CROSS-PROJECT LEARNING: A STUDY BASED ON THE ISRAELI ELECTRONICS DEFENCE INDUSTRY

by

Ilan Oshri

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Marketing and Strategic Management/
Technological Innovation Research Unit
Warwick Business School
University of Warwick

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This thesis is dedicated to my wife, Yael.

DECLARATION

This is to declare that:

- I am responsible for the work submitted in this thesis.

- This work has been written by me.

- All verbatim extracts have been distinguished and the sources specifically acknowledged.

- During the preparation of this thesis a number of papers were prepared as listed below. The remaining parts of the thesis are unpublished.

1. Oshri I., Pan S.L. and Newell S. (under revision after 2nd review), "Managing Dynamics of Knowledge Activities: A Case Study of a High-tech Company", Journal of Management Studies.

2. Oshri I. (June 2000), "Managing Knowledge in a Multiple-Project Environment: Developing Knowledge and Transferring Knowledge", Project Management Institute Conference, Jerusalem, Israel

3. Oshri I. (July 1999), "Conditions for Inter-Project Knowledge Transfer: Interactions between Problems and Solutions", 15th EGOS colloquium, University of Warwick, UK

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ABSTRACT

This thesis aims to develop a comprehensive understanding of *cross-project learning* in multiple-project environments. Cross-project learning is the process through which technologies are transferred and reused within organisations. Recent years have seen a growing interest in cross-project learning. However, research in this area has emphasised the rational, classical approach to cross-project learning. Also, the majority of research on cross-project learning has largely been on the automobile industry in Japan and the USA. Thirdly, research in this field has failed to assess the impact that cross-project learning has had on other organisational processes in product development. The conclusions of these studies are context-specific, fragmented and lack any critical assessment of the process of introducing cross-project learning.

This study argues that a rather different approach to cross-project learning is needed. A three-level analysis is applied in the present study that highlights operational, dysfunctional and strategic aspects in cross-project learning. The empirical core of the research is the evidence from three in-depth case studies conducted in the Israeli electronics defence industry.

Three different approaches to cross-project learning have been identified at the operational level, offering organisational mechanisms and managerial practices that have not previously been reported. At the dysfunctional operations level, the study reveals that the introduction of innovations in cross-project learning has impacted the past harmony between expertise development and knowledge management practices. The findings suggest that this harmony has broken down while the knowledge management and expertise development practices have been further transformed and developed. Lastly, at the strategic level of analysis, two potential cross-project learning strategies have been detected: *exploit product success* and *design to reuse.* A contingency model that emphasises the evolutionary development path of 'modes of reusability', subject to the 'strategic development' of the studied companies, concludes this study.

1 CHAPTER ONE: INTRODUCTION

1.1 Research Objectives

This thesis aims to develop a comprehensive understanding of *cross-project learning* in multiple-project environments. Cross-project learning is the process through which technologies are transferred and reused within organisations. Cross-project learning is argued to be a central factor in knowledge management practice.

Specifically, this research sets out to achieve the following objectives:

⇒ To study the organisational mechanisms and managerial structures that support successful cross-project learning;

⇒ To develop a theory which helps explaining the transformation of activity systems by analysing the impact that the introduction of knowledge management practice had has on other practices in the R & D environment;

⇒ To account for greater or lesser degree of cross-project learning.

The study embraces three distinct levels of analysis: the operational, the dysfunctional and the strategic. Data are drawn from an in-depth study of the Israeli electronics defence industry.

1.2 Research Background

In recent years, large manufacturers have faced a growing need to manage their product line as a multi-project environment; however, they have rarely exploited the efficiencies that cross-project learning may offer (Nobeoka 1995). Cross-project learning has been considered as one of the factors that contribute to the management of product development as a multi-project environment (Clark and Fujimoto 1991; Nobeoka 1995; Meyer and Utterback 1993; Cusumano and

Nobeoka 1998). Nevertheless, there has been limited empirical research on the process of and strategy for transferring a technological platform or component between projects in an R & D environment.

Only recently has research paid attention to the growing trend in intensive R & D and manufacturing firms to reuse technological platforms and components (Cusumano and Nobeoka 1998). Yet the context within which previous studies have been carried out, the Japanese and U.S. automobile industry, has led to specific conclusions, which though valuable, cannot be generalised to other industries that operate in different contexts. Other studies (e.g. Sanderson and Uzumeri 1994; Meyer and Utterback 1993) have acknowledged the phenomenon, but have placed emphasis on the management of product families, which is only one element in cross-project learning.

There have been a few attempts to study organisational processes and mechanisms that support cross-project learning. On the strategic level, Meyer and Utterback (1993) advise companies to move towards the management of product families. On the operational level, Cusumano and Nobeoka (1998) offer managers four knowledge transfer strategies that are related to situations in managing new, sequential, concurrent and design modification projects. New organisational structures have been suggested in order to ease tension between functional- and project-centred structures (Nonaka and Takeouchi 1995). Another area which has recently attracted attention is the concept of knowledge in organisations. Some studies have treated knowledge as an object (Smith 1985; Nobeoka 1995), a view which emphasises the instrumental, functional character of knowledge in organisations. Yet knowledge has also been described from a social construction perspective (Blackler 1995), an approach that highlights its contentious, provisional, contested nature. The first part of Chapter 2 presents the main debates in the literature concerning the organisational processes and mechanisms that support cross-project learning and reviews the main empirical studies in order to reveal the 'known wisdom' in this area.

There has been an ongoing debate between the individualist, structuralist and interactive process perspectives in the process innovation literature. Each school of thought has emphasised a different set of elements in the process of innovation. Because the present study concerns the introduction of cross-project learning, the main literature on process innovation is reviewed in the second part of Chapter 2. In particular, a major weakness of this specific literature is the lack of reference to the impact of process innovations, such as cross-project learning, on other organisational processes.

The empirical core of the research is provided by three in-depth case studies conducted in the Israeli electronics defence industry. There were two main reasons to choose the electronics defence industry for a study on technology transfer. The first reason is that the defence industry presents many cross-project learning related characteristics that make it a promising candidate for such a study. Among these characteristics are lines of products that are based on a single technological platform, and a growing competition in defence markets that push these companies to improve product development processes. Secondly, changes in defence markets since the beginning of the 1990s have changed the process through which products are developed in this industry. This has given the researcher an opportunity to investigate the nature of these changes, in particular those which are related to cross-project learning, and the impact that these changes have had on the entire product development system. Therefore, Chapter 3 will discuss these considerations at length. In addition, issues related to the research process and the applied research methods will be debated in Chapter 3.

