the project can stem either from the parent organisation or from outside the parent organisation.

Hence, projects have not only an environment in terms of an organisational context but also a history and a future that may influence the occurrences of a project. This framework proposed by Engwall (2003) will serve as an important starting point for analysing inter-organisational projects in a context, in terms of including both a time context and an organisational context.

In the subsequent section, inter-organisational projects are looked at in more detail, which will be of relevance since inter-organisational research projects are in focus in this thesis.

2.2.4 INTER-ORGANISATIONAL PROJECTS

An inter-organisational project has, in contrast to an intra-organisational one, project members from (at least two) different parent organisations; see Figure 2.4. Each project member may consist of one or several people representing the respective parent organisations. The project members and the resources devoted to the project from each parent organisation thus make up an inter-organisational project.

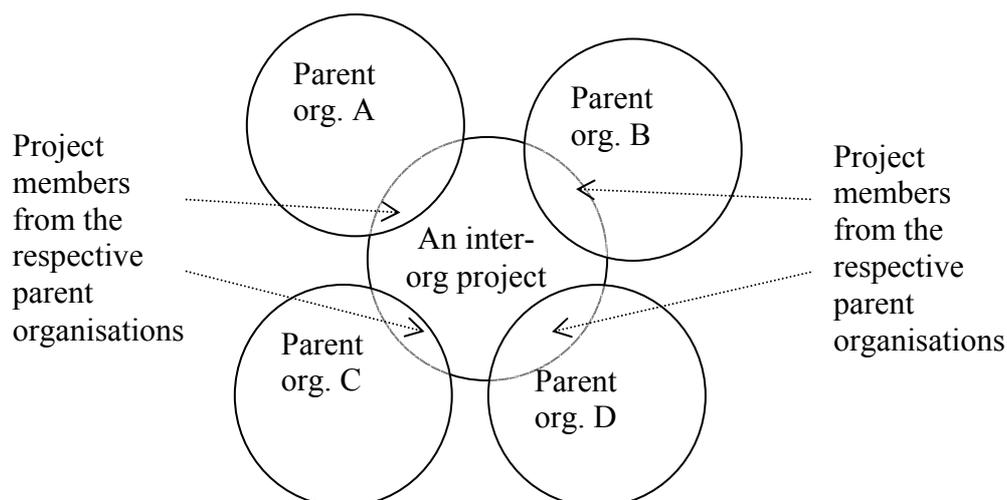


Figure 2.4: An inter-organisational project.

An inter-organisational project may, for example, be a joint effort between firms, such as suppliers and customers, or university departments working together in a project. Another example, which will be discussed at length in the empirical inquiry of the thesis, is that of a firm, a co-operative, and university departments engaged in a joint research project.

The members of an inter-organisational project may have various reasons to be involved in a project and they are not only motivated by a common project goal. In inter-organisational projects there may be an array of goals, partly supporting and partly conflicting (Hellgren and Stjernberg, 1995). Hence, each of the participating parent organisations might have its own purposes or backgrounds of participating in a certain project, which can come to light in different priorities, investments or focus.

The project members of an inter-organisational project may be involved not only in one single project, but in several projects at the same time. In projects where the members come from different parent organisations, the complexity is likely to become high with regard to project members' other involvements. For example, one of the project members may be totally devoted to a certain project while the other members have other activities that they need to prioritise. This may also be the case for intra-organisational projects; however, the impact is likely to be manageable if the project is run within a single parent organisation. Below, project members' potential involvement in several projects is discussed on the basis that it is an issue of particular importance in inter-organisational projects.

Project members' involvement in several projects

The individual project members may be involved in several projects. Weick (1979, p. 95) discusses how people are engaged in several groups at the same time and refers to this as "partial inclusion". Partial inclusion means that: "*A person does not invest all behaviour in a single group; commitments and interlockings are dispersed among several groups*".

Returning to the members of projects, they may be involved in several projects or non-project activities at the same time. Blomquist and Packendorff (1998, p. 38) refer to this phenomenon of people being involved in several projects as "embedded projects". In embedded projects "*most team members have positions in the surrounding permanent structure and they also refer to that structure in terms of social/cultural belonging and career path*". The degree of project embeddedness varies among projects, from having members fully appointed to the project task to project members working full-time in the organisation. The more embedded a project is, the harder it will be to distinguish the project organisation from its surrounding permanent structure.

Project embeddedness according to Blomquist and Packendorff (1998) can thus have both positive and negative impacts. The impacts could be positive in terms of the project members finding similarities between projects and being aware of what else is going on in other projects, or negative in terms of the project members experiencing a low degree of commitment to each project.

From Weick's (1979) point of view, partial inclusion is a phenomenon that always is current since a person always has several roles or positions, for example in private life and in a career. In contrast, Blomquist and Packendorff (1998) stress that for one project member the case may be that the project member is embedded in several projects, while some project members are fully dedicated to one project. Another difference between partial inclusion and project embeddedness is the purpose with the two related concepts. Weick (1979) presented partial inclusion for the purpose of explaining group development and collective behaviour, while Blomquist and Packendorff (1998) aim for understanding projects and learning in projects.

Hence, in inter-organisational projects the complexity with regard to project members' different involvements besides a certain project can become high. This needs to be handled in some way or at least a solution needs to be found in order to satisfy all the members. Furthermore, inter-organisational projects have different features and are used in many areas. This is discussed below.

Features of inter-organisational projects

Inter-organisational projects appear to be a common organising form in several fields (cf. Söderlund, 2004). One area where inter-organisational projects are used frequently, strongly related to the topic of this thesis, is development, often performed in collaboration or in networks (cf. Powell et al., 1996). The motives for starting inter-organisational projects might be getting access to information and resources not being accessible elsewhere. According to Pinto and Nedovic-Budic (2002), information sharing is an important argument for engaging in inter-organisational projects. In addition, there is a potential for knowledge creation based on joining complementary knowledge bases. There is also a risk dimension of sharing resources with counterparts some of which never have been worked with before. In addition, there are risks due to the lack of control over knowledge, resources and information in relation to the risk of opportunistic behaviour of the counterparts. Both the risks and the motives for engaging in inter-organisational projects are similar to starting inter-organisational collaborations.

Bengtsson and Ericsson (2002, p. 82) study inter-organisational innovation projects and they argue that: *“An innovation project must be linked to its context and such links develop if there is a flow of information, knowledge, and*

physical resources into and out of the project and context.” This flow between the project and the context can be characterised by “leakiness” and “stickiness”. A project requires an easy flow of knowledge and resources into the project, so-called positive leakiness. On the other hand, an innovation project also needs to prevent itself from leakiness of undesired information and resources, so-called negative leakiness out of the project. Stickiness is the opposite of leakiness and refers to “*mechanisms that hinder the flow*” (ibid., p. 82). Stickiness is important in order to protect ideas from spreading to competitors, that is, positive stickiness. If the stickiness hinders the flow among partners, this is regarded as negative stickiness.

Many studies of projects and especially inter-organisational projects are based on the construction industry. Inter-organisational projects hold both formal and informal elements with regard to decision-making processes (Kadefors, 1997), and the project constellations are re-composed for every project based on the principle of competitive bidding. This means that there is little room for inter-firm relationships to develop and for the parties to learn or adapt to each other, since the contractors are working with new counterparts in almost every project (Dubois and Gadde, 2000). This is regarded a problem for industry as a whole, and national councils have initiated programs to promote inter-firm collaborations (Holmen and Pedersen, 2001). The construction industry is in some aspects unique; still, it is relevant to look at the use of inter-organisational projects in the construction industry.

Inter-organisational projects as part of networks

Inter-organisational projects have been described as “project networks”. Hellgren and Stjernberg (1995) discuss the concept “project network” in their studies of the construction industry and the building of shopping malls, and in particular regarding the two phases of designing and implementing.

The concept “project network” has also been used in other sectors besides the construction industry. Staber (2004, p. 31) argues that a project organisation is “*best thought of as a project network. Projects are normally produced through a dynamic network of transactions involving specialised firms, sub-contractors and freelancers*”. “Project networks”, as project-based dynamic inter-organisational and inter-personal relations, are also identified in the German TV movie industry (Manning, 2005).

Inter-organisational projects can thus be seen as temporary “project networks”. Dubois and Gadde (2000) argue that a temporary network is part of a larger network structure where the temporary and the permanent networks are two “network layers”. In other words, an inter-organisational project may be seen as a “*network within the network*” (ibid., p. 212). The network within the network

refers to the fact that a project organisation formed to perform a certain task is part of a permanent network.

Dubois and Gadde (2000) suggest a framework to be able to capture the different network layers and the coordination dimensions of the networks within networks in the construction industry; see Figure 2.5. This framework was developed for analysing activity coordination, which is not the focus of this thesis. Still, the illustration is used below as a point of departure for discussing resources and an inter-organisational project in a context.

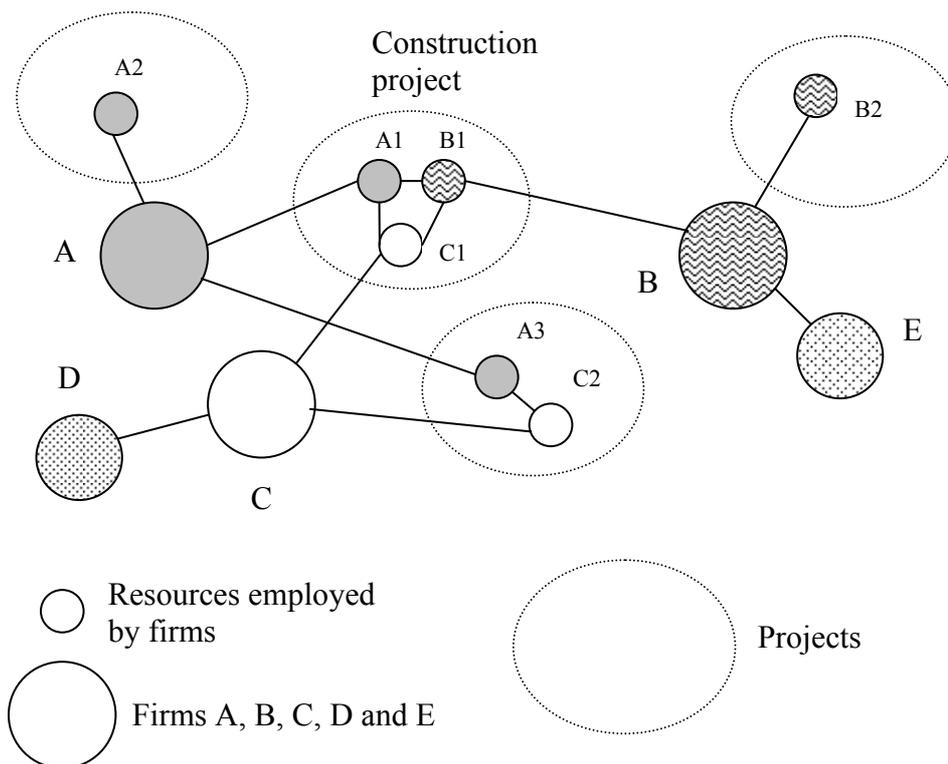


Figure 2.5: A construction project in its context (Dubois and Gadde 2000, p. 212).

Firms A, B and C are involved in a construction project together and can be regarded as parent organisations of this specific project. The parent organisations provide the project with resources (A1, B1 and C1), such as people and equipment. The people with whom they provide the project can be regarded as project members. Within the project, the resources from the parent organisations respectively will be combined in order to fulfil the project goals. This makes the members of the project, and their resources, inter-dependent and brings interaction among them to the fore.

In parallel to this project, the three firms (A, B and C) are involved in other projects, regarded as the context of this specific project. The parent

organisations thus provide other projects with resources as well; in some of these projects the constellation of parent organisations may be similar to the one in this project. However, it is as likely that there will be other constellations of project organisations in the other projects, which make learning and developing routines across projects difficult. There are also third parties in relation to the project, e.g. suppliers to the parent organisations.

From the above discussion it follows that resource combining in relation to inter-organisational projects is not a straightforward or easy task. There are several parent organisations involved in the project contributing their resources, which need to fit with resources of the other involved parties. In parallel, their resources are used in other projects. The complexity with regard to resource combining is likely to become high. The framework required for this study therefore must be able to capture and handle this complexity. In the next section, the industrial network theory is described as a suitable tool for the analysis of resource combining in inter-organisational projects.

2.3 Industrial network theory

This section presents the Industrial Network Approach, also referred to as the Industrial Marketing and Purchasing (IMP) tradition. The section starts by describing the network model, consisting of activities, resources and actors. This is followed by a focus on the resource dimension, and some aspects of resources of significance for resource combining. The third part discusses interaction, a vital aspect for the combining of resources, while the final part regards the role of embeddedness, where a project is seen as embedded in a network context.

2.3.1 THE NETWORK MODEL

One of the basic assumptions in the Industrial Network Approach is that the industrial reality² includes relationships among organisations, and connections between these relationships, which form network-like structures (Axelsson and Easton, 1992). Thus, what happens in one relationship between two parties affects and is affected by what happens in another, due to inter-connectedness.

² One of the starting points for the IMP tradition was that *industrial markets* were concluded to be characterised by long-term exchange relationships between firms (cf. Håkansson, 1982), which formed network-like structures. The industrial reality referred to is thus industrial markets, i.e. business-to-business markets. The actors in markets are mainly firms, which strive for surviving and making profits. However, in these network-like structures there are also other types of actors, such as university departments and co-operatives, which engage in other types of activities besides buyer-seller relationships, e.g. research projects.

One model for describing and analysing the network-like structure is the network model based on activities, resources and actors, referred to as the ARA model (Håkansson, 1987). See Figure 2.6. The definition of activities, resources and actors is circular: “Those who perform activities and/or control resources within a certain field are defined as actors” (ibid., p. 14).

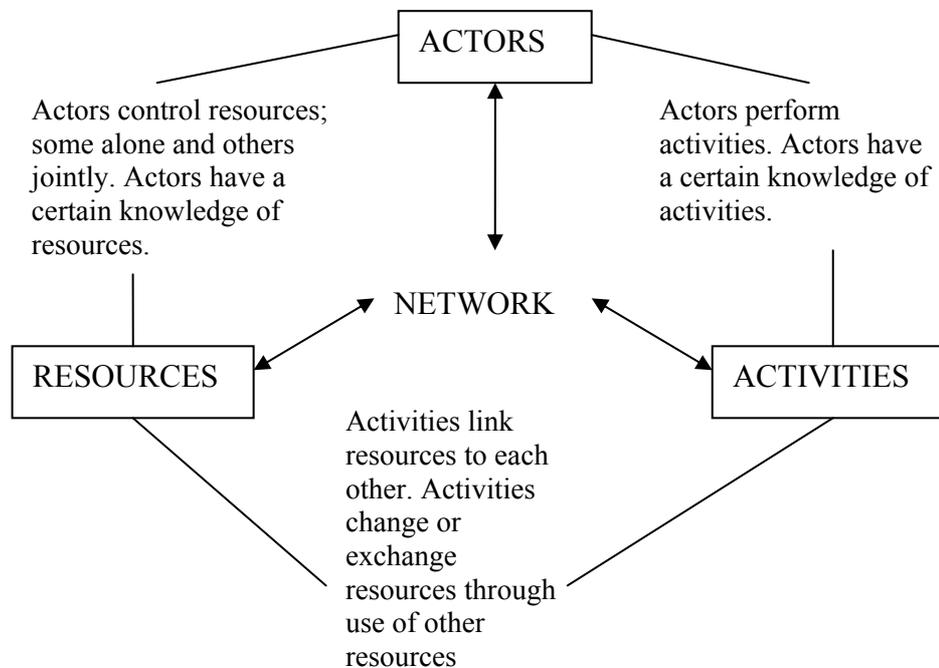


Figure 2.6: The network model (Håkansson, 1987, p. 17).

Resources may consist of physical, financial and human assets (ibid.). In addition, knowledge and experience of resources are important in order to use and develop resources. The resource dimension is discussed further below (see section 2.3.2).

There are two main types of activities: transformation and transaction activities. Transformation activities refer to activities where one resource is improved, based on the use of other resources, while transaction activities link transformation activities to each other. Activities are performed within firms but may be adapted to how other firms perform their activities. Hence, activities are interrelated across firm boundaries (cf. Dubois, 1994).

The actors are those that act in industrial networks, and may be companies or individuals. “Companies or individuals as actors in business networks are bounded in their perceptions, knowledge and capabilities and therefore different from each other.” (Håkansson and Snehota, 1995, p. 192) An actor is thus defined as having ascribed motives and intentions and is able to behave purposefully. Furthermore, actors are “goal-oriented”; their general ends are to

increase control of resources and thereby increase autonomy (Holmen, 2001). In turn, the increase in control may be used for achieving other ends. Closely related to the actor concept is identity, central for an actor and for how others perceive an actor (Håkansson and Snehota, 1995).

One of the basic assumptions of the ARA model is that its three components are interdependent. Therefore, although one dimension may be in focus, the other two dimensions are explicit or implicit parts of the network. In this thesis, resource use and development are in the centre; thereby, the resource dimension is in focus in the subsequent section.

2.3.2 THE RESOURCE DIMENSION IN FOCUS

Resources are and have been in focus for a long time in several research traditions in the fields of business and economics. The definitions of resources vary from one research tradition to another. In the Industrial Network Approach, resources are assumed as heterogeneous, which is explored below.

Resource heterogeneity

In the Industrial Network Approach, resources are viewed in the perspective of the assumption of resource heterogeneity, building on Penrose (1959), who aimed at understanding the growth of firms. Penrose (1959) argued that the value of resources is dependent on the services they can render, and that every resource consists of a bundle of potential services. Viewing resources as heterogeneous is in contrast to considering resources as homogeneous, which implies a fixed value of a certain resource. The heterogeneity assumption also draws on Alchian and Demsetz's (1972) theory of teams, which states that a team is more than the sum of its parts.

The value of a resource is thus not a given. Instead, the heterogeneity assumption implies that the value of a resource depends on how the resource is used or related to other resources. In general, what makes an element a resource is that it has a known or potential use value to someone (Håkansson and Snehota, 1995; Holmen, 2001). An element thus needs to have a *known or potential use* in order to be defined as a resource, and the resource value depends on how the resource is combined with other resources.

One effect of viewing resources as heterogeneous is that knowledge about resources and how resources may be combined with other resources becomes important. Increased knowledge about resources and their combination potential can be regarded as learning (Håkansson and Snehota, 1995; Gressetvold, 2004). Another effect of the assumption of heterogeneity is that the resources an organisation has access to needs to be combined with other

companies' resources in order to create value. This is discussed below in terms of organisations' resource collections and constellation.

Resource collections and the resource constellation

The resources a firm has access to and uses are referred to as the individual organisation's resource collection (Håkansson and Snehota, 1995). The resource collection of a firm consists of the resources the firm owns, for example production equipment, plants and routines. The resource collection also consists of the personnel of a company, i.e. the skills and knowledge within the staff. In more general terms a resource collection consists of resources that a firm controls and influences and thereby can use (Holmen, 2001). Hence, the resources of a resource collection are not necessarily owned or controlled internally but can also be accessed externally. These external resources may, for instance, be accessed through relationships with other actors. As a consequence, trust becomes an important issue in relation to accessing and mobilising resources from other actors.

Both internal and external resources are thus part of a resource collection of a company. Some of the resources of a resource collection are also part of other organisations' resource collections, which together form the resource constellation of the network. The resource constellation spans over several organisational units (Håkansson and Snehota, 1995)³ and consists of connected resources of different resource collections.

Based on the heterogeneity assumption, the combining of resources within a resource collection becomes a central issue for the use and development of resources. However, the combining of internal and external resources of a collection is important but not sufficient for making the most out of resources. The resources also need to be combined and related to the resources of other actors, i.e. the resource constellation of the network. In an inter-organisational project, the members access resources from their resource collections respectively, which need to be combined in various ways in order to come up with novel outcomes of the project.

The possibilities to use and develop resources depend on the variety of resources. Håkansson and Waluszewski (2002) discuss resource variety, which refers to how unique a resource is in relation to other resources and its possibilities to be combined with other resources. A variety of resources with

³ "Resource ties" refer to how resources of two parties are connected in a relationship. While resource ties develop, the resource constellation emerges (Håkansson and Snehota, 1995). In this study, business relationships are not in focus, and therefore the concept of resource ties is excluded from the discussion.

regard to both the resource collections and the constellation appears to be central for resource combining.

The role of the existing resources and the issue of change

Bengtson (2003) studies technological development in a context, and in particular the re-introduction of a certain resource in the construction industry. In this study, the role of the “established” resource constellation is emphasised. It is concluded that in the use of a new resource, adapting and thereby building on the established resources is significant.

In a similar vein, Håkansson and Waluszewski (2002) identify “heaviness” in resource structures. Heaviness refers to that the existing resource structures may be characterised by “friction” and thereby be difficult to change. Heavy resource structures may have a long history, with a number of adaptations and investments made. Changing these resource structures can be difficult, not to say impossible, due to interdependencies among the resources and/or resistance of the actors controlling the resources. Hence, when a new resource is to be used, the existing or the established resource structure forms an important starting point.

From the discussion above, it can be concluded that regarding the use of a new resource in an existing resource constellation, adapting what has been established is crucial but may be difficult due to friction. However, the existing resources may be vital not only in the use or integration of a new resource in an established structure, but also for resource combining in inter-organisational projects. Returning to the resource collections discussed above, the existing resources of a resource collection, i.e. the resources that an organisational unit accesses, are significant for resource use and development. As pointed out earlier, increased knowledge about resources or the combining of resources is seen as learning. Learning about the existing resource collections’ potential combinations might become necessary in order to achieve a certain sub-goal in a project.

In addition, this enhanced knowledge can result in the use of a resource changing over time and in the recombining of resources. Hence, based on using or developing resources, the collections of which the resource is part may change. Although several authors point to the significance of the existing resources, some also point out the dynamic issues of resource constellations. According to Jahre et al. (2006, p. 43), the “...*combining and recombining with other resources in a network context brings dynamics to the forefront*”. Bengtson (2003) argues that it may be necessary to adapt the established constellation to make use of a new resource. The established resource constellation must change in order to allow resources to be combined in new

ways. This could also be described as an attempt to find and use additional combinations of the already established resources, which relates to variety of resources.

Hence, the resource collections are important as starting points for resource combining. In addition, the resource collections may change over time due to an increased knowledge of resources, and the combining and recombining of resources. This is also in line with Holmen (2001), who discusses the use of a new resource in relation to an existing resource structure. She pinpoints the need for building on the existing resources but also changing some aspects regarding their use.

Holmen (2001) identifies four principal ways in which single resources may be combined. These are: (1) existing resources used in existing combination and use routines. This points to the fact that the resources' embeddedness in the resource collection and the constellation is preserved. In other words, this principle emphasises the importance of the existing resources.

(2) Existing resources used in new combination and use routines refer to how the existing resources are used in new ways. Firms may use resources in new ways but at the same time build on the existing resources in terms of investments already made.

(3) Existing resources which are modified. A firm may be interested in modifying some of the existing resources, and when modified they become used in new combination and use routines. By modifying the existing, a firm builds on the existing resources but is also open to change.

(4) Resources that are new to the user. This principle refers to acquisition of new resources, which may be either totally new or new to the user and thus existing resources from another firm's perspective.

Hence, the role of what already exists is emphasised but also the crucial aspect of change in terms of using the existing resources in new ways, or modifying and thereby building upon or adding to the existing. As shown above, combining of resources is an interactive effort. Therefore, the role of interaction is discussed in the next section.

2.3.3 THE ROLE OF INTERACTION

Interaction has been touched upon above as a central aspect of the industrial network theory in general, and resource development in particular, but not explicitly discussed so far. Interaction among firms has been one of the cornerstones of the Industrial Network Approach since the Interaction

Approach was outlined as a model for analysing customer-supplier relationships (Håkansson, 1982). A certain interaction episode may be seen as the smallest unit of analysis of a network. Interaction episodes may be complex or simple, and based on no previous relationship or on a well-established relationship (Gadde and Håkansson, 1993). Interaction episodes over time thus build up business relationships, which in turn impact on the interaction episodes. Furthermore, several interaction episodes form relationships that become connected into networks.

A model is suggested where the interaction process is seen in the perspective of two contexts (Jahre et al., 2006). See Figure 2.7. The first context concerns the current situation of a particular interaction episode, referring to the fact that interaction is always influenced by what happens in the present. The two parties involved in interaction are at a certain point in time concerned with particular issues, e.g. solving problems or working with technical issues. In the current situation, the two parties may also to various degrees be involved in other interaction episodes with other counterparts respectively.

The second context concerns time, not only during the ongoing episode but also in terms of an extended time context. The second context contains the history, in terms of the parties' memories of previous episodes, and the plans for the future in terms of expectations about future interaction. A particular interaction episode thus connects past and future episodes.

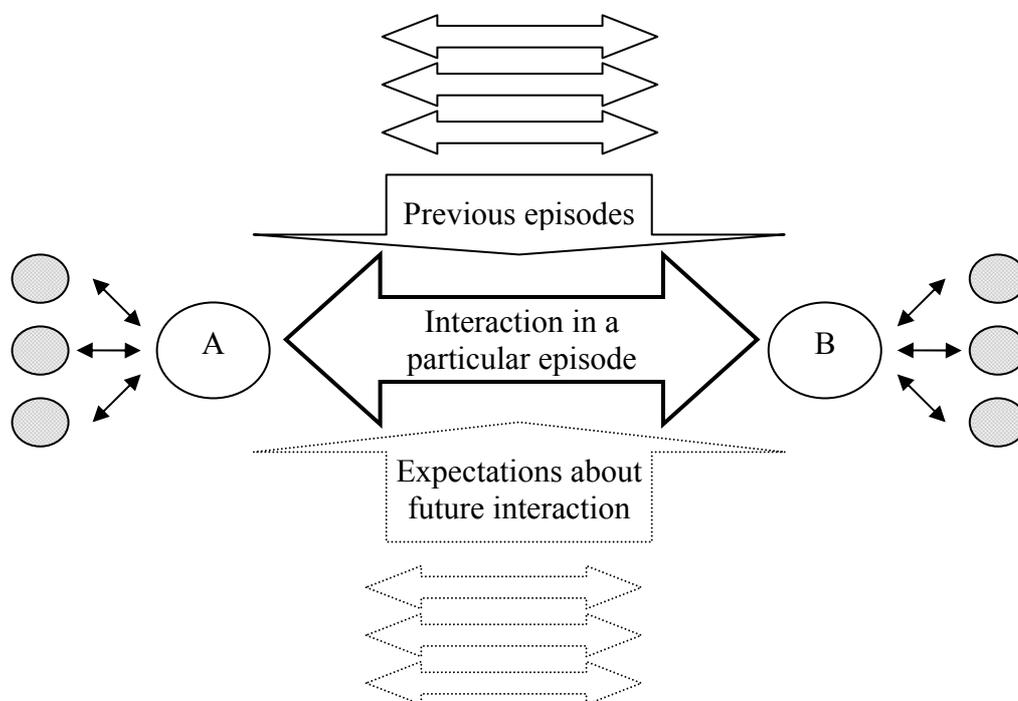


Figure 2.7: Factors determining the interaction in a particular episode (Jahre et al., 2006, p. 52).

Interaction is thus related to what happens outside a particular interaction episode in the current situation. Interaction is also related to time in terms of the parties having a history of previous episodes, a planned future and expectations about the future. Each interaction episode may thus be seen in the context of the current situation and in the context of history and expectations for the future. It is to be noted that this model builds on the same logic as the framework proposed by Engwall (2003), in which a project was regarded in terms of time and space. The model where an interaction episode is seen in the light of a two-dimensional context is developed in the network tradition; therefore this model will be used for widening the scope around the focal project.

Returning to the resource combining in an inter-organisational project, interaction stands out as crucial in two different ways. Firstly, the interaction among the project members is of great concern in order to make use of and combine the members' resource collections respectively. This is also related to the potential for finding new ways of combining and using resources. While the project members interact, they can learn from each other regarding resources and their combinations.

Håkansson and Snehota (1995) discuss different types of learning with regard to the use and provision of resources. Two types are of relevance for resource combining in inter-organisational research projects. First, learning from actors, i.e. project members, refers to making use of the other parties' knowledge and experience. This type of learning can be achieved through acquiring knowledge or taking directions from others. The actor can thus make use of another party's resources without developing them internally. Second, joint learning refers to learning where several actors' knowledge is utilised in an interaction process. Joint learning requires mutual orientation and adaptations and, through this type of learning, joint value can be created. Nevertheless it is to be striven for; joint learning does not come automatically. It may take time for companies to understand and get to know each other (*ibid.*).

Secondly, interaction is essential in terms of the interaction between resource use and resource development. These processes taking place in a project both influence and are influenced by each other. Thus, to understand resource use and development, the interactive element needs to be taken into account.

In conclusion, interaction is crucial for resource use and development in inter-organisational research projects. Interaction is to be seen in a context, which implies that the context of an inter-organisational project becomes important. This project context is taken into consideration in terms of the embeddedness

of projects. The subsequent section examines embeddedness and defines the network context of a project.

2.3.4 EMBEDDEDNESS AND A NETWORK CONTEXT

Several studies within the Industrial Network Approach focus on embeddedness⁴, for example in terms of companies in network structures. The network model (Håkansson, 1987; Håkansson and Snehota, 1995) builds on viewing resources as part of – or as embedded in – resource constellations, activities as part of activity patterns, and actors as part of a web of actors. Halinen and Törnroos (1998), in their study of evolution of industrial networks, introduce six types of embeddedness (temporal, spatial, social, political, market and technological). Hence, resources, actors and activities respectively can be seen as embedded in the larger network structures.

The notion of resource embeddedness has specifically been addressed (cf. Wedin, 2001; Holmen, 2001; Hjelmgren, 2005) in studies of resource development. In addition, Bångens et al. (1997) distinguish resource embeddedness in the surrounding resource structure as one dimension argued to be central for analysis of resource combination and governance forms. Hence, the concept of embeddedness may be used for several different purposes, as understanding markets, the evolution of industrial networks and resource development in interaction.

The most common reference when it comes to embeddedness is Granovetter (1985), which introduced the concept to explain that economic action is embedded in structures of social relations. Granovetter (1985, p. 487) points to the importance of personal relations or networks in terms of actors' actions being “...*embedded in concrete, ongoing systems of social relations*”. Furthermore, Granovetter takes a point of departure in theories dominant at the time, criticised for being either under- or oversocialised: “...*most behaviour is closely embedded in networks of interpersonal relations and that such an argument avoids the extremes of under- and oversocialized views of human action.*” (ibid., p. 504). The behaviour concentrated on is the economic behaviour in markets.

The embeddedness concept has, as argued above, been used extensively on the basis of Granovetter (1985) to explain how markets work. For example, Uzzi (1997) focuses on exchange relationships and categorises them as arm's-length

⁴ The concept of embeddedness has frequently been used and discussed in several research fields besides the Industrial Network Approach, e.g. economic sociology. The different ways of using and building on the concept have been reviewed critically by Krippner (2001), who goes back to the original concept of embeddedness introduced by Polanyi in *The Great Transformation* (1944) and Granovetter (1985).

ties and as embedded ties. For embedded ties, trust and fine-grained information transfer and joint problem-solving stand out as important characteristics. In addition, Uzzi (1997) discusses issues of “over-” and “under-embedded” firms respectively. While an over-embedded firm is a firm with mainly embedded ties, an under-embedded firm is a firm with a dominance of arm’s-length ties. It is concluded that a mixture of embedded and arm’s-length ties is preferable since the two types of ties fulfil different functions (ibid.).

Concluding from the above, firms have been studied fruitfully as embedded in various ways. In the next section, projects are treated explicitly as the focal objects embedded in a network context.

A project embedded in a network context

Projects are regarded as organisations, temporary in character, characterised by uncertainty and for which project goals are central. The project context is defined as the network context of a project, which exists in time and space. Hence, the network context of a project consists of:

1. A context with regard to time
2. An organisational context

The time context consists of two dimensions, which are defined on the basis of episodes taking place during the project. The first dimension is the history of the project, referring to earlier episodes, i.e. projects or non-project activities, related to or influencing the project in focus. The second dimension is what will happen after the project is finished, which refers to the episodes planned to take place after the project is completed, related to the project. The time context is illustrated below in Figure 2.8 with a starting point in a number of episodes.

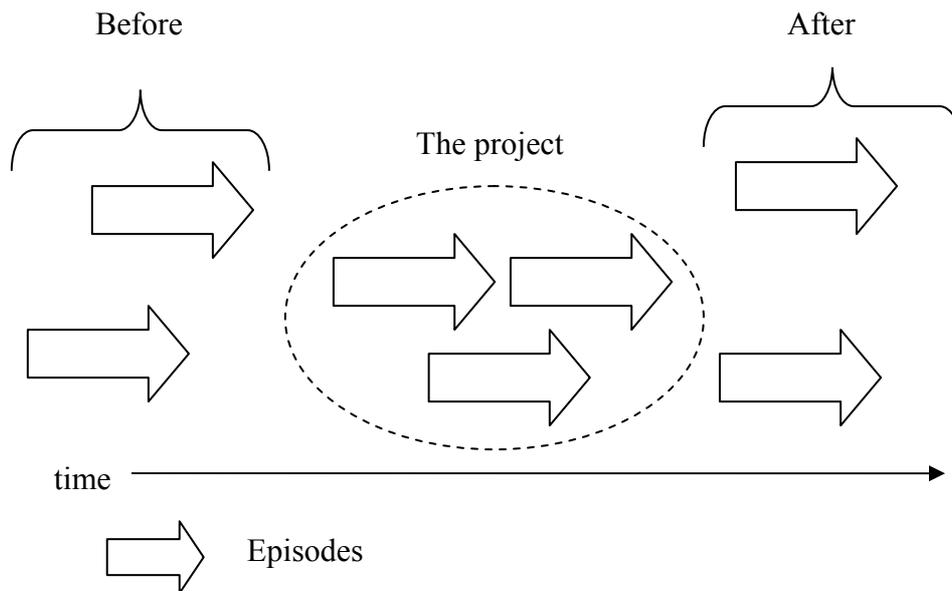


Figure 2.8: The time context of a project.

It is to be noted that the members of an inter-organisational project may have different perspectives on what episodes preceded and what episodes will follow when the project is completed. One reason may be that their memories and expectations are different. Nonetheless, each project can be described as having a history in terms of some episodes, and a future in terms of planned episodes.

The organisational context of a project consists of three parts; see Figure 2.9. The first part is the project members, belonging to different parent organisations respectively, and specifically the project members' involvements besides the project. Hence, the project members' resources and other potential involvements in parallel activities or projects are included in the first part.

The second part is the parent organisations. These have access to resources and commonly do a number of other things, such as other non-project activities or projects, which may be more or less related to a certain project. Thus, the parent organisations' other resources and related activities constitute the second part of the organisational context.

The third part of the organisational context consists of the parties outside the project that influence or are influenced by the project. These other parties are referred to as third parties, and may be either other organisations or projects. Third parties may be organisations that the parent organisations have relationships with, as illustrated in Figure 2.9. They may thus be related to the project either directly or via the parent organisations' network of relationships.

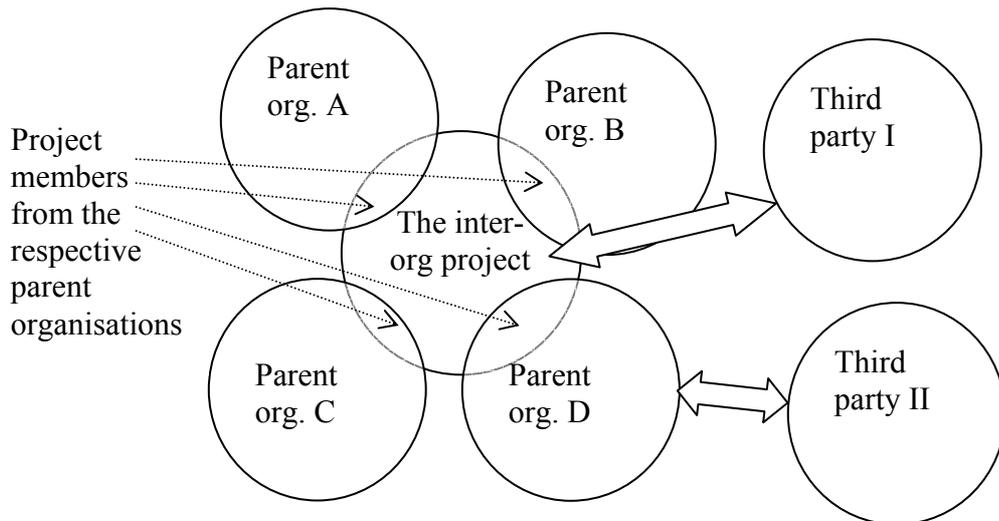


Figure 2.9: The organisational context of a project.

The time context and the organisational context of a project are interrelated. The inter-organisational project only exists during the time it is ongoing. However, the project members and the parent organisations involved in the project have both a history and a future. Hence, the project members or the parent organisations may further use the resources developed in a certain project after the project is finished. Third parties, if they are organisations, have both a history and a future; however, if the third parties are other projects they only exist during a limited time.

The description of a project embedded in an organisational context takes the starting point in actors, i.e. project members, parent organisations and third parties, although the thesis concerns *resource* combining. The reason for this is to give an overall view of what is regarded as the project context, and in the next step, resources are added to the discussion.

To sum up, the project context consists of contexts in time and space, which may influence or be influenced by the project. The time context consists of two dimensions, defined by the episodes during the project: the history and the planned future of a project. The organisational context of a project consists of three parts: the project members' and parent organisations' other resources and activities and third parties related to the project.

In the next section, resource combining is looked at in more detail in the setting of projects in a network context. In addition, four research issues are elaborated on and presented.

2.4 Resource combining in relation to projects

Overall, this section connects the previous sections of the theoretical frame of reference regarding resource combining, inter-organisational projects and the network context. Most importantly, four research issues are formulated, and accordingly this section consists of four parts.

The first part below discusses resource use and development in projects embedded in a network context.

The resource collections of a project in combination with interaction among the project members form important starting points for resource combining. The resource collections of a project are discussed in the second part below.

Projects are embedded in their network contexts. Project embeddedness is explored in different dimensions and this is focused on in the third part below.

The project context is dynamic in character. The dynamics and the role of the project goals are in focus in the fourth part.

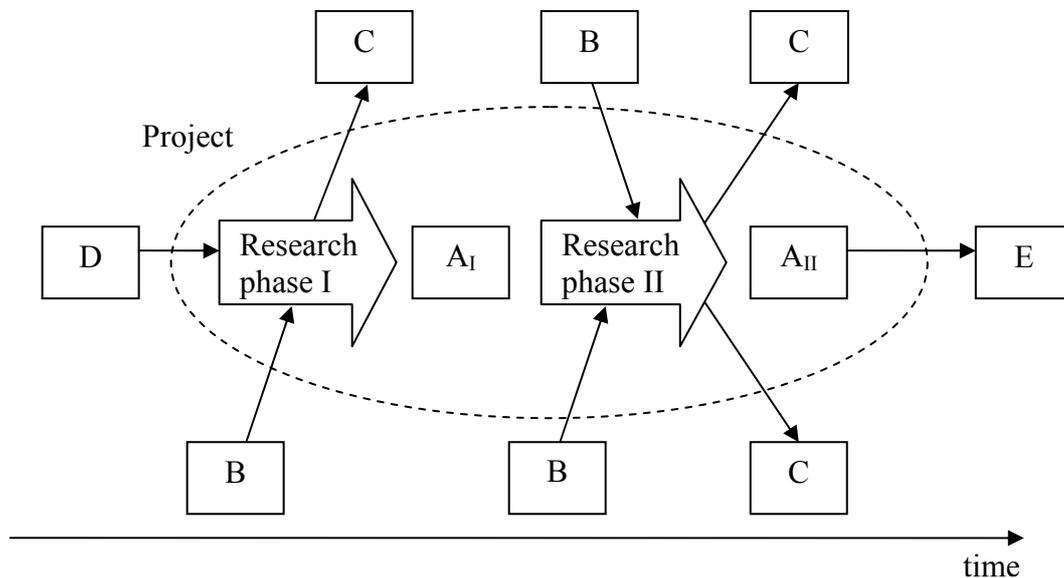
2.4.1 RESOURCE USE AND DEVELOPMENT CATEGORIES

An inter-organisational research project exists in a time context and an organisational context. The time context refers to the fact that resources may be used and developed before, during and after the project is completed – before and after the project can be seen as outside the project boundary in time, while during the project is seen as within the project boundary in time.

The second part of a project context is the organisational context. Within the organisational context refers to the resources used and developed within the project towards the project goals. Outside the project boundary in the organisational context refers to the resources used and developed in other efforts, i.e. not related to the project goals. These might be resources that are used and developed by the project members for other purposes or resources used outside the project by third parties.

Five different categories of resource use and development are identified in relation to a project in time and the organisational context. The first category concerns resources developed and used within and during the project, illustrated as category A in Figure 2.10. Two different phases are illustrated in the figure, research phases I and II. The former results in a resource (A_I) that is further used and developed in the subsequent phase, which also results in a resource both used and developed within the project (A_{II}). Hence, both the phases result in resources which are used and developed within the project.

This development and use category is thus taking place both within the project in the organisational context and during the project in time.



Categories of resource use and development:

- A - Resources developed and used within the project.
- B - Resources developed outside and used within the project.
- C - Resources developed within and used outside the project.
- D - Resources developed prior to and used during the project.
- E - Resources developed during and used after the project in time.

Figure 2.10: Resource use and development categories in relation to a project.

The second category concerns resources developed outside the project that are used within the project. The resources of this category are thus crossing the project boundary in the organisational context. This category is referred to as category B.

The third category concerns resources that are developed within the project that are used outside the project. This resource category is illustrated as category C in Figure 2.10. These resources are crossing the project boundary in the organisational context. Both categories B and C occur during the project in time, in contrast to the two subsequent categories. However, it is possible that some of the resources of category C become used not only outside the project, but also after the project is completed.

The fourth category concerns resources developed outside the project in time that become used within the project. The resource category includes resources developed prior to the project that are used during the project. The resources of

this category cross the project boundary in time. The fourth category is referred to as category D.

The fifth category involves resources that are developed during and within the project that become used outside the project in time – that is, resources developed during the project that are used after the project is completed. The resources of this category, referred to as category E, cross the project boundary in time.

It is to be noted that each resource is part of a single resource use and development category at a certain point in time. The same resource will possibly be part of another resource use and development category either in parallel, in the past or in the future.

Hence, five categories of resource use and development are identified in relation to projects. Category A is mainly oriented towards the project internally while the other four categories (B-E) cross the project boundary either in time or in the organisational context. Crossing the project boundary means that they are forming a link between the project and the project context. Based on the resource use and development categories, the first research issue is formulated.

The first research issue explores the interplay between resource use, resource development and resource combining.

This research issue is divided into three sub-issues:

- a) *How resources are combined during the project.*
- b) *How resources are developed within the project through using internal and external resources.*
- c) *How resources developed within a project become used within and outside the project boundary.*

Some of the resources developed and used in relation to a project are accessed through the resource collections of a project. The resource collections are discussed in the next section.

2.4.2 THE RESOURCE COLLECTIONS OF A PROJECT

The project and the project context consist of project members, parent organisations and third parties, which access resources through their resource collections. See Figure 2.11.

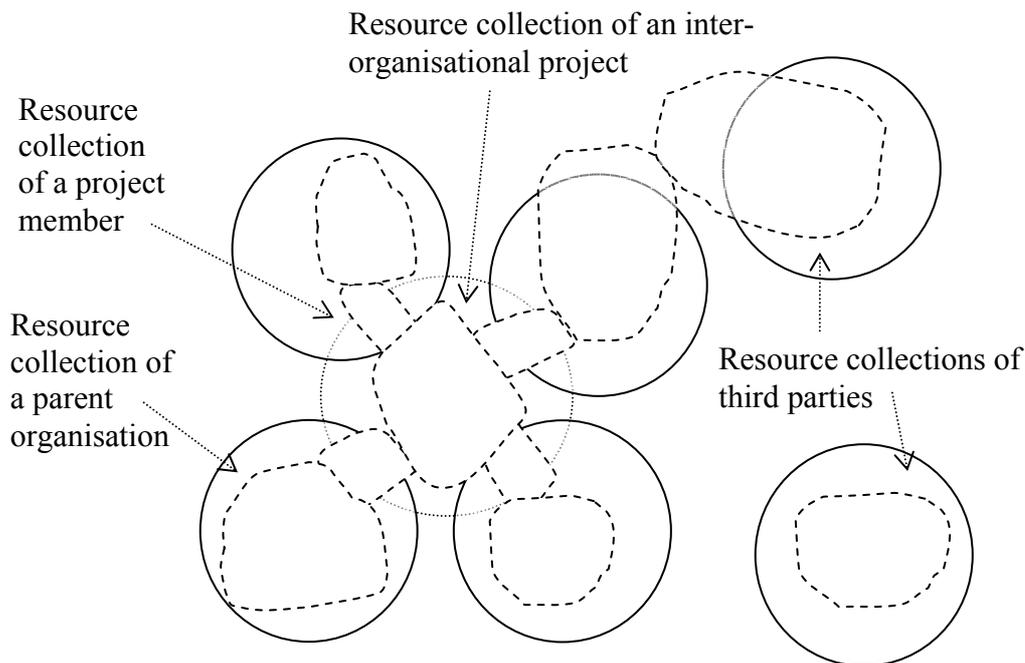


Figure 2.11: The resource collections of an inter-organisational project.