Understanding the context within which the present study has been carried out is imperative (Pettigrew and Whipp 1991). Changes in R & D practices will be examined in the present research in the context of recent changes in the global and domestic spheres, and in specific companies. Product development practices in the Israeli electronics defence industry, which are based on the historical cost-plus contracting system, have changed. Since the beginning of the 1990s, as the cost-plus system faded and was replaced by the strict fixed cost contracting system, the

Israeli electronics defence industry has faced growing competition, clients have become more demanding and sophisticated and R & D budgets have shrunk significantly (Sadeh 2001). To relate the findings of this study to the context within which these companies operate, a three-tier analysis of the defence industry, i.e. global, domestic and company-specific, is presented in Chapter 4.

The process of cross-project learning involves the transfer of specific know-how between projects and the coordination of product development activities across multi-functional groups through organisational mechanisms and managerial practices. The 'glue' behind these daily routines is the system of norms, values and motivational factors that supports, but also occasionally inhibits, cross-project learning. Thus far, research in this area has provided empirical findings of unique organisational structures that support technology transfer in the automobile industry, mainly in Japan (Cusumano and Nobeoka 1998). Chapter 5 will present empirical findings on the organisational structures, the managerial practices and the system of motivational factors that support cross-project learning in the three studied companies. This chapter will also focus on the differences between the studied companies in terms of the organisation of cross-project learning, the applied organisational structures and managerial practices. Several competing interpretations will be used to explain the disparity in cross-project learning capabilities between the studied companies.

Cross-project learning is perceived in the present study as a knowledge management practice (Coombs and Hull 1998). Yet this practice does not exist in a vacuum. There are other practices in the R & D environment: for example, expertise development. This, of course, begs the question: how did the introduction of cross-project learning and the acceleration of product development affect the expertise development practice? An activity theory lens has been applied (Engestrom 1992) in order to answer this question. The examination of the historical development path of these two practices reveals that the past coherence between expertise development and knowledge management has broken down following the introduction of cross-project learning and the acceleration of product development. Chapter 6 will discuss the sources of the tension between expertise development and knowledge management. Furthermore, the elements that drive the transformation of these activity systems will be examined. It will be suggested that mini-innovations, such as new tools, technologies and procedures, introduced by individuals in situations of uncertainty or confusion ease the tension between 'domain innovation' and 'boundary innovation' (Boland and Tenkasi 1995) and between inter- and intra-community interests. A theoretical argument that examines the 'breakdown' point of an activity system will be developed in Chapter 6. This chapter will conclude by extending the activity theory argument to the transformation of activity systems, based on the empirical data.

The unique contextual characteristics of the studied companies suggest that the technology transfer strategies offered by Cusumano and Nobeoka (1998) are inappropriate to the electronics defence industry and perhaps to other manufacturing and service industries. Two cross-project learning strategies emerge from the empirical data: *exploit product success* and *design to reuse.* A possible evolutionary trend of cross-project learning strategies, which is subject to present identity and future strategic direction, is proposed in Chapter 7. Present identity is explained in this study as a socially and symbolically structured notion intended to lend meaning to experience (Whetten and Godfrey 1998:27). Based on the empirical data, the framework presented in Chapter 7 suggests that the path of development of cross-project learning is subject to the dynamics of change in present identity and future strategic direction. Several competing propositions with regard to the future development of cross-project learning conclude this chapter.

The concluding section of the study summarises the main theoretical, empirical and method contributions made by this research. In addition, Chapter 8 will discuss practical implications, outline the limitations of the present study and highlight opportunities for future research.

2 CHAPTER TWO: LITERATURE REVIEW: CROSS-PROJECT LEARNING IN MULTIPLE-PROJECT ENVIRONMENTS

2.1 Introduction

This thesis explores the introduction of, and the conditions for, the success of innovations in cross-project learning in multiple-project environments. Such introductions not only accelerated product development in the studied companies, but also led to fundamental changes in some internal processes, in knowledge management and expertise development.

The challenge in this chapter is to integrate the relevant knowledge accumulated in the existing literature into a workable framework that will assist in explaining cross-project learning activities and their implications in the case study companies. Therefore, our approach in reviewing the literature is first and foremost to become familiarised with the areas that have already been studied.

Secondly, this review aims to highlight the shortcomings of existing studies and hence to identify the scope for future research. It must be stressed that, because of the limited scope of this thesis, some studies were either only briefly reviewed or excluded from this chapter. This is by no means to imply that other perspectives are ignored. It simply reflects the fact that some of the areas relating to cross-project learning and process innovation have attracted the attention of numerous academics and practitioners, and that it is therefore impossible to cover fully the entire body of knowledge on this subject. The area of literature covered in this chapter was carefully selected based on several criteria. Studies that confirm the findings of the present study were included in this chapter. Also, studies that contrasted with the findings of this research were included below. Lastly, studies that use different research methodologies and methods were reviewed and assessed. These areas of study are provided below in order to assess the strengths and weaknesses of the existing literature and to explore opportunities for future research.

Cross-project learning, technology transfer and process innovation are at the centre of this thesis, and therefore these areas will be extensively reviewed. Other areas of research, such as product development and the management of projects, are of concern here mainly because of the context within which this research was carried out. Appendix 1 provides an elaborative review of the latter, offering links between cross-project learning and product development.

The following sections will pave the way for understanding cross-project learning in a multi-project environment by bringing into the discussion aspects of technology transfer, knowledge, and organisational structures and processes in product development.

Section 2.2 will present the body of knowledge on cross-project learning. Section 2.3 will address some key aspects of the literature on process innovation in the context of cross-project learning. Sections 2.4 and 2.5 will outline the justification and foundation of activity theory as applied in the context of this study.

2.2 Cross-Project Learning in a Multi-Project/Product Family Environment

2.2.1 Introduction

Only in recent years has research paid attention to the process of technology reusability. Markus (2001) coined the term 'reuse' while Cusumano and Nobeoka (1998) preferred to discuss its implications in the context of a multi-project environment referring to cross-project learning as the transfer of designs. Victor and Boynton (1998) positioned the reusability process as the highest stage in their model for internal growth, suggesting that the central theme of reusability is modularity[1] in technology, products and processes. The present study accepts the above references and uses, in some cases, these terms interchangeably because in essence they refer to the same thing: the *process* through which project-specific components are shared by a set of projects or products (Meyer and Utterback 1993). The objective of this process, from a company perspective, is the same; to reduce R & D costs, accelerate product development, improve responsiveness to customers by enhancing learning in specific areas, and achieve better integration across projects in R & D environments (Cusumano and Nobeoka 1998).

The product platform, which refers to the content of the design and the components shared by a set of products, is at the heart of the product family. A product family typically addresses a market segment, but not always (Meyer and Utterback 1993). An example is the Sport Walkman by Sony, which is based on the Walkman product platform versions, or Toyota, which manages the ES 300 and the Supra models as one product family and yet targets two different niche markets, luxury sedan and sport respectively (Cusumano and Nobeoka 1998).

Studies (for example, Sundren 1999) link the emergence of product family as an organisational concept to the need to maintain competitiveness by quickly introducing new products and yet maintaining low costs. The complexity and costs involved in introducing new products can be a tremendous burden for most companies. Thus, academics and practitioners have been interested in the techniques that support the successful and efficient management of the product family. These include modularity in design (Baldwin and Clark 1997), knowledge/design transfer in a multi-project environment (Nobeoka and Cusumano 1994; 1995; Cusumano and Nobeoka 1998), and interface management (Sundren 1999). Because the present study revolves around cross-project learning, a greater emphasis will be given to debating the literature on design transfer in a multi-project environment.

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[1] The concept of modularity is also presented by Baldwin and Clark (1997).

2.2.2 Cross-Project Learning: A Strategic Move Towards Product Family Management

Clark and Fujimoto (1991: 215) acknowledge that:

> [...] the success of early involvement depends on the level of knowledge available prior to commencing a given problem-solving cycle. Because much of this knowledge will have originated outside the project (i.e. the lessons from past development projects and the results of advanced research projects), cross-project knowledge transfer – that is, the mechanisms by which a firm stores and makes available to current projects information about past engineering problems – is crucial.

Meyer and Utterback (1993) conducted one of the most comprehensive studies of product families. They assume a correlation between core capabilities and product family. Core capabilities are associated with 'sustained success in the sense of product development effectiveness, financial performance or learning and employee satisfaction' (ibid.: 34). The study shows that not all product families have matured to the degree that success can be exploited. Hence, their conclusion is that some specific conditions need to be maintained in order to turn product family into a core capability. Amongst the barriers that companies face in achieving this goal are, first, short-term objectives for the development of new technology, thereby not allowing time for the technology to mature and start exploiting success. Secondly, a lack of the resources needed to invest in the product family to maintain its competitive edge may endanger the development of the product family. And lastly, breaking up design teams once the development of the product is finished might reduce communications and end the synergy between key players in the multifunctional team.

Meyer and Utterback (1993) conclude by proposing a new policy for companies seeking to ensure that the product platform will have a positive impact on their performance. It is essential to have a clear and deep understanding of what potential clients need and how the company can integrate the product with its other offerings in order to develop a product family. Secondly, there is a need to transform product planning into product family planning. This means that companies need to oversee how their product platforms can be applied in products across a number of product generations (Victor and Boynton 1998). Consequently, resource allocation needs to change, allocating more resources to long-term developments. Meyer and Utterback's (1993) study confirms some of our findings. Their observation concerning the necessary integration between markets and product development is appreciated, and the present study provides new findings about the organisation of product development close to markets.

The vast majority of the literature[2] on processes in a multi-project environment, such as cross-project learning, is based on the classical approach (Chandler 1962). This approach assumes that management sets a strategy by deciding on long-term goals and objectives, guiding employees through a course of actions and allocating resources when and where they are needed. In the same manner, classical theorists assume that a presumably 'planned' strategy to transform the management of product development from a single-project to multi-project management would be a well-planned process, one that will only positively impact product performance. The present study suggests that the product development environment is far more complex (Blackler et al. 1999). Perhaps the quotation provided by one software engineer summarises our view on this matter 'One touches one place and the rest of the system can be affected'[3]. This poses a challenge to research and perhaps to the classical approach – can research assume no 'side effects' when a new 'strategy' is introduced?

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[2] For example, Meyer and Utterback (1993), Cusumano and Nobeoka (1998), Nobeoka (1995).

[3] See reference in section 6.5.3.

2.2.3 Techniques to Transfer Designs

Nobeoka (1995) and Cusumano and Nobeoka (1998) proposed four different techniques to transfer designs between projects. These techniques are strongly related to the sequence of projects in an organisation.

The first type is *new design*, which enables the incorporation of the latest technology or totally new designs without putting too many restrictions on the development team (ibid.:10). The second type is *concurrent technology transfer*, which suggests that a new project borrows a platform or a component from a preceding project before the preceding project has completed its design work. The authors suggest that this type offers effective and efficient technology sharing. The third type is *sequential technology transfer*, which describes a case in which a project inherits a platform or component from a base project that has finished its design work. In this case the second project reuses a relatively old component, Cusumano and Nobeoka (1998) argue. Furthermore, changes may have to be forced in the reused component in order to adjust the transferred unit to product specifications. They conclude that sequential transfers may not be as efficient or effective as concurrent technology transfer (also see Thompson 1967). The fourth type, *design modification*, describes the case of a project that reuses a platform or component without needing to borrow components outside the project: for example, when a project team is designing a series of product generations by using the same technological platform.

The above four types of technology transfer are also found in the present study. Nevertheless, Cusumano and Nobeoka (1998) present the sequential knowledge transfer technique as the least favourite choice and later on (ibid.:189) recommend managers to apply concurrent technology transfer techniques. This recommendation needs to be examined in the context within which the organisation operates. For example, in the context of the present study, the Israeli electronics defence industry, the contracting method with clients is based on tenders. Hence, a company cannot choose the beginning of the project and plan concurrent technology transfer, but rather follows the client's requirements. Considering this context, would this mean that the Israeli electronics defence industry would inevitably choose the least effective technology transfer method? Obviously the context within which a company operates needs to be considered (Collinson 2001).

2.2.4 Organisational Structures for Cross-Project Learning

The theme of organisational structure in the context of this study is crucial. Studies related to knowledge management and cross-project learning indicate a few organisational structures that would support the transfer of knowledge between divisions, directorates, projects and teams.

For example, Sanchez and Mahoney (1996) suggest a modular organisational design combined with a modular product design. Nonaka and Takeouchi (1995:161) offer the 'hypertext' structure for knowledge creation, which combines a formal organisational structure and a non-hierarchical, self-organising organisational structure (Gold et al. 2001).