A resource collection may consist of internal resources, i.e. resources that are owned, and external resources, i.e. resources that are accessed externally and can be used in a project. In addition, a project over time will build up a collection of resources that are developed within the project. *The resource collections of a project* thus refer to the project's, the project members', parent organisations' and third parties' resource collections.

In an inter-organisational project, the project members and parent organisations access resource collections respectively. However, there may be some overlaps among their resource collections. Some of the resources of a project member may also be part of a parent organisation's resource collection. Some of the resources of the project's collection may also be part of a project member's or parent organisation's collection. Still, in a certain situation, each resource can be seen to belong to a certain resource collection.

The resource collections of a project need to be combined with the wider resource constellation in order to pursue resource variety. In this process, increased knowledge about the resources and the combining of resources may be necessary, which may result in changes in the resource collections.

The second research issue explores the impact on the resource collections of a project due to resource combining within and across the project boundary.

Thus, the resource collections are crucial starting points for resource combining. In addition, the resource collections of the project members can be seen as a way in which projects are embedded in their context. This is discussed in the next section.

2.4.3 PROJECT EMBEDDEDNESS

Projects are seen as embedded in a network context consisting of the project members, parent organisations and third parties related to the project. This view of project embeddedness can be seen as based on the actor dimension in the network model.

Taking the starting point in resource use and development within and across project boundaries, project embeddedness can in addition to the actor dimension be seen in two other dimensions. Projects can be embedded with regard to resources and activities.

Embeddedness with regard to activities and resources

Blomquist and Packendorff (1998) point out that there is a risk for lack of focus on each project when project members are involved in too many different activities (such as projects) at the same time. Still, there are some possible advantages with project members being involved in many activities, such as possibilities for learning between projects, and for using experiences from one project in another. It means that project members can be seen as embedded with regard to their involvement in terms of activities. A project member may be engaged in a project to a low extent, which means that there is room for other parallel activities that can be more or less related to the project. A project member that is involved in a certain project to a low extent and in parallel involved in a number of other activities may be seen as *embedded to a high degree with regard to activities*. The opposite situation is a project member that is involved in a certain project to a high extent and in other activities to a low extent. This project member may be seen as *embedded to a low degree with regard to activities*.

In relation to project embeddedness with regard to resources, two aspects are identified as important. These are the project's internal resource collection and the resource collections of the project members. Extensive resource collections might correspond to the greater opportunities for identifying new ideas for resource combining. Project members that over time have been involved in a number of projects, or are involved in several projects in parallel, may have access to more extensive resource collections, which can be useful for combining resources in new ways. Project members with access to extensive resource collections are seen as *embedded to a high degree with regard to*

resources. A project member with access to a limited resource collection is seen as *embedded to a low degree with regard to resources*.

Hence, projects are seen as embedded in two dimensions: activities and resources. Project embeddedness with regard to these two dimensions to a low or high degree, respectively, implies four different situations of projects. See Figure 2.12. Four principal situations of project embeddedness are thus identified.

Degree of project embeddedness with regard to activities

		High	Low
Degree of project embeddedness with regard to resources	High	Situation 1	Situation 2
	Low	Situation 3	Situation 4

Figure 2.12: Project embeddedness with regard to activities and resources.

Depending on how the degree of project embeddedness with regard to activities and resources respectively is composed in a project, the effects achieved in relation to the project and the project members will be very different. The four principal situations of project embeddedness form the point of departure for the third research issue.

The third research issue explores how the extent of project embeddedness with regard to activities and resources impacts on resource combining within and across the project boundary.

The project context is not a given once and for all, but changes during a project. In the next section, the dynamics of the project context is discussed.

2.4.4 DYNAMICS OF THE PROJECT CONTEXT

The project context is dynamic in character in terms of changes taking place. The changes may e.g. concern achievements of other projects, technological solutions or the access to resources. The dynamics of the project context may be a cause of uncertainty in relation to projects and have an impact on projects and their embeddedness. While there are changes in the project context, there can be consequences for a project in terms of the project goals.

Project goals are difficult to formulate initially in a project due to the issue of uncertainty and the project context as changing or drifting. If the goals of a project are formulated on the basis of certain premises, and these change during the project, it may be difficult or irrelevant to fulfil the project goals. Changes in the context may also have a positive impact on the realisation of project goals. The fourth research issue deals with the project goals and the impact from the dynamics of the project context.

The fourth research issue explores how the project goals are affected by changes in the project context.

Based on the four research issues, the intention is to reach an increased understanding of resource use and development in relation to inter-organisational research projects.

2.5 Research issues

This final section summarises the research issues in order to provide an overview of Chapter 2.

The aim of the thesis concerns analysing resource combining in relation to an inter-organisational research project in its context. Based on the formulated aim, the theoretical frame of reference has focused on resource combining, the characteristics of inter-organisational projects, and the context of the project that was defined in terms of network embeddedness, consisting of a time context and an organisational context.

Overall, the Industrial Network Approach has been used as a conceptual ground for approaching resource combining in inter-organisational research projects. The four building blocks of the frame of reference formed the base for the formulation of the following research issues.

The first research issue explores the interplay between resource use, resource development and resource combining.

- a) How resources are combined during the project.*
- b) How resources are developed within the project through using internal and external resources.*
- c) How resources developed within a project become used within and outside the project boundary.*

The second research issue explores the impact on the resource collections of a project due to resource combining within and across the project boundary.

The third research issue explores how the extent of project embeddedness with regard to activities and resources impacts on resource combining within and across the project boundary.

The fourth research issue explores how the project goals are affected by changes in the project context.

While this chapter has outlined the theoretical framework and presented four research issues, the next chapter presents the method used in the study underlying the thesis.

3 Method

This chapter describes and discusses the method used in the study underlying the thesis. While the research design of a study includes the overall assumptions regarding data collection and analysis, the research method contains the techniques used in order to collect data (Bryman, 2002). The overall research design used in this thesis is case study research and the research method involves personal interviews in combination with other sources of data.

Like all projects, this thesis has been written in a particular context. The context is the Division of Industrial Marketing, Department of Technology Management and Economics, at Chalmers University of Technology. One of the things that unite this division is the theoretical base of the Industrial Network Approach. This approach may thus be described as one of the starting points for the thesis.

The aim of the thesis, to analyse resource combination in relation to inter-organisational research projects, led to the case-study research design. The aim of the thesis has emerged through an interplay with empirical reality, theory, the case and the framework, as will be discussed below. Given the initial theoretical interest in the Industrial Network Approach, the case study design became the point of departure.

In section 3.1, case study research in general is described, including why it is particularly useful for studies of industrial networks. Section 3.2 describes systematic combining as a way of working with an abductive approach, and discusses the emergence of the case study of resource combining in an inter-organisational research project and the theoretical framework. Section 3.3 focuses on the data collection of the case study, while the final section 3.4 discusses the trustworthiness of the study.

3.1 Case study research

In conducting case study research, basic theoretical assumptions often form the starting point in order to know what to look for in the empirical world (Dubois and Araujo, 2004). Furthermore, case study research is argued to be fruitful in

relation to the development of theory (Eisenhardt, 1989; Denscombe, 2000). According to Ragin (1992, pp. 224-5):

As researchers our primary goal is to link the empirical and theoretical – to use theory to make sense of evidence and to use evidence to sharpen and refine theory.

What is a case, then? On the above basis, a case seems to be a combination of both theoretical and empirical insights. According to Ragin (1992, p. 218) “...making something into a case or ‘casing’ it can bring operational closure to some problematic relationship between ideas and evidence, between theory and data”. Hence, cases are to be found or developed in the research process; they cannot be known beforehand. In “casing”, theory forms the starting point and, when the cases are developed, they may be used for refining theory.

A case may be regarded both as a methodological “product” (Ragin, 1992) and as a “tool” (Dubois and Gadde, 2002) in which both theoretical frameworks and empirical insights are combined. One issue concerns how to delimit and draw boundaries around the case. A case needs to be distinguished from its context in order to be studied and have distinct boundaries (Denscombe, 2000). An issue related to the case boundary is what the case is a case of. This may be changed or refined during the process. To know what the case is a case of should not be regarded as the starting point but rather as one of the final steps in the research process (Dubois and Araujo, 2004, p. 225): “*What constitutes the phenomenon of interest and its boundaries is often the outcome of the study rather than a decision that can be firmed up prior to conducting the study*”. Thus, when it is clear how to draw the boundaries around the case, it is also known what the case is a case of.

In studies of industrial networks, the case study method has come to be regarded as the method most often pursued (Easton, 1995a; Dubois and Gadde, 2002; Dubois and Araujo, 2004; Halinen and Törnroos, 2005). Industrial networks are complex in character in terms of a number of companies being interdependent. Moreover, industrial networks are, as suggested above, characterised by embeddedness in various dimensions and the context may be understood in several ways depending on the focal entity of the study. In order to be able to understand these processes, a research design that allows for this complexity and multitude is needed. According to Easton (1995a, pp. 385-6), industrial network researchers “*have been driven to cases because they make sense of the phenomena we [industrial network researchers] have sought to understand*”.

Reasons why case research is well suited for studies based on the Industrial Network Approach are that case studies offer depth and enable a multi-dimensional view of the phenomena in focus. When scrutinising a case in depth, new aspects may be identified, which can result in development of existing theory. Studying several cases with the same resources means breadth but less depth (Easton, 1995a). Hence, while depth is desirable, one case becomes the straightforward choice. Case study research building on a single case has emerged as a method commonly used (Dubois and Araujo, 2004). For example, several recent doctoral theses are based on single case studies (cf. Holmen, 2001; Wedin, 2001; Hulthén, 2002; Hjelmgren, 2005).

Even though case studies have a number of advantages in relation to studies of industrial networks and may be argued to be *the* method, there are some challenges for case research in a network context. First, there is a problem of network boundaries, referring to the difficulty of separating the content and context of a business network. This has an impact on case studies in industrial network settings. Hence, what forms the case and what belongs to the context becomes a vital issue, which is related to the definition of industrial networks.

Dubois and Araujo (2004, p. 210) identify the problem of boundaries and suggest a solution of how to handle it:

The task of the analyst is often to progressively construct the context and boundaries of the phenomenon, as theory interacts with the method and empirical observations. The research object, its boundaries, context and horizon are thus emergent and unfolding outcomes of the research process.

Thus, in interaction with theory, what is in focus for the case and what is not emerge. Halinen and Törnroos (2005) suggest that certain concepts in the Industrial Network Approach help the researcher to sort out the problem of boundaries. One way of creating a starting point in a case study conducted in the context of industrial networks is by introducing a focal object, for instance a focal company, a focal relationship or a focal project as in the empirical inquiry of this thesis. Based on the starting point, the focus of the case study over time emerges in interplay with theoretical ideas of what the case might be a case of.

Another potential problem concerns the complexity of networks (Easton, 1995b). Industrial networks contain so many issues and aspects that trying to cover all of them is not a feasible research strategy. Halinen and Törnroos (2005) suggest that the complexity can be mastered by setting objectives and

limitations of the work. How to formulate these objectives, however, needs to emerge in interaction with theory, as the following section discusses at length.

The time aspect in case studies of industrial networks is another important issue that needs to be handled (Easton, 1995b; Halinen and Törnroos, 2005). Time is central in studies of networks because change processes are central aspects of industrial networks. Network processes are embedded in their context and, to acknowledge the embeddedness, it is suggested that both temporal and contextual dimensions need to be included in the analysis (ibid.).

Hence, case studies present challenges in terms of scope due to the lack of “natural” boundaries in time and space (Dubois and Araujo, 2004). Nevertheless, case studies seem to be appropriate for studying and analysing industrial network-related issues. Below, case studies are discussed in relation to the research strategy of abduction.

3.2 An abductive approach

Induction and deduction are two research strategies (cf. Bryman, 2001). While induction takes a starting point in the empirical world and theories are generated on the basis of data, deduction starts with theoretical assumptions that are tested in empirical reality. Abduction may be considered a third research strategy in which both the theoretical and the empirical realities form the background (Alvesson and Sköldberg, 1994). On the one hand, there are similarities between induction and abduction in terms of taking the empirical field as the point of departure. On the other hand, there are similarities between deduction and abduction since both acknowledge theoretical assumptions as vital starting points. However, abduction is to be considered as different from a mixture of induction and deduction (Alvesson and Sköldberg, 1994; Dubois and Gadde, 2002) since there are combinatorial effects of passing between theory and the empirical world.

The research process underlying this thesis may be described as abductive. One way of conducting case study research in an abductive research approach is referred to as “systematic combining” (Dubois and Gadde, 2002).

3.2.1 SYSTEMATIC COMBINING

Systematic combining takes the non-linear elements of conducting case study research into account. In addition, systematic combining acknowledges the iterative elements of going back and forth between the theoretical concepts and empirical reality. According to Dubois and Gadde (2002, p. 554):

Systematic combining is a process where theoretical framework, empirical fieldwork, and case analysis evolve simultaneously, and is particular useful for development of new theories.

There are two main processes of systematic combining: (1) matching between theory and the empirical world and (2) direction and redirection between the framework and the case, illustrated in Figure 3.1. Hence, the matching between theory and reality depends on the matching of the evolving case and framework, which necessitates a process characterised by directions and redirections. While direction refers to the case and the framework developing in a certain direction, redirection refers to a change in that direction, for instance in terms of another focus.

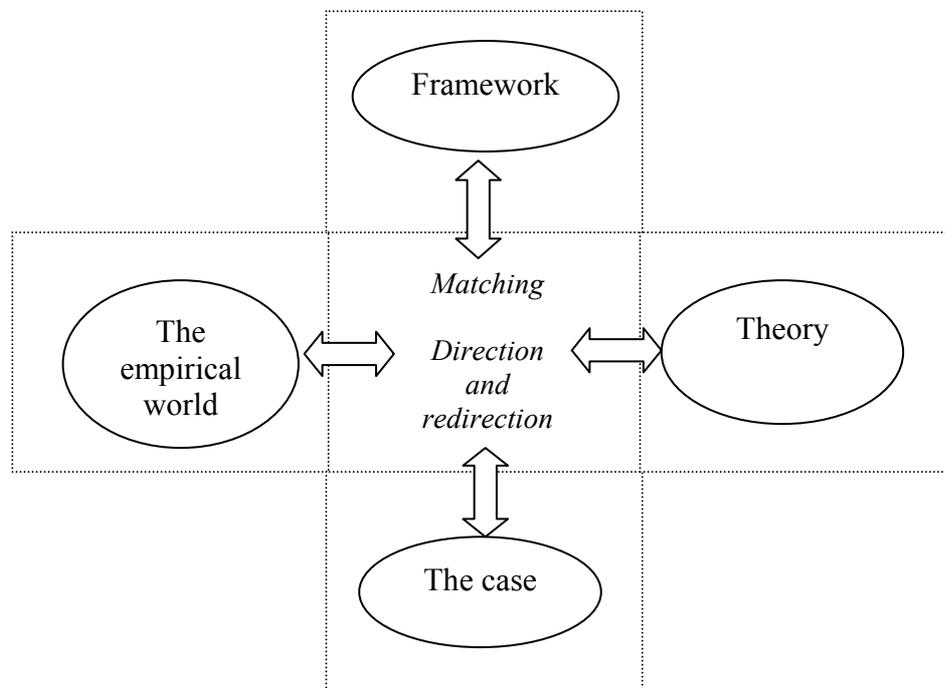


Figure 3.1: Systematic combining (Dubois and Gadde, 2002, p. 555)

When systematically combining the empirical evidence, theory, the framework and the case, these are developed by going back and forth between the empirical world and the theory. In this process, the understanding of all of them may be increased. In systematic combining the framework evolves. “*The reason to that the framework is evolving during the study is because empirical observations inspire changes of the view of theory and vice versa*” (ibid., p. 558). These changes may result in redirection, as discussed above. Hence, not only the framework but also the case evolves during the study. This means that the case may be regarded both as a tool for interacting with theory and

framework and as a product, i.e. as a result at the final stage of the research. In addition, the theory is developed over time; in fact, the need for theory is created in the research process in which the framework, the case, the empirical world and the theory are interplaying.

Based on systematic combining, the understanding of theory and the empirical world may enrich each other. The theory becomes focused in a framework that guides the process of developing the case based on the empirical world. In a similar vein, the theoretical assumptions guide the search in the emerging case. Hence, in systematic combining the emerging framework and the case may guide and enrich each other.

3.2.2 EMERGENCE OF THE FRAMEWORK AND THE CASE

The empirical inquiry of this thesis is the case of resource combining in the setting of an inter-organisational research project (described in Chapter 4). The framework concerns resources, projects, and industrial networks, and focuses on resource combining in relation to a particular project (see Chapter 2). Both the case and the framework have evolved during the research process leading up to this thesis. At large, six phases or steps may be identified in retrospect in which the framework and the case have been developed.

Overall direction: Bioinformatics and resource development in interaction

The field of bioinformatics in the Gothenburg area was chosen as an “arbitrary starting point” (Halinen and Törnroos, 2005) for the case study. Reasons for starting in bioinformatics were that, at the time, several investments were made in bioinformatics from research councils, such as a national research school hosted by Göteborg University, and that Swegene had bioinformatics as one of its areas of focus in the southwest of Sweden. In addition, Chalmers University of Technology made a strategic investment in the cross-disciplinary field of bioinformatics. The investments were made in relation to the mathematics and statistics departments at Chalmers University of Technology and the molecular biology and microbiology departments at Göteborg University, which were planned to collaborate in those bioinformatics efforts. During the first phase of the research process, bioinformatics was broadly regarded as “the case”. A further reason for taking bioinformatics as the arbitrary starting point was that another research group at Uppsala University in the “research network” carried out biotech-related studies at that time.

In the first phase not only the understanding of the empirical world started to develop, but also the understanding of theory, consisting mainly of the Industrial Network Approach. An interest in technological development in collaboration emerged, and the plan was to study this as resource development in interaction with the case of bioinformatics.

Redirection in the empirical material: The winter oats project

One of the initial ideas regarding the focus of the PhD study was to capture theoretical notions of interaction between the two previously separate fields of research in bioinformatics. However, the description of the field of bioinformatics was too broad to enable any useful applications of the industrial network theory, and it was understood that more detailed empirical data were needed to go further in any matching in relation to the general theoretical interest. Concentrating on one particular research project in bioinformatics was concluded to be a good starting point for further scrutiny. Hence, a second arbitrary starting point was chosen. This was the winter oats project.

The reasons for focusing on the winter oats project were threefold. First, among a number of ongoing bioinformatics projects, the winter oats project was inter-organisational, which suited the theoretical base of the Industrial Network Approach. Second, in comparison with other potential projects, the winter oats project seemed comprehensible. Third, the members of the project agreed to be studied.

At the end of this phase, the case description included both a general description of the bioinformatics activities in the southwest of Sweden and a more detailed description of the particular project. The case description had become extensive and was regarded as the “raw case”. Since the raw case contained all the data that had been collected, it became a tool useful for discussion of further inquiries.

Redirection in theory: Introducing projects

Still, the theoretical ideas of resource development in interaction did not fit either the general empirical description of the bioinformatics in the Gothenburg region or the winter oats project. Consequently, new theoretical ideas regarding projects were added to the more general framework based on the Industrial Network Approach. Based on the theoretical ideas of projects and especially this broader view of projects in a context, it was possible to make sense of the winter oats project in a new way. In turn, the new theoretical ideas of projects made sense based on the empirical description of the winter oats project.

The theoretical ideas of viewing projects in a context resulted in further direction for developing the case. The focus of the case thus became a project in its network context. The empirical part describing the bioinformatics activities in general was at this point cut out of the case description.

Redirection of the empirical material: In-depth information about the project context

Based on the emerging framework, additional empirical material about the project was needed. Therefore, based on the theory added to the framework, supplementary interviews were made with the project members, specifically asking about certain issues in the project context.

In the second round of interviews, the project members were asked about counterparts providing inputs to be used in the project, how they were accessed and used, and why. Moreover, the resources developed in the project, and their use internally and outside the project, were added to the case description. Based on these additional data, the case became refined.

Redirection of the framework: Combining the theoretical ideas about projects and industrial networks

Towards the end of the research process, it became possible to re-integrate the concepts that were part of the initial theoretical ideas on resource development but could not be used in relation to the general case of bioinformatics. Thus, when the case of an inter-organisational research project in a context emerged, some of the theoretical ideas that provided guidance at initial stages of the process proved useful in a new and fruitful way. This new use of the industrial network theory would not have been possible without the previous re-direction in theory, i.e. integration of projects in the framework.

The framework was thus developed to include industrial network theory and specifically resource use and development in combination with a broader view of projects, i.e. inter-organisational projects and their environments.

Redirection of the case: A case of resource use and development in an inter-organisational research project in a network context

Based on the emergent case description of the winter oats project in its context, the analysis of the empirical material was conducted. The analysis of the case had the result that the focus of the empirical material became resource use and development in the setting of an inter-organisational research project. In other words, even though the empirical material stayed the same, it became a case of something else. The project members' collaboration on winter oats was not the most important aspect any longer; instead, resource combination in relation to the project, and the interplay with the context, were in focus.

However, the detailed knowledge gained about the specifics of the winter oats project was a precondition for developing the framework. The framework could never have been developed without the deep empirical descriptions. When the

framework was developed, the central entities were not only the resources used and developed – the different categories of resource use and development also came into focus. In addition, internal aspects of inter-organisational research projects, and how projects relate externally to their network context, were analysed. Based on the analysis of the empirical material, the project boundary emerged as an interesting phenomenon to explore further. The discussion of the role of the project boundary may thus be considered a result of the analysis of resource use and development in inter-organisational research projects, even though the discussion opens up further inquiries.

The case of resource use and development in an inter-organisational research project in a network context may be regarded as a product. In viewing the case as a product, the issue of case boundaries comes to the fore. As discussed above, time is an issue in relation to case boundaries. In the case of the winter oats project this issue arose since, when the case study was completed, the project was still ongoing. Unquestionably, there would have been more illustrations providing an even richer view of resource use and development if the project had been completed. However, although the project was not completed, the development and use of resources within and across the project boundary were possible to capture. The case provided several illustrations of resource combination across project boundaries, and it was therefore regarded as saturated even though the project was still ongoing.

In conclusion, six phases or steps may be identified regarding direction and redirection in theory and of the empirical material in developing the case and the framework. Those steps or phases are identified in retrospect and were thus not planned, but developed gradually by taking one step at a time.

3.3 Data collection

A case study method typically combines several different sources of data, such as interviews, questionnaires, archives and observations (cf. Eisenhardt, 1989). The case study underlying the thesis builds mainly on personal interviews, specialist literature, books, and articles in business press, newspapers and information from the Internet. Hence, both primary and secondary data have been used.

3.3.1 CONDUCTING INTERVIEWS

In total, this study builds on 35 “semi-structured” interviews with researchers involved in or related to the field of bioinformatics or the winter oats project. Of these interviews, 21 were for orientation, while 16 were related to the winter

oats project specifically⁵. The interviews lasted between 45 minutes and 4 hours, and were performed at the informants' offices. I have conducted the majority of the interviews, while some of the initial interviews were performed together with my supervisors.

Notes have been taken during all the interviews and transcribed as soon as possible after each. On some occasions, the interviewees have requested to see the transcripts, which have then been sent to them for approval.

Almost all the interviews have been booked by telephone and then e-mails were sent with an introduction to the PhD study, some general notes of interest for the interview, and also my contact information and a confirmation about the date, place and time. A few interviews have been conducted on the telephone, such as some of the supplementary interviews with the project members due to their locations in other towns. Concerning the supplementary interviews I had already interviewed and visited the interviewees at least once before.

At the first interview with a certain person, I began by introducing myself, the PhD project, the Division of Industrial Marketing, and the reason for interviewing that specific person. In addition, if I had obtained the person's name from somebody else, this was stated. When ending the interviews, I generally tried to thank the interviewees for their time and ask if it was acceptable to contact them again. For example, technical details of the research activities were at times difficult to grasp and these were asked about again for clarification if necessary, usually by sending additional e-mails.

Interviews build on inter-personal meetings and the interviewer has a central role in the interview situation. All the interviews were prepared in terms of thinking through what to talk about and ask during the interview. Often some bullets (or themes according to Kvale, 1997) were prepared and provided guidance during the interview. The themes have been followed to varying degrees, but they were useful as a structure and for support during the interviews. The preparations and introductions functioned as a way of setting the scene for conducting fruitful interviews.

There were also difficulties in conducting the interviews. Some were related to the interview situation, e.g. telephone calls and people knocking on the interviewee's door during the interviews, interviewees being late and thereby the time for the interview becoming shorter than planned. These problems were handled by trying to make the most out of each interview situation and, when needed, additional contact was taken. There are also issues regarding

⁵ Two of the interviews are thus regarded as both orientation and project-specific interviews.

confidentiality in relation to interviews (Kvale, 1997). In conducting the interviews of this study, the question of confidentiality arose mainly in connection with some of the promising results that the interviewees had produced. At times it was explicitly expressed that these results or plans were confidential due to e.g. pending patents or forthcoming publications, and that they could therefore not be written about. However, the results were still interesting to hear about to get a sense of the interviewed researchers' reality. While some of the results became public with time, some are still regarded as confidential.

The conducting of interviews may be divided into two main phases, in line with the emergence of the case described above. In the first phase, the aim was to get an overview of the field of bioinformatics, in terms of the activities going on, central efforts and people in the field. In the second phase, the interest was specifically directed towards the ongoing, planned and past activities of the winter oats project. In addition, the parallel activities related to the project were in focus. The interviews are described below in terms of these two main phases: (1) orientation phase and (2) the project-specific phase. This is followed by a description of the other sources of data.

Orientation interviews

The orientation interviews were performed between 2001 and 2003 (see Table 3.1). Regarding whom to interview in the first phase focusing on bioinformatics, the names of some people who were assumed to be central within the field of bioinformatics were found in articles in newspapers and on the Internet. During the initial interviews, explicit questions were asked regarding whom they would recommend that I talk with, in order to get a better understanding of the network within the field of bioinformatics.

Table 3.1: Orientation interviews in the field of bioinformatics.

	Number of interviews	Year of the interview	The position of the interviewee	Additional phone or e-mail contacts
Companies:				
<i>Arexis</i>	1	2001	Manager	No
<i>Astra Zeneca</i>	3	2001, 2002, 2003	Managers	Yes
<i>Spotfire</i>	1	2001	CEO	No
<i>Angio Genetics</i>	1	2002	CEO	No
<i>Carlsson Research</i>	2	2002, 2002	Researchers	No
<i>Innovationskapital</i>	1	2002	Analyst	No
Research units:				
<i>Department of Mathematical Statistics</i>	5	2001, 2001, 2002, 2002, 2003	PhD student, professor, assistant professor, coordinator of the master program in bioinformatics and a student of the same program	Yes
<i>Centre for Bioinformatics, Uppsala University</i>	1	2001	Director / Professor	No
<i>Department of Cell and Molecular Biology</i>	2	2001, 2001	Professor, director of national research school in bioinformatics	Yes
<i>Department of Computer Science</i>	1	2001	Lecturer	Yes
<i>Östra sjukhuset</i>	1	2002	Geneticist	No
<i>Department of Medical Biochemistry</i>	1	2002	Lecturer	Yes
<i>Bioinformatics Institute, University of Manchester</i>	1	2003	Senior lecturer	No
Total:	21			

Themes commonly discussed in the orientation interviews were the research discipline of “bioinformatics”, the ongoing bioinformatics activities in the southwest of Sweden, and collaborations within and among different organisational units. These interviews were to be regarded as “semi-structured interviews” (Bryman, 2002).

During the interviews of the orientation phase, the winter oats project was mentioned as one of several projects. Eventually, as described above, this led to the choice to study the winter oats project as an in-depth case.

Project-specific interviews

The project-specific interviews were performed during 2002 and 2004 (see Table 3.2). By then, some interviews had already been conducted with project members and collaboration partners of the project, without having the winter oats project in focus. Out of these, two are regarded as project-specific based on their partial focus on the winter oats project.

Table 3.2: Interviews related to the winter oats project.

	Number of interviews (telephone interviews)	Year of the interview	The position of the interviewee	Additional phone or e-mail contacts
<i>Project members:</i>				
<i>SFA co-operative</i>	2 (1)	2002, 2004	Manager / researcher	Yes
<i>Svalöf Weibull</i>	2 (1)	2003, 2004	Plant breeder	Yes
<i>Department of Cell and Molecular Biology</i>	3	2002, 2003, 2004	Professor and PhD student	Yes
<i>Department of Computer Science</i>	5 (2)	2001, 2003, 2003, 2003, 2004	Lecturer, master student and PhD student	Yes
<i>Organisations related to the winter oats project:</i>				
<i>Department of Cell and Molecular Biology</i>	2	2001, 2003	Professors	Yes
<i>Department of Food Science</i>	1	2003	Professor	No
<i>Oats farmers</i>	1	2003	Oats farmer	No
<i>Total:</i>	16			

Concerning the project-specific interviews, the questions were initially related to understanding the research activities of the project and, in addition, the background to the project, whether the project members had worked together before this particular project, and the planned future research activities. During these interviews, it became clear that the project had several external links.

As a second step in the project-specific phase, how the project related outwards was concentrated on. What the project members were doing in parallel to this

project and what they had been doing, which may have influenced their efforts in the project, are examples of topics that were asked about. By asking the project members, I tried to figure out the parent organisations' other activities and to identify third parties that may have influenced, or been influenced by, the research activities of the project. The interest was also directed towards collaboration partners of the project members.

One interview was to be arranged with the sequencing firm MWG Biotech AG in Munich, Germany. Even though contact persons were requested from the project members, and phone calls and e-mails were sent to the company, this interview never materialised. However, it was partly compensated by all the information found on the web page and the information received from the project members regarding the analyses made by the firm. Still, not interviewing this firm had the result that the analyses it performed are only described from the perspectives of the project members.

3.3.2 OTHER SOURCES OF DATA

As shown by the above, interviews have been an important source of data. In addition to the interviews, a number of newspaper articles, magazines and Internet sites have been used in order to understand the fields of bioinformatics, biotechnology, computer science, molecular biology, oats, farming and hybridisation, which can all be considered as sub-fields of expertise related to this case study.

One of the interviewees made the suggestion that it might be appropriate to take the Master course "Introduction to bioinformatics" given at Chalmers University of Technology as an orientation in the field. This course was taken by me during the autumn of 2002 and provided the basics of computer science, mathematical statistics and molecular biology. In addition, I tried hands-on bioinformatics during computer laboratory work.

Moreover, specialist books on bioinformatics, molecular biology and computer science (cf. Zweiger, 2001; Lesk, 2002; Stekel, 2003) have been read in order to follow the interviewed persons' descriptions of what they do. Some of these books were related to the course. Biotechnology-related reports from the Swedish Government Official Report Series (SOU), the Swedish Agency for Innovation Systems (VINNOVA), the Swedish Institute for Growth Policy Studies and other sources have also been used.

The Internet has been exploited and, in particular, the companies interviewed have had extensive web pages. Also several seminars, lectures and workshops have been attended in related areas, such as university–industry interactions and commercialisation of research.

3.4 Trustworthiness

In this section, four different criteria for ensuring trustworthiness of the thesis are discussed. The four criteria concern the following: (1) The understanding of the empirical field has emerged from participation in several activities such as Master courses and workshops in biotech-related topics. (2) The empirical description was sent to representatives in the project for approval. (3) The understanding of the case finally reached a degree of saturation and triangulation was pursued to ensure the content of the data. (4) Draft papers and results have continually been presented to other researchers, allowing review and elucidation of the study, method and results.

3.4.1 UNDERSTANDING OF A “NEW” EMPIRICAL FIELD

Bioinformatics was a new field to me when starting this study, and there was a threshold to get over in order to grasp its empirical reality. As mentioned above, I participated in the Master course “Introduction to bioinformatics” at Chalmers University of Technology as an orientation to the field in the autumn of 2002.

During the research process, I have also taken part in a number of biotech-related conferences and meetings. Thus I have interacted with other researchers in the fields of business, economics and social sciences who study biotechnology as their empirical field – for instance, as a member of the “Management and Economics of Biotechnology Network” in which other biotech researchers, policy makers, people working in biotech companies, and venture capitalists take part. In this forum, a research proposal of the thesis has been presented and discussed.

Furthermore, I have presented my research at three workshops dealing explicitly with the management and organisation of biotech: “The Economics and Business of Bio-sciences & Bio-technologies: What can be learnt from the Nordic Countries and the UK?” in September 2002 (see Wennerström, 2002b), “Innovations and Entrepreneurship in Biotech / Pharmaceutical and IT / Telecom” in May 2003 (see Wennerström, 2003a), and “To Sell Biology” in January 2003. The latter presentation resulted in publication of the bioinformatics part of the case study (see Wennerström and Dubois, 2004a). Those workshops also gave opportunities to interact with other researchers concentrating on biotech.

During the spring of 2003, I visited the Centre for Research on Innovation and Competition (CRIC) at the University of Manchester for six weeks to interact with a research group focusing on bioinformatics in an international perspective. During this stay, feedback was also received on my work.

These presentations and the feedback received may be described as “peer debriefing” (Lincoln and Guba, 1985) since the case and the results were discussed with other biotech-related researchers. Based on these different biotech-related contexts, not only the understanding of the empirical area increased but also the insights regarding central issues in the biotech sector.

3.4.2 MEMBER CHECKS

In member checks, the empirical material is tested with the respondents to investigate whether the data have been correctly understood and interpreted; the ones best qualified to tell are the people who have been interviewed. According to Lincoln and Guba (1985, p. 314) member checks are central: *“The member check, whereby data, analytic categories, interpretations, and conclusions are tested with members of those stakeholding groups from whom the data were originally collected, is the most critical technique for establishing credibility.”* Bryman (2002) refers to member checks as “respondent validation”.

In this study, one representative from each of the four project members has approved the empirical descriptions of the project overall and the parts concerning the project members respectively. By letting one person representing each of the four central members of the winter oats project read and approve the empirical case description, a certain degree of trustworthiness in the case study can be ensured.

In relation to the contacts with the members of the winter oats project during the member checks, the case was updated about what had happened in the project lately. The update regarded both project-internal aspects and some external collaboration partners.

3.4.3 SATURATION AND TRIANGULATION

One way commonly used for evaluation of research is triangulation of data sources. Data triangulation means to *“collect information from multiple sources but aimed at corroborating the same fact or phenomenon”* (Yin, 1989, p. 92).

Regarding data triangulation in relation to the winter oats project, the main sources of data are the interviews with the four project members and some of the collaboration partners outside the project. In addition to the interviews, the other sources available have been pursued – above all, the project website, newspaper articles about the project, master theses based on the project, and material from the funding institutes. Insofar as other sources of data were available, they have been used in order to triangulate data. The multiple sources of data have also been important in understanding and analysing the project.

Another type of triangulation is “informant triangulation” (Kvale, 1997), which refers to whether the interviewed people give a uniform picture of the phenomena in focus. Informant triangulation has been important in this case in two respects. First, it has been achieved in relation to the four project members; the four interviewed project members⁶ were all asked to describe the joint research activities of the project. Questions were asked sometimes to hear answers once more from another perspective, and sometimes to have a certain issue clarified. In fact, it was a common pattern to hear a description or the background to a certain activity from one of the project members and then hear it again from another of the interviewees in order to grasp it.

Sometimes the answers received did not complement each other or could not be regarded as clarification of what the others had said. On those occasions, the differences might have reflected their different perspectives, due to their own areas of expertise and position in the project. The differences may also owe to the fact that the four project members were not equally involved in all activities. In the cases where the answers differed, questions were asked again until I either got a uniform picture or understood why their answers differed.

The fact that a multidisciplinary research project was studied may have increased the need for informant triangulation, since the project members were all more or less new to each other’s respective fields. At least one of the project members was unfamiliar with the other members’ fields. Therefore, it became possible to hear explanations from different perspectives. These views were often complementary and resulted in increased understanding of the activities. Returning to the issue discussed above of the occurrence of non-complementary views, it may have been partly due to the various degrees of expertise among the project members’ respective fields.

Secondly, informant triangulation was also achieved in relation to some of the external collaboration partners of the project. By capturing views on the project from actors not involved in the project, the project was seen in another light and thereby another kind of triangulation arose. Sometimes specific results produced in the project or a certain step in the research process became better understood, based on other researchers’ perceptions of them as significant (or the opposite).

After a number of interviews, the understanding of the research process in the project reached saturation, in that the answers no longer added new information. It was possible to consider the empirical data in relation to the

⁶ For clarification, a project member does not equal one individual. Thus, several people may have been interviewed within each project member group.

winter oats project at a certain point in time as saturated. Further, it can be concluded that by interviewing people representing different actors, their perspectives on the phenomena in focus became a way of triangulating data.

3.4.4 CONTINUOUS REVIEW AND ELUCIDATION

Another means of ensuring trustworthiness of the thesis is the continuous review and elucidation that the thesis chapter drafts have gone through when presenting them to, and gaining feedback from, other researchers. Research proposals and chapter drafts have been presented not only in biotech-related settings, but also in academic settings where the theoretical ideas have been discussed.

As mentioned above, my PhD studies have been conducted at the Division of Industrial Marketing, which in turn is part of a larger network of other research groups. Two arenas to be noted are the annual Nordic Workshop on Inter-organisational Research and the annual Industrial Marketing and Purchasing (IMP) conference, where I have presented several research proposals, thesis chapter drafts and working papers (cf. Wennerström, 2001, 2002, 2003, 2004b; Wennerström and Dubois, 2004b; Lind, 2005; Lind and Dubois, 2005). The feedback, response and interest met in these settings have been important drivers of the study.

Related theories in areas such as innovation systems and evolutionary economics also form the theoretical base of the Department of Technology Management and Economics. This has resulted in participation in related PhD courses (for instance the Economics of Technological and Institutional Change (ETIC) summer school at the University of Louis Pasteur, Strasbourg, and MERIT, University of Maastricht) and workshops (for instance the DRUID PhD workshop, Aalborg University: see Wennerström, 2004a).

Thesis chapter drafts have been presented at a number of internal seminars at the Division of Industrial Marketing, for example each year before Christmas at the yearly “PhD student day”, where the PhD students present their work. In addition, at a visit to the Department of Industrial Economics and Technology Management, Norwegian University of Science and Technology (NTNU), a paper was presented at a seminar.

Moreover, the supervisor committee has read and commented on several thesis drafts. In this process, when the analyses and the framework of the thesis were emerging, ideas were continually tested with regard to matching.

Hence, research proposals and chapter drafts have been presented at several workshops and conferences within the Industrial Network Approach, biotech-

related contexts and other related fields of theory. These occasions are referred to as peer briefing, in which feedback was received that made me think through and reflect on the content and direction of the thesis.

In conclusion, this thesis can be considered trustworthy on the basis of three main arguments. First, the member checks ensure a certain degree of trustworthiness. Representatives from the four project members have approved the content of the empirical descriptions. Second, triangulation has been pursued in different ways. The data have been triangulated by using both multiple sources and multiple informants. Third, by presenting thesis draft chapters, peer debriefing has been used in terms of review and elucidation. Chapter drafts of the thesis have been presented at workshops, seminars and conferences in the field of industrial network studies and in biotech-related contexts, which also promote the trustworthiness of the thesis.

While this chapter has presented the method of the thesis and provided a background to how the framework and the case study have emerged, the next chapter presents the case of the winter oats project, focusing on how resources were used and developed within and outside the scope of the project.

4 The empirical inquiry

This chapter presents the case study of an inter-organisational research project, forming the empirical basis of the thesis. The project is active in the field of plant biotechnology and focuses on oats as a crop. In particular, the project aims at making oats resistant to low temperatures and cold weather, that is, developing winter oats.

The chapter starts with section 4.1, a brief description of the project, followed by section 4.2 presenting the project background. Section 4.3 describes the four project members, their background and other parallel activities in which they are involved. In section 4.4 the four main research phases of the project are explained and in section 4.5, the final section of the empirical inquiry, the current research situation of the project is presented.

4.1 The winter oats project

The inter-organisational research project in focus has four members: two university departments, one company and one co-operative. The goal of the project is to develop frost-resistant oats, so-called winter oats. This goal has also given the project its name – the winter oats project. Discussions regarding the project started during 2001 and became more formalised during 2002, and the project was still continuing in 2005. According to the project plan, the winter oats project is to be finished in 2006.

Of the four organisations taking part in the project, one is *the Swedish Farmers Supply and Crop Marketing Association*, a co-operative where the majority of the members are farmers. The co-operative's development division has an interest in improving certain characteristics of oats, in this case frost tolerance. The second member of the project is *Svalöf Weibull*, an international plant breeding and seed group specialising in developing new varieties and producing seed for customers in cold climate areas. The rationale for this firm to be involved in the project is that it has not been able to breed oats that survive the winters, in spite of several attempts. The cold-resistance characteristics of oats are expected to be of high interest for farmers, due to the higher yields that would be the result of sowing in the fall instead of in the spring. This is apparently the reason why both the above-mentioned actors have initiated, and been involved in, the project.

In addition to these two organisations, two research groups are involved, representing two university departments. One is *the Department of Cell and Molecular Biology, Göteborg University*, specialised in molecular biology and conducting research on, for example, organism and plant structure and function. The other is *the Department of Computer Science, Skövde University*, specialised in computer science and especially on developing methods and algorithms for structuring and handling huge amounts of biological data. The data focused on in this project consist of “gene-sequence information” in which the key to frost resistance, a first step towards developing winter oats, is expected to be found. Hence, the activities of the project are mainly directed towards identifying the genes involved in regulating frost resistance in oats. In contrast to winter crops developed through hybridisation, which requires their cold adaptation to be a monogenetic characteristic, the cold resistance of oats is assumed to be dependent on the interplay among several genes.

Below in the project description, the university departments are simply referred to as “the molecular biologists” and “the computer scientists” respectively. Svalöf Weibull (SW) is at times referred to as “the plant-breeding firm” and the Swedish Farmers Supply and Crop Marketing Association (SFA) as “the co-operative”.

The winter oats project and its four project members are illustrated in Figure 4.1. This is intended to represent the project only internally; therefore, no external connections are included.

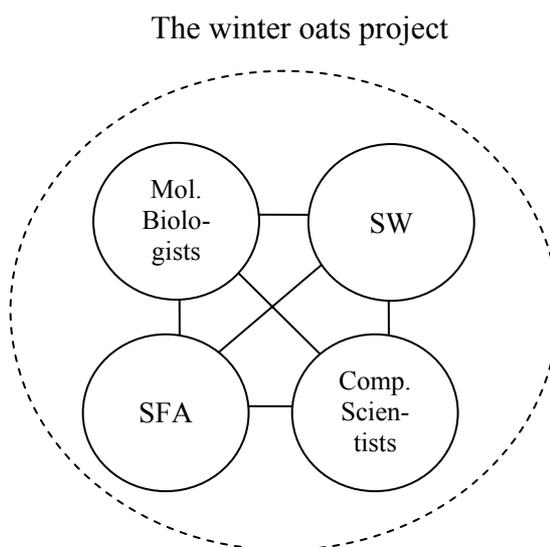


Figure 4.1: The winter oats project and the four project members.

The winter oats project is financed by three main sources. The first one is the West Swedish Farmers Supply and Crop Marketing Association Funding Body, to be described below. The second source is the development division of the Swedish Farmers Supply and Crop Marketing Association, which invested in the cost for sequencing. The third source of funding is the National Research School in Bioinformatics and Genomics, hosted by Göteborg University. This research school funds two PhD students involved in the project. The PhD students started in 2002 and there is one PhD student at each of the participating university departments. In the next section, the project background is described.

4.2 Project background

Oats are described below as a background to the case study. This is followed by a description of one of the funding bodies and its main research projects. Then winter oats are focused upon and the attempts to develop winter oats with plant-breeding methods are outlined. In the final section, the specific background to this winter oats project is presented.

4.2.1 OATS – A SMALL BUT HEALTHY CROP

The four largest crops grown in the world are corn, soy, wheat and rice. Oats are thus not one of the largest. In 2001, the main oat-producing countries in the world were Canada and Russia. Canada accounted for 22 percent of the world production in tonnes and Russia for 27 percent⁷. Elsewhere, the European countries accounted for 25 percent, and their three largest oat producers were in order Finland, Germany and Sweden. Sweden exports around 300,000 tonnes every year to the US.