On the other hand, empirical studies emphasise the centrality of a matrix structure with functional departments for cross-project learning (e.g. Nobeoka 1995; Cusumano and Nobeoka 1998). Yet this structure may create some problems, such as the level of authority held by the project manager as opposed to the functional department's authority in particular when it comes to decisions around technical problems (Cusumano and Nobeoka 1998:160). The second issue relates to the responsibilities and the physical location of engineers. Allen (1986) suggests that three conditions settle the dispute between project-centred or functional-centred structures. These are, (i) the rate of technological change, (ii) the length of the development project and (iii) the degree of interdependency among functional components being developed for the product.

An organisation is inclined to introduce functional structure when its R & D environment experiences high rate technological change, lengthy projects and a high degree of interdependency among functional components (Cusumano and Nobeoka 1998). The logic for this argument is based on the trade-off between keeping up with the state of the art (through functional structures) or serving the short-term goals of the project.

Gold et al. (2001) look at the same issue but from a different perspective, arguing that a company may have to trade off between some structural elements that are in conflict with each other. These structural elements might inhibit collaboration and knowledge-sharing across internal organisational boundaries and yet might promote and reward small units.

The debate between functional and project-centred structures manifests the tension between the ability to develop technology excellence (functional) and to differentiate products for various niche markets (projects with a high level of coordination). This tension can be approached from different angles, such as between exploration and exploitation (March 1999). Perhaps balancing between these two extremes would be the goal that organisations attempt to achieve when they organise their operations. Therefore, organisations would like to be somewhere in the middle, where they can enjoy the benefits that these two structures offer. The matrix structure combines projects with permanent functional engineering departments. Therefore, the matrix structure would perhaps provide the flexibility and coordination required for cross-project learning.

However, early indications of the pitfalls embedded in the matrix structure and creating coordination problems were provided by Peters (1979). Waterman et al. (1980) refer to the matrix structure as a 'modish variant' that often caused more problems than it solved. However, McCollum and Sherman (1993) defended the advantages embedded in the matrix structure. They suggested that the application of the matrix structure is first and foremost a result of a lack of specialist personnel that could be allocated to a sole project. Because of this, individual's expertise must be shared. This means that the intention behind the matrix structure was to solve a staffing problem and not to improve knowledge sharing or coordination. These are, when implemented properly, 'added values' that the matrix structure can offer. McCollum and Sherman (1993:25) support their argument with a statistical analysis of the correlation between R & D personnel assigned to one, two or three (or more) projects and performance outcomes. Their analysis suggests some leading performance indicators, such as ROI, growth in sales, and deadlines, are significantly improved when an individual is assigned to three or more projects.

Recent years have seen a shift from the traditional matrix structure (see Quinn et al. 1988:260 for a detailed description). New variations of the matrix structure have emerged. Cusumano and Nobeoka (1998) offer an insight into some of these structures. In particular, they describe the *Differentiated Matrix* structure (ibid.:66) as a mechanism in which project manager and functional managers share authority. Within this structure, management has introduced coordination mechanisms that link multiple projects. Their findings have been confirmed in the present study; however, on a different scale, mainly because of the different contexts of these two studies. In addition, the importance of design centres in the matrix structure has received little attention by Cusumano and Nobeoka (1998). Thus, recent variations in the matrix structure, such as design centres and the grouping of projects into one programme, need further study.

2.2.5 Coordination and Integration in Cross-Project Learning

Coordination and integration of cross-project learning concern, in fact, the strategic shift from a single-project to a multi-project management.

Nobeoka (1995) identifies cross-functional integrity through the organisational structure as one major enabler of the inter-project knowledge transfer process. In line with Meyer and Utterback (1993), Nobeoka (1995) provides empirical evidence of companies shifting their orientation from the management of a single project to multiple projects. One example is Toyota. In practice, the nomination of cross-project roles and the introduction of cross-project mechanisms are the manifestations of coordination of tasks between projects, and the integration of know-how across projects.

Toyota appointed a number of chief engineers above project mangers responsible for multiple concurrent projects (Cusumano and Nobeoka 1998; Sobek et al. 1998). Amongst many other responsibilities, the chief engineer enhanced the rapid transfer and sharing of new designs among multiple projects. In addition, Toyota created a variety of working structures supporting the development of design tasks across projects. A similar organisational structure was also found at Sony (Sanderson and Uzumeri 1994). These working structures are flexible and may change according to management recognition of the degree of either inter-project or cross-functional learning required in this process.

Nobeoka's contribution to this area of study is of major importance. Yet his approach is atheoretical and does not integrate theoretically with existing research on corporate strategy. He also does not report insignificant findings in his study. These three elements inhibit theory building (Brown and Eisenhardt 1995). In addition to the further empirical evidence provided in Chapter 5 on coordination and integration mechanisms, the present study will seek to integrate these mechanisms, or perhaps capabilities (Meyer and Utterback 1993; Coombs 1996) into the area of corporate strategy.

Lastly, Hauptman and Hirji (1999) examine integration and coordination mechanisms in R & D environments. The emphasis in their study is on cross-functional teams. Though cross-functional teams are not the main concern of the present study, the conditions for coordinating and integrating these teams may be imperative. This is because the context of a cross-functional team is very similar to the context within which cross-project learning takes place.

Some of the barriers to coordination and integration between members of a team in concurrent engineering indicated by Hauptman and Hirji (1999) are cognitive differences, cultural differences, physical distance, and time differences. On the supporting side one may find characteristics such as group reward, job rotation, the use of IT systems, and the power of the project manager.

2.2.6 The Theme of Knowledge in Cross-Project Learning

The theme of knowledge and knowledge capabilities in R & D environments has attracted the interests of many researchers (e.g. Davenport et al. 1998; Davis and Wilkof 1988; Nonaka and Takeouchi 1995; Blackler 1995; Collinson 2001; 1999). The contribution of the above studies to understanding the meaning and the process of knowledge is invaluable.

Yet the debate in which this thesis engages in is broader and mainly concerns aspects of cross-project learning. We refer mainly to the debate between cultural and economic images of knowledge (Scarbrough 1999). Perhaps the tension between the social conditions that promote the formation of knowledge and the economic conditions that allow the appropriation of its value (ibid:.6) is the reflection of the tension between viewing the reusability process as technology transfer rather than knowledge transfer.