Sweden is thus a rather large producer of oats in an international perspective, and oats are one of the largest crops in Sweden. Of the arable land in Sweden, 43 percent is devoted to cereals, including barley, wheat, oats and miscellaneous cereals, 35 percent to green fodder and the rest to fallow field – i.e. potatoes, sugar beets, rapeseed and other crops. Among the lands dedicated to cereals, 34 percent is wheat, 34 percent is barley, 24 percent is oats and the remaining eight percent is mainly rye and rye-wheat⁸. Oats are thus the third largest crop. Furthermore, there is a long tradition of growing and exporting oats in the southwest of Sweden. One reason is that the cold and rainy climate actually is a suitable environment for oats. Another reason is that there has been a positive effect from learning and experience; the farmers in

⁷ Interview with the SFA.

⁸ According to Jordbruksstatistisk årsbok 2002.

southwestern Sweden have become good at producing oats. Already in the beginning of the 20th century, the west of Sweden was exporting oats to London to feed horses, which at that time were the main means of transportation. Because of this, oats are sometimes referred to as the “west Swedish oil”. Hence, Sweden is a fairly prominent producer of oats with long traditions. Nevertheless, oats are only regarded as the third largest crop in Sweden.

In Sweden, the main use of oats is as fodders for both cattle and horses, which account for 700-900 tonnes in total per year. The second largest use of oats is for foods and groceries, e.g. in cereals, porridge and oats-based drinks. Oats are also fractioned and used as additives in foods. In addition, oats are used in industrial applications, for example as lubricants. A small part of the oats produced in Sweden is used in cosmetics and drugs.

The two largest crops in Sweden are wheat and barley, as mentioned above. Their main advantage over oats is that the output levels are higher. One reason for this is the existence of both winter wheat and winter barley. In winter crops, the core of the crop can grow longer, which has a positive effect on the harvests. Furthermore, winter crops survive unexpected weather and temperature changes, adding to the positive effect on the harvests. Another advantage of wheat over oats is that it contains protein bridges, making wheat-based dough able to hold air and rise. This is not the case with oats and consequently it is not possible to bake, for example, bread with oats.

On the other hand, an advantage of oats over the others is that oats are considered to be the most nutritious grain, filled with fibres, vitamins, minerals and trace elements such as zinc and copper. Oats also contain beta-glucan, scientifically proved to lower the cholesterol level in the human body. Moreover, oats were the first substance to be classified as a functional food by the Food and Drug Administration (FDA) in the US. Hence, oats are a rich crop from a health point of view.

It is argued that an increased amount of financial resources has been invested in the largest crops in the world⁹, i.e. corn, soy, wheat and rice. With these investments follow specialisation and learning effects, which give those four crops comparative advantages. The more they are grown, the better the farmers will be at growing those crops in particular. Smaller crops, in square metres and output in tonnes, such as oats, are less heavily invested in and consequently less developed. This has been viewed as an incentive for investing in oats, as will be seen below.

⁹ See for example SOU 2000:103 (Swedish Government Official Report Series).

4.2.2 PREVIOUS RESEARCH EFFORTS

Several research efforts have preceded the winter oats project. Some of these previous projects and a funding body central for oats research are described below. In addition, previous attempts to breed winter oats are described.

The WF Funding Body

The West Swedish Farmers Supply and Crop Marketing Association Funding Body (WF Funding Body) was founded in 1986 and oats have been one of the main areas supported since then. In total, various kinds of research and development projects focusing on oats have received around 23-24 million SEK. In the 1990s the WF Funding Body had a vision of making Gothenburg a centre for plant biology research. At that time, the focus in Gothenburg was mainly on research with a medical focus. In relation to the plant centre vision, recruitments were made to Göteborg University's Department of Cell and Molecular Biology.

The WF Funding Body had an interest in oats research, because of the history of growing oats in the region of southwestern Sweden. Moreover, the members of the WF Funding Body had noticed that other funding institutes, e.g. hybridisation programmes, primarily funded larger crops in terms of output levels such as wheat, as mentioned above. This had the result that the WF Funding Body made investments in oats. With the vision of creating Gothenburg as a plant centre in mind, the WF Funding Body reckoned that if they started funding oats research it was more likely that oats would attract further research in the future.

The WF Funding Body has supported several oats projects during the years, as noted above, and there have been different foci. An initial project involved Svalöf Weibull, which worked with hybridisation methods to increase the fat level of oats in order to develop oats suitable for horse fodder. When it comes to horse fodders, the more fat the better. This project was followed by another related project in which the Department of Cell and Molecular Biology at Göteborg University was involved. The latter project concerned increasing the fat levels of oats beyond the abilities of hybridisation. To do so, an understanding of synthesis of lipids was needed, meaning how fat is created. In relation to this project, it was concluded that a gene transformation method was required – a way of transferring genes into a genome or activating already existing genes. During those projects, the Department of Cell and Molecular Biology, Svalöf Weibull and the SFA started to work together.

Development of the transformation technique

The plant group at the Department of Cell and Molecular Biology worked with the development of the method for transformation of genes in oats, the so-called transformation technique. In this work, oat plants from Svalöf Weibull were used as a starting point. The technique was seen as an important crossroads, being necessary in order to continue the work on fat regulation. It would have been difficult to continue the research on fat-regulating mechanisms if there was no knowledge of how to make them work in oats. In 2001, the molecular biologists managed to complete the transformation technique for oats. The transformation technique has the same logic as a Trojan horse; the genes are matured in bacterium in soil and then the oat plants are grown in this soil. The bacteria are of such a character that they go into the roots of the plant, and then the DNA finds its way into the oat plant as well. This method is known from other plants, such as rapeseed and tobacco¹⁰. The transformation method is described as follows on the web page of the oats project¹¹:

Our group have also been able to develop a Agrobacterium mediated gene transfer system for oat. We obtain transgenic oats by using mannose as a selection system during the callus formation and regeneration steps. We can also demonstrate that the Agrobacterium mediated gene transfer and integration into the oat genome actually occurs. To our knowledge, our group is the first group in the world to report a successful Agrobacterium-based transformation and regeneration of oat.

Before this project nobody had succeeded in developing the transformation technique for oats, and hence it was regarded as a significant step forward.

Plant-breeding trials to develop winter oats

Breeding refers to the starting point in the appearance of the offspring of two combined species. Breeding is sometimes referred to as hybridisation; these two words are used interchangeably. In hybridisation, the offspring is evaluated on the basis of how it looks in certain dimensions, such as straw thickness, and the “best” plants are selected for new rounds of sowing. Then they are combined by interbreeding again and, among these, the best plants are chosen again, etc. This is a traditional way of improving certain characteristics of plants, practised by farmers and plant breeders for centuries. The process normally takes ten to twelve years from initial interbreeding to a new variety.

¹⁰ SOU 2000:103 (Swedish Government Official Report Series) .

¹¹ <http://g4v.lundberg.gu.se/avenagene/>, 2005-01-26.

Until today, it has not been possible to develop Swedish winter oats with plant breeding.

The winter oats project takes partly another starting point, as will be described in detail below. This project is based on understanding exactly which genes regulate the cold-acclimatisation process of oats. However, different oat plants and plant-breeding methods are also needed in the research process. Different oat plants are needed during the process of understanding the cold-acclimatisation process, as will be seen below.

In addition, when a new plant variety is developed eventually, one must demonstrate that the variety is unique and fulfils a number of legal demands. The validation and approval process is based on breeding principles. The Swedish University of Agricultural Sciences, in co-operation with the state authority for control of new varieties in Stockholm, is responsible for this validation. It means that plant breeding, as a method, is needed finally in order to develop a new variety.

4.2.3 BACKGROUND TO THE GOAL FORMULATION

The WF Funding Body's sponsoring of the development of the transformation technique was followed by a discussion of possible applications, involving the SFA, Svalöf Weibull and the Department of Cell and Molecular Biology. These three parties had been involved in the previous oats research projects, funded by the WF Funding Body.

Svalöf Weibull knew and had experience of which characteristics the farmers would appreciate and, of equal importance, what could be done with plant breeding. Breeding is a less costly and a more common method for developing new types of oat varieties. Starting a research project to develop something that could be done in the field by breeding was not of interest to any of the three parties. The SFA contributed experiences from the farmers' needs. The farmers' needs are important from the SFA's perspective since the farmers are not only the members of the co-operative but also the owners. If the members receive good oat varieties, these might in the end increase their sales. Hence, based on what could not be done with breeding, in combination with what were regarded as important characteristics for the farmers, the goal of the winter oats project was formulated.

The overall goal of the project became to develop oats that can survive the Swedish winters, i.e. to develop winter oats. In specific, the goal meant that there were special characteristics of oats which were to be understood biologically. The characteristic in focus was the ability of oats to stand cold weather, meaning both cold temperature and frozen land with no access to

water. At that time, the overall goal was considered as an “impossible” goal, since until then there had never been any oats surviving the Swedish winters. Nonetheless, it was considered a challenge and something all the three parties had an interest in, although in different ways.

The first step in the winter oats project was to understand and identify the genes regulating the cold-adaptation process in oats. In order to do that, it was necessary to work with gene-sequence data. The three project members concluded that in order to draw any conclusions from the gene-sequence data, appropriate methods would be needed. This was the background for establishing contact with the Department of Computer Science, Skövde University, and eventually involving it in the project. Before contacting the computer scientists, the SFA knew that Skövde University had started specialising in the new discipline of bioinformatics¹².

One of the members of the winter oats project contacted the Department of Computer Science in Skövde in 2001, and the computer scientists expressed an interest in becoming involved in the project. The rationale for the Department of Computer Science to join the research project was to get access to real biological data, which is a promising condition for development of new algorithms or databases, and thus in their interest. During the spring of 2001, there were discussions on how to proceed and what to do in collaboration regarding winter oats, and in 2002 the inter-organisational project became more concrete.

In conclusion, this is the background to the involvement of these four project members in the winter oats project. Three of them had worked together prior to this project while one of them, the Department of Computer Science at Skövde University, was completely new to the other three. Up to the point of goal formulation, the SFA, the molecular biologists and the plant-breeding firm were the active parties. These project members had worked with oats before the project, and initiated this particular project; see Figure 4.2.

¹² Bioinformatics is a way of working across disciplines, building on co-operation between, on the one hand, molecular biology and medicine, and on the other hand computer science and mathematics. The winter oats project may thus be regarded as a bioinformatics research project with a practical application in oats. Regarding it as a bioinformatics project is also in line with the fact that funding partly comes from the National Research School in Bioinformatics and Genomics.

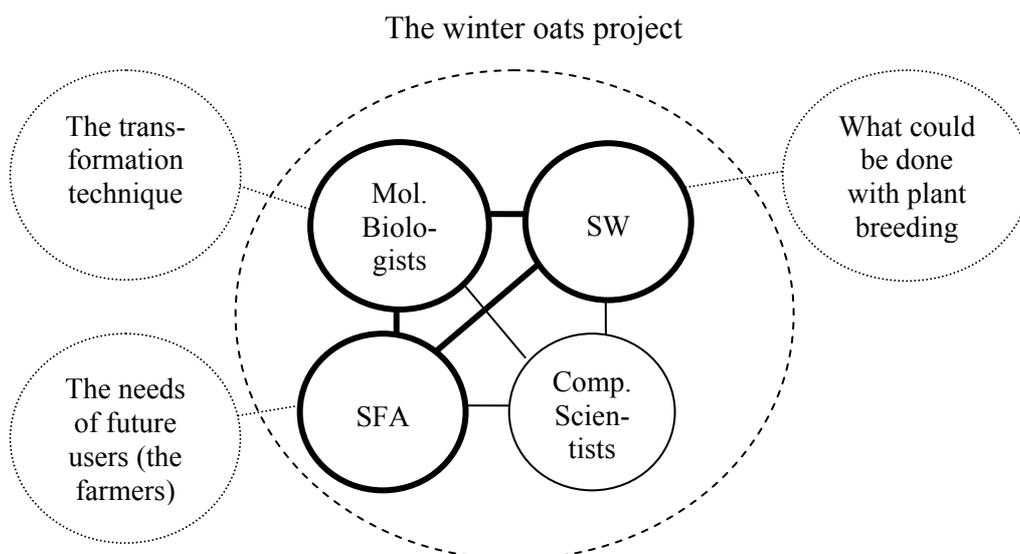


Figure 4.2: The project members and their initial interests.

In the next section, the four project members of the winter oats project are described in terms of their main activities, collaboration partners and other ongoing projects.

4.3 The four project members

In this section, the four members of the project are described in more detail. The section starts with the co-operative and continues with the plant-breeding firm Svalöf Weibull, the Department of Cell and Molecular Biology, and the Department of Computer Science.

4.3.1 THE SWEDISH FARMERS SUPPLY AND CROP MARKETING ASSOCIATION¹³

The Swedish Farmers Supply and Crop Marketing Association (SFA) is a co-operative in which the members also are the owners. Most of the members are farmers, and a single farmer pays around 10-15,000 SEK per year to be a member of SFA. It is thus important for SFA to know the farmers and understand their needs, as discussed above. One aspect important from the farmers' perspective is growing oats on a large scale. Thereby it becomes a central concern for SFA to find varieties of oats that give high-quality harvests. Of equal importance is to identify applications for oats that demand large quantities of oats, which will encourage large harvests. Today, oats-based foods account for only a small part of the oats used. Hence, SFA aims both for

¹³ <http://www.lantmannen.se/>

identifying new applications for oats that will demand large quantities and for developing reliable varieties that generate high yields.

In addition to farmers, the SFA co-operative contains a number of other companies, such as producers of products – like macaroni by “Kungsörnen”, muesli and oats porridge by “AXA” – and producers of machinery. SFA thus has a number of subsidiaries, which all are related to the process of refining crops in some way. For example, Svalöf Weibull, also involved in the winter oats project, is part of the SFA co-operative. The WF Funding Body is also related to the SFA, but the SFA and the funding body are legally separate units and the funding body is thus not a member of the co-operative.

There is at least one organisation similar to SFA in Sweden, Swedish Fodders, which has around 25 percent of the farmers. Some farmers are also independent, i.e. not members of any co-operative.

The development division of SFA

Research and development take place in various organisations and at several levels within SFA. Development takes place both at a central level in the development division and within the companies which are members of the co-operative. The central development division concentrates on activities and projects aiming to improve the conditions for the farmers. One example of an ongoing project is a project regarding bio-diesel based on ethanol. Another example is fractioning of corn, which is a new use of gluten. A third example is alternative ways of keeping the pine weevil, a noxious insect, away from the forest. The latter project started by focusing on methods for keeping noxious insects in general away from the corn, but has evolved to become specifically directed at pine weevils. A further example is the project in focus for this case study, aiming at making oats frost-tolerant. An example of research and development among the members of SFA is the research firm Biodoc, which develops oats-based drugs for curing grave stomach problems.

In addition, the development division at SFA has contacts with the Swedish University of Agricultural Sciences (SLU) in Skara. At a general level, both the SFA and the university have a joint interest in farming and some projects are important for both the organisations. For example, one project is about “precision growing”, which aims at developing tools for accurately measuring the content of the soil. In this project, techniques of geostatistics are used and the goal is to develop a small device for tractors that will govern the exact content of dung spreading.

The development division is also involved in a programme managed by the West Swedish region, called “Innovative groceries”. In this project, in addition

to the SFA, the Business Region of Göteborg and the Department of Food Science, Chalmers University of Technology, are involved. The focus of this project is new aspects of food – such as new content of food related to health aspects, i.e. functional foods, or new packing material or new production processes. Oats are one of the crops looked at in this programme, particularly aspects such as oats causing feelings of increased fullness even though the amount of food has not increased.

The development division also has connections with the American firm Syngenta, dedicated to crop protection and seed production. Syngenta is one of the largest agribusiness firms in the world with an annual turnover of 600 million dollars. In addition, the WF Funding Body has been involved in the contacts with Syngenta.

4.3.2 SVALÖF WEIBULL¹⁴

Svalöf Weibull is a firm dedicated to commercial plant breeding for Sweden and the Nordic countries. Svalöf Weibull is a member of the SFA¹⁵ and supplies plant varieties to the SFA, which in turn functions as a reseller for these varieties and has contracts with farmers to grow them at scale.

As mentioned above, breeding, hybridisation and plant improvement in general refer to the same thing: artificial insemination of plants in contrast to self-fertilisation, which is the normal way of reproduction for plants. It is only possible to plan breeding to a certain extent. This means that certain characteristics are not combinable and thus not possible to develop with breeding. An example of such a characteristic is cold resistance, a central characteristic in the oats project. One explanation for this is that it depends on multiple genes, in contrast to single gene characteristics. Several genes thus regulate the characteristic of cold resistance. At Svalöf Weibull there are groups specialising in breeding one particular crop, such as oats, wheat and barley.

The oats-breeding group

At Svalöf Weibull, one group is working specifically with oats, namely the group involved in the oats project. The group for oats-breeding works with developing oat varieties that are commercially interesting, which the farmers would like to grow, or which might be of interest from a food perspective.

¹⁴ <http://www.swseed.se>

¹⁵ SFA owns 60 percent of Svalöf Weibull while the other 40 percent is owned by BASF: <http://www.swseed.se/>, 2005-10-31.

The group focusing on oats-breeding travels around, looks at land in different climates, and thus has good contacts with farmers. The oats breeders have managed to double the breeding pace thanks to connections with plant breeders in Chile and New Zealand. These countries are good geographical places for experiments because of the climate and the fact that they have summer while the Scandinavian countries have winter. It is thus possible to try out new types of varieties by breeding in Sweden during the summers and on the other side of the globe in the winters. The plant breeders from the other side of the globe do not commonly try out varieties here.

Svalöf Weibull and SFA, before this particular oats project, worked together in other development projects. One example is a project where the firm Cerelia, also part of the SFA co-operative, collaborated with SFA and Svalöf Weibull on developing a special variety of oats for muesli. Cerelia develops and produces mueslis. In that project, the three of them had meetings where they discussed different types of oats and their characteristics. The new oat variety, *SW Betania*, was focused upon, which resulted in joint experiments. In this work, Svalöf Weibull sowed small quantities of oats and then sent them to Cerelia, which investigated how they fitted into the muesli. Making muesli places certain demands on the oats; they should, for example, contain a high level of betaglucan and be soft enough. Today, muesli based on the oat variety SW Betania is available.

4.3.3 THE DEPARTMENT OF CELL AND MOLECULAR BIOLOGY¹⁶

The Department of Cell and Molecular Biology is a department at Göteborg University consisting of four research areas: genetics, interface biophysics, microbiology and molecular biology. The focus of the respective research groups is diverse, but they comprise a broad range of bio-molecular, biomedical and bioinformatic research. Education is also an important part of the department. Hence, the laboratories and experimental equipment are not only available for research but also used by students. There are several research groups in each research area; for example in microbiology, groups work on different aspects of yeast, such as salt tolerance, proteome analysis and environmental responses. In the area of molecular biology, one research group focuses on plants, and this is the group involved in the oats project. It is the only group at the department that mainly concentrates on plants.

The department is located in the same premises, the Lundberg Laboratory, as other related departments, e.g. the Department of Molecular Biotechnology at Chalmers University of Technology. In total, there are hundreds of researchers belonging to different research groups working in the Lundberg Laboratory.

¹⁶ <http://www.cmb.gu.se/>, <http://www.molbio.gu.se/>

The different research groups of the Department of Cell and Molecular Biology, and at the Lundberg Laboratory in general, have their offices and teaching responsibilities in common. Thus they can pursue their research interests or view of creating synergies by working together.

The plant research group¹⁷

There is one research group focusing on plants within the Department of Cell and Molecular Biology, as described above. The two plants studied in this group are *Arabidopsis thaliana* and oats. The oats-based research of the plant group is directly involved in the winter oats project.

The research on the *Arabidopsis thaliana* plant has been ongoing for many years, and the understanding of the genes active in this plant is extensive. These genes are both identified and known, which make it a good model plant. Thus, by investigating it, other plants and characteristics may be understood.

The plant group has discussed collaborative projects with another research group at the department working with yeast. Yeast is argued to be an appropriate organism to work with in order to understand frost resistance. In addition, a dialogue has been established with a research group working with worms, also regarded as a good organism to study in understanding the mechanisms behind cold adaptation in oats. A further collaborative partner is a research group in Canada working with wheat hybridisation. Cold adaptation in wheat is assumed to be genetically close to that in oats, particularly frost resistance in oats. The plant research group meets other researchers on a continuous basis at conferences and workshops, which can result in the establishment of new contacts.

4.3.4 THE DEPARTMENT OF COMPUTER SCIENCE¹⁸

The University of Skövde is a rather young regional university, established in 1977. In 1994, the university was in a phase of expansion and the principal came up with the idea to combine subjects in order to create new programmes and thereby attract students. A task group was initiated to investigate the possibilities of starting a programme where biology and computer science were combined. In this task group were people from the Department of Computer Science at Skövde University, from the School of Physics at Chalmers University of Technology, and from Lund University.

¹⁷ Today one of the research groups at the Department of Cell and Molecular Biology is “Molecular biology”, to which the plant research group belongs: <http://www.molbio.gu.se/>, 2006-02-09.

¹⁸ Computer science is now a part of the newly formed School of Humanities and Informatics instead of being a separate department: <http://www.his.se/>, 2005-10-31.

During this time, people from the department visited two universities in the US: the Santa Fe Institute, New Mexico, and an artificial life centre at Stanford University, which had education in related areas. In addition, Lund University was visited to see how education in related areas was built and organised. Based on the work in the task group it was decided to start an undergraduate education, which was put into practice in 1997. The name of the education, which originally was to last for four years and today lasts for three, is the *Bio-Computer science programme*¹⁹. In this programme, one of the areas of specialisation for the final year is bioinformatics. Hence, at the Department of Computer Science a focus on bioinformatics has developed not only in relation to education but also in research.

The bioinformatics research group

There is a group of researchers at the Department of Computer Science focusing on computer science and biological data, the so-called bioinformatics research group. Some of the researchers of this group are involved in the winter oats project. In the group, there are no other projects similar to the winter oats project. The other members of the bioinformatics group work on publicly available data; thus, there are no biologists involved in the other projects. Instead, they search the Internet for data, e.g. published DNA sequences in public databases or in scientific articles, and based on these, they formulate their own research questions about the data sets. A problem with public data is that the quality is variable and it is difficult to know without having any contact with biologists whether a certain passage in the data has a biological explanation or is due to errors. Therefore, at the department in Skövde this type of project with both biologists and representatives of the future users is unique.

From the computer scientists' perspective, there are several advantages with having molecular biologists involved in the winter oats project. One of the advantages is that the biologists formulate what issues they are interested in and then it becomes clear what to focus on. In addition, the molecular biologists may be able to explain strange passages in the data sets. This is comforting since it may ensure that the data are correct, or sometimes the molecular biologists state that there is something wrong with the data. On the other hand, the molecular biologists' interests can be very specific. Working in the winter oats project has the effect that the research issues become specialised, which has resulted in limited exchange with the other research groups at the department.

¹⁹ Thirty students were accepted in 1997 and 20 graduated in 2001; two of these chose to specialise in bioinformatics. Both of them are today employed as PhD students at the department and one of them is involved in the winter oats project. During the second year the education was given, 10-12 students chose bioinformatics as a final-year area of specialisation.

There is another project at the Department of Computer Science financed by the national research school, which might change the picture of the oats project as unique. In addition, there are discussions with a research group at the Royal Institute of Technology, but it is not clear what will happen in that potential project.

In the next section, the research process carried out by these four project members in the winter oats project from 2001-2004 is described.

4.4 Research activities in the project

There are a number of research activities in the winter oats project, constituting four research phases. The project members, the organisations they belong to, and some external organisations are involved in the activities. The four main research phases are: (1) preparations for sequencing, (2) sequencing, (3) EST-data analysis and (4) preparations for microarray analysis. The activities during the phases are described in detail below.

4.4.1 RESEARCH PHASE 1: PREPARATIONS FOR SEQUENCING

One important stage in developing winter oats is the identification of genes that regulate frost tolerance, including the tolerance to both cold air and frozen lands and, thereby, a lack of water. To achieve this, the firm MWG Biotech AG was engaged as a supplier to perform sequencing and clustering analyses. Sequencing refers to deciding the order of the nucleotide bases of the oats genome. Knowing the order is a first step towards identifying the genes and understanding their function. In order to sequence oats, greenhouse experiments and oat-plant preparations were made as starting points. These preparations were ongoing during 2001.

Greenhouse experiments

A number of greenhouse experiments were done by the molecular biologists to prepare the oat plants to be sequenced. The greenhouse experiments were performed outside the Lundberg Laboratory close to the university department of the molecular biologists. The oat plants that were starting points for the greenhouse experiments came from a project member, the plant-breeding firm. The firm could access different kinds of oat varieties from the international breeding firm of which it is part. Some oat varieties were English winter oats, e.g. Gerald, which are commonly used in Great Britain. There were also some oat varieties coming from the US, e.g. Nebraska varieties that were accessed via Svalöf Weibull. In addition, the plant-breeding firm contributed winter oats from Russia, which were found via a database on the Internet.

During the greenhouse experiments, it was observed that if the oat plants were moved from the ideal temperature of +20°C to an environment at -15°C, no plants survived. The oat plants were thus first put in +20°C, next moved to +4°C for three hours and after that to -15°C. Apparently some of the plants then survived, because of the time they were given to acclimatise. This was an important observation that was not known before the greenhouse experiments. The observations were carefully documented with e.g. photographs of the oat plants in different phases. It was clear that the plants go through an acclimatisation period that makes them resistant to cold weather. It was concluded that understanding the acclimatisation phase was a central issue for identifying the genes that regulate frost tolerance. The genes that start up the acclimatisation phase were assumed to be crucial for the development of frost-tolerant oats. Hence, understanding the initiation of the acclimatisation phase that the plants go through became a central concern.

A mixture of oat leaves and roots of ideal temperature and the plants that had gone through the acclimatisation phase were used as a starting point. Thus, plants from three points in time were combined. Two types of oats, the UK winter oat variety Gerald and Swedish spring oats, were used from the greenhouse experiments as a point of departure for sequencing. The plants were around three weeks old when they were prepared. The oats-based mixture of leaves and roots was carefully prepared in test tubes with several fluids, above all a particular enzyme in order to generate total RNA. The biologists did this in a cost-effective way by not removing all the other genes than the ones active particularly in the acclimatisation phase. The test tubes were sent to MWG Biotech in 2001. In sum, well-prepared test tubes were delivered to MWG Biotech and provided the starting point for the sequencing.

Field tests

The winter oats from other parts of the world provided a point of departure for field experiments managed by the oats-breeding group at Svalöf Weibull. Those field experiments are still ongoing, since plant breeding is a long-term process. During the first winter the plants were tested, one of the *Nebraska* varieties survived to everyone's surprise, since the first winter was an extraordinary cold winter. Thus, only one oat variety survived the first winter. Only one was not regarded as negligible; instead the project members were pleased that one variety in fact survived. The following winter, several varieties survived partly due to their characteristics and partly because the winter was milder. In addition, the *Nebraska* variety surviving the first winter also survived the second winter. The field tests are ongoing and have yet to show whether any, and which, oat varieties will endure.

The SFA is also partly involved in starting up the field tests of winter oats, as it represents the farmers and takes an interest in the results. The field experiments may be seen as an activity parallel to the greenhouse experiments and preparations for sequencing, since it was initiated in parallel.

Involved project members in the preparations for sequencing

In the first research phase, focusing on preparations for sequencing and starting up the field tests, the molecular biologists and the plant-breeding firm were the parties mainly involved; see Figure 4.3.

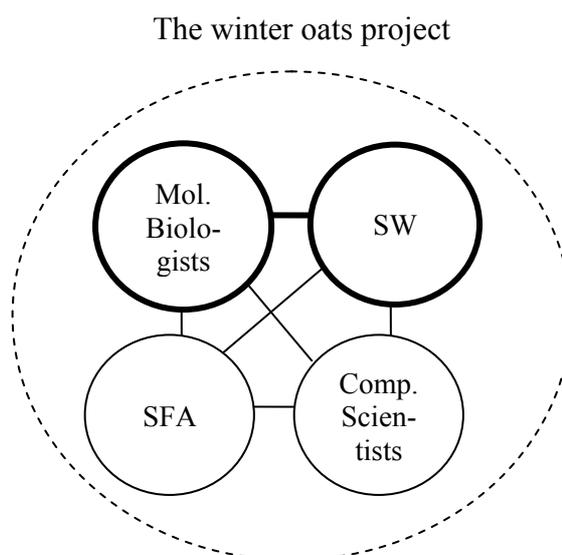


Figure 4.3: The project members involved in the first research phase.

While the plant-breeding firm contributed material for varieties, the molecular biology department prepared the oats material to be used as a starting point for sequencing. In addition, the plant-breeding firm set up and initiated field tests based on winter oats from abroad. In the next section, the research phase of sequencing is described.

4.4.2 RESEARCH PHASE 2: SEQUENCING

The winter oats project engaged an external firm, MWG Biotech, as a supplier of sequencing and additional analyses of the sequence data. The reason why MWG Biotech was engaged as a supplier was simply on the criterion of lowest price. Initially one of the project members, the molecular biologists, searched the Internet for potential suppliers of sequencing and around twenty potential suppliers were found. Out of those twenty, two were chosen for further evaluation. Separate meetings were organised in which their offerings and services were presented. Eventually MWG Biotech seemed most appropriate, based primarily on the price of their offerings. At that time, in 2001, MWG

Biotech had a sales office with sales staff in Sweden. Today the Swedish office has closed down and the Danish office is serving the Scandinavian countries.

The price for the services purchased was between 600,000 and 700,000 SEK. The purchasing process dragged on due to formal purchasing procedures. The purchase was a regulated process due to the high price based on the university regulations.

The sequencing firm is described below, followed by a description of the analyses it performed for the winter oats project. In addition, there are some plans and preparations going on within the project during this phase, also described below. In the final section, the results from the sequencing delivered to the project in May 2002 are described.

MWG Biotech AG²⁰

MWG Biotech started as a competence centre in Germany in March 1996²¹. The sequencing department currently consists of 22 people, some located in Ebersberg, Germany, and some in High Point, North Carolina, US. The sequencing machines run 24 hours a day and generate approximately 6.5 mega base raw sequencing data. Depending on the size of the genome, sequencing of a complete bacterial genome takes three to five months.

The service used by the winter oats project is called EST sequencing, and is described on the web page in the following way:

Do you want to have fast access to genomic information of a eukaryotic²² organism for which nothing is available, yet? Would you benefit from knowing which genes are expressed in a tissue under certain circumstances such as organ development or under stress? To establish the expressed genome of a eukaryotic organism you can order sequencing of cDNA clones from both the 3'- and the 5'- end²³ plus the corresponding bioinformatic analyses (clustering and assembly) from MWG.

This description of the EST sequencing service suited the analyses of the winter oats project in three respects. First, oat is an organism that is not well researched, which meant that most of the oat genome was unknown. Second,

²⁰ <http://www.the-mwg.com>

²¹ In 1998, people from MWG Biotech participated in the first publicly financed genome-sequencing project. MWG Biotech contributed to the sequencing of chromosomes II and V in the *Neurospora crassa* project (bread mould).

²² All organisms with a cell nucleus are eukaryotic, in contrast to e.g. bacteria.

²³ DNA is directional, meaning that it has a head (called 5') and a tail (called 3') (Hunter, 1993).

the winter oats project was interested in oats under certain circumstances, namely under cold stress. Third, oats were sequenced from one side to the other, i.e. from 3' or 5'. The starting point for sequencing is important because each set of DNA can be read in four different ways, discussed below in detail. Sequencing is a matter of costs, and sequencing from one end is a less costly alternative.

Description of MWG Biotech analyses

MWG Biotech performed three types of analyses: sequencing, clustering and assembly analysis, consisting of a number of sub-steps.

Generation of cDNA libraries

Sequencing starts with transforming total RNA, i.e. the oat mixture delivered in test tubes, into complementary DNA (cDNA). So-called cDNA libraries are generated. The reason for transforming RNA into cDNA is that the latter is more stable to work with.

Sequencing

The actual process of sequencing follows the generation of cDNA libraries. The oat plants are sequenced on the basis of the principle of *expressed sequence tags* (ESTs), which means that the sequenced oat is delivered in terms of short pieces of the active genes, i.e. ESTs. The ESTs are the most important results from the sequencing, and after the sequencing they are referred to as the raw data.

At MWG Biotech, sequencing is an automatic process done at large scale. Sequencing includes a number of different steps performed by automated equipment. A main issue during sequencing is thus handling the equipment properly.

Chromatograms – quality control of sequence reactions

There is a first quality control step of the raw data after sequencing, based on chromatograms. Chromatograms are like diagrams in which the nucleotide bases of the ESTs are laser-detected. The four different nucleotide bases, i.e. ACTG..., are visualised in different colours. The quality evaluation is based on how the peaks of different colours look in the chromatograms. MWG Biotech does the quality evaluation of the sequences with the tool Trace Tuner 2.0, supplied by the American firm Paracel.

Clean-up of the data

In the clean-up phase, the raw data are “cleaned” in order to get proper sequence. Cleaning the data means e.g. that contaminating sequences are removed. The Paracel filtering package is used for that purpose, according to the web page of MWG Biotech. For example, it may be remnants of the

plasmid such as *E. coli*, the bacteria used in the sequencing equipment, mitochondrial and rRNA sequences that are removed. The plasmids may have self-reacted, and if so, they are cleaned from the data. If there are many repeats, e.g. ATATATA, the repeats are masked. In addition, low-complexity regions and PolyA tails are masked.

PHRED value – the second quality measurement

The data quality is also measured with the PHRED value, which is based on a logarithmic scale between 0 and 50. The value 20 means that one nucleotide base out of 100 may be incorrectly sequenced by the equipment; and in the same manner, 30 means that one out of 1000 may be incorrect. The PHRED value normally lies around 20–30. According to the MWG Biotech web page, “*the average read length is in the range of 600 to 800 bases PHRED 20*”²⁴. It means that at least the level of PHRED 20 should be reached in the EST sequencing.

Clustering

The clean-up is followed by the clustering analysis, where the ESTs are matched together. MWG Biotech did the matching process with a software program called the Paracel Transcript Assembler (PTA). PTA is based on an algorithm, the Hayes algorithm, managing to match all sequences against all. The Hayes algorithm performs pairwise alignments in regions of 1000 nucleotide bases and, when the match is > 93 percent, the ESTs are put in the same clone²⁵. When the clones are alike, they are grouped together into contigs²⁶. Some of the clones will not match any of the others; they are treated separately and referred to as singlets.

In the cluster analysis, the contigs are analysed as clusters, visualised in Figure 4.4. The raw data consist of several contigs and singlets, while the contigs concluded to match each other form clusters.

²⁴ <http://www.the-mwg.com>, 2004-02-19.

²⁵ A clone refers to “*a collection of identical DNA molecules derived from the same DNA template*” (Zweiger, 2003, p. 235)

²⁶ A contig (contiguous clone map) is “*a series of overlapping DNA clones of known order along a chromosome from an organism of interest...*” (Lesk, 2003, p. 75)

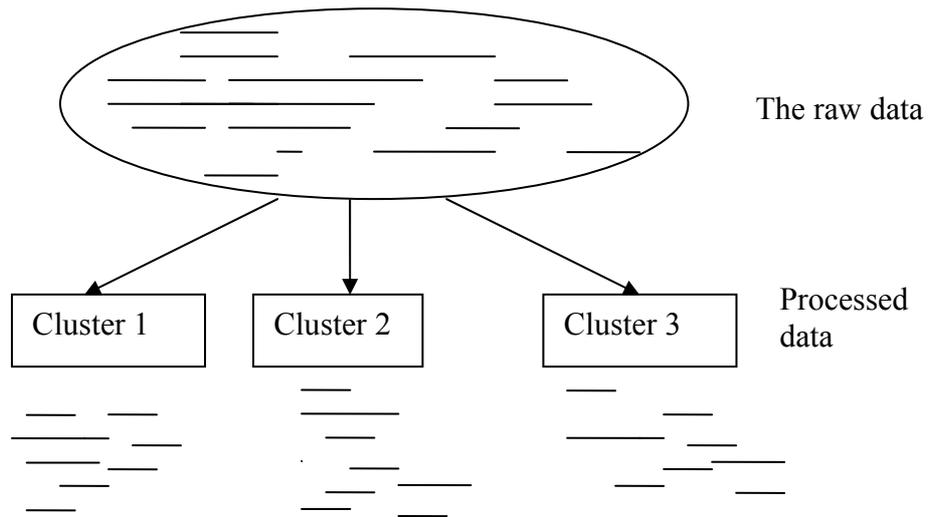


Figure 4.4: The clustering process from raw data to processed data (adapted from the MWG Biotech webpage²⁷).

Hence, the processed raw data consist of a number of clones grouped together into contigs and singlets. The contigs and the singlets are considered as candidate genes.

Assembly process

In the assembly process, the clustered contigs are assembled together into genes. This is done with a program, CAP 4, included in the Paracel Transcript Assembler. CAP 4 is able to put the overlapping sequences together. However, what the program cannot do is to put together the sequences that follow after each other. See Figure 4.5.

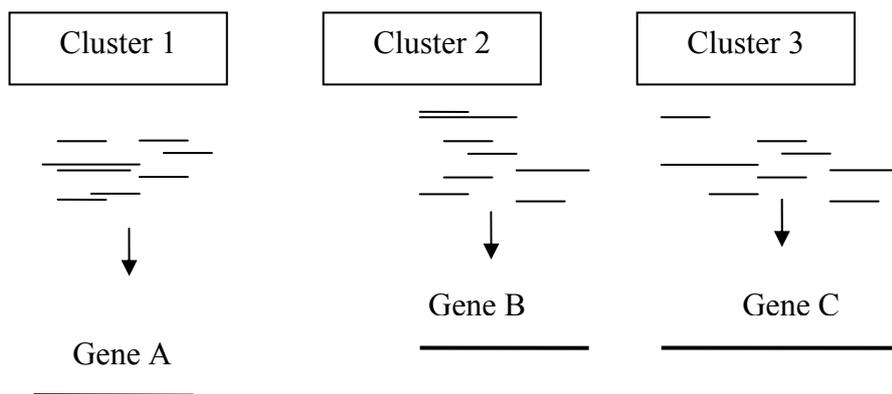


Figure 4.5: The process of assembling ESTs into genes (adapted from the MWG Biotech webpage²⁷).

²⁷ <http://www.the-mwg.com>, 2004-02-19.

MWG Biotech also offers three additional sets of analysis: Manual checking of clustering results, Matching genes with physiological functions, and Gene Ontology Classifications. But these were not purchased by the winter oats project. The three steps are bioinformatics-oriented types of analyses, and were instead performed within the project by the project members.

The results of the analyses, planned to be delivered early in 2002, were delayed several times and finally delivered in May 2002. While waiting for the data, the project members performed different kinds of preparations and plans for what to do with the data when received; these are described below. Afterward comes a description of the results from the analyses performed by MWG Biotech.

Plans and preparations for the data arrival from MWG Biotech

The computer scientists did not take part actively in the greenhouse experiments and field tests. However, they were all the more engaged in preparing and planning for the arrival of the results from MWG Biotech. Initially the molecular biologists explained and described for the computer scientists what the forthcoming data would look like, with a starting point in the test tubes that the biologists had delivered to MWG Biotech. Furthermore, the computer scientists tried to understand how the molecular biologists planned to analyse the data and what type of questions the biologists would like to be answered by the data. In addition, the computer scientists formulated their own ideas and interests in the forthcoming data set.

The descriptions of the coming data set were needed to systematise and organise the data in the best possible way when it arrived. The discussions before the data arrival, taking place about every third week between the molecular biologists and the computer scientists, were about getting the best possible description of the coming data. The forthcoming data set was in general expressed, during those discussions, in terms of libraries of the four clones: cold-adapted, not cold-adapted, winter oats and spring oats, illustrated in Figure 4.6.

	Ideal temp.	Cold-acclimatised
Spring oats		
Winter oats (Gerald)		

Figure 4.6: The four types of oats sent to the sequencing firm.

In addition to trying to understand what type of data was coming, the computer scientists derived a theory-based idea of how to find the cold-associative genes in the coming data. In particular, a master thesis student, supervised by one of the computer scientists, did a formulation of an algorithm for exclusion of genes which were not cold-associative (Thorburn, 2002). In the thesis a method was presented that can be used to perform rapid gene prediction of function-specific genes in EST data, as well as results and accuracy estimation of the method. Rapid gene prediction involves searching published articles and public databases for key words related to cold association. Different types of search phrases were used, including obvious words like “cold” but also part of sequences from cold-associative genes identified in other organisms.

The thesis consisted of three steps of which the first was done before the access to the data. The three steps were: (1) design of a database with genes known to have cold-associated properties based on genes published in the public domain in both scientific journals and databases; (2) use of the database to identify homologies²⁸ with the raw EST-data set, which generated a list of candidate genes regulating cold resistance; (3) verification of each of the candidate genes performed in order to estimate accuracy in the rapid gene prediction and to support removal of candidate genes which were not cold-associative. The verification was built upon searching the putative sequence against protein databases and DNA databases to see if the matches were cold-associative or not. The master thesis showed that 135 candidate genes were identified from the data. Of these, 103 were verified by additional searches to be cold-associated. Hence, the method was prepared before the EST data arrived, but it was tested and the results²⁹ were verified when the data came²⁹. The results from the thesis were used as a point of departure in the EST-data analysis.

Results from the MWG Biotech analyses: the EST data

In May 2002, the data were delivered. Their arrival was seen as an important step in the winter oats project, and to some degree all the work until then may be seen as preparations for the data. In this section, the results from the MWG Biotech analyses are described. Table 4.1 below illustrates the results delivered.

²⁸ Homology = Similarity attributed to descent from a common ancestor (<http://www.ncbi.nlm.nih.gov/BLAST/>, 2004-03-03).

²⁹ Master thesis abstract on <http://www.ida.his.se/ida/htbin/exjobb/2002/HS-IDA-MD-02-307>, 2003-09-23.

Table 4.1: Results delivered by the sequencing firm.

Supplied results by MWG Biotech:
Raw data <ul style="list-style-type: none">• Consisting of 10,000 ESTs
Processed raw data <ul style="list-style-type: none">• The ESTs clustered together into 4487 candidate genes
Physical material

The data set that MWG Biotech supplied consisted of about 10,000 ESTs, referred to as *the raw data*. The exact numbers of ESTs supplied were 9896, but this figure still varies and, for this reason, the approximate figure of 10,000 ESTs is used. However, 10,000 ESTs do not equal 10,000 genes, since ESTs are small pieces of genes that need to be put together in an appropriate way in order to constitute genes. In the oats-EST data, the average EST length was 600-700 nucleotide bases, which implies a rather high performance level of MWG Biotech's equipment.

Based on the clustering analysis, MWG Biotech delivered 4487 candidate genes. These candidate genes are referred to as the *processed raw data*. The processed raw data consisted of the ESTs grouped together, based on homology search methods. The homology searches were done with the tool PTA into contigs and singlets, constituting candidate genes.

MWG Biotech also supplied physical material, e.g. glycerol stocks, to enable the project members to grow the clones again themselves. Both the raw and the processed raw data were delivered via a secure solution based on an FTP server and the physical material was delivered by normal mail.

The project members and external firms involved in sequencing

During the sequencing phase, an external organisation, MWG Biotech, performed the main part of the work. In the meantime, both the university departments did plans and preparations for the arrival of the results from the sequencing. MWG Biotech is regarded as a supplier of a standardised service and thus not as a collaboration partner. During the subsequent phases, there will be some additional interactions with MWG Biotech. Hence, the three parties actively involved during sequencing were MWG Biotech, the molecular biologists and the computer scientists. See Figure 4.7.

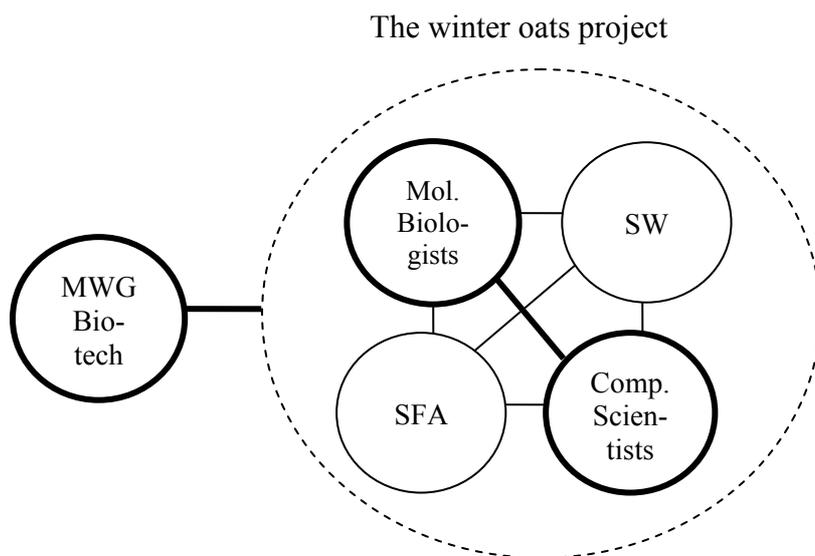


Figure 4.7: Project members and external organisations involved during sequencing.

In the next section, the results of the sequencing are used and analysed.

4.4.3 RESEARCH PHASE 3: EST-DATA ANALYSIS

Using the EST data for identification of cold associative genes is the central issue in the third research phase. As seen above, MWG Biotech delivered raw data and processed raw data. These are both referred to as “the EST data” in the text below unless there is a specific aspect discussed of either the raw data or the processed data.

Initially the involved university departments tried to get an overview of the EST data and to get a picture of what was delivered from MWG Biotech. In this work, they followed an overall principle of trying to reduce the EST data in order to come closer to the cold-adaptation genes. In this way, a number of tools were used and developed. After a while, there seemed to be some problems with the EST data, which the project members handled in different ways.

Overall, the project members performed a number of steps during the EST-data analysis. Below, the principal way of analysing the EST data is described, followed by a description of the tools that were used. In the subsequent section, the identified problems are highlighted and the specific steps of reducing the EST data are explained. Then, the project members involved are discussed and, in the final section, plans for commercialisation and experimental testing that never were realised, as well as the project members involved in these activities respectively are described.

The principal way of analysing the data

There are hundreds of genes involving cells, cell walls, proteins and ion pumps active in the process of cold adaptation. It is thus a very complex pattern of genes interplaying, far from easily understood or explained. The ambition was to be able to understand the mechanisms starting up the process of cold acclimatisation. Understanding the initiation of cold adaptation implies that the whole cold-adaptation process would not be needed to be understood fully. Hence, studying the initiation might be seen as a “short cut”.

There are four overall steps³⁰ in the process towards identifying the genes regulating frost tolerance; see Figure 4.8. The first step aimed to understand and observe which ESTs among the 10,000 originated from the same gene; it meant distinguishing which ESTs were overlapping. This was done on the basis of the cluster analysis performed by MWG Biotech, to be described in more detail below.

The second step included understanding how many unique genes there were among the clustered ESTs; some of the clusters may also be overlapping, and consequently they then belong to the same gene. Already during this step, some genes were identified.

The third step was to investigate what types of functions those identified genes regulate. It meant understanding which proteins the genes code. During both the second and the third step, the publicly available tools and databases were used frequently.

The fourth step, not fully completed yet, is to understand which of the identified genes may initiate or regulate the cold-adaptation process.

- | |
|---|
| <ol style="list-style-type: none">4. Cold-adaptation genes?3. What are the genes? (What does the protein do?)2. How many genes are there?1. Which ESTs originate from the same gene? |
|---|

Figure 4.8: Four steps in EST-data analysis towards identifying cold-adaptation genes in oats.

In the next section, the different types of tools used in this process are described, followed by a section that describes the identified problems with the data. Then the gradual reduction of the 10,000 ESTs is described.

³⁰ Formulated by one of the members of the project.

Publicly available databases and software

There are several different types of tools used in analysing the EST data. Two main types are software programs and public databases. They are often used in combination, for example a software program used for searching a database. Many of the tools used in the winter oats project are available in the public domain, which means that they are free of charge and possible to download or access from the Internet. The number of tools and databases available on the Internet is enormous, so it is not a straightforward choice which ones to use. Databases and software commonly used in the winter oats project are those supplied by the National Centre for Biotechnology Information.

The National Centre for Biotechnology Information (NCBI) is an American organisation, established in 1988 as a national resource for molecular biology information. NCBI assumes responsibility for the GenBank sequence database, which is a huge database with sequences and their functions, submitted by individual researchers all around the globe, and with international partners – the European Molecular Biology Laboratory (EMBL) and the DNA Database of Japan (DDBJ). The GenBank builds on research groups submitting their results to these databases. In addition to the GenBank, NCBI supports and distributes a variety of databases for the medical and scientific communities. These include for example the Online Mendelian Inheritance in Man (OMIM) and a journal database called PubMed, which has a web search interface with access to 11 million journal citations. Moreover, NCBI has a search and retrieval system called Entrez that provides users with access to sequence, mapping and taxonomy of structural data.

NCBI has developed BLAST, a program for sequence similarity searching, frequently used in the project. The BLAST (Basic Local Alignment Search Tools) programs are a set of sequence comparison algorithms introduced in 1990, used to search sequence databases for optimal local alignments to a specific sequence, called a query. Today the BLAST programs include five different programs³¹, building on the same algorithm. The core of the BLAST services is to take a protein or a nucleotide sequence and compare it against a selection of NCBI databases. The BLAST algorithm was written to balance speed and sensitivity for sequence correlations.

The most frequently used BLAST program in the winter oats project is BLAST X, which “*compares a nucleotide query sequence translated³² in all six reading*

³¹ blastp, blastn, blastx, tblastn, tblastx: see <http://www.ncbi.nlm.nih.gov/BLAST/>, 2004-03-03

³² Translation is according to Zweiger (2001, p. 238) the process of producing a chain of amino acids whose sequence is derived from nucleotide sequence of a mRNA molecule.

*frames against a protein sequence database. You can use this option to find potential translation products of an unknown nucleotide sequence*³³.

A nucleotide query sequence refers to the specific oats-EST sequence that is used as a starting point in the search. Reading frames means that the sequence is read in six different ways, i.e. with three different start nucleotides in both directions. This refers to all possible reading directions of a sequence. Hence, when the sequence is read in six ways, there are no possibilities to fail to see any genes in the sequence. Then this protein sequence is searched against a protein sequence database. The quotation above also highlights that it can be used for finding out what type of proteins the sequence codes for, a way of identifying a gene.

A difference among the six different BLAST programs is what databases they can be combined with. For example, the T BLAST X program cannot be combined with the non-redundant database on the BLAST web because it is too computationally intensive. A non-redundant database is a database where each DNA sequence or protein is represented only once. It means that, to get access to and search against all the published sequences on the BLAST web, the appropriate BLAST program needs to be chosen. There are also protein and DNA databases provided by NCBI used in the winter oats project. Besides those, there are other databases and tools used, for example Interpro, a database containing publicly available protein sequences.

It is not only difficult to decide on exactly which tools to use, but it is also a complicated matter to adjust the different settings in the programs. In BLAST it needs to be decided what species the searches should be set against. It is possible to search against all species represented, all plants, or only *Arabidopsis thaliana*. The reliability of the searches also needs to be adjusted manually in terms of a number of parameters that need to be set up. The possibility to search against the *Arabidopsis thaliana* plant is used by the project members in relation to another ongoing research project, described below.

When a database is searched and there is a “hit”, it might be easy to jump to conclusions. However, there are huge uncertainties when comparing sequences. The database searched against might contain errors, which result in hits that are not really hits. Thus, not only choosing the database, the parameters in the database and program to search are complicated matters, but also concluding that there actually is a hit.

³³ http://www.ncbi.nlm.nih.gov/Education/BLASTinfo/query_tutorial.html, 2004-03-03

Development of the EST database

There are databases developed within the winter oats project. One of those databases has a structure built around each EST. Every EST in the raw data has its own place in the database and the ESTs are also related to each other in terms of this EST is similar to this one etc. The EST structure is also the reason for calling the database “the EST database”. The reason why the database takes its starting point in each EST instead of each identified gene is that each gene can have a number of ESTs referring to it. If the database had taken a starting point in each gene, the information of how many ESTs were referring to each gene would be lost.

The goal with the EST database is that it should be possible to click at one EST and display all the attached sources of information. If all related objects show similar results or point towards one type of function, the database may enable an indication of gene functions. For example, results from BLAST searches in the NCBI databases are attached to each EST in the database.

The EST database thus contains sorted EST sequences in combination with new information. It becomes possible to get an overview of the EST data by using the database, but also to find specific knowledge about one EST or one gene. Important characteristics of the database are the ability to perform searches and traceability, i.e. finding out from where the piece of information came from.

The database is constructed with a web interface and built with SQL and standard tools, and so-called open source software is used. Today the database is used internally as a tool for working with the EST data. However, at one point in time there were plans for commercialising the developed database. Those plans are described below.

Use of related research

Results from related research areas were also commonly used in the project. Above all, research about the model plant, the *Arabidopsis thaliana* plant, is used since the model plant is well researched in terms of identified genes and known functions. In the public databases, there are enormous amounts of articles about the model plant. As seen above, it is possible to choose the model plant as an option to search against in the databases.

Another reason why the *Arabidopsis* plant is frequently used is that one of the project member groups, the molecular biologists, is involved in a project focusing on the model plant. Furthermore, the *Arabidopsis* plant is an appropriate plant to work with since it grows fast and thus has short life cycles. It may thus be possible to observe and learn from it during a rather short

period. If a gene is assumed to be central for frost tolerance in oats, that or similar genes may be identified in the *Arabidopsis* plant in which those genes might be known. Based on their function in *Arabidopsis*, it might be possible to draw conclusions about the gene of interest in oats. Specific examples where the *Arabidopsis thaliana* plant is used are seen below in the section about reduction of the EST data.

In addition, other characteristics and plants are used as references for the winter oats project. For instance, dry and salt resistance is assumed to be close to the frost tolerance genetically. Consequently, published articles regarding other types of stresses are of interest. For example, an article about salt stress in tomatoes was relevant for and provided inspiration to the winter oats project. Research regarding wheat is also assumed to be of relevance for the project. One of the project member groups, the molecular biologists, has had, since before this project, contacts with a research group in Canada, specialised in wheat breeding. Their conclusions regarding the wheat plant's cold-adaptation process were also used as inputs to the project.

Identified problems with the EST data

After a few months, the project members suspected that there were some problems with the data. There seemed to be a problem with the processed raw data. When the data were analysed and tested in different ways, it was concluded that each cluster was not unique.

Increased understanding of clustering procedures at MWG Biotech

The project members concluded that more knowledge regarding what analyses MWG Biotech had done was needed. At that time neither the molecular biologists nor the computer scientists knew what types of programs had been run at MWG Biotech, or how or why. The starting point became the program Paracel Transcript Assembler that MWG Biotech had used and trying to understand how the clustering analysis was made.

An old version of a Paracel Transcript Assembler (PTA) manual was found on the Internet. The PTA manuals are difficult to get hold of if the PTA program is not bought, which is why the Internet was searched for information. They considered buying the program but did not because of the high price³⁴. Besides, the winter oats project had paid MWG Biotech for performing accurate analyses with the commercial tool PTA.

³⁴ For an academic research group, a licence for PTA costs around \$36,000 per year, which was above the budget of the oats project.

From reading the old manual, it was understood what types of questions were relevant to ask MWG Biotech regarding how the PTA was used. Another issue noticed when reading the old manuals was that the PHRED value is of high importance in the clustering analysis. An important matter that should be handled is to put a threshold of 20 on the PHRED value. It ensures that only sequences longer than 100 nucleotide bases are included in the analysis. MWG Biotech had not done this in the case of the oats sequencing. It was concluded that the analyses made by MWG Biotech were not made at acceptable levels, and that too short ESTs were included in the cluster analysis.

Eventually, MWG Biotech was contacted in order to learn more details about the oats clustering analyses. When it was known, based on the old PTA manual, what questions to ask, answers were received – but no more than that. The effects of the questions and comments from the oats researchers regarding the quality of the analyses were limited. However, eventually the identified weaknesses were financially refunded. The winter oats project in the end did not have to pay full price for the analyses where there were obvious shortcomings in the data. The winter oats project's account was closed at MWG Biotech and because of that, it was not possible to redo the analyses.

One effect of the incomplete setting of parameters was a discussion with the Royal Institute of Technology in Stockholm regarding possibilities to use their core facilities to run the analyses again. From the oats project's perspective, it would be interesting to see whether the results would have been different or not. This discussion with the researchers at the Royal Institute of Technology developed to compensate for the incomplete set-up at MWG Biotech. However, the plans were never realised.

Actions against the identified problems

It was discovered that too short ESTs, i.e. below PHRED 20, and some low-quality ESTs were included in the clustering analysis. The researchers in the oats project managed to improve the data themselves and in this way reduce the number of candidate genes further by excluding some of the too short ESTs. It was possible to remove the short ESTs among the singlets but not from the contigs, because the cluster analyses were already made at MWG Biotech and not possible to redo.

The oats sequencing was done only from the 5' end to the 3' end, which may imply other weaknesses of the EST data. For this reason, some genes could have been overlooked, for instance if one gene starts just past one of the ends. This is a problem that cannot be solved with Paracel Transcript Assembler (PTA), the program used by MWG Biotech. The molecular biologists and the computer scientists handled this problem by using the BLAST X algorithm and

search against a database. The candidate genes were searched against the public databases in six different ways, because it is impossible to know which nucleotide base is the start base. If the PTA analyses had been perfect, there would only have been one hit on each candidate gene. That was not the case, and one reason was suspected to be the short ESTs included in the clustering analysis.

The CAP 4 assembly algorithm in PTA, which was used by MWG Biotech, is considered a very good tool for identifying and assembling the overlapping sequences in the processed raw data. What the PTA and the CAP 4 algorithm cannot do is finding the sequences right after each other without overlap. This is a problem because only the overlapping parts of the ESTs sequences will be assembled, which may result in incomplete genes. The project members also handled this issue with BLAST X in combination with a NCBI protein database.

The BLAST X formatted the EST data from DNA sequence to protein. Then each EST and each cluster were searched against the NCBI protein databases to see if the hits were similar, meaning that the hits came from the same gene. The results from those searches were stored in the developed EST database, described above. The solution to the problem of not being able to spot the sequences being right after each other without overlap was the match with the proteins. When the proteins were identified, it became possible to go backwards and see what sequences matched the protein structure and thereby came from the same gene.

Hence, there appeared to be some issues with the EST data. Those were identified and actions were taken to compensate for them. Below, the gradual reduction of the EST data is described.

Gradual reduction of the EST data

The realisation of the four steps presented above in Figure 4.8 is described in this section.

STEP 1: ESTs from the same gene?

The first step concerned investigating which ESTs originated from the same gene. MWG Biotech performed the first step of narrowing down the data in the clustering analysis. The raw data consisted of *10,000 ESTs* and the processed data consisted of 4487 contigs and singlets, the first step in elimination of data. Hence, MWG Biotech reduced the data set from 10,000 ESTs to *4487 candidate genes*.

The action taken, to compensate for the identified problem with short ESTs not removed, resulted in an additional reduction of the EST data. The removed short ESTs among the singlets had the result that the 4487 candidate genes were reduced by 700 to around 3800 *candidate genes*.

STEP 2: How many genes?

The second step concerned investigation of the number of candidate genes. BLAST X translated the 3800 candidate genes to protein structures. The 3800 candidate genes were searched against the NCBI protein databases. Some of them matched the same protein. These candidate genes were studied carefully to conclude that it was not due to randomness that they referred to the same protein. In the cases where the candidate genes matched the same proteins, the best version in term of length and quality was chosen as an illustration of that particular candidate gene. This process resulted in a reduction of candidate genes to 2867. These 2867 candidate genes contain unique sequences (transcripts) since each of them codes for a unique protein. The whole set of unique sequences is referred to as a “unigene”.

During these two steps of reducing the EST data, several genes were identified. For example, the insulin gene was identified in oats and a number of other genes that were concluded to be non-cold-related were identified. One example of a non-cold-related gene identified is the rubisco gene. It means that even though the cold-related genes were still to be identified, new understanding of the oats genome was gained.

STEP 3: The function of the genes?

Based on the unigene set, the third step concerned what functions the unique transcripts were related to. In this step, it was not clear how to go from the unigene set to the function of the genes. It was important to build on the results of other researchers, e.g. regarding cold adaptation in other plants or specifically regarding the oat plant. One of the project members tried to figure out the functions of the 2867 identified unique transcripts, pursuing the best available method. No directly related work was available apart from textbooks about gene functions in general.

First, textbooks were used to understand what functions the oats genes would be related to. What types of genes and proteins might be related to cold adaptation in order to be able classify them into gene families were looked for. This method was considered subjective and the results were unreliable. Before the project members started to write articles about the textbook-based work, some interesting results were found on the Internet. There was an *Arabidopsis* database with all genes classified according to function. It was the Munich Institute for Protein Sequencing (MIPS), at the Planck Institute in Germany,

which had published a function classification of *Arabidopsis thaliana* on the Internet.

Initially the classification database was not as complete as it became later on (in 2003-2004), when each gene of *Arabidopsis* was classified into a gene and protein family and received an ID number of a functional class. This research forming the basis for the functional classification was performed and completed in parallel to the winter oats project. The project members accessed the results via the Internet and thus had no contacts with the research groups performing the research. Each of the candidate genes was searched against the Gene Ontology Consortium (GOC), another database accessed via the Internet, which also had an *Arabidopsis thaliana* database. That database was used together with the tool Interpro to identify the functional domains by going backwards from protein to gene. Sometimes the Gene Ontology Consortium database did not contain that protein domain; nevertheless, those searches had the result that almost 600 sequences out of 1600 were matched. Hence, for these 600 candidate genes, a connection between the protein domain and a gene family was identified. Hence, it became possible to functionally classify these oat genes.

A Linux cluster consisting of five computers with double processors was set up to test the similarity. In the Linux cluster, a sequence similarity search was done for all the genes against the GOC database. The best hits' ID numbers all got some hit although of varying quality, run against a file with the functional classification. The results, in terms of a pie diagram of the different functions of the genome analysed so far, are illustrated in Figure 4.9. The winter oats project's own description of this process is referred to below, based on a description from the Internet³⁵:

To create the functional classification we performed protein signature searches, using InterProScan, and homology searches at the protein level, using BlastX. We were able to functionally classify 59% of the 2838 unique transcripts, which leaves 41% of the sequences unclassified. 568 of the unclassified sequences could be oat-specific since they lack any significant sequence similarity to any sequence in the public databases. Among the functionally classified transcripts more than 500 sequences show strong homologies (e-values > 1e-30 after BlastX search) to proteins involved in cold-related processes. Various transcription regulators and members of known signal transduction pathways were also found. Of special interest for cold stress is the CBF

³⁵ <http://g4v.lundberg.gu.se/avenagene/> 2005-01-21.

transcription family. Eight such genes were found, belonging to 5 gene families. The EST collection and the accompanying database will now be a valuable resource for research directed towards understanding the genetic control of cold acclimation in particular and in modification of oat properties for agricultural use.

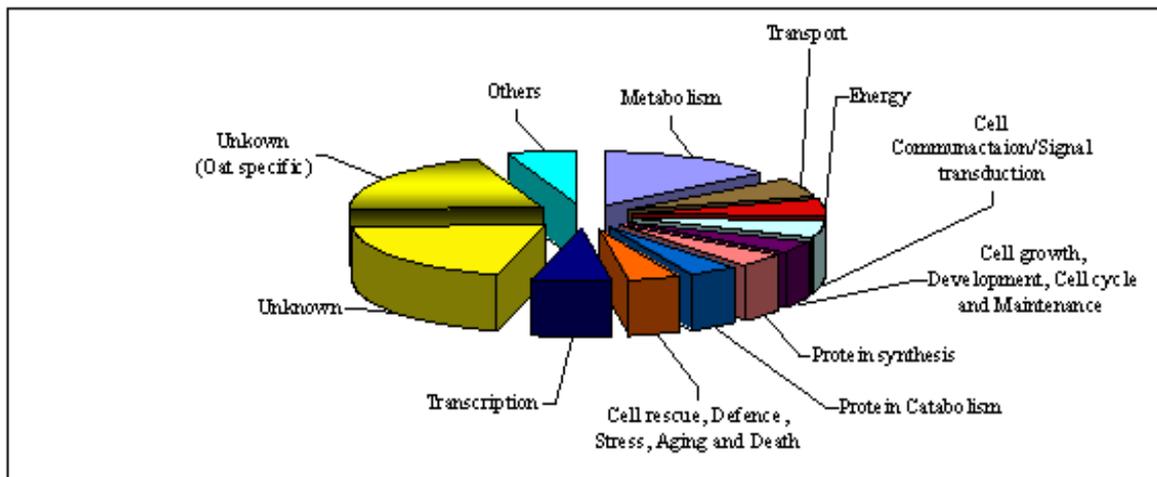


Figure 4.9: Pie diagram of oats classifications developed in the winter oats project³⁵.

Hence, based on these three steps and the number of searches, oat-specific and potentially cold-adaptive genes were identified from the EST data.

STEP 4: Cold-regulating genes?

The next step planned was to test the cold-adaptation candidate genes experimentally with microarray analysis. This is a method showing all active genes and it is easy to compare species under different conditions, described in more detail in the next research phase. Microarray analysis is an expensive and time-consuming method, which also needs to be carefully planned statistically. However, there are scientific articles based on microarray analysis where the expression profiles, i.e. the experimental results from others, are attached. The expression files thus contain the results of experiments and it is possible to see which genes are active, i.e. up-regulated, and which are not. Hence, the experiments done by other researchers were used as a starting point and as a source for information. This type of computer-based microarray work is referred to as “in-silico microarray analysis”.

For example, the results of cold-induced *Arabidopsis* plants are available on the Internet. The winter oats project is also working with a database containing the results from the microarray articles in order to get an overview of what experiments already have been done. In those files and articles it is important to be restrictive with what is regarded as a similarity and what is not.

The preliminary results from the in-silico microarray experiments were that *around ten percent of the 2800 genes* were suspected to be cold-related, which equals around 300 genes. Of these, four transcription factors have been tested, and two of them have generated positive results. Two master thesis students in molecular biology worked with testing these more deeply and as full-length genes.

In the EST-data analysis, two project member groups performed a main part of the research: the molecular biologists and the computer scientists. See Figure 4.10. They performed research jointly and separately during the EST-data analysis and they managed to come closer towards understanding the cold-adaptive genes in oats. In this process, they used several tools found on the Internet; they built on and related to research performed by other research groups.

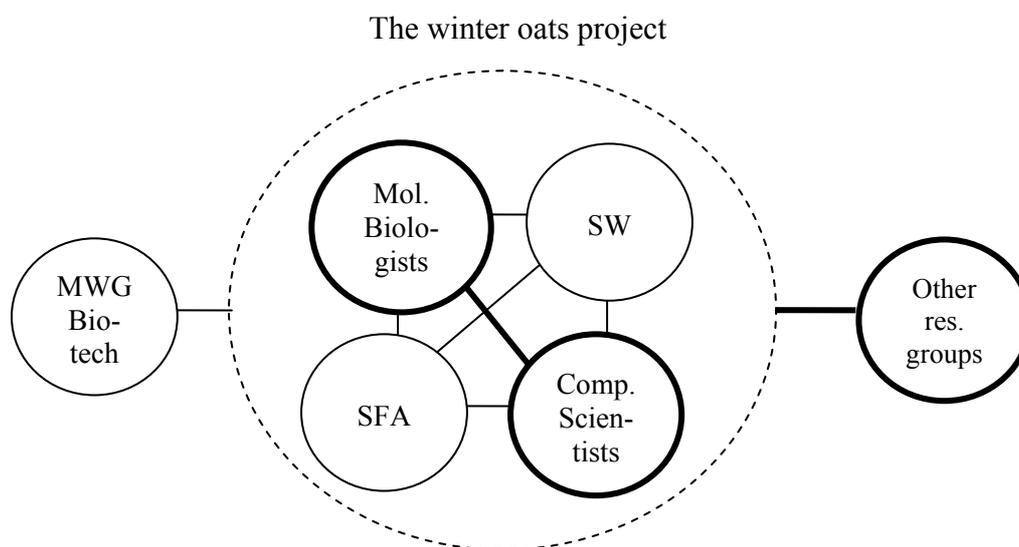


Figure 4.10: Project members involved during the EST-data analysis.

In sum, based on the different steps described above, the 10,000 ESTs have been reduced to around 300 candidate genes that might be cold-related. In addition, the winter oats project has managed to functionally classify a large share of the oats genome. Based on the sequencing and the EST-data analysis, the winter oats project learned about oats in general and came closer to the understanding of cold association. The remaining step might be the microarray analysis, which is currently under preparation and described as the fourth research phase below. However, regarding how to perform the next step, there were several plans that never became realised, described below.

Unrealised plans

During 2002-2003, there were thorough plans regarding commercialisation and the possibilities to create a research firm around the research performed in the winter oats project. There were also ideas regarding how to test genes experimentally in other organisms. Regarding the commercialisation, the EST data in particular were in focus. One business idea was to commercialise the EST database, both how it is built and the content of the database. In this commercialisation plan, one step was to try to get closer to applications and customers. In particular, two potential customer projects were of interest. Neither of them, described below, was realised in the end. Nevertheless, an organisation number, a business plan and a name, Avena Gene, are registered for the firm.

Unrealised commercialisation plans

The EST database was the centre of attention regarding opportunities to commercialise. There were plans for commercialising the EST database in two different ways. First, the content of the database could have become valuable, since other genes might be identified on the basis of how information is stored in the database. Second, the structure of the database in itself could have been used for other purposes. The project members currently own the EST database. If the EST database had become commercially practicable, the ownership would have needed to be worked out in detail.

One potential customer that the project members of the winter oats project discussed with was the Malaysian Rubber Board. One of the project members had a contact there. In Malaysia, rubber and especially latex is an important product. Latex is grown under the bark at certain trees and needs to be collected every second hour, days and nights. The Malaysian Rubber Board owns around 200,000 trees, which means that they need to have extensive staff to collect all the latex. Furthermore, collecting latex is a demanding task and, therefore, the Malaysian Rubber Board expressed a need for alternative products.

One of the molecular biologists knew from previous tree studies that there were certain cell zones in those trees that, under the right circumstances, form firewood. The idea was that Avena Gene could have analysed EST data from the rubber trees, to conclude what mRNA was active in wood building. Based on that, it would have been possible to gain knowledge about how to grow trees suitable for wood production, an alternative to latex. Thus, based on the knowledge of oats and the experience the oats researchers had from analysing all the ESTs, it was suggested that they could do EST-data analysis for rubber trees. However, the discussions ended with the Malaysian Rubber Board deciding to do it themselves in-house. What the oats researchers have heard is that a budget ten times the one discussed with Avena Gene is invested in this

project internally. In retrospect the researchers believe that they should have been more protective regarding their ideas. Instead, they presented the ideas without contracts, and consequently the potential customer used the idea but not the set of analyses offered by Avena Gene.

Another potential customer was Plant Science BASF, a plant-breeding firm, related to one of the members of the winter oats project. This project was based on wheat breeding. The idea was that Avena Gene should build a database with genes based on tissue cultures. Avena Gene could have used knowledge from building its EST database in a new setting. A proposal was presented to Plant Science and arguably came close to a deal, but did not bear fruit.

Unrealised experimental testing plans

During this time, research plans in collaboration with other research groups also arose that were not carried out. The members of the winter oats project had connections with the American firm Syngenta regarding microarray analysis. As mentioned earlier, Syngenta is dedicated to crop protection and seed production, and is one of the largest agribusiness firms in the world, with annual turnover of 600 million dollars. Syngenta is the result of a merger between Novartis and another firm. The winter oats project previously had a connection at Novartis, which then became Syngenta, specialised in sequencing and conducting microarray analysis.

Members of the winter oats project visited the Syngenta premises in San Diego together with members from the WF Funding Body. The plan was that Syngenta and the winter oats project, or the research firm Avena Gene under construction at that time, would jointly apply for money and study frost resistance in rice. Since Syngenta had expertise in designing microarray chips, the plan was that Syngenta would design chips as part of this joint work on rice. Rice and oats are argued to be similar genetically, implying that if the mechanisms behind cold resistance were understood in rice they would likely also be understood in oats.

Even though Syngenta is such a large firm with enormous facilities, there was only one research group working with different types of stresses of interest for the winter oats project. With time, Syngenta has invested less in that section focusing on crops and the main contact person has switched jobs. Therefore, the connection and the joint plans have faded out.

Other plans concerned engaging in co-operation with either the yeast or the worm group at the Department of Cell and Molecular Biology, for experimental testing of candidate genes in other organisms. Yeast is a good organism to work with since it is well researched, and all the 6,000 genes are

known. In addition, yeast has short reproduction cycles and is cold-sensitive in itself.

The yeast group and the molecular biologists in the winter oats project had plans to start co-operation about experimentally testing candidate genes in yeast. The dialogue concerned technical issues, such as whether it would be possible to set up yeast experiments to test several hundreds of candidate genes simultaneously. The yeast researchers had systems for managing large-scale experiments. This system was also one of the reasons why the dialogue developed. In this system it would be possible to study yeast behaviour at one thousand points simultaneously. Another issue discussed was how to measure whether the genes have an impact.

At the same department, there is a research group working with worms, regarded as another potential collaboration partner in experimental testing. Worms are small transparent organisms with a minimum number of genes. The worm has 900 cells, which makes it easy to work with. The transparency also facilitates observation of changes. This potential co-operation was in an early phase of dialogue and developed partly on the basis of sharing laboratories.

During this phase, some plans were realised. Those activities are described below in terms of other uses of the EST.

Other uses of the EST data

As mentioned above, a number of genes were identified in oats already during the preceding phases. Among other things, these genes have resulted in two unexpected uses of the EST data.

Development of a family tree for oats

One use of the EST data is the development of a gene family tree. The gene family tree enables investigation of which plants – among wheat, rye, corn and rice – oats are most closely related to. It can be useful to know which species are most similar to oats if, for example, a certain characteristic, such as frost-tolerance, not known in oats is studied.

In the work with the oat family tree, one particular gene, the rubisco gene, was in focus. The reasons why the rubisco gene was chosen for comparison among plants were twofold: First, it was *not* cold-related, and the researchers in the oats project did not want to release the potentially cold-associative genes before their own analysis was completed. Initially nine genes were selected from the EST data for the family tree research, including the rubisco gene. These were all chosen on the criterion that they were not cold-related. Second, the rubisco

gene in particular was chosen because it was publicly available and known in the plants to be compared against.

Based on the sequence of the rubisco gene in the respective plants, a family tree was drawn. The software program Phylip was used for studying the kinship. Phylip is specialised for comparing genes in order to determine the kinship among organisms. PHYLIP is a *free* package of programs for inferring phylogenies (evolutionary or family trees). It is distributed as source code, documentation files, and a number of different types of executables³⁶.

The computer scientists have performed most of the research concerning the family tree. It has also involved the molecular biologists, who have become interested in the results of this application. The molecular biologists also contributed with input regarding whether it is more interesting to compare with corn or with another plant. In addition, the molecular biologists explained why the EST sequences looked as they did. The family tree has resulted in contacts with the Botanical Garden of Göteborg University, which has been able to contribute to the work with the oat family tree.

Oats as healthy food

The SFA and the molecular biologists in the winter oats project have started co-operation with the Department of Food Science, Chalmers University of Technology. What brought these three parties together was their joint interest in oats. The background for this co-operation was that the SFA previously had worked with the Department of Food Science in other projects. In addition, the results generated in the search for cold-associative genes in oats and the transformation technique constituted a good starting point for further research on oats.

An article in a newspaper, supplied by the Business Region of Gothenburg in 2003, discussed the food scientists and the winter oats project. According to the article, one positive side-effect of the search for cold-associative genes in oats is the detailed knowledge of the oat genome and, in particular, the identification of healthy fractions. One healthy substance identified is lipids, which will be interesting to focus more on.

One area of oats research at the Department of Food Science concerns antioxidants, which are thought to decrease risks of heart and blood-vessel diseases. There are researchers at the Department working with antioxidants in herring and, since the laboratory methods are known, it would be possible to use them in oats as well.

³⁶ <http://evolution.genetics.washington.edu/phylip/general.html>, 2004-03-24

Among the food researchers, oats in general constitute a research challenge due to their unique characteristics of containing high levels of the cholesterol-decreasing betaglucan and of fytanic acid, which limits the iron absorption of e.g. iron and zinc. The food scientists aim to increase the production of fytase in oats, enabling mineral absorption. Thus, oats as a nitrous crop hinder the human body from absorbing minerals. The research challenge is to have oats that both contain the nitrous characteristics and enable mineral absorption.

The three parties started their discussion in relation to an ongoing large project application of making minerals available in food. This project focused specifically on herring, yeast and oats. The project was part of the Swedish Agency for Innovation Systems' "Vinnväxt" programme in 2003. However, that programme did not receive any continued funding. The three parties have continued discussions on filing for joint research funding of oats from other sources.

Project members involved in other uses of the EST data

The project members involved in the other uses of the EST data during the EST-data analysis were the SFA and the molecular biologists, regarding further research on health aspects of oats. This new project is under planning in cooperation with the Department of Food Science at Chalmers University of Technology. See Figure 4.11.

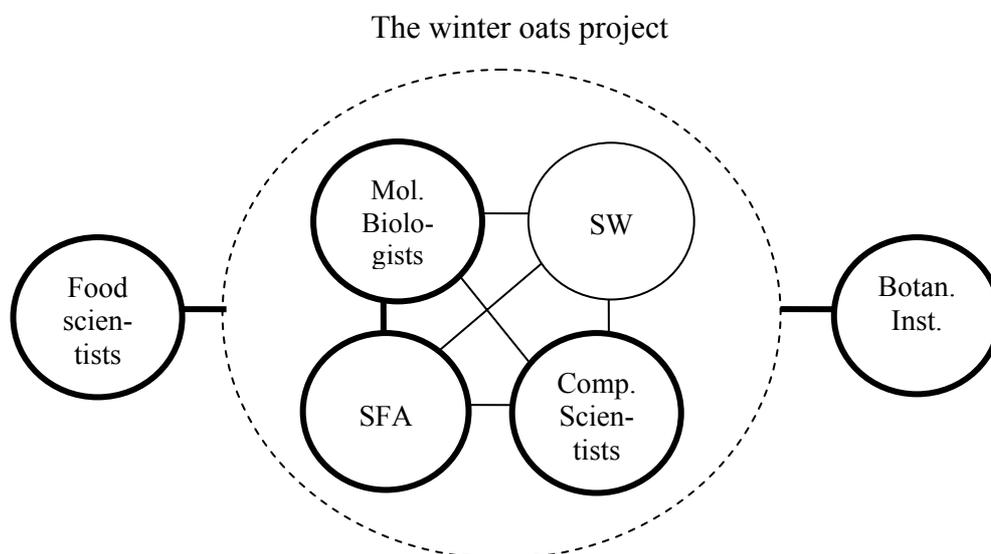


Figure 4.11: The project members using the EST data outside the project.

The computer scientists have also managed to use the EST data outside the project, and in particular the rubisco gene in constructing a family tree. That research has resulted in a new contact with the Botanical Institute.

4.4.4 RESEARCH PHASE 4: PREPARATIONS FOR MICROARRAY ANALYSIS

Already when planning the winter oats project, microarray analysis³⁷ was part of the plan. However, it was not clear *how* it was to be performed. For example, it was not clear that the project members should manage the design of the microarray chips themselves, since there were plans during the project to develop them in co-operation with Syngenta, the large firm specialised in microarray analysis. To be able to conduct microarray analysis, gene-sequence data, i.e. the EST data, are a necessary condition. The EST data and in particular the potentially cold-related genes identified are thus preconditions for performing microarray analysis in general and designing the microarray chips in particular.

Microarray analysis is a technique for deciding exactly which genes are active in an organism at a certain moment under certain conditions. A microarray chip is a “grid” where each square represents one gene. The microarray technique is sometimes referred to as “the traffic lights of life” since each gene is displayed as a small dot, red, green or yellow depending on whether it is active or not. It is possible to have thousands of dots or squares, corresponding to genes, on one chip. During the analysis, an organism specimen is “pored” on a microarray chip and then the active genes in the sample are displayed as red dots. Depending on how many dots there are on the chip, how colourful they are and how many different specimens from different points in time are used, there may be a lot of data to handle. The chip is an important device, which has to be custom-made for the organism and circumstance in focus, cold-acclimatised oats in this case.

Design of microarray chips for oats

There are standard microarray chips available for some organisms, such as yeast, *Arabidopsis thaliana* and barley. These are well-researched and familiar organisms. However, in the case of oats, there are no chips available and they have to be designed.

The molecular biologists are working with the design of the oat microarrays. This is regarded as a complicated matter and the equipment needed is expensive. The molecular biologists have access to such equipment at Göteborg University, from which they can rent it. Several research groups thus share the

³⁷ ”DNA microarrays are devices that measure the expression of many thousands of genes in parallel. ... One of the principle features of microarrays is the volume of quantitative data that they generate. As a result, the major challenge in the field is how to handle, interpret and make use of this data” (Stekel, 2003, p. ix)

equipment. In the process of designing microarray chips, one molecule at a time is attached to the chip and that process is referred to by the term “spot”.

The ESTs are used as the point of departure for designing microarrays for oats. In particular it is the roughly 300 genes that might be important for the cold-adaptation process which are used as a point of departure for the microarrays. Those 300 and some extra genes, around 500 in total, to be sure of not excluding central genes, are represented in each microarray as a dot. In fact, it is not the whole EST but a unique section of around 20 nucleotide bases that form one dot in the microarray. Each extra gene in the microarray costs money, so it is a balance between reducing costs and including all potentially interesting genes.

Each dot in a microarray thus represents one gene, potentially being important for cold adaptation. The computer scientists have influenced which genes to study more deeply, how many experiments are needed and how large or small a difference is required; some extra experiments will ensure significance.

Combining microarray analysis and field experiments

When the microarray chips are available, real oat plants from the field experiments are tested against the chip. In this process, the plants are used that Svalöf Weibull grows in the field experiments. For this purpose, the plant-breeding firm regularly sends plant specimens to the molecular biologists to be used in the microarray analysis. When the plants are received, they are transformed into mRNA, which constitutes the basis for testing the plants against the microarray. The goal is to be able to design a chip for cold adaptation in oats, meaning a chip that could be used as a test for screening which plants will survive the winter and which will not. That chip, though, is far from reality yet.

In the microarray analysis, still ongoing, the researchers in the project take plant specimens from the field at ten degrees below zero, perform the microarray analysis at that temperature, and see which genes are active. Then the same thing is done for eleven degrees below zero, etc. As can be seen, there will be a lot of data generated, with around 500 dots at each microarray and several different plants at different temperatures. Based on all these microarray data and corresponding statistics to ensure appropriate results, the objective is to be able to determine which genes regulate cold adaptation in oats.

Barley field experiments are also used as a starting point for the microarray analysis. The ambitions are to use available standard microarray chips for barley, then to compare them with oats and identify similarities and differences.

The results from the microarray analysis are still not finalised. All the project members seem to agree that when the microarray experiments are finalised, there will be exciting data to work on for all the project members for a long time.

Project members involved in the preparations for microarray analysis

In the process of designing microarray chips, the molecular biologists are the most involved party, but also the computer scientists and the plant-breeding firm are indirectly contributing to this work, illustrated in Figure 4.12.

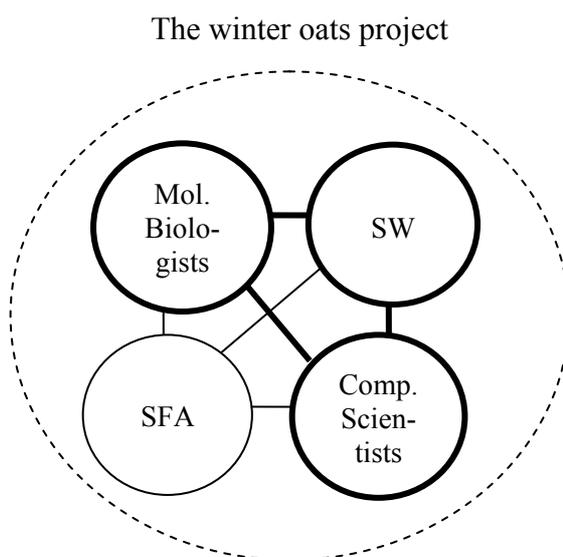


Figure 4.12: Project members involved in the preparations for microarray analysis.

The plant-breeding firm contributed plant specimens from the field experiments to be used as starting points in the analysis. There are also barley field experiments ongoing, planned to be used as a reference analysis.

Other uses of the EST data

The EST data have been used as input to a plant-breeding programme in England. It is via the parent organisations of one of the project members, Svalöf Weibull, that the EST data are transferred and further used in this new setting. This was not at all planned initially, but is an opportunity that has arisen during the project.

In England there is rather extensive activity regarding oats-breeding in terms of national programmes, compared to Sweden where there are no national breeding programmes regarding oats or winter oats. Svalöf Weibull England (former Saemundo) is involved as a member in one of the English breeding programmes, called IGR. Part of this programme is a project, called Oat Link,

in which Svalöf Weibull England also is one of the main participants. The Oat Link project started during the spring of 2004, and one of the goals is to develop breeding markers for oats. A breeding marker is a section of the genome that is related to a certain characteristic. One type of breeding markers commonly used is microsatellites, which consist of highly repetitive areas of the genome.

The EST data will be used in the Oat Link project as a starting point for developing breeding markers for oats. The EST data consist of 600 microsatellites, i.e. areas of repetitions, but it is still to be investigated whether any of these is close to a gene regulating any interesting characteristic and thereby qualifies as a breeding marker. Hence, it is to be evaluated whether the microsatellites within the EST data can be used for developing breeding markers. The ESTs have been sent to Svalöf Weibull in Canada, which has personnel specialised in preparing EST data for microsatellites. Svalöf Weibull Canada will then forward the prepared microsatellites to the Oat Link project.

The breeding markers to be developed in the breeding programme may also be of value for the winter oats project. They may constitute important contributions to the process of developing winter oats. However, it is not guaranteed that the Oat Link project can contribute results back to the winter oats project. The EST data are in any case an important contribution to the national breeding programme and the Oat Link project in particular. The parent organisation that is a member of the programme may thus benefit from the use of the EST data, even if the winter oats project does not.

Another use of the results from the project during the microarray analysis is related to dry resistance. Dry resistance as a genetic characteristic is assumed to be close to cold resistance, which imply that it may be possible to learn between the two characteristics and understand both of them better based on the other. A dialogue has been initiated with an Australian research group, focusing on dryness. Dryness is a huge problem internationally and a common reason for harvests not surviving. Hence, understanding dry resistance at crops has a broad general interest. This collaboration is still in an early phase.

Project members involved in the other uses of the EST data

During the phase consisting of preparations for the microarray analysis, primarily one of the project members has managed to make use of the EST data in a new setting (see Figure 4.13). The plant breeder, via its parent organisation Svalöf Weibull, has been able to use the EST data as input to a plant-breeding programme in England. In addition, the molecular biologists have initiated a dialogue with an Australian research group regarding the relatedness of dry- and cold-resistance at crops.

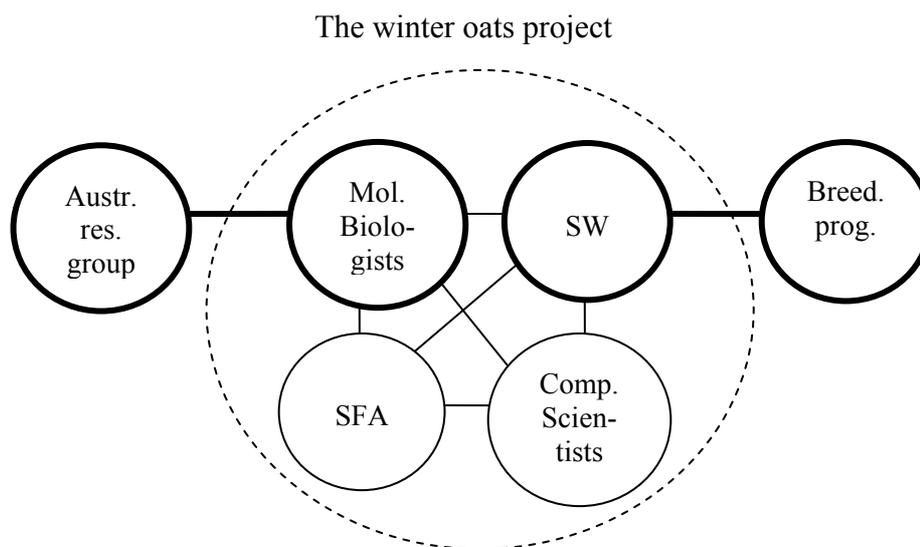


Figure 4.13: Project members involved in another uses of the EST data during the preparations for microarray analysis.

The winter oats project has gone through four main research phases, all aiming towards pursuing the overall goal of the project. While some results developed during these phases have been possible to use and develop further outside the project for other purposes, some plans in relation to results of the winter oats project were never realised. In the next section of the empirical inquiry, the current situation of the still ongoing project is described.

4.5 The current situation

As of 2005, the winter oats project is continuing and the focus is set on the microarray analysis. Since it is still uncertain exactly how to design the chips and whether the analysis functions or not, this is the main priority of the project members. When the microarray analysis is completed, the generated data will be of great importance for identifying the cold-adaptation genes in oats. All the project members look forward to this and the results that may emerge.

The two PhD students are still in the process of finishing their doctoral theses. Based on the EST data and the forthcoming microarray data, it seems clear that there is material to write several publications³⁸.