Indeed, the vast majority of the studies that have examined cross-project learning referred to the subject of the transfer process as if knowledge is an object (e.g. Cusumano and Nobeoka 1998; Nobeoka 1995; Meyer and Utterback 1993). Some of these studies realised the problem in treating knowledge as an object; however, they preferred to ignore any investigation of the source of the problem. For example, Nobeoka (1995) presents a caveat regarding the practice of knowledge transfer: he proposes that face-to-face learning is much more efficient than learning through specification and drawing, particularly with regard to some types of knowledge. Engineers complained that in order to change a base design, they often needed more knowledge than could be found in standard drawings in CAD data. Nobeoka (1995:437) concludes that 'knowledge about the base design may also include other types of intangible or tacit understanding'. Though the observation is accurate, i.e. face-to-face knowledge transfer is much more effective than a similar process through design sheets, the implications for knowledge transfer are far more complex than Nobeoka suggests. The present study challenges the distinction between these two types of knowledge transfer, face-to-face and through drawing and would argue that a socially constructed perspective is needed in order to understand the extent of the differences between types of knowledge.

In conclusion, it is only recently that the area of cross-project learning in multi-project environment has received attention by researchers (Nobeoka 1995; Cusumano and Nobeoka 1998). Research in this area, in particular by Nobeoka and Cusumano, reveals some of the main mechanisms for the transfer of designs between projects. Yet research in this area has focused on the Japanese automobile industry, a very specific context that invites researchers to test current wisdom on cross-project learning and extend the body of knowledge on this young and emerging field of research.

Because this thesis is also concerned with the impact of cross-project learning and acceleration of product development on other organisational processes, and because cross-project learning is considered in this thesis as process innovation, we now would like to review some of the relevant main literature on process innovation.

2.3 Understanding Cross-Project Learning as Process Innovation

Innovation is a process of change. Change can take two forms: change in the things (products/services) that an organisation offers, and change in the ways in which the products/services are created and delivered. The latter type of change is also known as process innovation and is the main concern of this thesis (Tidd et al. 1997). In particular, the emphasis in this thesis is on cross-project learning as a process innovation (Cusumano and Nobeoka 1998).

Tidd and his colleagues distinguish between five types of innovation, each with its own distinctive strategic advantage (see Table 1).

Type of Innovation	Strategic advantage
Novelty	Offering something which no one else can
Competence-shifting	Rewriting the rules of the competitive game
Complexity	Difficulty of learning about technology keeps entry barrier high
Robust design	Basic model product or process can be stretched over an extended life, reducing overall cost
Continuous incremental innovation	Continuous movement of the cost/performance frontier

Table 1: Strategic Advantages through Innovation (Tidd, Bessant and Pavitt 1997: 6).

Innovation in this research is studied through the observation of the Israeli electronics defence industry, which it is first and foremost related to robust design with elements of the competence-shifting type of innovation. Innovation and strategic change will be treated here as interchangeable terms (Slappendel 1996), mainly because both concern the process and implications of change.

The management of process innovation is especially complex because 'most firms will work on a portfolio of innovations, some of which represent incremental developments and improvements on existing and proven products and processes whilst others will focus on more radical change' (Tidd et al. 1997: 9).

The aim of the management of innovation is to bring together people with varied skills to work effectively on the change process and thereby to introduce a new process or product. Thus, the integration of these efforts into a coherent package is essential in order either to deliver new products to markets or to diffuse new practices in the organisation (Clark and Wheelwright 1994). Indeed, most studies of innovations seek to reveal the factors that enable successful process innovation, such as cross-project learning. For example, Pettigrew and Whipp (1991) identify five crucial factors in the management of strategic change: understanding the environment, leading change, linking strategic and operational change, human resources as assets and liabilities, and coherence.

Walton (1987: 17-23) argues that the capacity for innovative change depends on the soundness of the model that guides the development of the innovations, the economic pressures on those who have the power to initiate change, the extent to which the social context supports the innovation, the strength of the institution's internal unification (which is essential for problem solving), and the knowledge and skills held by individuals.

Slappendel (1996) organised the literature on innovation into three main streams: the individualist, structuralist and interactive process perspectives. Innovation is here defined as 'any idea, practice, or material artifact perceived to be new by the relevant unit of adoption' (Zaltman et al. 1973:158). Table 2 outlines the fundamental differences between these three perspectives.

	Individualist	Structuralist	Interactive Process
Basic assumptions	Individuals cause innovation	Innovation determined by structural characteristics	Innovation produced by interaction of structural influence and actions of individuals
Conceptualization of an innovation	Static and objectively defined objects or practices	Static and objectively defined objects or practices	Subject to reinvention and reconfiguration. Based on perception
Conceptualization of the innovation process	Simple linear focus on adoption stage	Simple linear focus on adoption stage	Complex process
Core concepts	Champion Leader Entrepreneur	Environment Size Complexity Differentiation Formalization Centralization Static type	Shock Proliferation Innovative capability Context
Research methodology	Cross-sectional survey	Cross sectional survey	Case studies Case histories

Table 2: Main Features of the Three Perspectives on Innovation (Slappendel 1996).

Wolfe (1994) takes a rather different approach to the organisation of the literature on innovation. He identifies three different bodies of knowledge on innovation. These concern (i) the diffusion of innovation, (ii) the determinants of innovativeness, and (iii) the process of innovation (process theory models). Process theory models refer to the same body of knowledge as the interactive process perspective. Since the diffusion of innovation and determinants of innovativeness are not at the centre of this thesis, we will review the relevant studies briefly, mainly referring to the work of Slappendel (1996).

2.3.1 The Individualist Perspective: The Overemphasis on the Role of the Individual in Innovations

The individualist perspective overemphasises the role of the individual in the innovation process and ignores internal and external organisational attributes that influence that process. The individualist perspective is most clearly expressed in the organisational innovation literature that identifies individual antecedents of innovation. These antecedents have been defined in terms of individual characterises and individual concepts such as age, education level, values, personality, goals, creativity, leadership, and cognitive style. Its emphasis on the individual as the driver of change has been subject to much criticism (van de Ven et al. 1989). Moreover, Slappendel points out that individual characteristics may be diminished by the effect of organisational role and by the impact of organisational power (Pfeffer 1982). Lastly, the tendency to portray individuals as 'rational beings' who are able to introduce innovations with relative ease seems quite unrealistic (Slappendel 1996; Cyert and March 1963). The behaviour of individuals searching for solutions does not necessarily produce all possible alternatives. Rather, according to the individualistic perspective, an individual will only usually identify a few options which prove to be a satisfactory solution to the problem at hand (Cyert and March 1963). This approach to innovation assumes that the adaptive behaviour over time at the 'aggregate level' of the organisation is the evidence of organisational learning.

Chapter 5 and 6 will engage in this discussion in an attempt to explain some of the findings of this study. However, a more realistic view is needed which acknowledges the bounded capacity of humans to deal with complexity and which takes into account non-routine issues.

2.3.2 The Structuralist Perspective: Mistreating Organisational Processes

This perspective assumes that innovation is determined by organisational characteristics. It sees the organisation and its subsystems as striving to achieve organisational goals. Unlike the individualist perspective, the structuralist perspective stresses the importance of understanding the relations between the organisation and its environment. In particular, this perspective highlights the contribution of customers to the pool of ideas, depending on their sophistication and their association with an industry (Crocombe et al. 1991). Also, enhanced communications between the organisation and its customers were found in one study to promote innovations (Saren 1987). The type of industry (i.e. service or manufacturing) has emerged as a differentiating factor. Yet existing studies have failed to highlight the different types of relationships that companies maintain with customers, even within the same sector. Here we refer to the level of involvement of customers in the innovation process. For example, there are some differences between innovation in companies that design and produce made-to-order products and others that design and produce products based on the assumed demand in the markets (Pavitt 1984). For the first type the relations between an organisation and its customers are quite close. This is illustrated in the case of the Israeli electronics defence industry, which designs and produces products that are 'made to order'. The companies in this industry maintain close relations with their customers to the extent that sometimes their customers have an office on the premises of the company. Customers in this specific industry are sophisticated, are involved in product and process innovation, and maintain a high level of communications with management and engineers. So far the literature has paid little attention to the contribution, positive or negative, of this type of relationship with customers to cross-project learning.

Another interesting element in the environment that affects innovation is the rivalry between competitors. Competition tends to stimulate 'the minor, but relatively common, "nuts and bolts" type of innovation' (Slappendel 1996:114). Also, the study of rapid environmental change and the uncertainty that often accompanies it points to the conclusion that this scenario will stimulate innovation in organisations (Ettlie and Bridges 1987). These findings are confirmed in the present study of firms in the Israeli electronics defence industry.

Researchers associated with this stream have also studied the relations between innovativeness and other factors such as the organisation's size, the formalisation of job descriptions, the professionalism of the organisation's members, and the centralisation of power. Despite the breadth and depth of these studies, the correlation between innovations and these factors has not been demonstrated conclusively (Slappendel 1996). This is mainly because of the lack of agreement among researchers concerning the precise definitions of these factors, which has resulted in a fragmented, unintegrated body of knowledge. For example, the concept of specialisation has been interpreted in different ways in the literature on innovation. Such a varying interpretation highlights the challenges involved in maintaining clear and effective communications between different functional departments in the organisation (such as marketing, production and research). These challenges are likely to hinder innovation mainly because of the excessive segmentation between different groups within the organisation and their varying perceptions of innovation (Kanter 1985). The stream of studies on segmentation has led scholars from other schools of thought, e.g. Boland and Tenkasi (1995), Blackler et al.(1999), to develop the concept of 'perspective' in organisational studies. Yet how can the concept of 'perspective' be used in the context of technology transfer? The present study will propose a rather different meaning of 'perspective' in the context of cross-project learning.

One major shortcoming of the structuralist approach is the tendency to ignore the role of central processes (such as strategy and technology) in innovations and treat them as organisational features. These features are here perceived as 'objective realities whose factual character is unchallenged' (Slappendel 1996:114).

Thus far a brief review of the individualist and structuralist perspectives has been provided, emphasising the tendency of researchers from these streams to identify the key determinants of innovation by using cross-sectional surveys. Despite the weaknesses and shortcomings of the individualist and structuralist perspectives, we value the body of knowledge accumulated by these perspectives and consider it to be of fundamental importance to the understanding of the role of the major players in cross-project learning.

Because this thesis studies cross-project learning from a process point of view, the methodological approach is different from the survey-based approach applied by these two perspectives. However, the body of knowledge on the innovation process is also itself fragmented. There are at least two competing views of how this perspective has evolved and what its main arguments are. The two perspectives on the innovation process will be presented in the following section. Slappendel's (1996) work will be described at some length because it is particularly relevant to the theoretical approach applied in this thesis.

2.3.3 Interactive Process Perspective : The Challenge of Action-Structure Multi-Level Analysis

There has been a growing interest in the study of the transitory continuousness of activities which take place during the development and implementation of innovations (Slappendel 1996). In particular, innovations need to be studied as a continuous interplay between actions and structure. Accordingly, Wolfe (1994) argues that process theory models, which are equivalent to the interactive process perspective proposed by Slappendel (1996), emphasise the nature of the innovation process mainly by addressing this question: how and why do innovations emerge, evolve and end? Wolfe identifies two stages in the development of the literature on the process of innovation. One view relates to earlier work on stage research, which perceived innovations as a series of stages and attempted to identify, characterise and put them in order. More recently, *process research* has emerged as a second phase of this stream, demonstrating researchers' attempts to describe fully the sequences of the innovation process and the conditions that determine those sequences.

Important contributions to the process theory models include the work of Pelz (1985) and Rogers (1983), who show that identifiable stages in the innovation process do occur. They suggest that innovation stages tend to be blurred when innovation originates within the organisation, whereas they can be identified clearly when innovation is adapted from an external source. Another major contribution is related to the understanding of the 'messiness' of the innovation process (van de Ven 1989). These efforts extended the use of qualitative research methods when studying innovations and opened up the discussion to new areas of research, such as strategy (Dean 1987), organisational structure (van de Ven and Poole 1989) and politics in organisations (Dean 1987).

Slappendel (1996), who prefers to refer to this body of knowledge as the interactive process perspective, highlights some recent trends in the theory and methodology applied by researchers. One focus -- on understanding the dynamic nature of innovations -- has become crucial to this stream. The 'messiness' associated with how innovation starts, evolves and ends, and the implications of this for other processes within the organisation are vitally important. Secondly, the application of longitudinal case studies based on a 'grounded theory' approach has attracted interest in recent studies and is gradually becoming more acceptable in the academic community (van de Ven et al. 1989). Lastly, studies in this stream have rejected the rational economic model of decision making and have emphasised the *non-rational* aspects of organisational behaviour, for example the bounded rationality of managers. Increasingly, these non-economic aspects are attracting attention in the study of innovations. The present study will debate some of the findings in the light of the above.