The co-operation with the Department of Food Science at Chalmers, SFA and the molecular biologists has been developed further. Based on the previously

³⁸ See for example *BMC Plant Biology* (2005), Vol. 5, No. 18.

initiated dialogue, they are now jointly involved in a new setting with firms, representatives from the authorities and other universities. The extended co-operation takes place in a setting where all the Nordic countries are represented. These plans are under development, and it is yet to be seen what comes out of this new project.

The plant-breeding experiments of winter oats also continue. Plant breeding is, as described above, a long-term process. As long as the oat varieties continue to survive the winters, there might be Swedish winter oats based on plant-breeding methods even though experts thought this impossible. Another option is that we will have Swedish winter oats based on the plant-breeding programme in England, which in turn is based on the EST data developed in the winter oats project. That is for the future to reveal.

5 Categories of resource use and development

In this chapter, the five categories of resource use and development that were suggested in section 2.4.1 will be discussed and elaborated on, with the starting point in the empirical description of the winter oats project. The resources in focus are those used and developed within and outside the scope of the project.

In section 5.1 the resources and activities of the empirical description are identified. This is followed by section 5.2, a discussion of the resource use and development categories concerned. In this section, the resource categories are also related to the winter oats project in order to provide an overview.

5.1 Identifying resources and activities

Below, the winter oats project is described with a point of departure in the four empirically based research phases. These four phases are: (1) Preparations for sequencing, (2) Sequencing, (3) EST-data analysis and (4) Preparations for microarray analysis. In Figure 5.1 the series of phases is illustrated.

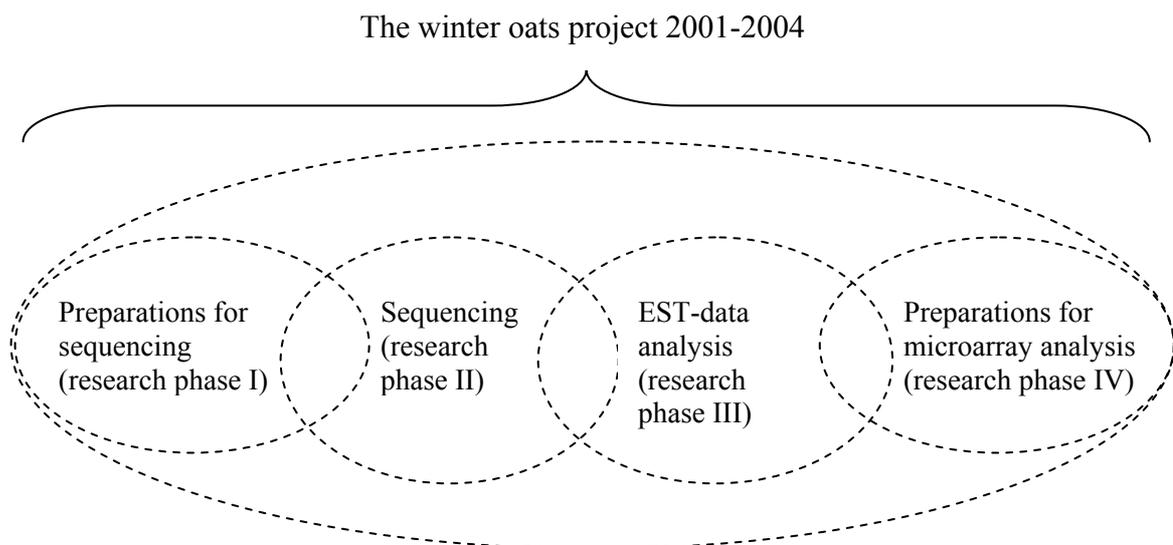


Figure 5.1: Overview of the four research phases of the winter oats project (2001-2004).

The four research phases lasted from 2001 to 2004, implying that there will eventually be additional phases. Each phase consists of one or several research activities performed either in parallel or subsequently within the same phase. The phases are partly overlapping since the results of one phase form the starting point for another. For example, the results from the preparations for sequencing are a precondition for starting the following phase, sequencing. These four research phases are described thoroughly below with focus on the activities and the resources used and developed, beginning with the first phase, followed by the other three in chronological order.

5.1.1 RESEARCH PHASE 1: PREPARATIONS FOR SEQUENCING

In the first phase, two main research activities are performed in which several resources were used and developed; see Figure 5.2.

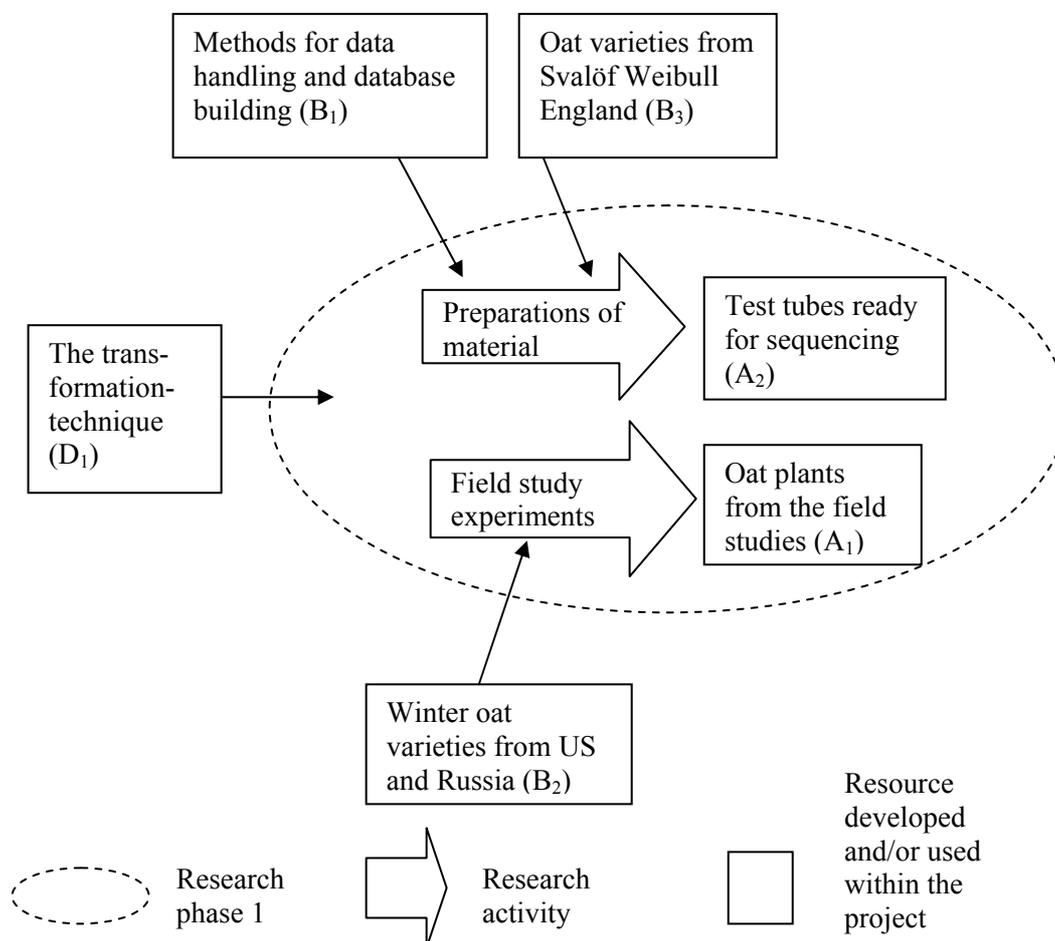


Figure 5.2: The resources used and developed during preparations for sequencing.

One resource considered central when the winter oats project started was the transformation technique (D₁). One of the project members had developed this resource in a previous development project, which was funded by the WF

Funding Body. The WF Funding Body also funded the winter oats project initially. From the WF Funding Body's perspective, the winter oats project was seen as a continuation of the previous oats project resulting in the transformation technique. The transformation technique was considered a unique resource. Consequently, this resource available from the project start was expected to play a central role later in the project (which, however, has not yet become the case).

One of the resources made available to the winter oats project during the preparations for sequencing is methods for how to handle huge data sets and build databases (B₁). The group of computer scientists, one of the project members, knew these methods. The computer scientists were not involved in the project from the beginning, as described in the empirical section. However, when it was realised that a huge amount of data was to be handled, it was concluded that experience in analysing huge data sets was needed. The realised need for computer science resulted in a discussion with the Department of Computer Science at Skövde University, which eventually became involved as a member of the project.

The plant-breeding firm contributed winter oat varieties to conduct field study tests by sowing oats in the south of Sweden. For that purpose, the plant-breeding firm managed to find Russian and American *winter* oat varieties on the Internet (B₂). These varieties were important resources to the field study tests. One of the American varieties, "Nebraska", has unexpectedly survived several Swedish winter field tests. Results from the oats field tests (A₁) turned out to be important resources later on in the work with microarray analysis.

One of the main research activities initially in the winter oats project was the preparation of material to be used as the starting point for the actual sequencing activity. In order to produce the material needed to sequence oats, different types of oat varieties were needed. One of the project members, the plant-breeding firm, contributed oat varieties from the international breeding firm it is part of. Notable were winter oat varieties from England (B₃) since there are oats that survive the mild English winters. However, these winter oat varieties do not survive the Swedish winters. Nevertheless, the English winter oat varieties were used as a point of departure for sequencing. For example, the oats variety "Gerald" was used. In addition, some spring oats varieties were used, also accessed via the plant-breeding firm. The English winter and spring oats varieties were prepared in accurate ways and delivered to the sequencing firm in test tubes (A₂), and formed important starting points for sequencing. The oats varieties are thus resources developed outside the project and further used within the project.

5.1.2 RESEARCH PHASE 2: SEQUENCING

During the research activity of sequencing, an existing and external resource for the project was used; see Figure 5.3.

MWG Biotech, a German firm, was engaged as a supplier of sequencing and performed the oats sequencing in facilities at its site. Test tubes with prepared oats (A_2), based on the English winter and spring oats, were delivered to MWG Biotech and in return, the results, so-called raw EST data, were supplied (A_3). A number of research groups all over Europe use these sequencing facilities, performing standard sequencing services.

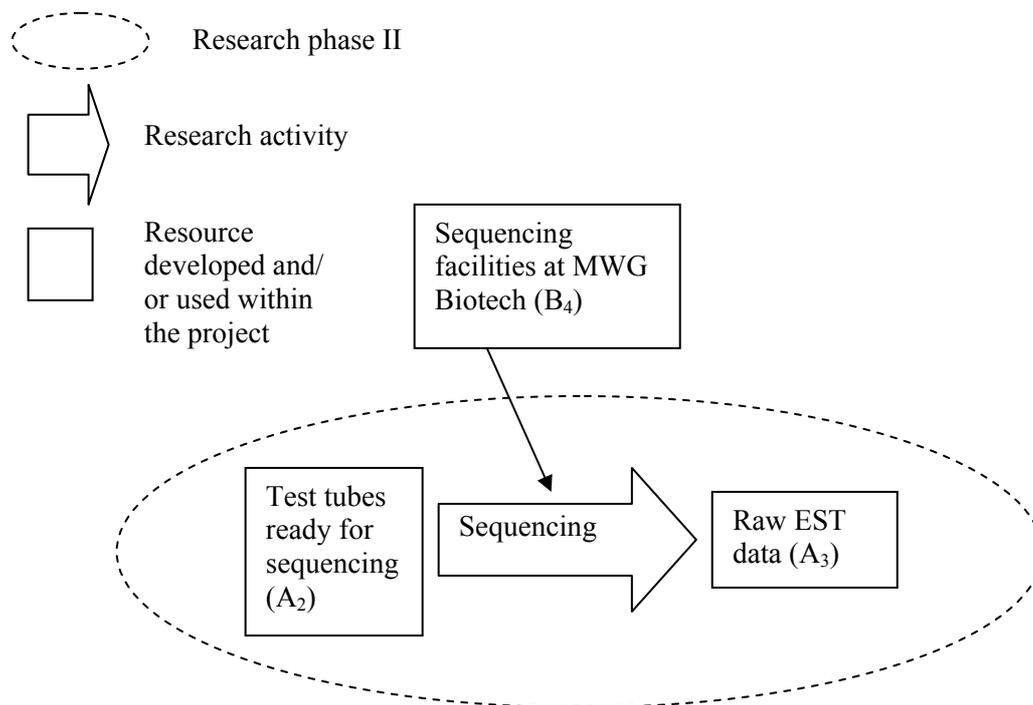


Figure 5.3: The resources used and developed during sequencing.

The sequencing performed by MWG Biotech resulted in the first main resource developed in the project to be further refined, used and analysed in subsequent research activities. The resource referred to is the “raw EST data”.

5.1.3 RESEARCH PHASE 3: EST-DATA ANALYSIS

The raw EST data supplied by MWG Biotech are a central resource developed in the project. The data themselves do not tell anything unless the tools and the knowledge of how to interpret the data are available. In analysing the raw EST data, a number of different resources were needed (see Figure 5.4).

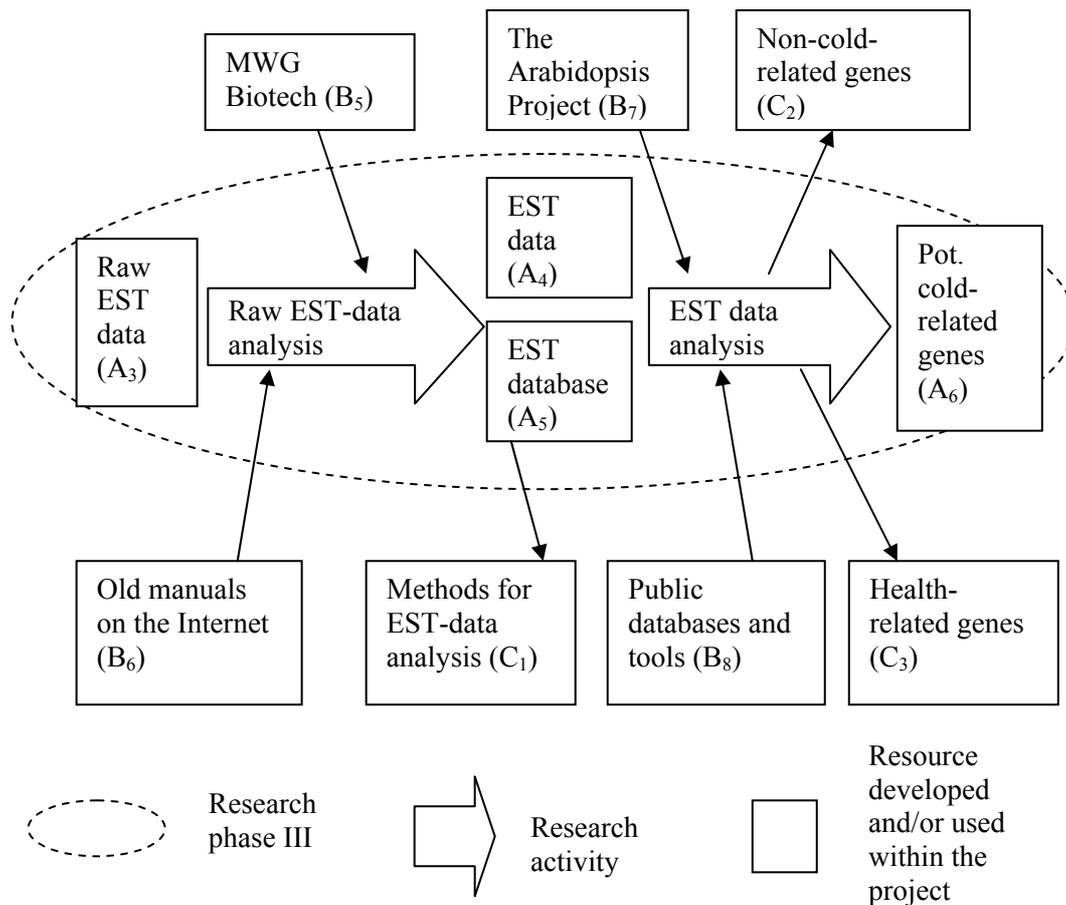


Figure 5.4: The resources used and developed during the EST data analysis.

Initially the project members worked with the raw EST data in order to understand what was delivered from MWG Biotech. As explained above, it was not clear at first what types of analyses the company had performed and how well they were performed. To understand and make sense of the raw EST data, the project members looked at the data and tried with, for example, old manuals found on the Internet (B₆) to figure out what had been done. MWG Biotech was also contacted to get some additional information (B₅). That contact resulted in little information since answers were only given to formulated questions. It was concluded that the sequencing performed at MWG Biotech had some weaknesses. By repeated studies of the raw EST data, an enhanced understanding was reached and some elements of the raw EST data could be removed. At the end, the winter oats project had a refined version of the raw EST data, referred to as “the EST data” (A₄), which is a central resource of the project.

In this work of refining the EST data, an EST database (A₅) was developed to give an overview of the data. The EST database was built with standard software tools consisting of publicly available software. The database contains the original raw data delivered from MWG Biotech and, moreover, new results were added to the database. For example, hits from public database searches were stored in the database, which made it possible to instantly get essential information about one specific EST. Hence, the EST database is a result of using a resource, the EST data, developed within the project. At the same time, it is a resource developed as such in the project for further use therein.

Another core resource for analysing the EST data consists of the results and the parallels drawn from the parallel research in the *Arabidopsis* project (B₇). One of the project members in the winter oats project managed a research project regarding the *Arabidopsis thaliana* plant, as described in the empirical section. The *Arabidopsis* plant has the potential, due to its simplicity, to explain characteristics of oats and further plants not understandable otherwise. In addition, there are vast research results published on the *Arabidopsis thaliana* plant which are also possible to use and relate to in the work with oats.

The project members also frequently searched and used publicly available tools (B₈) on the Internet to be able to analyse the EST data – tools consisting of publicly available databases, i.e. the results of other researchers stored in databases, and tools for searching among and getting an overview of other researchers' results in the databases. Examples of tools and databases used are BLAST, Entrez and the MIPS.

Results from the analysis of the EST data were identification of genes and understanding the function of genes in oats. Based on the EST-data analysis, there are a number of potentially cold-related genes identified in oats (A₆). Based on the research so far in the project, there is increased knowledge regarding the oat genome in general and the cold-associative part specifically. However, some research is still needed to understand the genes regulating the cold-association process. Some of these general results of the oat genome are resources that are used in other settings beyond the scope of the project.

One example of the project members' use of resources developed in the project for other purposes than the actual project is the commercialisation effort with the EST data and EST database. In this commercialisation work, the methods for generating, analysing and building an EST database (C₁) came close to be used in a totally different setting. It was the understanding of EST data in general based on the winter oats project, in combination with previously known details regarding characteristics of trees, that constituted the starting point. Equally important was a contact at the Malaysian Rubber board, which enabled

the project members to make an offer consisting of EST-data generation and subsequent analysis of rubber trees. The EST-data generation and analysis were to be done in order to identify the genes that regulate cell zones building firewood. As noted earlier, this research was not completed because the research plan offered was performed in-house without the oats researchers' involvement.

Another example from the plans for commercialisation work is that the methods used for building the EST database could have been used in another setting. There were discussions regarding building a wheat database for Plant Science, BASF, which works with wheat breeding. This idea was not brought to fruition either.

A specific fraction of the EST data, the non-cold-related genes (C_2), has been used further as a starting point for development of a gene family tree. One of the project member groups, the computer scientists, has developed an oat gene family tree. Constructing a gene family tree refers to investigating which other plants that oat is most related to. In this case, oats have been compared with wheat, rye, corn and rice. It can be useful to know such relationships if, for example, a certain characteristic not known in the oat itself is studied. Then it is possible to study a related plant more closely if the characteristic is known in that plant.

One particular gene, the rubisco gene, was in focus for the studies of kinship between plants. This gene was chosen on the criterion that it was not cold-related. Hence, among the identified genes during the EST analysis this one came to be used in the family tree application. This further use of a fraction of the EST data may contribute back to the winter oats project, but is not planned to do so. It is mainly an application that interests and benefits the involved project member.

In constructing the family tree for oats, external resources have been needed. One important resource has been the software program Phylip, which was used for studying the kinship. Phylip is specialised for comparing genes in order to determine kinship among organisms. In addition, the work with the family tree resulted in contact with the Botanical Institute, Göteborg University, which has contributed knowledge of botanical nature regarding the oat family tree.

Results from the EST-data analyses led to identification of health-related genes (C_3). These genes in combination with the transformation technique formed the basis for co-operation among the project members: the Swedish Farmers Supply and Crop Marketing Association (SFA), the molecular biologists, and the Department of Food Science at Chalmers University of Technology. In this

co-operation, the results provided the grounds for writing joint applications to intensify the study of oats and especially the health characteristics of oats. The health-related genes identified in EST-data analysis, not directly related to cold adaptation, were thus to be used outside the scope of the project.

The SFA had worked in earlier research projects on oats with the Department of Food Science at Chalmers University of Technology. Hence, one of the project members took advantage of its existing relationships to use the results from the winter oats project further. The third party in this application is a university department which manages several research projects, is involved in regional collaborative efforts, and possesses knowledge of oats that none of the winter oats project members have. On the other hand, the winter oats project members in this co-operation had knowledge about oats that the Department of Food Science did not. For example, the transformation technique, developed by one of the project members prior to the winter oats project, attracted the Department of Food Science's interest and attention.

5.1.4 RESEARCH PHASE 4: PREPARATIONS FOR MICROARRAY ANALYSIS

Both the design of the oat microarray chips and the microarray analysis are ongoing. Thus, the research activities are not finished yet and, to demonstrate this, the related arrows are dotted in Figure 5.5. It is still uncertain whether the development of the microarrays and the identification of the cold-association genes will be completed; they are also indicated in the figure as dotted boxes.

Microarray analysis may be seen as a planned further use of the resource EST data. Already when planning the winter oats project as a PhD project, microarray analysis was part of the plan. To be able to conduct microarray analysis, the EST data (A_4) and the potential cold-related genes (A_6) are necessary. Hence, these resources were conditions for performing microarray analysis in general and designing the microarray chips in particular. The fact that no oat microarray chips were available for purchase had the result that the first step towards performing microarray analysis became the development of the chips. In order to design chips, facilities at Göteborg University (B_9) were utilised. These facilities are accessed via the parent organisation of one of the project members, the molecular biology department.

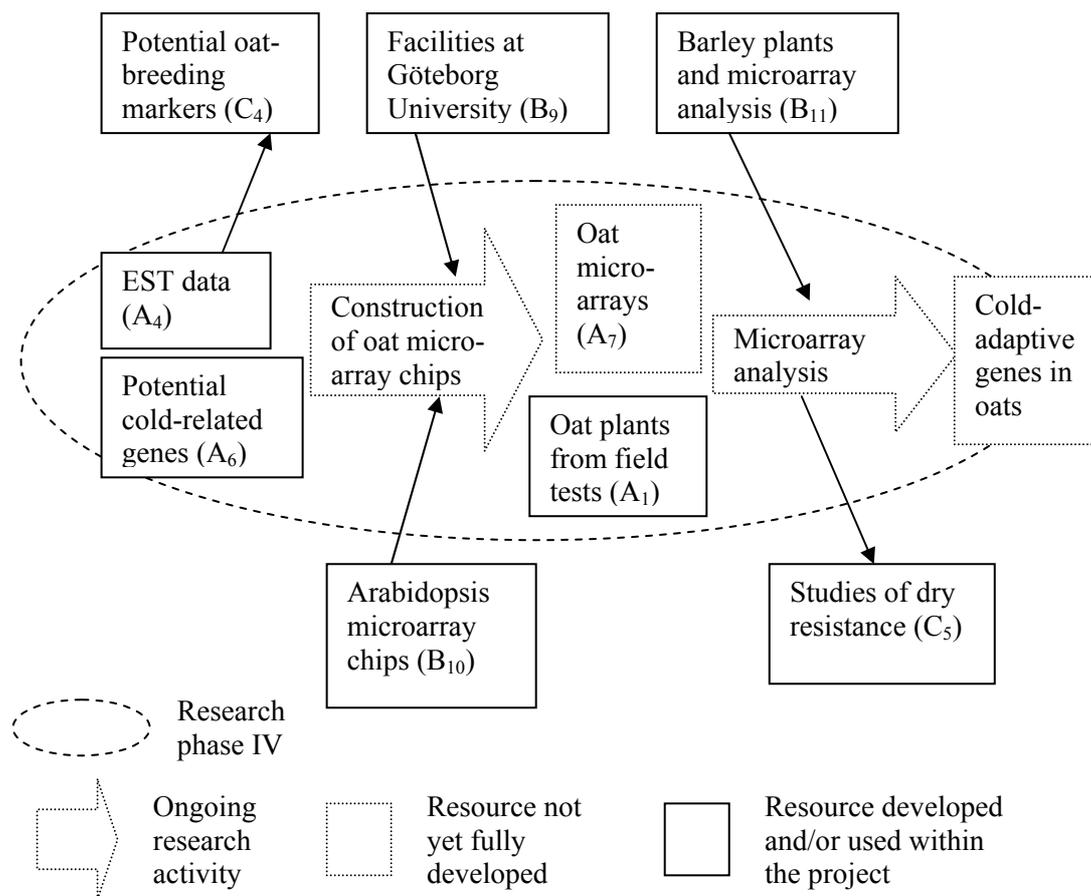


Figure 5.5: The resources used and developed during preparations for microarray analysis.

When the microarrays become available, real oat plants from the field experiments (A₁) will be tested against the chips. In this still ongoing test process, oat plants grown by the plant-breeding firm are used, i.e. the results of the still ongoing oats field studies introduced in the first research phase came into use in this phase. The plant specimens are sent on a regular basis to the molecular biologists in Gothenburg. These plant specimens are resources used in order to perform microarray analysis, and thereby to develop a new and deeper understanding of cold association in oats. In addition, barley field experiments (B₁₁) are used as a starting point in the microarray analysis. The barley specimens can be analysed with standard microarrays, and the barley analyses are resources since they constitute comparison material. Besides, *Arabidopsis* microarray articles have been reviewed and used as a point of departure.

The EST data have also been used outside the winter oats project in another setting, in terms of input to a traditional plant-breeding programme in England

(C₄). The parent organisation of one of the project members, Svalöf Weibull, has transferred the EST data and managed to use a fraction of the data further in this new setting. This further use was not planned initially but is an opportunity that has arisen in relation to a project, called Oat Link, within the breeding programme. As noted earlier, the Oat Link project started during the spring of 2004 and one of the goals is to develop breeding markers for oats. The EST data are thus used as a resource for such development outside the winter oats project via the parent organisation of one of the project members.

The breeding markers to be developed in the breeding programme may also be of importance for the winter oats project. These might constitute important contributions to the process of developing winter oats. There is, however, no guarantee that the Oat Link project can contribute resources back to the winter oats project. The EST data are in any case an important contribution to the national breeding programme and the Oat Link project in particular. The parent organisation, being a member of the programme, may thus benefit from the use of the EST data, but the winter oats project will not necessarily benefit from it.

During the microarray analysis, the dry resistance characteristic (C₅) has become an area of investigation. Dry resistance as a genetic characteristic is assumed to be close to cold resistance. Thus it may be possible to learn about and better understand each of these characteristics in the light of the other. Dryness is a huge problem internationally and a common reason for harvests not surviving, which means that understanding dry resistance in crops has a broad general interest. In this dry resistance research, co-operation has been established with a research group in Australia, focusing especially on dryness.

In this section, the resource use and development categories were identified and discussed on the basis of the empirical inquiry in the winter oats project. In the following section, each of the identified categories is discussed further.

5.2 The resource use and development categories

There are a number of resources used and developed within and outside the scope of an inter-organisational research project, as seen in the case of the winter oats project. In this section, the five suggested resource use and development categories are analysed, based on the preceding sections.

5.2.1 RESOURCES DEVELOPED AND USED WITHIN THE PROJECT

In a research project there are resources developed which become used within the project in subsequent research activities – that is, resources developed and used within the project, referred to as resource use and development category A

in Figure 2.10. The use and development of resources may be planned or unplanned; what distinguishes this category from the others is that the resources are both developed and used within the project. Also distinctive for this resource category is that the following research activity often builds on and further uses the resource developed, meaning that some of the resources are essential inputs to subsequent activities.

Returning to the case study of the winter oats project, the oat varieties prepared in test tubes delivered to the sequencing firm are an example of this category consisting of resources developed and later used in the project. Another example of a resource both developed and used within the project is the raw EST data supplied by MWG Biotech. The raw EST data are essential for starting up the EST-data analysis.

The EST data are another central resource, part of the category of resources both developed and used within the project. The EST data were developed in the EST-data analysis and were already then planned to be used later in the microarray analysis. During the EST-data analysis, additional resources to be used within the project were developed, above all the identified potentially cold-related genes in oats. These genes constituted an important resource for designing the microarray chips. Thus, the EST data in combination with the potentially cold-related genes formed essential starting points for the preparations for microarray analysis. Both are consequently examples of the category of resources developed and used within the project.

Another resource developed and later used within the project is the results of the field study tests with sowing oats and barley. The plants from the field studies constituted inputs to the microarray analysis, which was planned already from the project start.

In sum, there are several examples of resources developed and used within the project, i.e. category A. Some resources are developed in one activity and are the precondition for starting the subsequent research activities. There are also some resources developed that constitute essential inputs in later research activities.

5.2.2 RESOURCES DEVELOPED OUTSIDE AND USED WITHIN THE PROJECT

In addition to the resources developed and used within the project, there are resources needed from the outside of the project – that is, resources developed outside the project and used within, illustrated in Figure 2.10 as category B. The resources developed outside the project may come from the project

members, the parent organisations, or third parties that are not involved in the project.

In the winter oats project there are several examples of resources of the category consisting of resources developed outside the project that were used within the project. Instances are the winter and spring oat varieties that one of the project members contributed. The oat varieties came both from the parent organisation of one of the project members and via the Internet. The parent organisation Svalöf Weibull, as also mentioned above, specialises in plant breeding and has a selection of oat varieties that became of value in the project. The same project member also accessed other winter oat varieties via the Internet. The project member thus knew both what to look for and how.

Another example of resources of this category is the methods of handling huge data sets and building databases. One of the project member groups, the computer scientists, possessed these methods and became a member because they were needed in the project.

Also a resource developed outside the winter oats project that came to be used within it were the sequencing facilities at MWG Biotech. There were some contacts between the project and the supplier after the sequencing was finished, but they did not result in any interaction. In contrast to the example above where the computer scientists held important resources developed outside the project, which became part of the project, MWG Biotech remained an external resource used for sequencing. Partly to compensate for the lack of interaction, additional resources developed outside the project were used, such as the manuals found on the Internet to figure out exactly what type of analyses had been done at MWG Biotech.

The Internet was also used to get access to a number of other resources, e.g. publicly available databases and software tools for searching the databases in analysing the EST data. Publicly available databases and tools are thus other examples of resources that are part of the resource category B. Thus, the project members got access to several types of resources developed outside the project via the Internet. No interaction was necessary to acquire these Internet-based resources. However, an understanding of how to use them was needed.

The project members also used resources developed in other research projects in which they were involved. One example is the parallel involvement of the molecular biologists in the winter oats project and the *Arabidopsis* project. It was possible to find synergies between these projects and use experience from one project in the other, i.e. understanding one plant based on the other. For example in relation to the *Arabidopsis* plant, there are plenty of published

articles on the Internet, which are other external resources that came to be used via the Internet in relation to the winter oats project.

There is another example of how one of the project members got access to resources developed outside and used within the project via the parent organisation. The molecular biologists used the facilities at Göteborg University for designing microarray chips specifically for this project. Hence, by being part of this parent organisation, it became possible to use some of the parent organisation's facilities.

To sum up, there are several examples of the resource development and use category which builds on resources developed outside the project that were used within the project. The resources of this category were accessed to the project, e.g. via the parent organisations or the project members' use of the Internet, or by purchasing access to the resources.

5.2.3 RESOURCES DEVELOPED WITHIN AND USED OUTSIDE THE PROJECT

During the project there were also examples of the category of resources developed within and used outside the project. This is illustrated and referred to as category C in Figure 2.10. The resources that come to be used outside the scope of the project may be resources that already are used within the project but become externally used in another setting or with another purpose as well. It may be the project members, the parent organisations, or other organisations that use the resources developed in the project for different purposes.

In the case study of the winter oats project, there are several instances of the category of resources developed within and used outside the project. In the EST-data analysis, the project members have not reached the goal of identifying the cold-associative genes. However, they have identified a number of genes, for example, some that were concluded to have no effect on the cold adaptation process, as described in the empirical section. One of these non-cold-related genes has been used as the starting point for developing the gene family tree. Another example of identified genes that are used outside the scope of the project is the health-related genes, which are used in co-operation among two of the project members and a third party. While the first example shows how a project member may use a resource developed within the project for purposes outside it, the second example shows how this may be done with starting point in the project members' existing relationships, and thus how a third party which has been worked with before becomes a collaboration partner again.

Another example of this resource use and development category from the case study shows how a resource developed in the project came to be used outside it through one of the parent organisations. The EST data were used as a resource in a breeding programme in England, via Svalöf Weibull which is represented also in England and furthermore is a member of this programme. This use of the resources developed within the project was not in the project plans. The breeding programme may contribute to the winter oats project as well, but it is impossible to know today whether and in what ways this occurs.

The resources developed in the project and used outside may thus contribute to the project, but there are no guarantees. Mainly, the uses outside the project are applications that interest and benefit the involved project members or parent organisations. The outside use of resources developed within the project is also dependent on the project members' or parent organisations' ability to identify the opportunities for further use.

The case study also shows how research on a characteristic partly related to cold resistance has evolved and created a new relationship for one of the project members. Dry resistance, assumed to be genetically close to cold resistance, is in focus for an Australian research group. In this sense, the research in the project has resulted not only in the understanding of a new application, but also in the creation of a new relationship.

To sum up, several resources were developed within the project that saw further use outside it. The project members themselves used resources outside in ways not directly related to the project goals. The resources were also used outside the project via the project members' existing networks of relationships. Based on their networks, new constellations could be formed around the resources developed in this particular project.

5.2.4 RESOURCES DEVELOPED PRIOR TO AND USED DURING THE PROJECT

Research projects may have access to and use resources that are developed prior to the research project. Examples are resources held internally by the project members based on previous research projects, some of which may be developed prior to a project and have a planned use within it. In Figure 2.10, this resource use and development category is referred to as category D.

The most obvious instance of a resource developed prior to the project in the winter oats project is the transformation technique. This resource was developed by the molecular biologists before the project and was considered as a precondition for starting it. So far, this resource has not been used within the project, partly due to the results of other research activities in the project.

During the field studies, there were oat plants that survived the winter, which temporarily provided another way of reaching the overall goal than using the transformation technique. In that sense, the most important role of the resource in focus was as one of the reasons for starting the project.

There were also other resources held internally by the project members and developed prior to the project that came to be used within it. Examples on a general level may be the respective project member's skills, e.g. the understanding of how to handle data sets, of molecular biology, and of hybridisation methods. The understanding of computer science in relation to biological data resulted in inclusion of the computer scientists as a project member³⁹. Hence, all of the project members had their own resources developed before this project and these were used in the project.

5.2.5 RESOURCES DEVELOPED DURING AND USED AFTER THE PROJECT

There may also be resources developed during the project that come into use after it is finished. Such resources are illustrated in Figure 2.10 as category E. The project members, the parent organisations or third parties may use some of the resources developed in the project after its completion.

There are as yet no examples of this category in the case of the winter oats project, since it was still ongoing as of 2005.

5.2.6 THE RESOURCE CATEGORIES OF THE WINTER OATS PROJECT

On the whole, five categories of resource use and development within and outside the project boundary have been identified. These are resources developed and used within the project, resources developed outside and used within the project, resources developed within and used outside the project, resources developed prior to and used during the project, and resources developed during and used after the project. Of these, four are exemplified in the winter oats project, as discussed above. The project is represented in terms of all the different resource use and development categories in the respective phases; see Figure 5.6.

³⁹ The methods for data handling and database building that the computer scientists contributed are regarded as a resource developed outside the project and used within it, not as a resource developed prior to the project. The reason for this choice is that the need for these resources arose after the project was initiated.

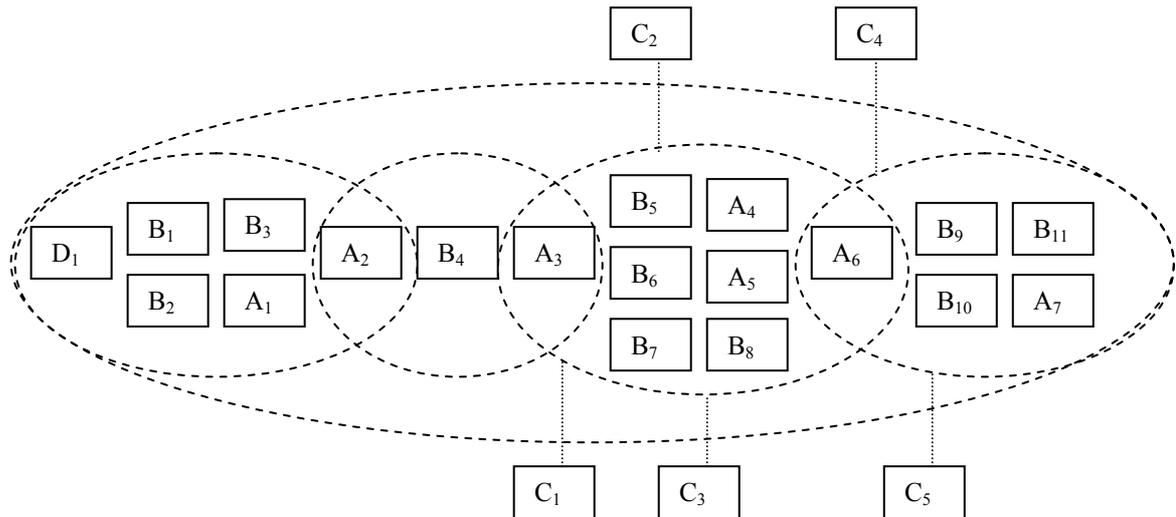


Figure 5.6: The resource use and development categories of the winter oats project.

All the resources that are used and developed within the project are illustrated within the project boundary in this figure, in contrast to previous figures. There are several examples of resources of category C, referring to resources developed within the project and used outside it, in the winter oats project. These resources are illustrated outside the project boundary in the figure, although they have influenced the research process of the winter oats project. One reason why they are displayed outside the project is that one of the aims of this illustration, which will be used in the subsequent discussion, is to show resources combining *within* the project to reach its goals.

Based on the previous sections, the resources of the winter oats project are categorised according to resource and development category (A-D), and are numbered (1-...) on the basis of the number of resources from the same category. Table 5.1 presents a key to what the resources of the different categories refer to in the winter oats project.

Table 5.1: The resource use and development categories of the winter oats project.

Resource	The resources used and/or developed
A ₁	Oat plants from the field studies
A ₂	Test tubes ready for sequencing
A ₃	Raw EST data
A ₄	EST data
A ₅	EST database
A ₆	Potential cold-related genes
A ₇	Oat microarrays
B ₁	Methods for data handling and database building
B ₂	Winter oat varieties from the US and Russia
B ₃	Oat varieties from Svalöf Weibull England
B ₄	Sequencing facilities at MWG Biotech
B ₅	MWG Biotech
B ₆	Manuals from the Internet
B ₇	The Arabidopsis project
B ₈	Public databases and tools
B ₉	Facilities at Göteborg University
B ₁₀	Arabidopsis microarray chips
B ₁₁	Barley plants and barley-microarray analysis
C ₁	Methods for EST-data analysis
C ₂	Non-cold-related genes
C ₃	Health-related genes
C ₄	Potential oat-breeding markers
C ₅	Studies of dry resistance
D ₁	The transformation technique

In the next chapter, resource combining within projects is discussed, with a starting point in these categories.

6 Resource combining within the project

Resources are used and developed within and across the project boundary, as seen in the previous chapter. In order to fulfil the project goals, a number of resources are combined within the project and, in this process, the resources are used and developed. Some of these resources are developed in the project, while some are developed outside or prior to the project. This chapter focuses on the combining of resources *within* the project towards the project goals.

The chapter begins in section 6.1 by discussing resource combining with a starting point in the empirical description of the winter oats project. Section 6.2 discusses internal processes of an inter-organisational research project, with emphasis on expanding resource collections of the project members and the project, interaction and learning, search and discovery, and the functions of the project goals.

It needs to be recapitulated that this thesis particularly concerns inter-organisational research projects. However, in the analysis below, these are simply referred to as projects.

6.1 Combining of resources towards the project goals

This section analyses resource combining towards the project goals of the winter oats project. Regarding resource combination internally, the resources of three categories may be combined towards the project goals. These are the resources developed and used within the project (category A), the resources developed outside and used within the project (category B), and the resources developed prior to and used during the project (category D).

Hence, this section focuses on combining resources internally in projects. As a consequence, the resource combinations within the project are emphasised and illustrated, while the resources developed within and used outside the project (category C) are not included although their development may have influenced the research process. Instead, these resources are focused on subsequently (see Chapter 7).

The resources of categories A, B and D may be combined in a number of ways, depending on the character of the project, the project task, the project members' previous experience and understanding. The project goals also influence the ways in which resources are combined internally. The project goals are described below, followed by discussion of a number of different resource combinations.

6.1.1 THE PROJECT GOALS

The overall goal of the winter oats project was clearly formulated – to develop winter oats. Already from the project start, all the project members related to this goal and worked towards it in one way or another. The overall goal is referred to as G_1 in Figure 6.1 below.

When the research process in the project started, the overall goal was translated into a more specific goal – to identify the genes regulating the cold-adaptation process, referred to as G_2 (see Figure 6.1). Thereafter almost all the research activities in the project were directed towards the specific goal of the project (G_2) and only a few were directly related to the overall goal of the project. Nevertheless, both of the project goals have provided guidance during the research process in the project, as will be seen below.

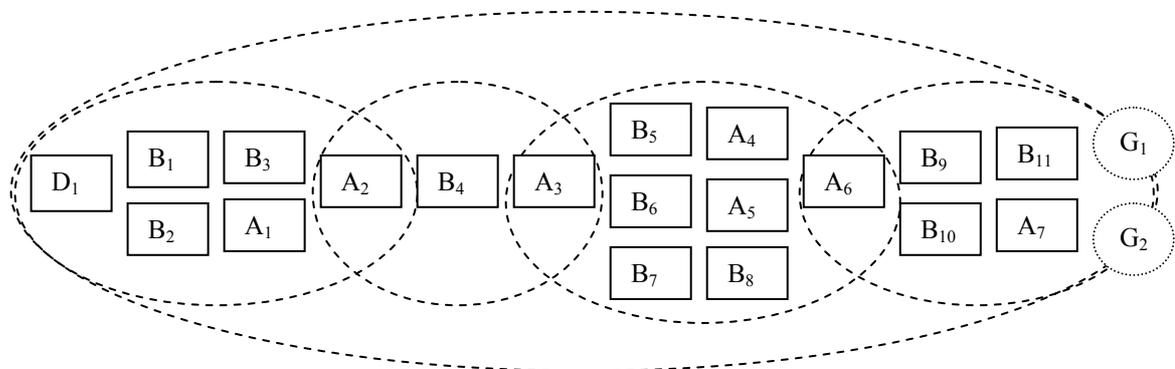


Figure 6.1: The project goals of the winter oats project.

How to reach the overall goal of the project was not evident at the time of the project start, and it was not known exactly what methods to use. However, there were ideas regarding how to pursue the goals and some methods, e.g. the microarray analysis, were planned to be used already at the initial stage. One resource developed prior to the project had a *planned* use in this particular project. The plan regarding the transformation technique (D_1) was based on the view that it would be used in the future to fulfil the overall goal of the project, and not on how it was to be used. The resource developed prior to this project

is thus related to the overall goal of developing winter oats. However, as discussed in the previous sections, the transformation technique (D_1) planned to be used in this project was never used. Therefore, this resource is not discussed below in the different resource combinations.

Thus, the point of departure for the project consisted of the formulated overall goal (G_1) that was developed into the specific goal (G_2). The specific goal was translated into the first plans and ideas for action. In relation to these plans, resources were mobilised and combined towards the project goal.

In the subsequent sections, eight examples are given of combining of resources based on the winter oats project. These examples do not provide the total picture of resource combination within the project, but are to be seen as illustrations of variety.

6.1.2 RESOURCE COMBINING TOWARDS THE OVERALL GOAL OF THE PROJECT

In this section, one example is presented of a resource combination directly related to the overall goal of the project. The character of the resources combined, how they were mobilised in the project, and how the resources relate to the project members' and parent organisations' resource collections are in focus.

Combining B_2 and B_3 – development of A_1

Winter-oat varieties from the US and Russia (B_2) and oat varieties from the plant-breeding firm (B_3) were combined with other resources within the project. Both of these resources were developed outside the project and used within the project. The plan with combining these resources was to test whether any of these oat varieties would survive the cold climate of the Swedish winters. The long-term plan of the combination was thus to pursue G_1 , the overall goal of the project, as emphasised in Figure 6.2.

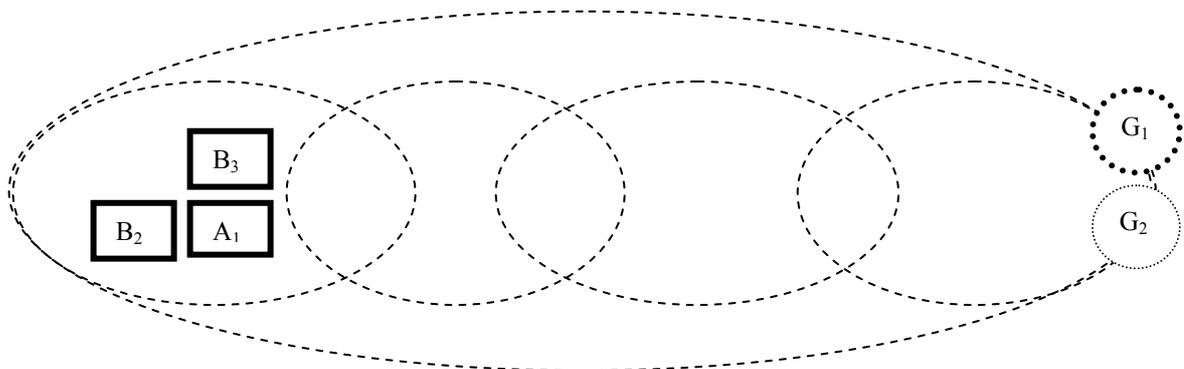


Figure 6.2: Combining of B_2 and B_3 towards the overall goal of the project.

Both the winter-oat varieties from the US and Russia (B_2) and oat varieties from Svalöf Weibull (B_3) were accessed via the same project member, the plant-breeding firm. The project member accessed B_2 via the Internet and, through this access of resources developed outside the project, managed to expand its resource collection by contributing resources developed outside the project. B_3 was accessed via the parent organisation of the project member, which meant that this project member mobilised resources from the parent organisation's resource collection to the project. The project member not only expanded its resource collection but also managed to get the resource collection of the parent organisation to be used within the project and thereby become part of the project's resource collection.

The combination of winter-oat varieties from the US and Russia (B_2) and oat varieties from Svalöf Weibull (B_3) resulted in oat plants surviving these field studies (A_1). The plant-breeding firm had never tried this particular combination before with the intention to develop winter oats. However, the firm continuously tests oat varieties for the purpose of developing new ones, and investigates in this work which varieties survive and which have certain characteristics. The resource combination performed within the project is thus clearly related to other resource combinations that the plant-breeding firm is involved in.

The combination of winter-oat varieties from other countries and oat varieties from the plant-breeding firm was to a certain degree planned. It was not clear that it was specifically B_2 and B_3 that were to be combined. However, at large it was planned that some oat plants were to be combined and tried out with plant-breeding methods. What was not planned was the characteristic of the developed resource (A_1) in this combination. It was not clear that some plants would survive the field tests, implying a first step towards winter oats for the Swedish climate. The resources of this combination (B_2 and B_3) may thus be argued to contain a degree of search and the resource developed (A_1) a certain degree of discovery, based on the element of surprise in finding some oat plants to survive the winter.

Thus, the oat plants surviving the field studies may be considered as a resource developed towards the overall project goal. On the other hand, as will be seen below, this resource (A_1), i.e. the oat plants surviving the field studies, also became used in another resource combination towards the specific project goal.

6.1.3 RESOURCE COMBINING TOWARDS THE SPECIFIC GOAL OF THE PROJECT

In this section, seven examples are presented where the resource combinations are related to the specific goal of the project (G_2). The final resource

combinations discussed below are still not fully completed, since the project is ongoing. The character of the resources combined, how they were mobilised, and how the combinations related to the project members' and parent organisations' resource collections are some of the issues discussed in connection with each resource combination. The resource combinations are also discussed with emphasis on why and how the resources are combined and whether the combining was planned or discovered during the research process.

Combining B₂ and B₃ – development of A₂

A more specific goal was formulated in terms of identifying the genes regulating cold-adaptation in oats, as mentioned above. It was concluded that, in order to reach this goal, an important step was to generate gene-sequence data. To do so, winter-oat varieties from the US and Russia (B₂) and oat varieties from the plant-breeding firm (B₃) were combined in order to prepare test tubes, which formed the point of departure for sequencing. Hence, the same resource combination as discussed above was used for another purpose within the project and, during this other use, mainly directed towards the specific project goal, as emphasised in Figure 6.3.

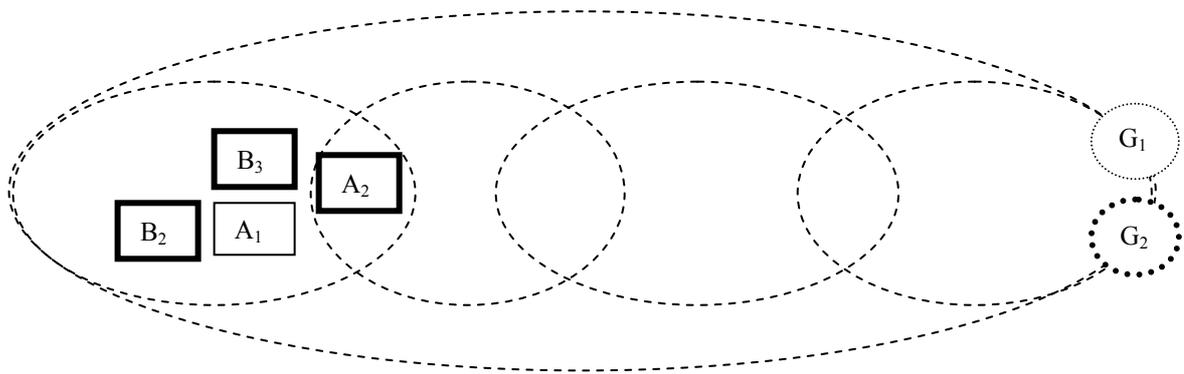


Figure 6.3: Combining B₂ and B₃ – development of A₂.

Both the resources (B₂ and B₃) were developed outside the project and combined with other resources internally in order to develop the test tubes for sequencing (A₂), which were needed to generate the gene-sequence data. As described above, the B₂ and B₃ resources were provided to the project through one of the project members, which accessed them from its parent organisation and from the Internet. However, this project member was not directly involved in the combination resulting in A₂. The project member involved in the combination of B₂ and B₃ resulting in the preparation of test tubes for sequencing was the group of molecular biologists. This project member thus managed to use resources that were part of the project's resource collection.

The preparation of the test tubes for sequencing based on the combination of the winter-oat varieties and the oat varieties from the plant-breeding firm was planned. The combination of resources may be argued to be planned since the resource combination of B₂ and B₃ was primarily seen as a step towards developing the resource A₂.

Hence, this resource combination was used for two different purposes directed towards the two goals of the project. In the former combination resulting in A₁, the project member managed to expand its resource collection and to contribute resources from its parent organisation's resource collection. By mobilising these resources to the project, they were made part of the project's resource collection. In the latter combination resulting in A₂, the involved project member made use of the project's resource collection.

Combining A₂ and B₄ – development of A₃

Based on the prepared test tubes developed through the combination of B₂ and B₃, the ambition was to generate gene-sequence data. It was an outspoken ambition and part of the original project plan, since gene-sequence data were considered to be a first necessary step towards the specific project goal. The combination of the test tubes prepared for sequencing (A₂) and the facilities at the sequencing firm's site (B₄) were related to the specific goal G₂, emphasised in Figure 6.4.

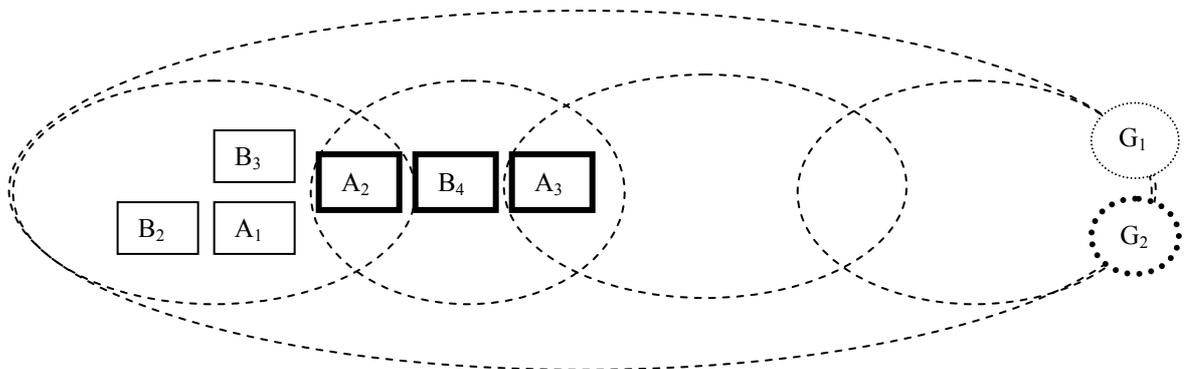


Figure 6.4: Combining A₂ and B₄ – development of A₃.

The plan with combining these resources was evident: to develop gene-sequence data. However, what resources to use in order to develop A₃ were not known in advance. None of the project members had any previous experience in either using or developing resources of this type. Consequently, it became obvious to use a resource developed outside the project. After searching for alternatives and evaluating them, the sequencing facilities at MWG Biotech were selected. The resource to be developed in this combination, the gene-

sequence data, was clear – while the resources needed to achieve that aim were not, and may thus be described as characterised by search.

The gene-sequence data were part of the plan already from the beginning of the project in relation to the specific project goal. However, the exact characteristics of A_3 in terms of regarding the gene-sequence data as *raw* EST data were neither part of the plan nor possible to plan.

The developed resource (A_3) was not only important in relation to the specific project goal: the resource can also be seen as an expansion of two of the project members' resource collections. Both the molecular biologists and the computer scientists may use the raw EST data for other purposes outside this particular project. The molecular biologists may identify interesting characteristics in the gene-sequence data that are related to other activities, e.g. in terms of developing new knowledge about biological functions of oats. The computer scientists may use the resource for other purposes such as developing methods or algorithms based on the characteristics of the resource.

Combining A_3 , B_5 , and B_6 – development of A_4

Similarly to the raw EST data (A_3), the resource developed in this combination – the EST data (A_4) – is strongly related to the specific goal of the project (see Figure 6.5). The EST data may even be seen as a precondition for reaching the specific goal. In this combination, the raw EST data were combined with additional information from the sequencing firm (B_5) and manuals found on the Internet (B_6). The project members involved in this combination were the molecular biologists and the computer scientists.

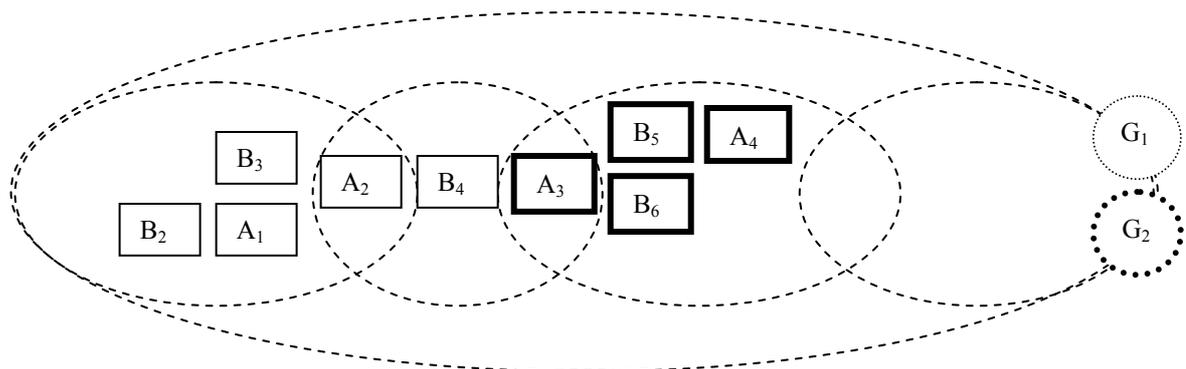


Figure 6.5: Combining A_3 , B_5 and B_6 – development of A_4 .

As in the previous combination, the plan with this combination was clear: to develop a refined version of the EST data. However, it was not apparent how to do so, meaning with what other resources the raw EST should be combined in

order to become EST data. The decision on which resources to use in order to improve the raw EST data may thus be characterised by search.

In this search, the project members tried to build on the existing resources they had access to, or knew about, to the extent it was possible – i.e. their resource collections were used as starting points. It was concluded that external resources were needed, with the result that the project members tried to get additional information from the supplier of the data (B₅). Since the received information was not enough, the Internet was searched for supplementary resources. Some additional resources were found in manuals (B₆), and the project members managed to make sense of and use these resources in relation to this combination. Regarding the Internet and the publicly available resources, it was not planned initially what resources they were looking for. On the contrary, based on which resources were identified outside the project, it was gradually planned with what other resources the EST data could be combined.

Already at the initiation of the project, there was a planned further use for A₄ in the microarray analysis. Thus A₄ was regarded as a resource to be used in subsequent combinations in the project.

As argued above, A₃ may be seen as an expansion of the two project members' resource collections, being of general interest for these two members. Consequently, an “improved version” of A₃ into A₄ can also be seen as an expansion of their resource collections. This resource may thus have a value for the two project members regardless of whether the project goals are fulfilled.

Combining B₁, A₄ and A₅ – development of A₄ and A₅

In the combining of methods of handling data and building databases (B₁), the EST data (A₄) and the EST database (A₅), both the EST data and the EST database were developed. The ambition with the combination was to come closer to G₂, the specific goal of the project, illustrated in Figure 6.6.

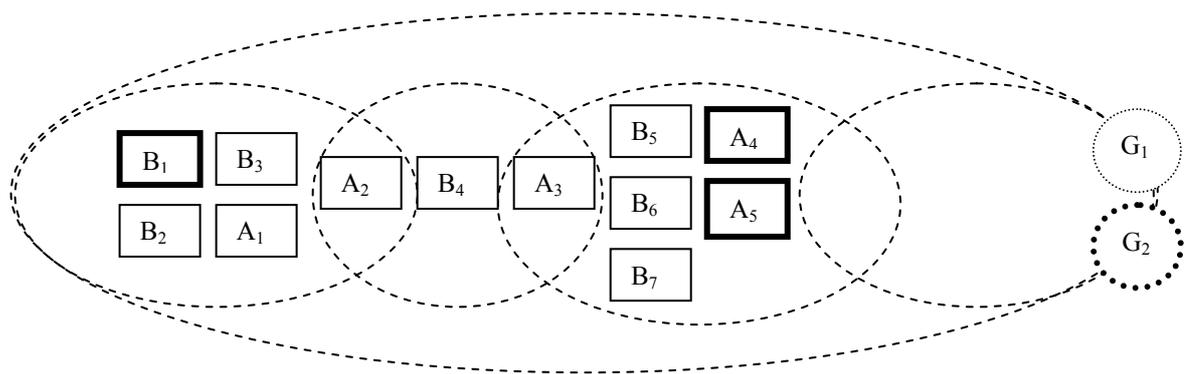


Figure 6.6: Combining B₁, A₄ and A₅ – development of A₄ and A₅.

The EST database may be regarded as a resource developed as a tool for understanding the EST data. On the other hand, the EST database does not have any value without the EST data, so the EST data are a tool for developing the EST database. The EST data and the EST database are thus interrelated since they build on and are understood in terms of each other.

The resource collection of the computer scientists, as regards methods of handling data and building databases (B₁), was used as a starting point in the development of the EST data (A₄) and the EST database (A₅). In addition to the resource collection of the computer scientists, additional resources from outside the project were needed. These resources were tools downloaded from the Internet, free for anyone to use. However, it is a craftsman's work to develop a resource like A₅ to fit the EST data, and the computer scientists' existing resource collection was needed in order to make use of the external resources. In turn, the external resources from the Internet may be seen as an expansion of the resource collection of the computer scientists. The molecular biologists' existing resource collection, in terms of biological understanding and interest in the content of the EST data and thereby in the EST database, was a necessary starting point in the analysis. It was a precondition for building the EST database to know what to look for in the EST data. By combining these two resources, the EST data and the EST database, the molecular biologists also expanded their resource collection by increasing their understanding of oats on the basis of the EST data.

As suggested above, the EST data may have an intrinsic value for two of the project members, the molecular biologists and the computer scientists. From the molecular biologists' perspective, A₅ is a tool developed in order to better comprehend A₄. It is interesting to note that the EST database (A₅) is a resource in itself as well, since the computer scientists regard the EST database as a result. In relation to the computer scientists, the EST data (A₄) can be

considered as a resource in order to develop A_5 . Hence, in this combination both resources are respectively an end and a means for the two project members. At the same time, the EST data and the EST database are viewed as resources to be used in the process towards the specific project goal.

Combining A_4 , A_5 , B_7 and B_8 – development of A_6

In this resource combination, the EST data (A_4) and the EST database (A_5) are combined with resources developed outside the project. These resources are the understanding gained from another ongoing research project, the *Arabidopsis* project (B_7), and resources publicly available on the Internet (B_8). The goal with the combination is directly related to the specific goal of the project. The notion was that, based on the resources with which A_4 was combined, the cold-associative genes might be identified and thereby the specific goal be pursued. However, that did not become the case based on this resource combination – although from this combination there are some potential cold-associative genes derived (A_6), which constitute the result coming closest to the specific project goal (see Figure 6.7).

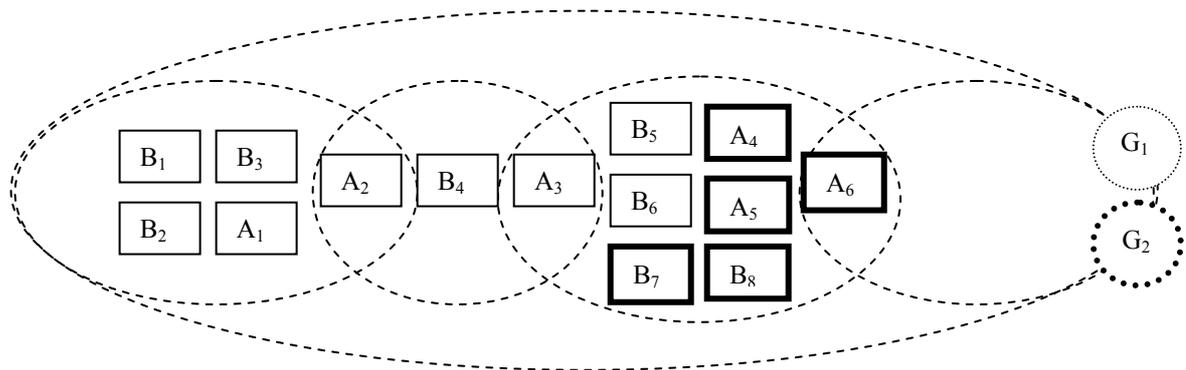


Figure 6.7: Combining A_4 , A_5 , B_7 and B_8 – development of A_6 .

The EST data may be considered as a given in this resource combination. The EST data were regarded as one of the central resources for coming closer to the specific goal of the project. The issue was to decide how this could be done best, which implies that the resources to combine A_4 with can be described as characterised by search. In this search, the project members again tried to build on their existing resource collections in terms of available resources they knew about.

The project members took the starting point in what already were known in two ways. First, the molecular biologists concluded it to be relevant to relate this project to a parallel research project (B_7), which made it possible to increase the understanding of the EST data. Thus, one of the project members

contributed resources from its resource collection. In this resource combination, it becomes evident that the resource collection of a project member could contribute to several projects.

Second, the project members tried to relate to existing knowledge in terms of what was published on the Internet (B_8). It was a process of relating to, and combining the EST data with, resources developed outside the project. The external resources were usable on the basis of the project members' existing resource collections. In this use of resources developed outside the project, the project members' resource collections were expanded to include the understanding of how to use publicly available tools (in relation to this task).

The resource developed in this resource combination (A_6) can be considered as close as the project members came towards the specific goal of the project, based on combining the EST data with resources developed outside the project. That is, the project members exploited the options concerning what resources to combine A_4 with in achieving G_2 . In the next combination, also partly based on A_4 , a new approach is introduced.

Combining A_4 , A_6 , B_9 and B_{10} – development of A_7

At this stage a new approach, the microarray analysis, was introduced as the general method in order to come all the way to the specific goal. The new approach was planned already from the beginning of the project. The resource to be developed in this combination, the oats microarray chips (A_7), is an important *tool* in this new approach. It is to be noted that this combination is not fully completed yet.

In this new approach, the EST data (A_4) and the potentially cold-related genes (A_6) were combined with external resources – above all, microarray facilities at Göteborg University (B_9) and *Arabidopsis* microarray chips (B_{10}). The combination of A_4 , A_6 , B_9 and B_{10} is thus related to the goal of identifying the genes regulating cold-adaptation in oats (G_2), as emphasised in Figure 6.8.

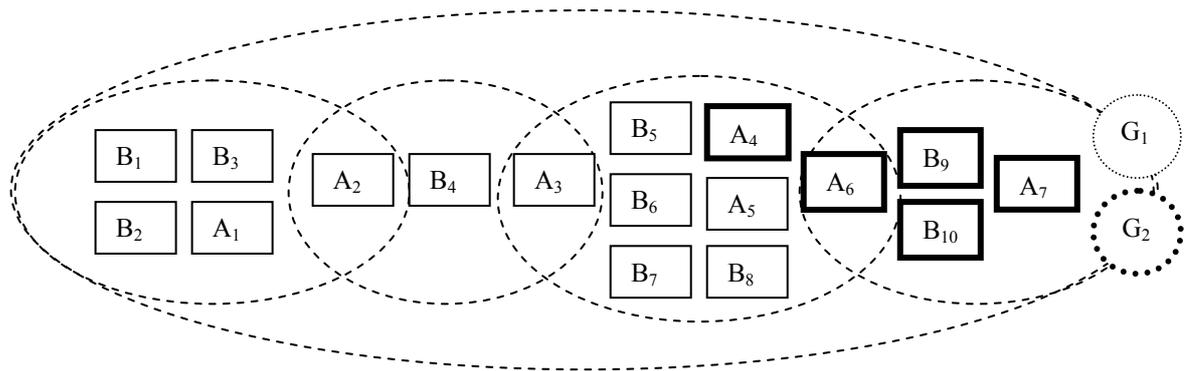


Figure 6.8: Combining A₆, A₄, B₉ and B₁₀ – development of A₇.

A consequence of introducing this approach was that new types of external resources were needed. However, two resources developed in the previous combinations still formed central points of departures. The EST data (A₄) and the potentially cold-related genes (A₆) developed in the previous combination were used in this combination. The EST data and the potentially cold-related genes may in fact be argued to form a precondition for the development of oats microarrays. Hence, the project's resource collection was pursued in the combining of resources based on this new approach.

Thus, the EST data and the potentially cold-related genes were combined in this use with the external resources: the microarray facilities at Göteborg University (B₉) and *Arabidopsis* microarray chips (B₁₀). To be able to develop the oats microarrays, the project members looked at *similar* resources, i.e. microarray chips developed for the *Arabidopsis* plant (B₁₀). Using these external resources means that one of the project member's resource collections again was expanded to include resources such as microarray chips for another plant. As discussed above, one of the project member's resource collections contained *Arabidopsis* plant-specific resources, and it became possible to further expand and relate to this resource collection concerning microarray analysis for the *Arabidopsis* plant.

Furthermore, the same project member via its parent organisation had access to the resource (B₉), i.e. the microarray facilities at Göteborg University, which was needed to develop and produce this type of tool. In other words, resources developed outside the project were accessed via one of the parent organisations and the project member managed to make use of the existing resource collection of its parent organisation in the project.

Combining B₁₁, A₇ and A₁ – development of A_x

This combination, as the previous one, is not completed yet, but represents an illustration of a future combining of resources directly related to G₂, the specific goal of the project (see Figure 6.9). When this combination is completed, the development of a resource A_x (not illustrated in the figure) may have the result that the specific goal of the project (G₂) is pursued. This combination is thus to be seen as one out of many potential future combinations towards the specific goal of the project.

The oats microarray chips under development in the previous combination are to be used in this combination. These chips (A₇) are in their first trials for use combined with experience from barley-microarray analysis (B₁₁) and oat plants (A₁), which are results from the field studies performed in the project by the plant-breeding firm. It is interesting to note that these oat plants from the field studies, developed in a combination directed towards the overall goal of the project of developing winter oats (G₁), are also used in this combination. The resource collection of the project is thus used as a point of departure for resource combination based on this new approach.

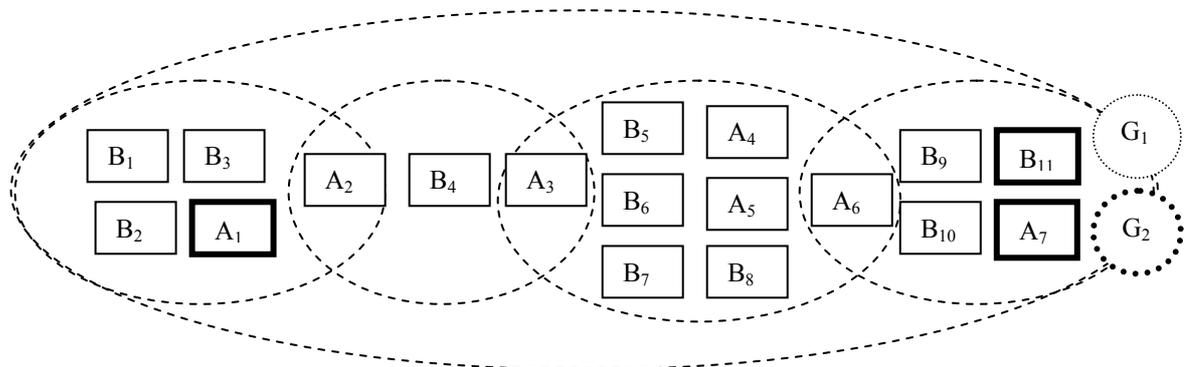


Figure 6.9: Combining B₁₁, A₇ and A₁ – towards fulfilling the specific goal.

As in the previous combination, the project members are taking the point of departure in another plant for developing this new approach for oats. In this combination, barley is used as a starting point. The project members try to build on the existing knowledge about barley in order to fulfil the oats microarray analysis. One of the project members is involved in the barley field experiments. Hence, one of the members makes use of its existing resource collection and contributes results from barley field tests. In addition, results from barley microarray analyses are accessed from scientific journals that are publicly available. The project members access external resources based on the character of their resource collections, which in turn are extended on the basis of using these resources.

When the oats microarray analysis is finalised, there will be large amounts of data generated, in which the answer (i.e. A_X) to the specific project goal G_2 may lie. Similarly to the case of the EST data, the computer scientists may consider the data as a resource in itself for finding fascinating patterns, and the molecular biologists may view these forthcoming data as a resource for finding biologically interesting mechanisms or characteristics of oats, not necessarily related to cold-adaptation. This particular combining is for the future to reveal since it is still not completed.

6.2 Processes in inter-organisational research projects

Based on the preceding discussion of resource combining towards the project goals, this section discusses internal processes of inter-organisational research projects. The project members access resources from their resource collections, which provide essential starting points for resource combining. The resource collections are dynamic in character and may change through resource combination. The research activities and the combining of resources are often characterised by search with regard to either what will be developed, or how, or both. In this process, the project goals appear to be of great importance in terms of providing direction.

With a starting point in the discussion of the winter oats project above, this section first investigates the changes of the resource collections of the project. This is followed by a subsection on interaction and learning, then a discussion of search and discovery. The final subsection focuses on the dynamics and functions of the project goals.

6.2.1 CHANGES IN THE RESOURCE COLLECTIONS

The starting points in the combining of resources discussed above are the existing resources, in terms of the resource collections of the project members and the parent organisations. The existing resources are not static entities but may change during resource use and development. The resource collections of the project members may contribute to the combining of resources and be affected in four different ways. First, some of *the existing resources of the project members' resource collections come to be used in new ways within the project*. This may correspond to what Holmen (2001) categorises as “existing resources and products used in new combination and use routines”. It refers to the fact that the existing resource collections are used in new ways. One example of using the existing resources in the project is the project members making use of their resource collections in several projects. As seen above, one of the project members managed to use resources developed in another research project in the winter oats project.

Another example of using the existing resource collections is the use of the parent organisations' resources (in new ways) in the project. In the winter oats project, resources were mobilised from the resource collections of the parent organisations, as with the plant varieties from the plant-breeding firm and the facilities for developing microarray chips from the university department.

Second, in the search for appropriate resources, it can be concluded that resources developed outside the project, i.e. external resources, are needed. Based on the resource collections, the project members are able to access *external resources that are related to the existing resource collections*. By using resources developed outside the project, the project members' existing resource collections become changed (or expanded).

For example, the computer scientists possessed methods of handling and building databases internally and, on their basis, could make use of publicly available tools. Another example is the molecular biologists' ability to make use of the microarray data for the *Arabidopsis* plant based on their existing resources regarding that particular plant. Hence, the existing resource collections of the project members can function as preconditions for being able to use external resources, which in turn may enable changes in the resource collections.

Third, not only the resource collections of the project members are changing during a project, but also the resource collection of the project, as is illustrated in the winter oats project. There are *resources developed in the project that become part of the resource collection of the project*. For instance, the EST data are a resource developed in the project that is a valuable part of the project's collection. This resource is also the input to subsequent resource combination regarding microarray analysis. Another example is the results from the field tests, also further used in the project in subsequent analyses.

The resources developed in the project may be regarded as existing resources of the project's resource collection. These existing resources can be used in new ways outside the project, which implies that the resources are also part of the project members' resource collections. This is illustrated by the examples with the EST data and the EST database, which have potential to be used outside the project by two of the project members. The EST data are a vital resource in the winter oats project but also a resource that can be used for further understanding of oats biologically. The EST database is a resource developed as a tool in the project. On the other hand, the EST database can also be regarded as a resource for one of the project members in terms of developing methods for building databases. Hence, the project members'

resource collections can be expanded on the basis of the project's resource collection, which in turn may enable further use of these resources.

The existing resource collections of the project members emerge as important both for using resources within the project and for accessing and using external resources. The existing resources may thus be necessary to build on or relate to in order to make use of external resources. The existing resource collections may imply hindering aspects, as illustrated by "heaviness" (Håkansson and Waluszewski, 2002) and "established" resource structures (Bengtson, 2003). However, as seen above, the existing resource collections are necessary both as starting points in combining resources and for making use of external resources in a project.

Fourth, the external resources used in a project may not be related to the existing resource collections. This may correspond to what Holmen (2001) categorises as "resources which are new to the user". By using *new resources* (in new ways), the resource collections of the project members become changed. Returning to the winter oats project, there is one illustration of the use of unrelated resources; however, the resource is still related to the task to be solved. The use of the sequencing facilities was not directly related to the existing resource collections, since neither of the project members had any experience of such an activity. This resource was nevertheless accessed by purchase, and can currently be regarded as part of the project members' resource collections since, for the next project demanding sequencing, it is likely that the project members will use this resource again.

It is important to emphasise, in accordance with Holmen (2001), that single resource combinations need to be seen in relation to the resource collections. By focusing on a single resource in a certain combination, wanted or unwanted effects may emerge from the resource collections. For instance, if a new resource is used, which is integrated as part of a project member's resource collection, that resource may enhance the value of the other existing resources. However, the value of the entire resource collection may potentially decrease due to inclusion of a certain resource, involving creation or disruption of ties among a number of resources.

The resource collection of a project member and parent organisation is related to the larger resource constellation of the network (Håkansson and Snehota, 1995). This means that each resource combination may affect the resource collections of the involved project members or parent organisations, which in turn may affect the resource constellation of the network. Changes in one resource collection may have impacts on the wider resource constellation.

6.2.2 INTERACTION AND LEARNING

It follows from the above that the respective resource collections of the project members and parent organisations are central for resource combining. However, this does not mean that interaction is superfluous. The interaction between the project members is important for a number of reasons. In the search for resources, interaction within the project may be decisive for the project members to settle upon a solution. For example, three of the project members interacted in order to formulate the project goals, which in turn had the result that one of the project members accessed plant varieties both from the parent organisation and externally. As another example, collaborating around the EST data led to the project members searching for appropriate resources to combine with the raw EST data in order to make the most of it. Thus, the project members may have access to resources, but interaction among the members is needed to activate these. Interaction among the members is also needed in order to understand the other parties' perspectives and interests.

Another important aspect of interacting within the project is that the project members may be able to learn from each other. One type of learning concerns making use of the other parties' knowledge and experience (Håkansson and Snehota, 1995). An illustration of this type of learning between the project members involves how to access and use resources. The understanding of how to access and use a certain resource is transferred from one project member to another. The molecular biologists and the computer scientists both searched for and used publicly available tools extensively. It might be argued that the computer scientists knew about these tools already at the project start, but during the project the molecular biologists have expanded its resource collection to also include how to access and use these computer-based tools.

Another type of learning is joint learning (Håkansson and Snehota, 1995), which means that two or more parties create joint value through interaction. One example from the winter oats project illustrating joint learning is the mutual development of the EST data and the EST database. The molecular biologists managed to understand the EST data by using the EST database regarded as a tool from their perspective, while the computer scientists managed to develop the EST database by using the EST data considered as a tool from their perspective. Both parties thus learnt from each other in terms of a simultaneous development of resources as tools and resources as results. Joint learning implies interactive effects of working together. None of the parties could have accomplished the same results on their own.

Two conditions argued to stimulate joint learning are stability and variety in relationships (Håkansson and Snehota, 1995). Stability in inter-organisational relationships refers to continuity and working together over time. The project

members in the winter oats project who had been working together previously, and who are planning future joint projects, may be argued to represent stability. Variety, on the other hand, refers to differences and complementarities. All the project members can be described as contributing their differences and at the same time complementing each other. None of the four had the same area of specialisation. One way to further analyse variety is in relation to search and discovery, to be discussed below.

6.2.3 SEARCH AND DISCOVERY

Search and discovery involves exploring the unknown but in different dimensions. While search means looking for something already identified, discovery refers to finding the unexpected (Kirzner, 1992; Håkansson and Snehota, 1995).

In the winter oats project, there are several examples of resource combinations towards the project goals containing aspects of search. Search refers to resource combining where the objectives of the research activities were clear, e.g. to develop gene-sequence data or refine the raw EST data. However, what resources to combine in order to achieve that objective were not as clear. In those cases, resources were often looked for among the existing resource collections, as discussed above. For example, in the use of the EST data, it was not known what other resources were needed to create the most value for the EST data. This was planned gradually during the search. The search was thus dependent on the resource collections of the project members, i.e. what other resources the project members managed to mobilise and knew about.

The discovery of new aspects may be related to the resource collection of the project. Discoveries could be unplanned resources or resources with unexpected characteristics developed in the project. One example from the winter oats project of a discovery further used within the project is the oat plants surviving the field studies during Swedish winters. The surviving oat plants may, on the one hand, be regarded as the results of search-oriented activities due to the direct relation to the overall goal of the winter oats project. On the other hand, the oat plants survived to the project members' surprise; oat plants surviving the cold climate of Sweden were an unexpected outcome of the field tests. It is to be noted that there may be resources which are not pursued by any of the project members, to be described as unexploited discoveries.

Some discoveries in the winter oats project are not possible to relate to the goals of the project but can be used in the project context. Examples of discoveries to be used outside the scope of the project are the identification of genes. The project members searched for cold-adaptation genes but, to their

surprise, managed to identify genes not expected to be found in oats. This will be returned to in the next chapter.

Thus, most of the resource combination towards the project goals was characterised by search, in terms of accomplishing an objective of a certain research activity. In a research project, the degree of uncertainty may be high regarding both search and discovery. Nevertheless, the goals of a research project provide direction and function as starting points for resource combination. The project goals are discussed further in the next section.

6.2.4 FUNCTIONS AND DYNAMICS OF THE PROJECT GOALS

Project goals can seldom be completely formulated at the start of a project due to limited knowledge, information and a changing project context but need to be refined during a project. However, the project goals of the winter oats project, G_1 and G_2 , were formulated already at the project start, despite the difficulties in initially formulating goals of a project.

Through scrutiny, the specific project goal (G_2) of the winter oats project was broken down for each research activity. The goal was thus refined in a systematic way during the research process of the project. Still, the objective for each research activity could be related to the specific project goal, which in turn could be related to the overall goal. The project goals thus provided guidance and necessary focus in the project for each research activity. In other words, in line with Engwall (2002), the project goals provided direction.

The subdivided goals for the research activities imply dynamic elements. The specific goal was refined in the process and thereby changed during the project, in terms of the different sub-goals for the respective research activities. On the one hand, the goals of the winter oats project can be described as formulated in the beginning and worked towards during the project. On the other hand, the specific project goal was broken down for each research activity and could thus be described as refined during the research process of the winter oats project.

The overall and specific goals of the winter oats project can also be argued to have supported each other and performed central functions in relation to the achievements of the project. “Latent project goals” are described as a combination of visions and the operationalised goals continuously refined during the project (Christensen and Kreiner, 1997). In the winter oats project, the overall and the specific project goals may have functioned as latent project goals in which both long-term visions and concrete goals are combined. The overall goal (G_1) may be described as a vision for the project members, long-term in character, and a goal that all the project members shared. The specific goal of the project (G_2) may be characterised as an operationalised goal since

most of the research activities and resource combining in the winter oats project were related to this goal, as discussed above. Hence, the overall and the specific goals of the project can be seen as important ingredients together forming latent project goals.

Another function of the overall and the specific goals of the winter oats project is related to the issue of setting extremely high project goals, more or less impossible to pursue. When the goals are set high, the results of the project members' achievements are argued to become higher than if the goals were set lower (Christensen and Kreiner, 1997). The overall goal of the winter oats project might be understood as an extremely high goal almost impossible to fulfil. This highly set project goal may have driven the research process several steps further than if the project goal had been formulated only in terms of the specific goal. By having this overall goal, resources may have been searched for more widely, and combined more persistently, than if the specific goal had been the only project goal. In addition, the overall goal of the winter oats project may have enabled the project members to share a common understanding of the project on a general level even though their interests in each research phase differed.

The formulation of the project goals is likely to have an impact on the results of a project. However, it may also be the other way around; the probable achievements of a project may influence the formulation of the project goals⁴⁰. Based on the existing resource collections, it may be possible to suggest goals that almost certainly will be fulfilled. This may have been the case in the winter oats project. While the overall goal was concluded to be impossible to fulfil, the specific goal was regarded as a likely achievement of the project. Hence, the overall goal may have been refined into a specific goal in order to suit the results, which potentially would come out of the process.

The combining of resources can be described as directed towards one or both of the project goals of the winter oats project. The opportunities for combining resources are countless but, in relation to the project goals and based on the existing resource collections, the number of possibilities become limited. The project goals thus function as limitations by providing direction regarding what resources to combine. Hence, the project goals provide guidance and direction in terms of a necessary focus for the resource combining.

⁴⁰ Lindkvist and Söderlund (2002) pursue similar reasoning with a starting point in plans and argue that plans may be made on the basis of the likely achievements of a project.

6.3 Summary

This chapter concerns the combining of resources within the project towards the project goals. Eight illustrations of resource combinations are given from the winter oats project; one combination was directed towards the overall project goal, while the others were directed towards the specific goal of the project. Of these illustrations, the latter were not yet completed, but these represent two of many possible combinations of resources in the process of reaching the winter oats project's goals.

In the combining of resources towards the project goals, four aspects related to the resource collections of a project are suggested as essential: (1) The project members' existing resource collections are used in new ways in relation to the combining of resources within the project. (2) The project members access resources external to the project related to their existing resource collections. (3) Resources developed within the project become part of the project's resource collection, and are used further in the project. (4) The project members access and use resources that are new to them, not related to their existing resource collections. Hence, the resource collections of the project members and the project form important starting points for resource combining towards the project goals.

Interaction among the project members is another central characteristic of resource combining within an inter-organisational research project. For example, interaction is vital in deciding which resources to access for the project. Interaction may also result in learning among the project members, either from each other or jointly.

Resource combination within projects entails aspects of search and discovery. Search refers to looking for the known, while discovery refers to identifying the unexpected. Most of the resource combinations towards the project goals are characterised by search, as the objective of a certain research activity was clear but how to attain the objective was not.

The project goals are vital in the process of resource combining within a project in terms of providing a necessary focus and direction. In addition, the specific and the overall goals of the winter oats project performed different functions. They functioned as latent project goals, the specific goal entailed dynamic aspects and the overall project goal may have driven the research process further, based on being almost impossible to fulfil and creating a shared view of the project.

While this chapter has concerned the combining of resources within an inter-organisational research project, the next chapter focuses on resource combining across the project boundary, i.e. how a certain project may contribute to other research activities.

7 Resource combining across the project boundary

A project uses not only resources developed within the project, but also resources developed prior to and outside the scope of the project, as discussed in the previous chapter. In this process, the resource collections may change and the project goals provide guidance and necessary focus. While the last chapter focused on resource combining within the project, this chapter concerns resource combining across the project boundary and how projects relate externally to their contexts.

Hence, this chapter deals with how projects in the combining of resources across the project boundary become interrelated with their contexts. This may provide one way of understanding projects in their network contexts. Section 7.1 concerns how resources developed within a project are combined with other resources outside the project, and thus how a project may contribute to other ongoing research activities or the initiation of new research efforts. This is followed by section 7.2 analysing the network context of a project in terms of project embeddedness, the links between a project and its context, and an evolving network context.

As a reminder, the projects in focus for this thesis are inter-organisational research projects, which below are referred to simply as projects.

7.1 Combining of resources outside the project

Some resources developed in a project become used outside the project or after the project is completed, and are referred to respectively as resource use and development categories C and E; see Figure 2.10. In this section, the resources within these categories are discussed with emphasis on how they are used outside the project.

For the winter oats project, several resources have been developed that are used outside the project (but no resources developed during that are used after the project, since the case study has ended before the project was completed). Below, three illustrations of resources used outside the project are discussed. These examples do not aim to present a total picture of resource use outside the

winter oats project, but are to be seen as illustrations of how resources developed in a project can be combined with other resources externally.

7.1.1 THE PROJECT'S CONTRIBUTION TO OTHER RESEARCH ACTIVITIES

Below, resource combination outside the project, in which resources developed within the project contribute to other activities, is discussed. These combinations illustrate (1) the development of a new application from one of the project members' perspective, (2) the development of a new research effort based on existing relationships, and (3) the use of a resource in an ongoing programme.

Combining of C₂ and other resources

During the combining of the EST data, the EST database, the understanding of oats based on the *Arabidopsis* project and the publicly available resources, the cold-related genes were not fully identified. However, there were a number of genes identified out of which some were concluded to be *non-cold-related* (C₂). This identification is regarded as a discovery since the project members looked for the opposite but happened to identify non-cold-related genes.

The computer scientists used one of these non-cold-related genes outside the project in developing a gene-family tree for oats. The identification of the non-cold-related genes in itself may have contributed to the formulation of this particular goal. The collaboration between this project member and the molecular biologists needs to be emphasised in relation to the formulation of this application. The interaction between these two project members constituted the ground for developing the resources to be used outside the scope of the project, above all identification of the non-cold-related genes. In addition, the interaction was an important ingredient in formulating the task – e.g. what plants were interesting to compare oats with, and which genes were to be compared.

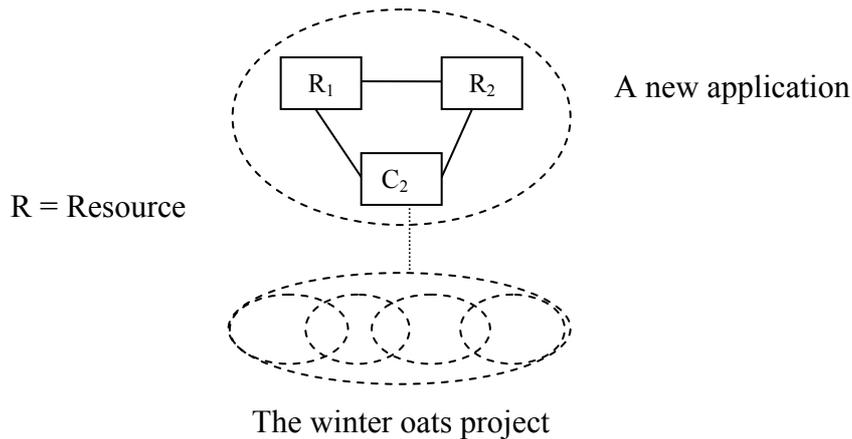


Figure 7.1: Combining of C_2 and other resources in a new application.

The use of the resource outside the project in this new application resulted in needs for external resources; see Figure 7.1. Above all, two resources were needed: first, a software program for developing family trees, which was new to the computer scientists (R_1). The project member was able to access and use this resource on the basis of its existing resource collection consisting of computer science methods. Hence, the understanding of computer science in terms of methods for data handling and database building enabled the access and use of an external resource.

Second, a contact was taken with researchers at a university department to gain botanical explanations (R_2), also new to the project member. The resource of botanical understanding was rather distant from the project member's existing resource collection, but was needed in order to develop the family tree further. This external resource was possible to access and use because of some specific issues that arose in relation to the new application.