From a methodological and theoretical viewpoint, the approaches that emphasise context and process, e.g. Pettigrew (1987), have attracted attention in recent years.

Like other perspectives, the interactive process approach has attracted criticism. Slappendel (1996) argues that while some studies have successfully correlated variables from more than one level of analysis with factors relating to innovations, they have failed to interconnect action and structure over time. Van de Ven and Poole (1988) suggest some future directions for researchers in facing this challenge: they argue that the use of the concept of time to relate action to structure, and the development of new theories of action-structure such as the structuration theory of Giddens (1984) or Activity Theory (Engestrom 1992; 1996) may enhance our understanding of the dynamics of change. In the late 1960s Normann (Slappendel 1996) presented a multi-level analysis study which stressed the interplay between action and structure. In his study, Normann linked factors from different levels of the organisations by describing product development processes and explaining how these processes were affected by the task, and cognitive and political organisational subsystems.

Slappendel (1996) evaluates the interactive process perspective and argues that in the future, researchers need to seek guidance on perspective mediation in order to integrate action and structure in a multi-level analysis. Another challenge is related to linguistic constraints. Slappendel (1996) argues that the complex patterns of processes in innovation, which sometimes present multiple, simultaneous, parallel relationships, may require 'thinking in circles' and 'writing in circles'. Put simply, the challenge for the researcher who engages in such research is to describe complex reality in a way that reflects and demonstrates the complexity and yet does not mystify the description.

Despite the shortcomings and challenges that the interactive perspective manifests, we conclude by adopting the view that the use of this perspective is likely to increase because, of the three perspectives, it would appear to offer more theoretical mileage in the study of phenomena such as new organisational forms and management practices, which tend to be highly embedded in social and historical contexts (Slappendel 1996:124). We position the present study within this stream and seek to contribute to the body of knowledge on process innovations by exploring the impact of cross-project learning and the acceleration of product development on other organisational processes.

2.3.4 Process Innovation: Concluding Remarks

The literature on the management of process innovation is generally prescriptive in nature. As we have seen, the existing theoretical approaches suffer from weaknesses in terms of either their theoretical approach or their applied methodology. The overemphasis on the individual is one major shortcoming of the individualist perspective, whereas the structuralist perspective considers the organisational process as a set of actions rather than a set of features or capabilities. The interactive process perspective faces the challenge of creating a robust interconnection between action and structure over time and needs to take into account the multi-level layers in the organisation.

Despite these shortcomings, the body of knowledge on innovation and strategic change has provided a broad understanding with regard to the main factors, determinants and processes central to successful process innovations such as cross-project learning. On the basis of our review, important opportunities for future research have emerged. The study of process innovation as an interactive process certainly needs further development. In particular, the literature in this stream has failed to develop an understanding of the role of *perspective* in process innovation. Additionally, a better understanding is needed of the impact of process innovation, e.g. cross-project learning, on the entire system. This relates closely to the work of Engestrom (1992) and Blackler et al. (1999), who seek to understand how systems change and what the relations are between individuals and their work throughout the change process. These directions for future research will be considered further in Chapter 6.

2.4 Cross-Project Learning in a Multi-Project Environment: Concluding Remarks

Based on the conclusions drawn from the above analysis, this section outlines the case for applying some aspects of activity theory (Engestrom 1992; 1999; Blackler 1993; 1995) in Chapter 6 as a theoretical lens to study the impact of cross-project learning and the acceleration of product development on existing processes.

Blackler and his colleagues (1999: 6), based on Engestrom's analysis, explain the meaning of activity theory: 'a general model for representing the relationships between personal knowledge and the cultural infrastructure of knowledge, and between individual actions and the broader pattern of activities of which they are a part. [...] the notion of activity offers a way of linking events to the contexts within which they occur'.

Thus, activity theory provides a framework to address the interconnection between action and structure. Furthermore, it encourages us to study these relations, as they are the avenues for understanding the process through which activity systems change (Blackler 1993: 868). Because the unit of analysis is the activity system, i.e. expertise development, knowledge management and product development, this means that the fragmentation between different disciplines within this space is avoided. Lastly, the relationships between individuals, their co-workers, and the activity are mediated by a number of factors including technology, procedures, rules, language, division of labour and others. These relationships are by no mean clear and tidy. Rather, activity systems generate tension, incoherence and inconsistency (Blackler et al. 1999). Nevertheless, unlike rational-cognitive theories, activity theory welcomes the investigation of tension and incoherence as a means of understanding the development of historically dependent activity systems. For example, studying the tension between processes of the same activity system, e.g. expertise development and knowledge management in product development, may assist in understanding the nature of the relationships between individuals participating in the activity, their relationships with mediating tools and mechanisms, and the relationships between these two processes as they change and evolve.

The next section will describe in detail the theoretical foundations of activity theory.

2.5 Activity Theory: Aspects of Change and Knowledge

Engestrom (1996:64) introduces the reader to activity theory with the following elaboration:

> When I write about *the* theory of activity, I am using a double-edged notion. On the one hand, it is necessary to emphasize the unique and self-consciously independent nature of the Soviet cultural-historical research tradition, which today is commonly called activity theory [...]. On the other hand, this tradition is not a fixed and finished body of strictly defined statement – it is itself an internationally evolving multivoiced activity system. *(italics in the source)*

Activity theory, which was developed by Vygotsky -- a Marxist scholar -- in the 1920s, has recently been applied to the study of work organisations (for example, see Blackler 1995: 1997; Blackler et al. 1999; Engestrom 1987; 1992; 1996; 1999). Elementary to activity theory are the relationships between material action, mind and society (Blackler 1993: 867). Because activity theory is based on Marxist methodology, the central argument is that it is not the consciousness of humans that determines their social being; rather, humans' social experiences shape their consciousness. Unlike rational-cognitive theories, which assume that individuals and organisations behave rationally and logically, activity theory suggests that emerging patterns of behaviour are strongly dependent on the interactions between the agent, the community and the object of the activity. Engestrom (1992) has provided a contemporary interpretation of the elements of activity theory. Figure 1 shows the dynamics of human interaction (in contrast to the animal form of activity) and demonstrates the use of tools and concepts that mediate between the subject, the community and the object of the activity system (Blackler 1993). Tension and incoherence are part of the activity system. Nevertheless, coherence is eventually achieved as individuals, guided by the system activity object, use their skills and creativity in order to overcome tension in the activity system (Blackler et al. 1999).