This resource combination illustrates the need for building on the existing resource collection of the project members for accessing external resources. By building on the existing resources as in the example with the software program, the project member's resource collection was expanded. The example of botanical understanding illustrates the opposite – needs for external resources not related to the existing resource collections may arise in relation to a specific issue. Hence, regarding discoveries, needs for unrelated resources may develop.

Combining of C_3 and other resources

Another example of how a resource developed in the winter oats project became used outside the project is the health-related genes. In this combining of resources outside the project, two of the project members were involved: the Swedish Farmers Supply and Crop Marketing Association (SFA) and the molecular biologists.

As described above, during the combining of the EST data, the EST database, the understanding of oats based on the *Arabidopsis* project, and the publicly available databases and tools, the cold-related genes were not identified. Not only genes concluded to be non-cold-related, but also some genes concluded to be health-related (C_3), were identified during this search for cold-adaptation genes. This resource was not possible to relate to the goals of the winter oats project. However, two of the project members considered this resource to be interesting and usable in another setting. This resource may be described as entailing aspects of discovery since the cold-adaptation genes were searched for and the health-related genes were identified.

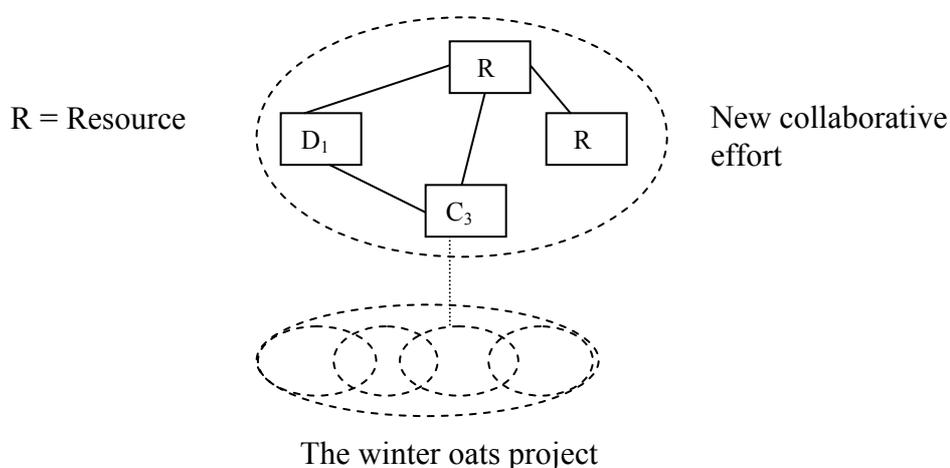


Figure 7.2: Combining of C_3 and other resources in a new collaborative effort.

The health-related genes (C_3) in combination with the technique for the transformation of oats (D_1) developed prior to the winter oats project became the starting points for a new collaborative research effort, illustrated in Figure 7.2. In this new effort, in addition to the two project members a university department specialised in food science became involved. The resources developed in and prior to the project, C_3 and D_1 , complemented the resources held by the university department specialised in food science. The C_3 resource thus became used as a resource in a new project in which it is to be combined with the resource collection of the third party. The resource collections of these three parties can be described as partly overlapping and partly complementary. They are overlapping in terms of a shared interest in oats, and complementary in terms of interests in different aspects of oats.

It is noteworthy that the D_1 resource, so far not used in the winter oats project, is considered as central also in relation to this new effort. Similarly to the winter oats project, D_1 is thus considered a resource that might be important in the future.

This collaborative effort was based on an existing relationship between the SFA and the food scientists. One of the project members thus used its existing network of relationships to further use a resource developed in the project in a new resource combination. Based on this relationship, it is possible for the other project member involved in the effort to collaborate and also build relationships with the third party.

Combining of C₄ and other resources

Two different aspects of the EST data in terms of identified genes, not related to the project goals, were used outside the project, as discussed above. In addition, another characteristic of the EST data, the highly repetitive areas, was used outside the scope of the project. This combining of resources across the project boundary was mainly organised by the plant-breeding firm, one of the parent organisations.

The repetitive characteristic of the EST data was identified during the analysis of the EST data. Although this characteristic did not particularly relate to any of the project goals, it might be useful in the development of breeding markers, in which the plant-breeding firm is especially interested. The repetitive areas of the EST data may qualify as the starting points for developing breeding markers (C₄). The parent organisation combined the repetitive sections of the EST data with resources held internally in order to prepare the EST data for being investigated for breeding markers. This further use of the highly repetitive areas of the EST data is taking place in an existing programme in which one of the parent organisations is a member. See Figure 7.3.

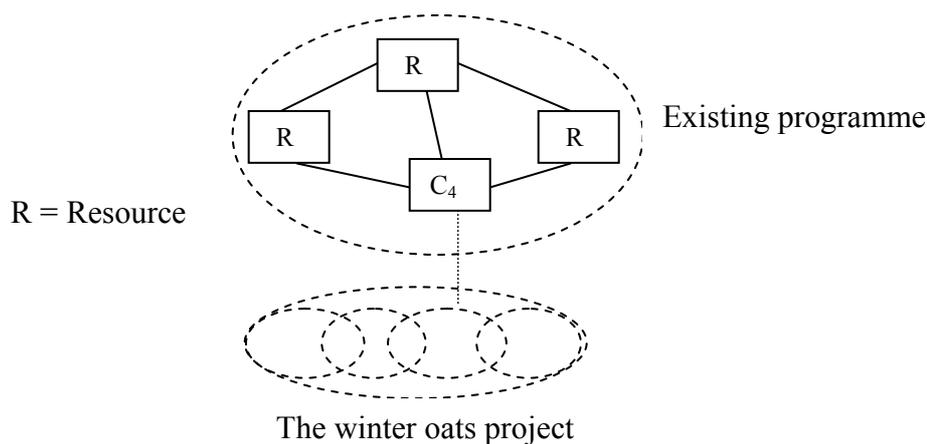


Figure 7.3: Combining of C₄ and other resources in an existing programme.

The repetitive characteristic of the EST data is further used on the basis of the existing resource collection of one of the parent organisations. The parent organisation thus managed to combine its existing resource collection and the

newly developed resources of the winter oats project. Thus, the parent organisation discovered an opportunity to use a resource developed in the winter oats project in another setting in which the parent organisation already was involved.

7.1.2 POTENTIAL CONTRIBUTION BACK TO THE PROJECT

Above, it has been discussed how the non-cold-related genes, the health-related genes and the repetitious areas of the EST data became combined with other resources in the context of the project. These combinations were made during the project, which implies that there are possibilities for the combining of resources to contribute back to the winter oats project.

Potential resources in relation to the project goals

In the case of non-cold-related genes (C_2), the identified genes were used further in the development of a family tree for oats, which in itself became an interesting application for one of the project members. However, the oat family tree might be of interest also in relation to the winter oats project. It could be important to know what other plants the oat is most related to, for instance when searching in public databases and comparing plants and their genes. Therefore, the oat family tree can be argued to be a potential resource in the research process towards the specific goal of the project, to identify the cold-regulating genes in oats (G_2).

Regarding the EST data as potential breeding markers (C_4), there might be possibilities for the breeding programme to contribute back to the winter oats project. Hence, the character of the resources developed in the hybridisation programme may be of great interest in relation to the winter oats project. However, an issue causing uncertainty is whether the resources are developed before the winter oats project is finished.

Uncertain contribution back to the project

Regarding the identified health-related genes of oats (C_3), it is not as clear how that new collaborative effort may contribute back to the winter oats project. This new combination can be seen as a way of further using resources developed in the winter oats project, which may not be possible to relate to the goal of the winter oats project. Nevertheless, to exploit the developed resources in the project can be regarded as valuable for the project members involved in both these efforts.

Using and developing the health-related genes in another effort means that the winter oats project has a sequel, i.e. is not an ending. The resources developed in the project are to be used further. These may be seen as resources developed

prior to a certain project, i.e. resources of category D from the new project's perspective. The project members that are involved in both these projects may also be seen as representing continuity between projects.

Hence, some of the resource combinations that were made outside the scope of the project may be possible to relate to the resource use and development in the project, as in the examples with the non-cold-related genes and the repetitive areas of the EST data. These may thus be "re-related" to the project. The combination of the health-related genes is somewhat different since it represents a further use of resources developed in the winter oats project. However, that use may be seen as valuable in itself from the involved project members' perspectives.

Concerning the resources developed in the project and used outside it (category C), there are possibilities that their further use may contribute back to the project since it is still ongoing – in contrast to the resources used after the project is finished (category E), for which there are no possibilities for contributions back to the project. However, there may be opportunities for the project members to use some of the resources further in a new setting and thereby benefit from this use.

Returning to the resource heterogeneity assumption (Penrose 1959; Alchian and Demsetz, 1972), this implies that the value of a resource developed in a project may be created after the project is completed. That is, even if a project would be regarded as a failure e.g. because the project goals were not fulfilled, resources developed in that project may be used outside it or after it is completed. Therefore, results from a project may become valuable outside the project, so that its value is perceived differently in retrospect.

This section has focused on resource combination outside the scope of the project, and additionally how the combining of resources may contribute to the project. In the next section, the context of projects is looked at in more detail, focusing on their network context in view of what has been discussed in this section.

7.2 The network context of a project

Based on the previous section concerning resources developed in the project and used outside the project boundary, this section discusses the network context of a project. In particular, the section examines four different aspects of inter-organisational research projects in their contexts, defined as their network contexts. First, the resource collections of the project members and parent

organisations are discussed in relation to discoveries made use of in the context.

Second, project members have access to different existing resource collections and are involved in other projects or activities in the context to varying degrees. The resource collections and the involvements are discussed in the second subsection below in terms of project embeddedness.

Third, the links between projects and project contexts are focused upon in terms of resource use and development. Five different patterns are suggested for analysing these links in the third subsection.

Fourth, the project context is concluded to be central for resource combination both within and across the project boundary. This subsection focuses on the evolving project context and how it may be handled on the basis of the suggested patterns.

7.2.1 RESOURCE COLLECTIONS AND DISCOVERIES

Three examples of unexpected resources and unplanned further uses of resources developed within the project are discussed above. These unexpected uses may be described as discoveries (Kirzner, 1992) as opposed to results from search, which has to do with planned results of the research efforts. All the three examples of discoveries are further used outside the scope of the winter oats project. Hence, the discoveries made in the project became exploited in the project context.

As discussed above, in resource combining within projects, the resource collections of the project members can be changed (e.g. expanded). The existing resource collections of the project members are important starting points for the combining of resources not only within projects but also outside the project boundary. In resource combination across the project boundary, the collections are not primarily changed; instead, the existing resource collections are used as a point of departure to explore the discoveries made. Hence, the existing resource collections of the project members are used in the exploitation of discoveries in the project context. This may also correspond to what Holmen (2001) calls “existing resources and products used in new combination and use routines”.

Based on the existing resources to which the project members and parent organisations have access, potentially interesting resources developed in a certain project can be pursued in the context of the project, as in the example with the plant-breeding programme and the health-related genes. The existing

resource collections of the project members are thus utilised in relation to discoveries pursued in the context.

In addition, there can arise needs for external resources in relation to the exploitation of discoveries in the context. As in the example with the family tree discussed above, the project members accessed external resources both related and unrelated to their existing resource collection.

By combining the resources, regarded as discoveries, with the existing resource collections, new endeavours can emerge, e.g. in terms of new research efforts, as in the case with the health-related genes, or new applications such as the oat family tree. Hence, new research efforts may be created in the context due to the existing resource collections and the resources regarded as discoveries.

It should be noted that the ideas for, and realisation of, resource combination across the project boundary are not predetermined processes based on the character of resource collections. Instead, the use of these resources is dependent on the project members' or parent organisations' abilities of identifying opportunities for further use⁴¹.

The project members may not be equally equipped to use resources developed in a certain project for other efforts in the context. One project member may be very good at making use of resources developed in the project outside its scope, while another project member may not be able to do so at all. This potentially uneven distribution of the resources developed within a project may be referred to as a "tension" of inter-organisational projects (Lind and Dubois, 2005). Such tension may arise owing to the project members' different opportunities to benefit from the results of joint achievements. This kind of tension may not result in direct conflicts. Nevertheless, when resources developed in the project outside the project are exploited in relation to other activities by project members, there may be a need to balance the various interests of the parties involved.

The existing resource collections of the project members are central entities in relation to resource combination both within and across projects. We return to the resource collections in the next section, which discusses how a project is related externally to the network context in terms of project embeddedness.

7.2.2 PROJECT EMBEDDEDNESS AND THE PROJECT MEMBERS

The case illustrates how the existing resource collections of the project members enable resource combination both towards the project goals and

⁴¹ This is what Kirzner (1992) refers to as "alertness".

outside the project boundary. This section discusses project embeddedness based on what resources the project members have access to, i.e. based on their resource collections, and the project members' involvement in different activities. This discussion derives from the winter oats project, consisting of the four different project members. However, it is a principal discussion with some examples from the project members discussed in the case study.

Project embeddedness is argued to be a two-dimensional issue with regard to resources and activities, as discussed above in the theoretical frame of reference. However, these two dimensions of project embeddedness are not necessarily related but can be combined in various ways. Depending on how the degree of project embeddedness with regard to activities and resources respectively is composed in a project, the effects achieved in relation to the project and the project members will be very different.

Hence, a project is seen as embedded in two dimensions: activities and resources. Project embeddedness with regard to these two dimensions to a low or high degree respectively implies four different situations, which are discussed below. See Figure 7.4.

		Degree of project embeddedness with regard to activities	
		High	Low
Degree of project embeddedness with regard to resources	High	<p>Situation 1:</p> <ul style="list-style-type: none"> • Extensive resource collection • Involvement in parallel projects 	<p>Situation 2:</p> <ul style="list-style-type: none"> • Extensive resource collection • Involvement in mainly one project
	Low	<p>Situation 3:</p> <ul style="list-style-type: none"> • Limited resource collection • Involvement in parallel projects 	<p>Situation 4:</p> <ul style="list-style-type: none"> • Limited resource collection • Involvement in mainly one project

Figure 7.4: Project embeddedness with regard to activities and resources.

Situation 1 refers to a project member which is embedded to a high degree with regard to resources, and which consequently has access to an extensive resource collection. An extensive resource collection may refer to a broad

resource collection, entailing possibilities for overview of a certain discipline, problem, research area or industry. The same project member is embedded to a high degree with regard to activities, meaning that the project member is involved in parallel activities, such as other projects. Being involved in several projects may result in synergies, but can also have negative effects such as time constraints and lack of focus.

Returning to the winter oats project, one of the project members can be characterised as a project member of situation 1. The development division of the SFA possesses a general picture of the oats activities in Sweden and a specific understanding about the farmers' needs and interests. The SFA is also involved in a number of projects aiming at improving the conditions for farming, among others the winter oats project. The SFA has in addition been involved in other projects previously and is thereby part of a network of relationships regarding these resources, which the project member managed to make use of in relation to the winter oats project.

Situation 2 describes a project member that is embedded to a low degree with regard to activities and to a high degree with regard to resources. This type of project member is mainly engaged in a single project and, in addition, accesses an extensive resource collection. The collection consists of a broad range of resources that could contribute to the single project. The activities of the project may be of such a character, e.g. in terms of coordination issues, that the project member needs to be involved in the project to a high extent in order to make use of the opportunities to overview.

Situation 3 describes a project member that is embedded to a high degree with regard to activities and to a low degree with regard to resources. It refers to a project member that is engaged in several other activities besides the project and accesses a limited resource collection. However, the collection may entail a specific understanding of certain resources. Hence, a resource collection may be limited with regard to broadness but still contain a depth necessary for the project task. This project member may find synergies between projects based on the other involvements. However, there are risks of not being able to focus on each task.

The winter oats project contains an illustration of a project member being characterised by situation 3 – the molecular biologists, who are involved in several different research projects but still contribute specific knowledge of plants and plant genomes. Hence, as seen in the case analysis above, it is possible to be involved in several projects and make use of resources across them. Situation 3 may be characteristic of research groups in general, in terms

of having a specific understanding of some resource(s) and being involved in several parallel projects.

Situation 4 describes a project member embedded to a low degree with regard not only to activities but also to resources. This situation describes a project member that is involved in a project to a high extent, meaning few other engagements. Furthermore, the project member has access to a limited resource collection. In relation to certain project tasks, it may be enough to have a limited resource collection for solving the task. The collection may be detailed regarding a certain aspect which is particularly needed in a project.

It is to be emphasised that project embeddedness with regard to resources and activities does not say anything about the value that a certain project member may create. How a project member fits in a certain project is dependent on several aspects, such as the project task, what the project tries to accomplish, and the composition of project members. Nevertheless, project embeddedness with regard to activities and resources is a way of conceptualising how a project member relates to the project and the project context in terms of access to resources and involvement in different activities.

Based on the reasoning above, it is possible to raise the question whether project members can be involved in too many activities and whether project members could have access to too extensive resource collections. Part of the answer is that it is not necessarily so that “large” resource collections or involvement in several activities will result in identified opportunities for resource combination. The more is not necessarily the better in relation to resource collections and activities. Project embeddedness with regard to resources is thus not only about having access to the most extensive resource collection, but also about how specific the understanding of the resource collection is and what type of resources is needed for a certain project. Hence, an extensive resource collection could be extensive in terms of breadth, or depth, or both. A limited resource collection may be narrow but can be specific, or specific enough regarding a certain issue.

Furthermore, it might be possible to complement the resource collection of one project member with another project member that contributes a different type of resource collection. This and other interactive aspects of project embeddedness are discussed below.

Understanding project embeddedness

In inter-organisational projects, the composition of different project members becomes essential. Since each project member can be seen as embedded to a

certain degree with regard to activities and resources respectively, some project members may function well together while some may not.

A way to discuss the mixture of the project members is in terms of *balance* based on the degrees of embeddedness of resources and activities. There are no easy answers to how to accomplish balance in inter-organisational research projects. However, one approach may be to engage project members that *complement* each other in terms of their degree of embeddedness with regard to activities and resources. For instance, a project member having access to an extensive resource collection and being involved in parallel projects (situation 1) may complement a project member that has access to a limited resource collection and is engaged in a certain project to a high extent (situation 4). The project member with the extensive resource collection may be able to contribute resources that the other project member can use and develop further internally towards the project goals. The project members complementing each other thus bring variety to the project in terms of the differences between their resource collections and other involvements.

Balance may also mean engaging project members whose embeddedness with regard to resources and activities are *similar*. The project members are involved in other activities to the same extent and contribute resource collections of similar depth. This type of balance could, for example, be appropriate if the project is a high-risk project, so that it may be good to have other engagements to fall back on.

Two aspects that appear important in relation to balance are that the resources accessed are relevant for the project task and that the degree of involvement invested in the project is appropriate. The balance of a project is also dependent on what the project aims to accomplish. For some projects, balance implies project members embedded to a low degree with regard to both activities and resources. If the project aim concerns activity coordination, the project member mixture may be different from a project aiming for resource combination in research and development. Another aspect that influences balance in relation to the composition of a project is how the activities and resources are related. Certain activities may demand certain resources. How well the project members know each other, and to what extent they have worked together previously, also influence balance.

It is also possible to create imbalances in a project – for instance, when all project members are embedded to a high or low degree with regard to resources or activities, or both, and this is neither relevant nor appropriate in relation to the project task. A project consisting of members with access to extensive resource collections, and being involved in a number of other activities in

parallel, may have difficulties in exploiting the resources they access. A project where all the members are embedded to a high degree with regard to both resources and activities may be considered “over-embedded” (see Granovetter, 1985; Uzzi, 1997). In contrast, a project in which all the members have access only to limited resource collections, and are focusing on the given project to a high extent, may find its task difficult to solve due to lack of external resources. A project whose members are embedded to a low degree with regard to both resources and activities may be characterised as “under-embedded” (see Granovetter, 1985; Uzzi, 1997).

In relation to balance, the aspect of variety comes to the fore, based on the resource heterogeneity assumption (Penrose, 1959; Alchian and Demsetz, 1972). The resource collections of the project members do not only need to be relevant; they also need to differ in order to create value. While the project members bring different aspects to the project, the results may be greater. Project members thus need to bring their differences as well as similarities to a project in order to allow for variety and to accomplish interactive effects from resource combination.

It can be concluded from the above that balance in relation to the degrees of embeddedness of project members is vital, although how to accomplish this must be concluded for each project since e.g. extensive resource collections do not necessarily create higher value in relation to a project. The value depends on how the resources of the different project members are combined and complement each other. Hence, it needs to be considered for each project what is meant by balance in terms of project embeddedness with regard to activities and resources.

Embeddedness is also discussed from another perspective in the next subsection about links (or their absence) between a project and its context in terms of patterns.

7.2.3 PATTERNS IN A PROJECT'S LINKS TO THE CONTEXT

In this subsection, five patterns are suggested to describe a project's links to its context. These patterns are principal ways that emerged from the analysis of resource use and development (see Chapters 5 and 6).

The patterns are identified on the basis of the analysis of a single project. Nevertheless, the patterns are suggested as five conceptually different ways in which a project may be linked (or not linked) to its context. This means that some projects' links may be dominated mainly by one pattern. The literature used for discussing the suggested patterns analyses different types of projects or teams and their external interactions.

The unidirectional pattern of resources into the project

The first principal pattern of a project's links that emerges from the analysis of the resource use and development categories is *the unidirectional pattern of resources into the project*. This pattern concerns projects whose links to the context are characterised by an emphasis on resources developed outside the project and used within it, referred to as resource use and development category B above. Hence, the link between the project and the project context is characterised by a unidirectional flow of resources into the project. The project members use resources that are developed outside the project; see Figure 7.5.

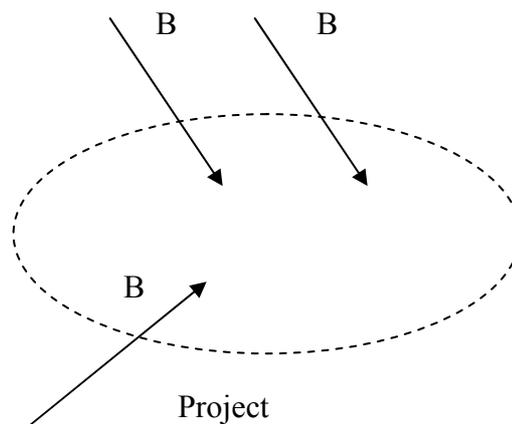


Figure 7.5: Unidirectional pattern of resources into the project.

A prerequisite for projects whose link to the project context is mainly characterised by this pattern is that the project members are aware of what is going on in the project context, in terms of parallel projects and necessary changes that ought to be made. Thereby the project may be adaptable to changes in the surrounding network.

While the purpose of a project is to use external resources for its own purposes, e.g. in confidential projects, the unidirectional pattern may be advantageous. A project may be able to integrate resources developed outside the project in internal processes. A potential drawback from the project's perspective is that the project may not be able to react to what is coming into it and influence the project context, since the link between the project and the context is unidirectional. Thus, the project may take resources in from the outside but not necessarily in interaction with the counterparts providing these resources. However, as mentioned above, in projects characterised by secrecy, taking resources in without spreading resources developed internally may be exactly what the project aims to accomplish.

“Hypersensitive” projects refer to projects that are oversensitive to changes in the environment, for example in terms of changing customer needs (Kreiner,

1995). At its extreme, i.e. too much of this unidirectional pattern of resources into the project, a project whose links to the project context are characterised by this pattern may be what Kreiner (1995) refers to as hypersensitive. On the one hand, hypersensitive projects may become disoriented and confused due to all the information that comes into them. On the other, projects receiving all the input from the outside at least get access to the necessary resources, which may be preferable to receiving no input.

However, it is to be noted that a project linked to its context with the unidirectional pattern of resources into the project does not necessarily become hypersensitive. The project will only become hypersensitive if the resources come to influence the internal process in new directions. A project linked to the context by this pattern can also use resources internally in the combining of resources towards already formulated goals of the project.

Different types of teams and their strategies for external interaction are also discussed by Ancona and Caldwell (1992). “Technical scouting teams”, as defined by these authors, point to the risks of taking in too much information, and thereby never settle for a solution but are trapped in a cycle of complexity and exploration. A project whose link to the context is characterised by this pattern may be similar to a technical scouting team. The members of such a team continue to search for new approaches to their product, bringing in large amounts of conflicting information, which require complex interaction in the team that may lead to conflicts.

Thus, on the one hand, the link between the project and its context, characterised by the unidirectional pattern of resources into the project, may become extreme and put the project at risk. On the other hand, resources coming into the project are necessary but call for caution, since a project whose link to the environment is unidirectional risks either being hypersensitive or becoming a technical scouting team.

The unidirectional pattern of resources out of the project

The second pattern suggested is when a project's link to its context is characterised by an emphasis on a *unidirectional pattern of resources out of the project*. This pattern concerns resources developed within the project that are used outside it, referred to as resource use and development category C. The link between the project and the project context is thus characterised by a unidirectional flow of resources out of the project. See Figure 7.6.

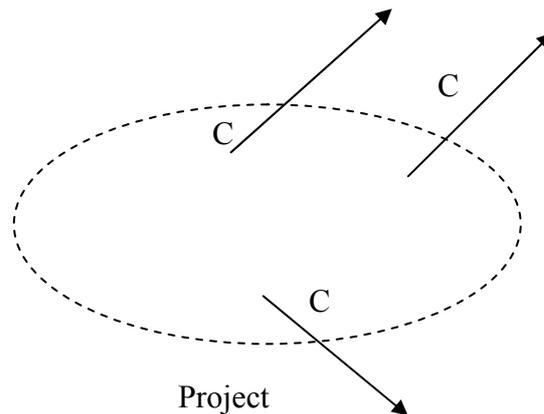


Figure 7.6: Unidirectional pattern of resources out of the project.

For projects whose links to the context are characterised by a unidirectional pattern of resources out of the project, the resource use outside the project does not necessarily contribute to the project significantly. However, the further resource use outside the scope of the project may not cause any problems either. Even though the further use of resources is not central from the project’s perspective, the use may be essential for the actors outside the project that use the resources. However, caution is needed for projects whose links to the project context are characterised by the unidirectional pattern out of the project, so as not to let the interesting resources out of the project too early. Since the pattern is unidirectional, there is no interaction with the counterparts that come to use the resources outside the project.

However, there may be situations where the aim of a project is to develop resources to be used outside the project – for example, a project that aims for influencing other actors in the context. In such projects, there is no need for caution about letting resources out too early; rather on the contrary, sharing resources with others as much as possible may be seen as the objective.

Returning to Kreiner (1995), the opposite of a hypersensitive project is a project characterised by “arrogance” in terms of not letting anything – e.g. feedback, changing customer needs or disturbances – affect the project. A project whose link to the environment is characterised by a unidirectional pattern of resources out of the project may be regarded as arrogant since there are no resources developed outside that are used within the project. Instead, there are only resources developed internally that are used outside.

For the counterparts in the project context, a project linked by a unidirectional pattern of resources out of the project could be advantageous since it implies getting access to or knowledge about certain resources.

The interactive pattern of resources out of the project

Based on the resource use and development categories, a third pattern is suggested, an *interactive pattern of resources out of the project*. This pattern is suggested on the basis of category B, resources developed outside and used within the project, followed by category C, resources developed within the project and used outside. The pattern is thus named after the second resource use and development category of the pattern. The third pattern describes links between a project and its context as an interactive pattern, since the links enable resources to be used within the project followed by a further use outside the project. See Figure 7.7.

Similarly to the unidirectional patterns of resources, there are two different kinds of interactive patterns. Both of these patterns concern two resource use and development categories in sequence.

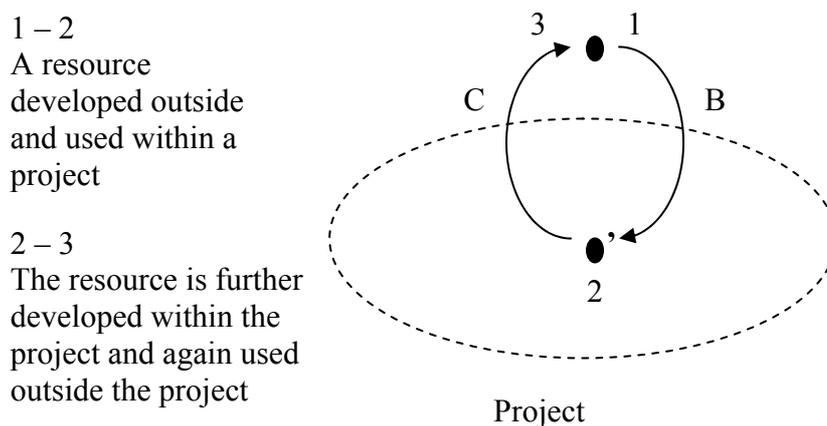


Figure 7.7: Interactive pattern of resources out of the project.

This interactive pattern may take different forms depending on who, in the project context, will develop and then use the resources. If the project members are involved in other settings and able to contribute resources to the project, it is likely that the project members will later be able to use the developed resources again outside the project. For parent organisations investing in a certain project, it may be interesting to pursue some of the resources again when they are further developed. Thus, an investment in resources for a certain project, based on this interactive pattern linking the project to the context, may contribute back to the project members or parent organisations. Regarding the project members' other activities and resource collections, a continuous interaction is likely – meaning that, for a project member or parent organisation in the project context, it is possible to be part of and thereby benefit from an interactive pattern out of the project.

If the resources developed outside the project come from third parties, it is not as certain that there is continuing interaction with the actors contributing resources. Thus, the investments from both the project and the third parties need to be larger in order to contribute back to the third parties. However, as long as there is an effort in the first place, it is likely that the project can contribute back to the third parties by sharing the resources from the project.

When an actor contributes resources to a research project, it can never be guaranteed that the project will develop some resources that the actor could use further. This depends, among other things, on the ability of the project members to use resources across projects. Members of a project whose link to the context is characterised by an interactive pattern may be regarded as collaboration partners since the project not only uses external resources but also can give resources in return.

Comparing with the unidirectional pattern of resources into the project, projects linked to the context by this pattern have the ability to react and interact with the counterparts. That is, the risk of becoming hypersensitive, arrogant or a technical scouting team is more limited since the project members are able both to receive resources and to provide others with resources. This pattern includes elements of interaction with the context.

The interactive pattern of resources into the project

The fourth principal pattern that emerged from the analysis of resource use and development is the *interactive pattern of resources into the project*. This pattern concerns resources developed within the project and used outside it, category C, after which these resources are further developed outside the project and used within the project, category B. The pattern is thus named after the second resource use and development category of the pattern.

Resources developed in a project may not be possible to relate to the project goals directly. Instead, these resources may gain a value outside the project for the project members, parent organisations or third parties in the context. In the further use and development of the resources outside the project, they may become developed in such a way that they can be re-related to the project.

The interactive pattern of resources into the project is illustrated in Figure 7.8. This pattern, like the previous one, implies interaction between the project and the project context.

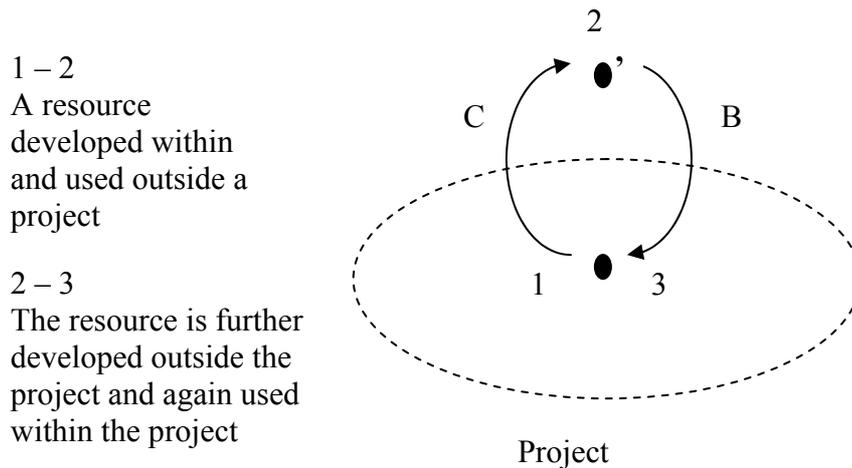


Figure 7.8: Interactive pattern of resources into the project.

Like the other interactive pattern discussed above, this pattern may take different forms depending on the counterpart. If the counterpart is one of the project members using or developing a resource outside the project in another setting, it is likely that, if applicable, the resource will be used within the project. If the project runs into trouble, letting one of the project members use a resource outside and thereby try to solve the problem may be a suitable solution. Since the project members also have an interest in the project, it is likely that they will provide the project with a further developed resource, if realisable. The same reasoning is valid for the parent organisations: if there is a potential for them to use a resource developed in the project for other purposes and, through this use, both contribute to the other setting and be able to contribute back to the project, it is likely that they will do so.

Regarding a third party of the project context as counterpart in the interactive pattern into the project, there is a risk of letting a resource out of the project with no guarantee of having a refined version into the project again. However, establishing relationships with actors in the context is interesting, since the counterparts can combine resources with their resource collections. In this combining with resources of other collections, unexpected discoveries can appear, such as solutions of problems or emergence of new characteristics.

Hence, in this pattern characterising the link between a project and its context, there is an interactive element. The project members interact with the counterparts of the project context in order to further develop the resources. From the project's perspective, this kind of link with the project context may be essential since the resources become combined with other resources outside the project. The project members might not have access to or even know about these other resources, for example in relation to the resource collection of third

parties. Hence, by allowing resources out of the project, it may be possible to further use the resources within the project towards the project goal.

The pattern of isolation

The thesis concerns a project in its context by looking at resource use and development. However, the literature refers to the fact that it may also be of interest to describe a pattern in which a project is not linked to its context, that is, *the pattern of isolation*. A project whose link is characterised by the pattern of isolation is dominated by resources developed and used within the project, referred to as resource use and development category A above. When resource use and development within the project become the main way of working, the result may be projects characterised by the pattern of isolation. See Figure 7.9.

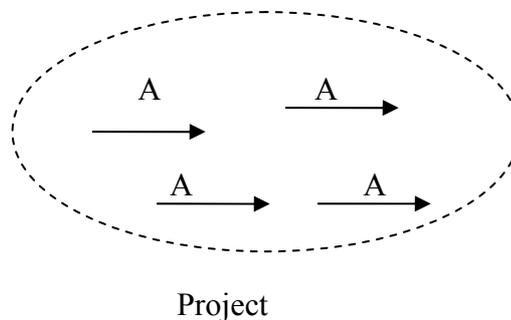


Figure 7.9: The pattern of isolation.

It is important to emphasise that every project by definition has a context. However, the project members or the researchers studying projects, or both, do not always consider the context, by either conscious or unconscious choice. Hence, projects can be handled as if they are isolated.

Projects that lack a link to the project context may be perceived as isolated projects. A project characterised by this pattern may have a strong focus on the task, since there are no disturbances from outside the project. However, there are also some severe risks for projects characterised by the pattern of isolation. Not only disturbances but also valuable resources are shut out – e.g. ideas, feedback and information about parallel projects. A project working according to the isolated pattern can, according to Kreiner (1995), be characterised by arrogance. This arrogance is reflected in the project manager’s treatment of significant threats in the context as nonsense. For projects working on the basis of the pattern of isolation or arrogance, there are severe risks in continuing long after the environment has begun to regard the project “as irrelevant” (ibid.).

Ancona and Caldwell (1992) discuss different types of teams and their strategies for external interaction. As one case, they identify the “isolationist”

strategy. Isolationist teams are argued to create impermeable boundaries and develop a “cocoon-like existence”. Internally the cocoon teams may work efficiently, but the work is ignoring the outside world, which is never beneficial when the resource under development eventually is to be used by others.

A project characterised by the pattern of isolation thus handles resource and development within the project. The resources being used and developed in the project are given, and new aspects are thus only related to the existing resources. As argued above, an advantage of the pattern not being linked to its project context is the focus on the project task. The pattern of isolation might be an appropriate way of working when both the project goals and the resources to fulfil these goals are known and thus can be regarded as given, e.g. towards the end of a project when all pieces should come together. Projects characterised by uncertainty about what to be developed and how imply that goals and means are considered as given only for a short period. The pattern of isolation can thus be a suitable way of working (at least) for a certain period.

It is to be noted that the pattern of isolation may only be a way of describing a project’s links to its context for a certain time. One reason for this is that the project boundary, discussed in the next chapter, has two essential functions: separating and relating. Hence, as long as the project exists, it would be appropriate to assume that the project boundary not only separates the project from its context but also relates the two.

Understanding the patterns

The patterns describe different ways in which resource use and development may link a project to its context. The patterns describe and analyse how projects’ links to their contexts look and function. The patterns are thus *not* mainly describing different types of projects – even though it would be possible, in a manner similar to that of Ancona and Caldwell (1992), based on the ways that projects interact with their contexts, to suggest project types and discuss possible advantages and disadvantages in relation to the project and the counterparts in the project context. These issues have been touched upon in the previous sections describing and analysing the principal patterns, although that has not been the main purpose with suggesting the patterns. The main ambition with the patterns is to identify different ways in which projects in resource use and development are linked to their project contexts.

In contrast to using the patterns for categorising projects, a project’s links to the context may be characterised by several patterns. This is also how the principal patterns have been identified, based on analysing resource use and development in relation to one inter-organisational research project. Overall, the patterns

work together, complement and support each other, and are not exclusive in character.

The patterns may work together not only in parallel but also over time. The two unidirectional patterns may function together and create a two-way link between a project and its context, allowing resources to come both in and out of the project subsequently. Hence, by combining the two unidirectional patterns, there may be a bi-directional pattern, if the counterpart is the same in both patterns. This means that a project's links to its context can be characterised by using resources developed outside and counterparts using resources that are developed in the project.

The links between a project and its context can also develop and change over time. Hence, the links between projects and their contexts are not static. For example, the isolation pattern may be appropriate for a certain period of time, e.g. during an intense working period where both project goals and the resources to accomplish these are considered as given. The isolation pattern may be both preceded and followed by unidirectional patterns allowing resources to be used within and outside the project.

A bi-directional pattern may, if the resources used within and outside respectively become related, develop into a link characterised as an interactive pattern. Whether the unidirectional patterns develop into an interactive pattern depends on, among other things, the counterpart that organises the resources used and developed within and outside the project. In addition, two unidirectional patterns or two interactive patterns working together may support each other and thereby create strong links between a project and its contexts.

However, a risk for a project, which has multiple links to the project context, is that there will be too much influence from the outside and not enough focus internally. On the other hand, a project having multiple links to the project context will be well protected from surprises and be updated on what is going on. In addition, the project will receive support in developing some resources further that are not possible to develop inside the project.

To conclude, in contrast to Ancona and Caldwell (1992) who categorise projects or teams by how they relate to their contexts, the identified patterns focus on how resources are used and developed within and across the project boundary. Acknowledging the dynamics of how projects are linked to their contexts, in terms of resource use and development, may be seen as a fruitful way to further the understanding of the project context.

Isolation and embeddedness of projects in theory and practice

The patterns discussed above suggest different links between projects and their contexts. While two of the patterns are unidirectional and two are interactive in character, the fifth pattern differs from the others since it offers no link to the context. The pattern of isolation also differs in being mainly derived from the literature rather than the case study. As been pointed out above, projects always have a context. However, at times in both theory and practice they are treated as if they do not. This treatment of projects as isolated phenomena is also part of the background to the thesis. The present section discusses, based on the suggested patterns, when and why projects are handled as isolated. Those projects whose link to the context is characterised by the pattern of isolation are thus handled as if they were isolated.

Strategies commonly used by projects are isolation from the environment (Karlsen, 1998)⁴² and project autonomy (Gemünden et al., 2005). There are a number of reasons why projects become isolated, e.g. prioritising the project task, secrecy issues and ignorance. No matter whether isolation is a conscious or unconscious choice, there exist secluded projects in practice. However, there also exist projects that are embedded in a context in reality, such as the winter oats project. In these projects, the context is present in terms of resource access, actors that the project members are collaborating with, and financial sources. Thus, practice offers projects whose links may be described by the patterns linking them to the context as well as projects whose links are at best described by the pattern of isolation.

As noted in the background of the thesis, some projects that are embedded in practice have been studied as isolated phenomena in theory. This formed the background to the thesis, analysing resource combination in a project in a network context. In other words, the thesis is a way of moving from B to D (see Figure 7.10). A need was identified for filling the gap between projects embedded in practice but studied as isolated.

⁴² Karlsen (1998, pp. 175-183) analyses in total eight different strategies that projects use, more or less successfully, to master uncertainty. These are (1) Preparation work and planning, (2) Establishment of buffers and readiness, (3) Isolation of project from environment, (4) Learning and competence development, (5) Selection of actors and environment, (6) Operational collaboration, (7) Administrational collaboration and (8) Other strategies.

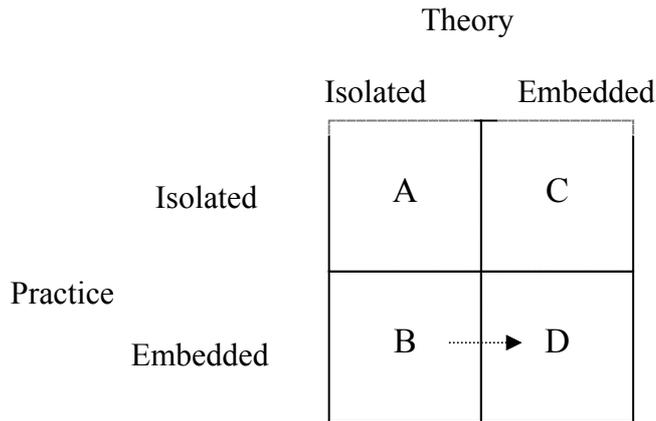


Figure 7.10: Isolation and embeddedness of projects in theory and practice.

However, there are also projects that are isolated in practice and these may fruitfully be studied either as embedded theoretically or as isolated. This means that not all projects are to be studied as embedded.

On the other hand, studying projects as embedded in theory may influence the people in the projects, e.g. project managers, to see them as embedded also in practice, which may result in benefits from their perspectives.

In conclusion, the perspective of this thesis is that all projects are embedded, but that it is possible to treat or study them as isolated. This implies the context as vital for projects. In the next section, project contexts are discussed with emphasis on their evolvement.

7.2.4 THE EVOLVING PROJECT CONTEXT

Returning to the literature, two main views of project environments appear. On the one hand, an immediate and outer project environment has been suggested (cf. Gilbert, 1983). On the other hand, the dynamic elements of project environments have been emphasised in terms of drifting environments (Kreiner, 1995), where both the project and environment are considered as dynamic entities. In this section, the dynamics of project contexts are in focus. Thus, this corresponds to the view of project environments suggested by Kreiner (1995).

The patterns suggested above describe links between a project and its context. The links may be characterised by different or several patterns and may change over time. The links between a project and its context are used as starting points for the discussion below of evolving project contexts.

The pattern of isolation enables no links between the project and the project context, although the context exists. This lack of links may entail risks that the project and context will evolve apart.

The unidirectional patterns of resources into and out of the project context contain links to the project context. In the unidirectional pattern of resources out of the project, resources developed within the project may be used outside the project. Some of the resources developed in the project are used in other resource collections, either existing or new, beyond the project boundary. This pattern forming a unidirectional link between the project and its context enables the project to influence the context and evolve with the project. In a similar manner, the unidirectional pattern of resources into the project allows resources developed outside the project to be used within it, and thereby the project can change with an evolving project context.

However, the unidirectional patterns may imply limited links, in terms of depth, between a project and its context. This implies a risk that the context will change while the project does not, or vice versa. On the other hand, the links may be unidirectional but there can be many different links between a project and its context, which enable extensive links in terms of breadth.

There may be new links formed between a project and the context based on “informal networking” (Kreiner and Schultz, 1993), for example taking place at industry meetings, research conferences and workshops. In the informal networking, people are updated as to what other researchers in the community are working on, which researchers are collaborating, on what topics, and from where the work is funded. In this process, it is possible for project members to establish external links, e.g. in terms of taking resources in, forming unidirectional patterns. It is also important to be able to tell others about ongoing projects, which other actors might be able to relate to. From these discussions, more specific collaboration can arise and therein interactive patterns be established.

Even though the context of a project may be described as evolving, the context is not totally open or random in relation to a project. The project members and parent organisations are part of an existing resource constellation (Håkansson and Snehota, 1995). Interactive patterns based on the existing resources may be a straightforward way of linking a project to the context. In the interactive patterns, the counterpart is the same with regard to both the resources used outside and the resources further used within the project. This means that a certain counterpart emerges as an important part of the project context. Therefore, the interactive patterns enable deep but not broad links with a specific counterpart of the context. In the interactive patterns, there are links

containing interaction between the projects and the counterparts of the context, which enable the project and context to co-evolve.

While projects exist, they seem to function as “centres of gravity” (Kreiner and Schultz, 1993), which attract other researchers. Collaborative projects and relationships seem to breed more collaboration with counterparts both known and new. Hence, based on interactive patterns in terms of ongoing projects, new patterns may develop – both unidirectional, isolated and interactive in character.

To conclude from the above, there are unique advantages with the different types of links provided by the patterns respectively. One way to handle an evolving project context is by establishing a mixture of links between the project and the context. A mixture of links refers to projects whose links to the context are characterised by multiple patterns. Depending on the type of change, multiple patterns will provide good possibilities for following, adapting to or influencing the context. The multiple patterns thus together form a starting point for co-evolving with the context, that is, handling a drifting project context. Hence, with multiple patterns, a project is protected and at the same time prepared for and able to influence the dynamics of the project context.

7.3 Summary

This chapter concerns resource combining across the project boundary, in terms of how resources developed within a project become used in the context. Three examples are given from the winter oats project of combining resources outside the scope of the project. These resources were unexpected and unplanned results developed in the project, and are thus regarded as discoveries. As a whole, the discoveries made in the winter oats project were mainly exploited outside the project, i.e. in the project context, in contrast to exploitation within the project towards the project goals.

It is noted that the existing resource collections of the project members were vital not only in the combining of resources towards the project goals, but also for making use of discoveries. The existing resource collections are concluded to be used in the exploitation of discoveries in the project context. In addition, needs for external resources emerged in relation to the discoveries, as regards both related and unrelated resources of the project members’ existing resource collections.

The embeddedness of an inter-organisational project in its context is explored, with the starting point in the project members’ resource collections and their

other involvements. Four situations of a project member's embeddedness with regard to activities and resources are analysed. Based on these situations, project embeddedness is discussed in relation to balance of inter-organisational projects. Balance is dependent on the composition of project members and argued to be seen in the light of each project.

Five patterns are suggested for describing and analysing a project's links to its context. While four of the patterns are unidirectional and interactive in character, one pattern is characterised by isolation with no links to the context. These patterns are suggested to co-exist, meaning that there may be an emphasis on one of the patterns at a certain point in time and, later in the project, several patterns can support each other.

A project that is linked to the context by a mixture of links, i.e. multiple patterns, is argued to be well protected from unexpected events in the context and be able to influence the context. Hence, a project linked to its context by multiple patterns has possibilities to co-evolve with the context and this can be viewed as a way of handling an evolving project context.

The project boundary appears to possess important functions in relation to resource combining in a certain project. Based on analysing the context, the project boundary forms the starting point for analysis in the next chapter (chapter 8).

8 The role of the project boundary

In general, boundaries define the inclusion and exclusion of something. Turning our attention to a project boundary, it distinguishes the resources that are combined within a project from those that are combined outside. Based on the previous chapter, it is clear that resource use and development occur not only within projects but also across the project boundary. Therefore, it seems interesting to inquire further into the functions of the project boundary.

The analysis of resource combination in relation to the winter oats project has taken its starting point in the project boundary as empirically given, i.e. as defined by the participating organisations. In this chapter, the role of the project boundary is discussed as part of a network context.

Generally the discussion of project boundaries in this chapter takes its starting point in the resource dimension and subsequently relates to activities and/or actors, i.e. the other dimensions of the network model. Section 8.1 focuses on the functions of project boundaries, while section 8.2 discusses perspectives on the effects of project boundaries.

8.1 Functions of the project boundary

By creating a project boundary, certain functions are made possible. In particular, the functions concern *separating* the project from the context and *relating* the project to it.

In the first subsection below, the two functions of separating and relating are investigated. Based on these functions, certain effects may be achieved in terms of creating a project identity and enabling access to a variety of resources. These effects are discussed in the second subsection.

8.1.1 SEPARATING AND RELATING

One of the main functions of a project boundary involves separating the project from the context as shown in the pattern of isolation. Separating or decoupling a project results in, for example, internal focus and interaction among the project members with little or no influence from the outside. The task of a

project may be of such a character that it can only be fulfilled in isolation from the context. The project may, in those cases, be separated not only in the organisational context but also in time, and referred to as decoupled by “bracketing” (Lundin and Söderholm, 1995). This means that the history and the planned future of the project are not considered during the project.

However, most often the second main function of a project boundary, relating the project to its context, is of equal importance for projects. The relating function clearly emerges in the unidirectional and interactive patterns, linking a project to its context by use and development of resources across project boundaries. Another way to view the relating function of a project boundary is in terms of “openness”. By having a project boundary with an emphasis on relating, the project is open to external influence. Openness is also discussed by Andersen and Drejer (2005) in terms of openness to alternative uses of developed knowledge.

The role of the two functions may change over time, and each may thus be vital at some times and less emphasised at others. The emphasis on the two functions may also vary over time. For instance, the function of separation may be dominant initially in a project, while the function of relating may be strong towards the end of a project. The reason for this approach may be that the members of a project need to focus on the task at hand in the beginning, while towards the end of the project the resources developed are to be used by others and thereby the project open up for interaction with the context. This is discussed by Lundin and Söderholm (1995) in terms of a project being initially decoupled from its surroundings and then reattached near the time of its completion.

The opposite is also possible, i.e. that there is an emphasis on the function of relating initially in the project, while towards the end the separating function is dominant. For example, the project members may be open initially to finding alternative uses or applications for the resources to be developed within the project. However, towards the end of the project, they need to focus in order complete the project task. Hence, the two functions of separating and relating appear to complement each other over time.

In a similar vein, von Corswant (2003) discusses the separating and relating functions of team boundaries in his study of interactive product development. He points to the risks of having a “weak” separating function since this may result in the team mainly becoming a forum for finding compromises. If the team boundary instead is related continuously to the surrounding resource structure, the outcome may be adapted to both the project and the context.

However, the risks of weak separating or relating functions respectively do not imply a solution in which both functions are continuously dominant. The functions work together and a project boundary may have emphasis on one function, e.g. separating, at some times and an emphasis on relating at other times. In addition, the functions may enable separating in some dimensions, while relating with regard to others. Hence, there is not a straightforward trade-off between them although it may be difficult to separate and relate to the context simultaneously. One function is not to be regarded as dominant at the expense of the other function. The functions of separating and relating are thus complementary and need to be handled in view of the situation.

Setting the focus on the activity dimension, the two functions not only complement each other over time but may also influence each other during a project. In search-oriented activities, referring to the fact that the objective of an activity is clear while how to accomplish that objective is not, there can be an emphasis on the separating function, which enables combining within the project. However, if in this process a need for external resources becomes identified, needs for the relating function of the boundary can arise.

The relating function of a project boundary may also create needs for the separating function. For example, while external resources are to be used and developed in a certain research activity, it may be necessary to perform that use and development separately from the context. Thus, separating may not only result in relating, but relating may also create needs for the separating function of a project boundary.

Effects of the separating and relating functions are discussed in the next subsection with regard to identity and difference of projects.

8.1.2 IDENTITY AND DIFFERENCE

The project boundary enables separating and relating of resources between the project and its context. A strong separating function of a project boundary may contribute to the development of some sought-after effects, while an emphasis on the relating function may contribute other wanted effects. An emphasis on the relating function may favour resource variety in a project. A project and its project members access resource collections of varying kinds, which together constitute a platform for resource combination.

Variety of resources is based on how unique a resource is in relation to other resources and the possibilities to combine it with other resources (Håkansson and Waluszewski, 2002). The value of resources depends on what other resources they are combined with – thus, having the possibility to combine a variety of resources may result in novel outcomes. Variety of resources in

relation to a project thus refers to the uniqueness of the resource collections of the project members and how these may be combined towards the project goal. In addition, the resource constellation of the network offers potential for variety. Combining a variety of resources within a project may lead to new aspects with regard to both search, i.e. identification of the known, and discoveries, i.e. finding the unexpected.

Resource variety of a project thus depends on the resource collections of the project members, and their differences. The project members may access different resources with regard to both the internal resources which they access directly and external resources accessed through third parties. The relating function of a project boundary may thus favour resource variety, which is realised through the differences among the project members in terms of the resources they may access. However, an emphasis on the separating function of a project boundary may result in another desirable effect: a strong separating function may contribute to the development of a project identity.

A project identity refers to the fact that the project members commit and share a sense of belonging. A project identity may in turn help to make project members work together towards the project goals. Project members that belong to different parent organisations and have unique backgrounds still need to become committed to the project. A project identity may be described as a type of organisational identity (Huemer et al., 2004). However, if too strong an identity is created, this may foster a strong reliance on the project boundary and, as a result, the project may not be able to make use of the differences and thereby the variety arising from the differences.

In accordance with this reasoning, Marshall (2003) discusses identity and difference for projects and suggests that there may be a paradox involved. The paradox is that, on the one hand, too much identity at the expense of difference might result in lack of creativity and defensive isolation in projects. On the other hand, without shared or at least compatible goals, it is not likely that inter-dependent tasks will be solved. This means that the separating function of a project boundary is necessary for creating project identity but, at the same time, the relating function needs to leave room for differences among the project members and for the project members to maintain belonging to their parent organisations.

To conclude from the above, projects may be seen as developing an identity in terms of the members sharing a sense of belonging and a feeling of commitment. While the project boundary is characterised by an emphasis on the separating function, the project may develop an identity which, in turn, may result in the project being perceived as an actor. Identity together with

commitment and trust are qualities that attribute an actor (Håkansson and Snehota, 1995). The project members thus form part of this new actor and their sense of belonging may become stronger in relation to this actor than their other belongings. Further actors in the network may also recognise the project as having a certain identity. Hence, a project may be perceived as an actor not only by the involved project members but also by the actors in the project context.

The project as an actor can have a positive effect on the realisation of the project goals. While the project members regard themselves as members of the project actor, their efforts are likely to be invested in the process of fulfilling the project goals. However, regarding the project as an actor entails both positive and negative aspects (von Corswant, 2003) – positive in that the project becomes an actor in the eyes of other actors, and negative in that there is still another actor to be handled. Another negative effect may be that the complexity increases when, for example, a project member acts according to the view of different actors.

Defining a project may result in difficulties in satisfying all related actors, such as project members, parent organisations, funding bodies or other stakeholders. One way in which this could be handled is through the actors' own interpretations of the project tasks and goals. The actors need to interpret the project goals in order to understand, make use of their resources in the project, or relate the project to their own goals. However, the differences among their interpretations may also be subject to disagreement among actors.

In conclusion, emphasis on the separating function of a project boundary is desirable in order to contribute to the development of a project identity. However, the differences of the project members in terms of the resources they access are also vital. Making use of the differences among the project members offers possibilities to benefit from resource variety.

8.2 Perspectives on project boundaries

In this section, project boundaries are explored further. In the first part below, project boundaries are discussed as multiple, where the resources used and developed within a project are one way of determining a project boundary. Subsequently, the effects on the project from the context are discussed on the basis of the different views of the project boundary. The third part concerns network effects from projects across project boundaries.

8.2.1 THE MULTIPLE BOUNDARIES OF A PROJECT

The starting point in the case study of this thesis has been the project boundary as empirically given, i.e. as defined by the participating organisations, to enable analysis of how resources are used and developed across the boundary. With a background in the fact that a research project sets out to develop resources, the resources used and developed appear to be a suitable ground for theoretically defining a boundary. Hence, the resource use and development within a project are used to define the project boundary in the resource constellation.

Resources have long been regarded as an appropriate starting point for defining *firm* boundaries (cf. Penrose, 1959)⁴³. Santos and Eisenhardt (2005) discuss organisational boundaries related to resources, in terms of a boundary of competence. They suggest that a competence boundary should be drawn in such a way that the value of the resource portfolio of a firm is maximised, which implies issues concerning what resources should be possessed and deployed internally. This is also related to the purpose of a competence boundary, to decide the internal resources of a firm.

However, in contrast to these views, industrial network researchers rather describe firm boundaries as blurred (cf. Håkansson, 1982; Araujo et al., 2003) since interaction with external actors, activities and resources are always of vital importance for the firm. Hence, in the project boundary with regard to the resources used and developed, the project members' access to resources is emphasised and, thus, external resources may be as important as the internal ones.

This view of boundaries, emphasising external activities, resources and actors, has also formed a point of departure for suggestion of another type of boundary in the resource constellation. This boundary is a "change boundary" based on a study of collaborative product development (Holmen, 2001). Within a change boundary, there are changes based on the new product developed, while outside the change boundary there are no changes.

The project boundary in the resource constellation may not fully coincide with a project boundary in the web of actors. Some of the resources a project member accesses may be controlled or owned by another actor, which implies that the boundaries in the resource constellation and the web of actors may be different. However, drawing a project boundary based on the members of a project is a common way of deciding the boundary. For example, according to

⁴³ The resource-based view of the firm (RBV) also takes its starting point in Penrose (1959), emphasising the firm-internal resources and how these can be combined most efficiently in order to achieve competitive advantage.

Scott (2003, p. 187) a frequent way of defining organisational boundaries is by “*who is and who is not regarded as a member*”.

This study suggests that some of the resources used and developed in a project are accessed from actors not regarded as members. The resources that the project members access are thereby included within the boundary in the resource constellation. On the other hand, some actors may be members, even though they do not contribute directly to resource use and development. These actors may contribute other aspects, such as identity or reputation, or it may be planned that they are to mobilise resources for the project in later stages. The resource constellation and the web of actors thus display different dimensions of project boundaries.

The project boundary in the web of actors may not fully correspond to a boundary in the activity pattern either. Some authors emphasise that there are problems with drawing organisational boundaries based on actors or individuals, because individuals may be involved in several activities at the same time. “*The reason there is so much difficulty in drawing social-system boundaries is that it is behaviours that are organized, not individual people*” (Pfeffer and Salancik, 1978, p. 30). Weick (1979) also notes that it is behaviour that is interlocked and not persons. Partial inclusion refers to the fact that a person can be involved in several activities at the same time. Due to partial inclusion, a certain actor may be involved in activities in an organisation and at the same time in its context (Pfeffer and Salancik, 1978; Weick, 1979). Therefore, these authors propose organisational boundaries based on the activities or behaviours of a certain organisation.

Both project members and other actors may perform activities in a project. Actors outside the project boundary, in the resource constellation, may thus perform activities that are within the project boundary in the activity pattern. The opposite situation is also possible: some of the members of a project may not take part in any activities of a project, but these actors may contribute aspects not shown in performed activities.

To conclude from the above, the boundaries within the resource constellation, activity pattern and web of actors may display partly different project boundaries, and consequently illustrate unique dimensions of how projects relate to their contexts. Hence, these boundaries may only partly coincide due to the notion of partial inclusion of actors. Furthermore, the three dimensions are interdependent; which implies that a change in one of the dimensions can result in changes in the other dimensions. For example, if a certain activity is to be performed or new knowledge is needed, a new actor can be included in the project, as in the case of the winter oats project where the group of computer

scientists was included as a project member. Another illustration of interdependence is that if a certain resource is developed, it can be necessary to perform an activity in order to make use of or understand the resource. Therefore, this new activity may become included within the project boundary in the activity pattern.

To conclude, projects may be seen as having multiple boundaries with regard to resources, activities and actors. By considering these different dimensions of project boundaries, a new understanding of projects and boundaries may come to the fore. The multiple project boundaries are seen as complementary illustrations of a project in its context.

8.2.2 THE CONTEXT'S EFFECTS ON THE PROJECT

Resources, actors and activities have been considered when discussing multiple project boundaries above. In the discussion of project embeddedness, activities and resources were used as the starting points. Hence, activities and resources are used in this section for exploring the effects of the context on the project.

Project embeddedness with regard to activities to a high degree seems highly related to viewing the context mainly as a problem, since the project members may experience a low degree of commitment (Blomquist and Packendorff, 1998). The context of a project can impose problems of different kinds, e.g. in terms of project members being involved in other activities in parallel and thereby only being partly engaged in a certain project or resources being occupied, implying limited possibilities to use these resources. Other types of problems may be caused by changes in the context, e.g. changing conditions, demands or access to resources. Project embeddedness with regard to activities to a high degree may thus be seen largely as assuming that, while resources are occupied or project members perform activities elsewhere, they cannot be pursued in a certain project. Therefore, the context tends to become problematic for a project and solutions to these problems can be isolating or protecting the project from the context.

However, research projects are often characterised by uncertainty with regard to how the goals can be achieved in terms of what resources may be needed in the process. This means that the context cannot merely be regarded as a problem. Instead, the context of a project can be described as a resource base, which is essential for accomplishing resource combination. Variety of resources was argued above to be necessary for value creation in projects, enabled through the uniqueness of the project's resource collections in combination with the resource constellation of the network. Hence, the context can be described as a vital source of opportunities for projects.

Project embeddedness with regard to resources to a high degree may correspond to a perspective where the context is filled with opportunities. Such embeddedness imposes assumptions of resources as heterogeneous. Based on the assumption that the context is constantly evolving, solutions concern limiting the number of opportunities for the resource combination of the project. This view of the context implies that the context is *not* to be regarded as a problem in terms of project members' other engagements in the context. On the contrary, it may be necessary to make use of the context for further resource use and development. Thus, the problem that comes to the fore is that too many opportunities may appear as a result of a large external pool of resources.

Too many opportunities can never be beneficial, since issues regarding what are to be prioritised and in focus emerge. The project members need direction for resource combination in order to come up with results. Direction is created by the project goals and the resources that the project members have access to, which together form starting points for resource combining.

One way to handle a project context with too many opportunities is by managing the resource use and development patterns linking projects to their contexts. In particular, the mixture of patterns can be seen as decisive for how a project relates to an evolving context. By having a mixture of patterns, the project can be both protected from, and linked to, the context. Thus, the project is able to use the direction provided by the project goals and the resources that the project members access, and thereby to make use of the opportunities of the context.

As long as resources are combined not only within but also across project boundaries, there are additional network effects across project boundaries. This is discussed further in the next subsection.

8.2.3 NETWORK EFFECTS ACROSS PROJECT BOUNDARIES

Recapitulating the introduction to the thesis, a need was identified for analysing the combining of resources in relation to projects studied as part of their contexts. The thesis illustrates how resources are combined within and across project boundaries.

The project goals and the project boundary provide particular direction for resource combination in projects. In the combining of resources towards the project goals, resources developed both prior to and outside the project may be essential. Hence, the context is vital for resource combination within projects. Furthermore, the resources developed in a project may be directly related to the project goals, or else the resources developed in a project could be far from

achieving the project goals. Still, these resources may come to use outside or after the project is completed. This means that there are effects of a project in the context in terms of further use and development of the resources in the context.

In addition to the effects of further using or developing resources in the context, there may be other effects in the network. The creation of a project boundary may have an impact on the surrounding network, which in turn conditions and affects the project.

One aspect facilitating network effects, with regard to project members, parent organisations and third parties, is the notion of project embeddedness or partial inclusion, which refers to that the actors potentially have other engagements. Due to project embeddedness, the resources developed in a certain project may be used and/or developed in other efforts. The embeddedness also works in another direction: the parties may be able to contribute to a certain project based on their other efforts.

One type of network effects of projects concerns the relationships among parent organisations. Some of the parent organisations may have ongoing relationships in which the resources developed in a project may be used and developed further outside the project. The existing relationships may also change as the result of the network effects of a project, in terms of e.g. focusing on new aspects, working more deeply in a certain field, or getting to know new aspects of the other party. The situation may also be that the existing relationships among the parent organisations are ended due to events during a certain project. The network effect of a project may thus be the termination of relationships.

Another possible network effect concerns the creation of new relationships among project members, parent organisations and/or third parties. If in the initial situation there are no existing relationships, apart from those based on the involvement in a project, new relationships between particular organisations may develop. Thus, based on the time-limited collaboration in a project, parties may build further and start collaboration in other areas.

Network effects sprung from an inter-organisational project appear to be created in multiple ways and at various locations in the network. This implies that evaluation of projects becomes a complicated matter, depending on the scope applied in the evaluation. Viewing projects in a broader perspective where the context is included may result in another view of whether projects are successful or not. Furthermore, viewing projects as part of an evolving context may also put new aspects on the agenda in managing projects. The

patterns describing the links between a project and its context may become essential, in particular the applied mixture of patterns as a way of handling an evolving project context. Acknowledging the project context and the importance of the context for resource use and development may also contribute an enriched view of projects from both the participating and external organisations' perspectives.

To conclude, this thesis suggests that resource combining takes place across project boundaries. This opens up for further studies of how projects affect and are affected by their contexts. These may result in a better understanding of how projects contribute to value creation in a wider context, beyond the project boundaries as such. They may also lead to identifying new challenges for project management if we allow that project-internal activities, resources and actors are not all that need to be managed in order to successfully accomplish project goals.

9 REFERENCES

Literature:

Alchian, A. A. and Demsetz, H. (1972) Production, Information Costs and Economic Organization. *The American Review*, Vol. 62, pp. 777-795.

Alvesson, M. and Sköldbberg, K. (1994) *Tolkning och reflektion – Vetenskapsfilosofi och kvalitativ metod*. Lund: Studentlitteratur.

Ancona, D. G. and Caldwell, D. F. (1992) Bridging the Boundary: External Activity and Performance in Organizational Teams. *Administrative Science Quarterly*, Vol. 37, pp. 634-665.

Andersen, P. H. and Drejer, I. (2005) Distributed innovation in integrated production systems – the case of offshore wind farms. *DRUID Tenth Summer Conference*, Copenhagen, June 27-29.

Araujo, L., Dubois, A. and Gadde, L-E. (2003) The Multiple Boundaries of the Firm. *Journal of Management Studies*, Vol. 40, No. 5, July, pp. 1255-1277.

Axelsson, B. and Easton, G. (eds.) (1992) *Industrial Networks – a New View of Reality*. London: Routledge.

Baraldi, E. (2003) *When Information Technology Faces Resource Interaction*. Dissertation, No. 105, Department of Business Studies, Uppsala: Uppsala University.

Bengtson, A. (2003) *Framing Technological Development in a Concrete Context – the Use of Wood in the Swedish Construction Industry*. Dissertation, No. 99, Department of Business Studies, Uppsala: Uppsala University.

Bengtsson, M. and Eriksson, J. (2002) Stickiness and leakiness in inter-organizational innovation projects. In Sahlin-Andersson, K. and Söderholm, A. (eds.) *Beyond project management- New perspectives on the temporary - permanent dilemma*. Malmö: Liber Ekonomi.

Bidault, F., Despres, C. and Butler, C. (1998) The drivers of cooperation between buyers and suppliers for product innovation. *Research policy*, Vol. 26, pp. 719-732.

Björkegren, C. (1999) *Learning for the next project: bearers and barriers in knowledge transfer within an organisation*. Licentiate thesis, Institute of Technology, Linköping: Linköping University.

Blomquist, T. and Packendorff, J. (1998) Learning from renewal projects: Content, context and embeddedness. In Lundin, R. A. and Midler, C. (eds.) *Projects as arenas for renewal and learning processes*. Boston: Kluwer Academic Publishers.

Bryman, A. (2002) *Samhällsvetenskapliga metoder*. Malmö: Liber Ekonomi.

Bångens, L., Dubois, A and Gadde, L-E. (1997) Coordination – Combining – Connection: the impact of governance form. *13th Annual IMP Conference*, 4-6 September, Lyon.

Christensen, S. and Kreiner, K. (1997) *Att leda och lära i en ofullkomlig värld*. translated to Swedish, Bjärred: Academia Adacta.

DeBresson, C. and Amesse, F. (1991) Networks of innovators: A review and introduction to the issue. *Research policy*, Vol. 20, No. 5, pp. 363-379.

Denscombe, M. (2000) *Forskningshandboken – för småskaliga forskningsprojekt inom samhällsvetenskaperna*. Lund: Studentlitteratur.

Dubois, A. (1994) *Organising Industrial Activities – An Analytical Framework*. Dissertation, Department of Industrial Marketing, Göteborg: Chalmers University of Technology.

Dubois, A. and Araujo, L. (2004) Research methods in industrial marketing studies. In Håkansson, H., Harrison, D. and Waluszewski, A. (eds.) *Rethinking Marketing – Developing a New Understanding of Markets*. Chichester: John Wiley & Sons.

Dubois, A. and Gadde, L.-E. (2000) Supply strategy and networks effects – purchasing behaviour in the construction industry. *European Journal of Purchasing & Supply Management*, Vol. 6, pp. 207-215.

Dubois, A. and Gadde, L-E. (2002) Systematic combining: an abductive approach to case research. *Journal of Business Research*, Vol. 55, pp. 553-560.

Dwyer, R. F., Schurr, P. H. and Oh, S. (1987) Developing Buyer-Seller Relationships. *Journal of Marketing*, Vol. 51, April, pp. 11-27.

Easton, G. (1995a) Case Research as a Methodology for Industrial Networks; A Realist Apologia. *11th Annual IMP Conference*, Manchester, September 7-9.

Easton (1995b) Methodology and Industrial Networks. In Möller, K. and Wilson, D. (eds.) *Business Marketing: An Interaction and Network Perspective*. Boston: Kluwer Academics Publishers.

Eisenhardt, K. M. (1989) Building Theories from Case Study Research. *Academy of Management Review*, Vol. 14, No. 4, pp. 532-550.

Eisenhardt, K. M. and Tabirizi, B. N. (1995) Accelerating Adaptive Processes: Product Innovation in the Global Computer Industry. *Administrative Science Quarterly*, Vol. 40, pp. 84-110.

Ekstedt, E., Lundin, R. A., Söderholm, A. and Wirdenius, H. (1999) *Neo-industrial organising- Renewal by action and knowledge formation in a project-intensive economy*. London: Routledge.

Engwall, M. (1995) *Jakten på det effektiva projektet*. Stockholm: Nerenius & Santérus Förlag AB.

Engwall, M. (1998) The project concept(s): On the unit of analysis in the study of project management. In Lundin, R. A. and Midler, C. (eds.) *Projects as arenas for renewal and learning processes*. Boston: Kluwer Academic Publishers.

Engwall, M. (2002) The futile dream of the perfect goal. In Sahlin-Andersson, K. and Söderholm, A. (eds.) *Beyond project management- New perspectives on the temporary - permanent dilemma*. Malmö: Liber Ekonomi.

Engwall, M. (2003) No project is an island: linking projects to history and context. *Research Policy*, Vol. 32, pp. 789-808.

Engwall, M. and Jerbrant, A. (2003) The resource allocation syndrome: the prime challenge of multi-project management? *International Journal of Project Management*, Vol. 21, pp. 403-409.

Engwall, M., Steinthórsson, R. S. and Söderholm, A. (2003) Temporary organizing – A Viking approach to project management research. In Czarniawska, B. and Sevón, G. (eds.) *The Northern Lights – Organization theory in Scandinavia*. Malmö: Liber AB.

Eskerod, P. (1996) Meaning and action in a multi-project environment: Understanding a multi-project environment by means of metaphors and basic assumptions. *International Journal of Project Management*, Vol. 14, No. 2, pp. 61-65.

Eskerod, P. (1998) The human resource allocation process when organising by projects. In Lundin, R. A. and Midler, C. (eds.) *Projects as arenas for renewal and learning processes*. Boston: Kluwer Academic Publishers.

Forbord, M. (2003) *New Uses of an Agricultural Product? – A case study of development in an industrial network*. Centre for Rural Research, Department of Industrial Economics and Technology Management, Trondheim: Norwegian University of Science and Technology.

Gadde, L-E. and Håkansson, H. (1993) *Professional Purchasing*. London: Routledge.

Gadde, L-E. and Håkansson, H. (2001) *Supply Network Strategies*. Chichester: John Wiley & Sons.

Gemünden, H. G., Salomo, S. and Krieger, A. (2005) The influence of project autonomy on project success. *International Journal of Project Management*, Vol. 23, pp. 366-373.

Gilbert, G. P. (1983) The Project Environment. *Project Management Journal*, Vol. 1, pp. 83-87.

Granovetter, M. (1985) Economic Action and Social Structure: The Problem of Embeddedness. *American Journal of Sociology*, Vol. 91, No. 3, pp. 481-510.

Gressetvold, E. (2004) *Product Development –Effects on a Company's Network of Relationships*. Dissertation, Department of Industrial Economics and Technology Management, Trondheim: Norwegian University of Science and Technology.

Gruner, K. E. and Homburg, C. H. (2000) Does Customer Interaction Enhance New Product Success? *Journal of Business Research*, Vol. 49, pp. 1-14.

Hagedoorn, J. (1995) Strategic technology partnering during 1980s: trends, networks and corporate patterns in non-core technologies. *Research Policy*, Vol. 24, pp. 207-231.

Halinen, A. and Törnroos, J-Å. (1998) The role of embeddedness in the evolution of business networks. *Scandinavian Journal of Management*, Vol. 14, No. 3, pp. 187-205.

Halinen, A. and Törnroos, J-Å. (2005) Using case methods in the study of contemporary business networks. *Journal of Business Research*, Vol. 58, pp. 1285-1297.

Hellgren, B. and Stjernberg, T. (1995) Design and Implementation in major investments – A project network approach. *Scandinavian Journal of Management*, Vol. 11, No. 4, pp. 437-455.

Hjelmgren, D. (2005) *Exploring the Interplay between Standard Products and Customer Specific Solutions*. Dissertation, Department of Technology Management and Economics, Göteborg: Chalmers University of Technology.

Hobday, M. (2000) The project-based organisation: an ideal form for managing complex products and systems? *Research Policy*, Vol. 29, Issue 7-8, pp. 871-893.

Holmen, E. (2001) *Notes on a Conceptualisation of Resource-related Embeddedness of Interorganisational Product Development*. Dissertation, Sønderborg: Southern Denmark Business School.

Holmen, E. and Pedersen, A-C. (2001) Managing product development projects across firm boundaries – Experiences from the construction industry. *17th Annual IMP Conference*, 9-11 September, Oslo.

Huemer, L., Becerra, M. and Lunnan, R. (2004) Organizational identity and network identification: relating within and beyond imaginary boundaries. *Scandinavian Journal of Management*, Vol. 20, pp. 53-73.

Hulthén, K. (2002) *Variety in Distribution Networks: A Transvection Analysis*. Dissertation, Department of Industrial Marketing, Göteborg: Chalmers University of Technology.

Hunter, L. (1993) Molecular Biology for Computer Scientists. In Hunter, L. (ed.) *Artificial Intelligence and Molecular Biology*. Boston: MIT Press.

Håkansson, H. (ed.) (1982) *International Marketing and Purchasing of Industrial Goods*. London: John Wiley.

Håkansson, H. (ed.) (1987) *Industrial Technological Development. A Network Approach*. London: Croom Helm.

Håkansson, H. (1989) *Corporate Technological Behaviour – Cooperation and Networks*. London: Routledge.

Håkansson, H. (1990) Technological Collaboration in Industrial Networks. *European Management Journal*, Vol. 8, No. 3, pp. 371-379.

Håkansson, H. and Eriksson, A-K. (1993) Getting innovations out of supplier networks. *Journal of Business-to-Business Marketing*, Vol. 1, No. 3, pp. 3-34.

Håkansson, H., Laage-Hellman, J., Lundgren, A. and Waluszewski, A. (1993) *Teknikutveckling i företaget: Ett nätverksperspektiv*. Lund: Studentlitteratur.

Håkansson, H. and Snehota, I. (1995) *Developing Relationships in Business Networks*. London: Routledge.

Håkansson, H. and Waluszewski, A. (2002) *Managing Technological Development*. London: Routledge.

Jacobsson, S. (2002) Universities and industrial transformation. *Science and Public Policy*, Vol. 29, No. 5, pp. 345-365.

Jahre, M., Gadde, L-E., Håkansson, H., Harrison, D. and Persson, G. (eds.) (2006) *Resourcing in Business Logistics – The art of systematic combining*. Malmö: Liber and Copenhagen Business School Press.

Kadefors, A. (1997) *Beställar-entreprenörrelationer i byggandet – samarbete, konflikt och social påverkan*. Dissertation, Department of Technology Management and Economics, Göteborg: Chalmers University of Technology.

Karlsen, J. T. (1998) *Mestring av omgivelseusikkerhet- en empirisk studie av prosjekter*. Dissertation, Department of Industrial Economics and Technology Management, Trondheim: Norwegian University of Science and Technology.

Karlsen, J. T. and Pedersen, A-C. (1998) Leverantören – prosjektets viktigste eksterne actör? *Nordnet '98, Nordisk prosjektkonferanse*, 21-22 September, Oslo.

Kirzner, I. M. (1992) *The meaning of market process- Essays in the development of modern Austrian economics*. London: Routledge.

Kline, S. J. and Rosenberg, N. (1986) An Overview of Innovation. In *The Positive Sum Strategy: Harnessing Technology for Economic Growth*. Washington D.C.: National Academy Press.

Kreiner, K. (1995) In search of relevance: Project management in drifting environments. *Scandinavian Journal of Management*, Vol. 11, No. 4, pp. 335-346.

Kreiner, K. and Schultz, M. (1993) Informal Collaboration in R&D. The Formation of Networks Across Organizations. *Organization Studies*, Vol. 14, No. 2, pp. 189-209.

Krippner, G. (2001) The elusive market: Embeddedness and the paradigm of economic sociology. *Theory and Society*, Vol. 30, pp. 775-810.

Kvale, S. (1997) *Den kvalitativa forskningsintervjun*. Lund: Studentlitteratur.

Laage-Hellman, J. (1989) *Technological Development in Industrial Networks*. Dissertation, Department of Business Studies, Uppsala: Uppsala University.

Lesk, A. L. (2002) *Introduction to Bioinformatics*. Oxford: Oxford University Press.

Lincoln, Y. S. and Guba, E. G. (1985) *Naturalistic Inquiry*. Beverly Hills, CA: Sage Publications.

Lind, F. (2005) Inter-organisational Projects and Networks. *15th Annual Nordic Workshop on Interorganisational Research*, Uppsala, August 19-21.

Lind, F. and Dubois, A. (2005) Resource Development and Use Across Project Boundaries. *21st Annual IMP Conference*, Rotterdam, September 1-3.

Lindkvist, B. (2001) *Kunskapsöverföring mellan produktutvecklingsprojekt*. Dissertation, Economic Research Institute, Stockholm: Stockholm School of Economics.

Lindkvist, L. and Söderlund, J. (2002) On goal-directed learning processes. In Sahlin-Andersson, K. and Söderholm, A. (eds.) *Beyond project management- New perspectives on the temporary - permanent dilemma*. Malmö: Liber Ekonomi.

Lundgren, A. (1991) *Technological Innovation and Industrial Evolution – The Emergence of Industrial Networks*. Dissertation, Economic Research Institute, Stockholm: Stockholm School of Economics.

Lundin, R. A. and Söderholm, A. (1995) A Theory of the Temporary Organisation. *Scandinavian Journal of Management*, Vol. 11, No. 4, pp. 437-455.

Lundin, R. A. and Söderholm, A. (1998) Conceptualizing a Projectified Society - Discussion of an Eco-Institutional Approach to a Theory on Temporary Organizations. In Lundin, R. A. and Midler, C. (eds.) *Projects as arenas for renewal and learning processes*. Boston: Kluwer Academic Publishers.

Lundin, R. A. and Midler, C. (1998) Evolution of projects as empirical trend and theoretical focus. In Lundin, R. A. and Midler, C. (eds.) *Projects as arenas for renewal and learning processes*. Boston: Kluwer Academic Publishers.

Lundin, R. A. and Hartman, F. (2000) *Projects as Business Constituents and Guiding Motives*. Boston: Kluwer Academic Publishers.

Lundin, R. A. and Steinhórsson, R. S. (2003) Studying organizations as temporary. *Scandinavian Journal of Management*, Vol. 19, pp. 233-250.

Lundvall, B-Å. (1988) Innovation as an interactive process: from user-producer interaction to the national system of innovation. In Dosi, G., Freeman, C., Nelson, R., Silverberg, G. and Soete, L. (eds.) *Technological Change and Economic Theory*. London: Pinter Publishers.

Löwendahl, B. R. (1995) Organizing the Lillehammer Olympic Winter Games. *Scandinavian Journal of Management*, Vol. 11, No. 4, pp. 437-455.

Maaninen-Olsson, E. (2004) *Det gränslösa projektet: En studie om förmedling och skapande av kunskap i tid och rum*. Licentiate thesis, Department of Business Studies, Uppsala: Uppsala University.

Manning, S. (2004) Managing project networks as dynamic organizational forms: Learning from the TV movie industry. *International Journal of Project management*, Vol. 23, pp. 410-414.

Marshall, N. (2003) Identity and Difference in Complex Projects: Why Boundaries Still Matter in the "Boundaryless" Organization. In Paulsen, N. and Hernes, T. (eds.) *Managing Boundaries in Organizations: Multiple perspectives*. New York: Palgrave Macmillan.

McKelvey, M., Rickne, A. and Laage-Hellman, J. (eds.) (2004) *The economic dynamics of modern biotechnology*. Cheltenham: Edward Elgar.

Nordberg, M., Campbell, A. and Verbeke, A. (2003) Using customer relationships to acquire technological innovation: A value-chain analysis of supplier contracts with scientific research institutions. *Journal of Business Research*, Vol. 56, pp. 711-719.

Morris, P. and Pinto, J. (eds.) (2004) *The Wiley Guide to Managing Projects*. Hoboken: John Wiley & Sons.

Oliver, A. L. (2004) Biotechnology entrepreneurial scientists and their collaborations. *Research Policy*, Vol. 33, pp. 583-597.

Penrose, E. T. (1959) *The Theory of the Growth of the Firm*. Oxford: Basil Blackwell.

Pfeffer, J. and Salancik, G. R. (1978/2003) *The External Control of Organizations: A Resource Dependence Perspective*. Stanford, California: Stanford Business Classics.

Pinto, J. K. and Nedovic-Budic, Z. (2002) Information sharing among partnering project organizations. In Sahlin-Andersson, K. and Söderholm, A. (eds.) *Beyond project management- New perspectives on the temporary - permanent dilemma*. Malmö: Liber Ekonomi.

Powell, W. and DiMaggio, P. (eds.) (1991) *The New Institutionalism in Organizational Analysis*. Chicago: University of Chicago Press.

Powell, W., Koput, K. and Smith-Doerr, L. (1996) Interorganisational Collaboration and the Locus of Innovation: Networks of Learning in Biotechnology. *Administrative Science Quarterly*, Vol. 41, pp. 116-145.

Powell, W. and Smith-Doerr, L. (2000) Networks and Economic Life. In (eds.) Smelser, N. and Swedberg, R. *Handbook of Economic Sociology*. Princeton, N.J: Princeton University Press.

Ragin, C. C. (1992) "Casing" and the process of social inquiry. In Ragin, C. C. and Becker, H. B. *What is a case? Exploring the foundations of social inquiry*. Cambridge: Cambridge University Press.

Rosenberg, N. (1982) Learning by using. In *Inside the black box: technology and economics*. pp. 120-140, Cambridge: Cambridge University Press.

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

Sahlin-Andersson, K. and Söderholm, A. (2002) The Scandinavian School of Projects. In Sahlin-Andersson, K. and Söderholm, A. (eds.) *Beyond project management- New perspectives on the temporary - permanent dilemma*. Malmö: Liber Ekonomi.

Santos, F. M. and Eisenhardt, K. M. (2005) Organizational Boundaries and Theories of Organization. *Organization Science*, Vol. 16, No. 5, September – October, pp. 491-508.

Scott, W. R. (2003) *Organizations- Rational, Natural, and Open Systems*. International, fifth edition, New Jersey: Prentice Hall.

Skarp, F. (2006) *Adaptations of Products to Customers Use Contexts*. Dissertation, Division of Industrial Marketing, School of Technology Management and Economics, Göteborg: Chalmers University of Technology.

Staber, U. (2004) Networking Beyond Organizational Boundaries: The Case of Project Organizations. *Creativity and Innovation Management*, Vol. 13, No. 1, March, pp. 30-40.

Stekel, D. (2003) *Microarray Bioinformatics*. Cambridge: Cambridge University Press.

Sydow, J., Lindkvist, L. and DeFillippi (2004) Project-Based Organizations, Embeddedness and Repositories of Knowledge: Editorial. *Organization Studies*, Vol. 25, No. 9, pp. 1475-1489.

Söderlund, J. (2004) On the broadening scope of the research on projects: a review and a model for analysis. *International Journal of Project Management*, Vol. 22, pp. 655-667.

Söderlund, J. (2005) *Projektledning och projektkompetens*. Malmö: Liber.

Tidd, J., Bessant, J. and Pavitt, K. (2001) *Managing Innovation: Integrating Technological, Market and Organizational Change*. Second edition, New York: John Wiley.

Thorburn, H. (2002) *Applying Bioinformatic Techniques to Identify Cold-associated Genes in Oat*. MSc. thesis, Department of Computer science, Skövde: Skövde University.

- Thompson, J. D. (1967) *Organizations in Action*. New-York: McGraw-Hill.
- Uzzi, B. (1997) Social Structure and Competition in Interfirm Networks: The Paradox of Embeddedness. *Administrative Science Quarterly*, Vol. 42, pp. 35-67.
- von Corswant, F. (2003) *Organizing Interactive Product Development*. Dissertation, Department of Operations Management and Work Organization. Göteborg: Chalmers University of Technology.
- von Hippel, E. (1988) *The Sources of Innovation*. New York: Oxford University Press.
- Waluszewski, A. (1990) *Framväxten av en ny mekanisk massateknik – En utvecklingshistoria*. Dissertation, Department of Business Studies, Uppsala: Uppsala University.
- Wedin, T. (2001) *Networks and demand: The use of electricity in an industrial process*. Dissertation, No. 83, Department of Business and Administration, Uppsala: Uppsala University.
- Wennerström, F. (2001) Resource Development - The case of bioinformatics. *Research proposal presented at the 11th Annual Nordic Workshop on Interorganisational Research*, Gothenburg, August 17-19.
- Wennerström, F. (2002a) Development of Bioinformatics: The Interplay between Actors and Projects and the Development of a 'Community of Practice'. *12th Annual Nordic Workshop on Interorganisational Research*, Kolding, Denmark, August 16-18.
- Wennerström, F. (2002b) Development of Bioinformatics: The Interplay between Actors and Projects and the Development of a 'Community of Practice'. *Paper presented at the workshop 'The Economics and Business of Bio-Sciences & Bio-Technologies: What can be learnt from the Nordic Countries and the UK?'*, Gothenburg, September 25-27.
- Wennerström, F. (2003a) Outcomes of an Inter-organisational Project: The case of Genetic Engineering. *Paper presented at the workshop 'Innovations and Entrepreneurship in Biotech/ Pharmaceuticals and IT/ Telecom'*, Gothenburg, May 19-20.

Wennerström, F. (2003b) Resource Development in Interaction: The case of Winter-oats. *13th Annual Nordic Workshop on Interorganisational Research*, Helsingfors, August 15-17.

Wennerström, F. (2004a) Research in cooperation: The case of Swedish winter oats. *Paper presented at the DRUID Academy Winter 2004 PhD Conference*, Aalborg, January 22-24.

Wennerström, F. (2004b) Resource Development in Inter-organizational Projects. *14th Annual Nordic Workshop on Interorganisational Research*, Oslo, August 20-22.

Wennerström, F. and Dubois, A. (2004a) Organising research interaction: A case study of a research project in bioinformatics. *Lychnos, Annual of the Swedish History of Science Society*.

Wennerström, F. and Dubois, A. (2004b) Projects and the interplay between ends and means - A case study of an inter-organisational research project. *20th Annual IMP Conference*, Copenhagen, September 2-4.

Weick, K. E. (1979) *The social psychology of organizing*. Second edition, Menlo Park, California: Addison-Wesley Publishing Company.

Wynstra, F. and Pierick, E. (2000) Managing supplier involvement in new product development: a portfolio approach. *European Journal of Purchasing & Supply Management*, Vol. 6, pp. 49-57.

Yin, R. K. (1989) *Case study Research – Design and Methods*. Sage Publications, Applied Social Research Method Series, Vol. 5, Second edition.

Zweiger, G. (2001) *Transducing the genome: Information, anarchy, and revolution in the biomedical sciences*. New York: McGraw-Hill.

Reports:

SOU 2000:103 *Att spränga gränser: Bioteknikens möjligheter och risker*. Swedish Government Official Report Series, Stockholm: Norstedts tryckeri.

Sandström, A. and Norgren, L. (2003) *Swedish Biotechnology – scientific publications, patenting and industrial development*. The Swedish Agency for Innovation Systems, Vinnova Analysis 2003:2.

Östhol, A. and Lembke, J. (2003) *Strategies and Partnerships for Biotech Regions: The Regional Innovation and Partnership Project*. The Swedish Institute for Growth Policy Studies (itps) A2003:005.

Internet sites:

Department of Cell and Molecular biology, Göteborg University, <http://www.cmb.gu.se/>, <http://www.molbio.gu.se/>

Department of Computer science, Skövde University, <http://www.his.se/>

The winter oats project, <http://g4v.lundberg.gu.se/avenagene/>

MWG Biotech, <http://www.the-mwg.com>

National Centre for Biotechnology Information, <http://www.ncbi.nih.gov/>

Phylip, <http://evolution.genetics.washington.edu/phylip/general.html>

Svalöf Weibull, <http://www.swseed.se/>

Swedish Farmers Crop and Marketing Association, <http://www.lantmannen.se>