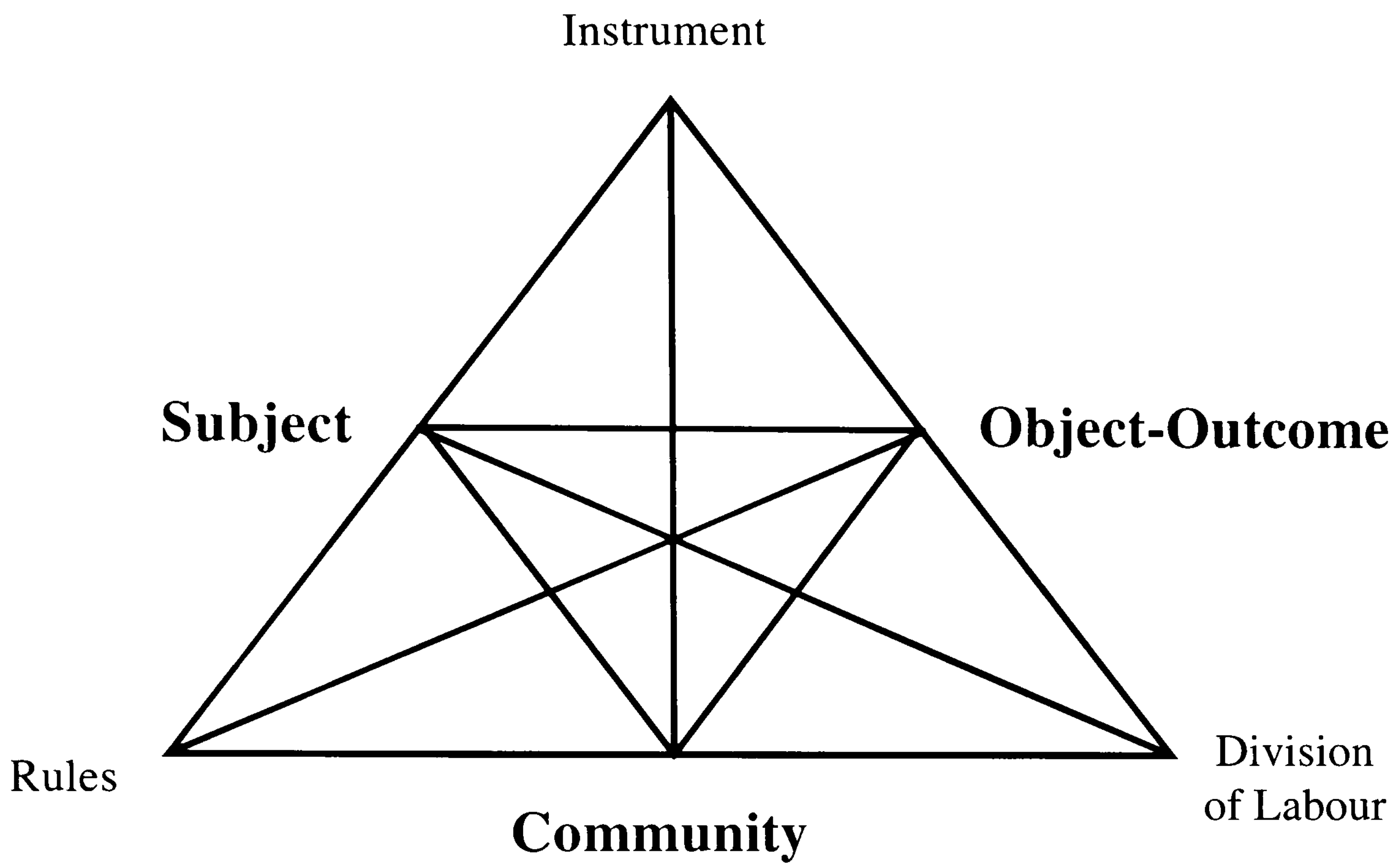

Figure 1: Engestrom's Model of the Structure of Human Activity (Blackler 1993: 869)

Mediation is central to Marxist Theory and hence plays a key role in activity theory, which extends the notion of mediation by adding other aspects and artifacts to this process, e.g. language and the division of labour. Blackler highlights the areas within which mediation takes place in activity systems, basing his observation on Engestrom's model: 'the three processes of mediation of tools between subject and object, of rules between community and subject, and of the division of labour between community and object' (ibid.:869).

The separation between thinking and acting, common to rational-cognitive theories, is avoided in activity theory. The theory asserts that people act together and in fact cannot divorce culture from other aspects of the organisation, e.g. technology or economic factors (Blackler 1993).

Activity theorists use the *activity system* as the unit of analysis in organisations. Activity is much broader than action or operation, as Blackler (1993) explains. Activity can be work, play, research or war. Nevertheless, understanding activity is far more specific and restricted than understanding other major elements in organisations such as culture.

Explaining complex situations in organisations requires a theory that aims to study a variety of organisational situations as a dynamic and interconnecting body of actions. Fundamental to activity theory is the need to understand how people develop their expertise and how practices evolve in society (Lave and Wenger 1991).

Change in the elements of an activity system often transforms the activity system, changing the relationships between individuals, groups, their object and the mediating artifacts. According to Blackler (1993), dialectics arise from this scenario. Thus, rapid change in the predominant perceptions of the object of the activity might trigger the contradictory views of the agents who participate in the activity. There are strong links between different activity systems, and often the output of one activity system is the input of the other. Thus, tension might emerge between different activity systems within the organisation, as they do not develop in isolation from each other.

Engestrom (1992) contributes to the understanding of activity transformation by identifying the contradictions within and between activity systems. The present study sees an opportunity to research further the interactions between different concepts that exist within the activity system in order to understand the impact that these interactions have on the activity system and other activity systems within the organisation.

Blackler (1993) concludes by arguing that Marxist theorists such as Vattimo have presented a strong and deterministic account of the relations between mind and society which does not correspond to the actual relations between different elements in societies or organisations. Although activity theory is an exception among Marxist theories in the way it identifies incoherencies as a feature of personal and social life, it offers a limited explanation of incoherencies in organisations.

Recent developments in activity theory take diverse forms. Still, the main focus in activity theory is to develop a unified account of knowing and doing which emphasises the collective, situated and tentative nature of knowing (Blackler 1995). Figure 2 presents the relationships between the various elements of the activity system.

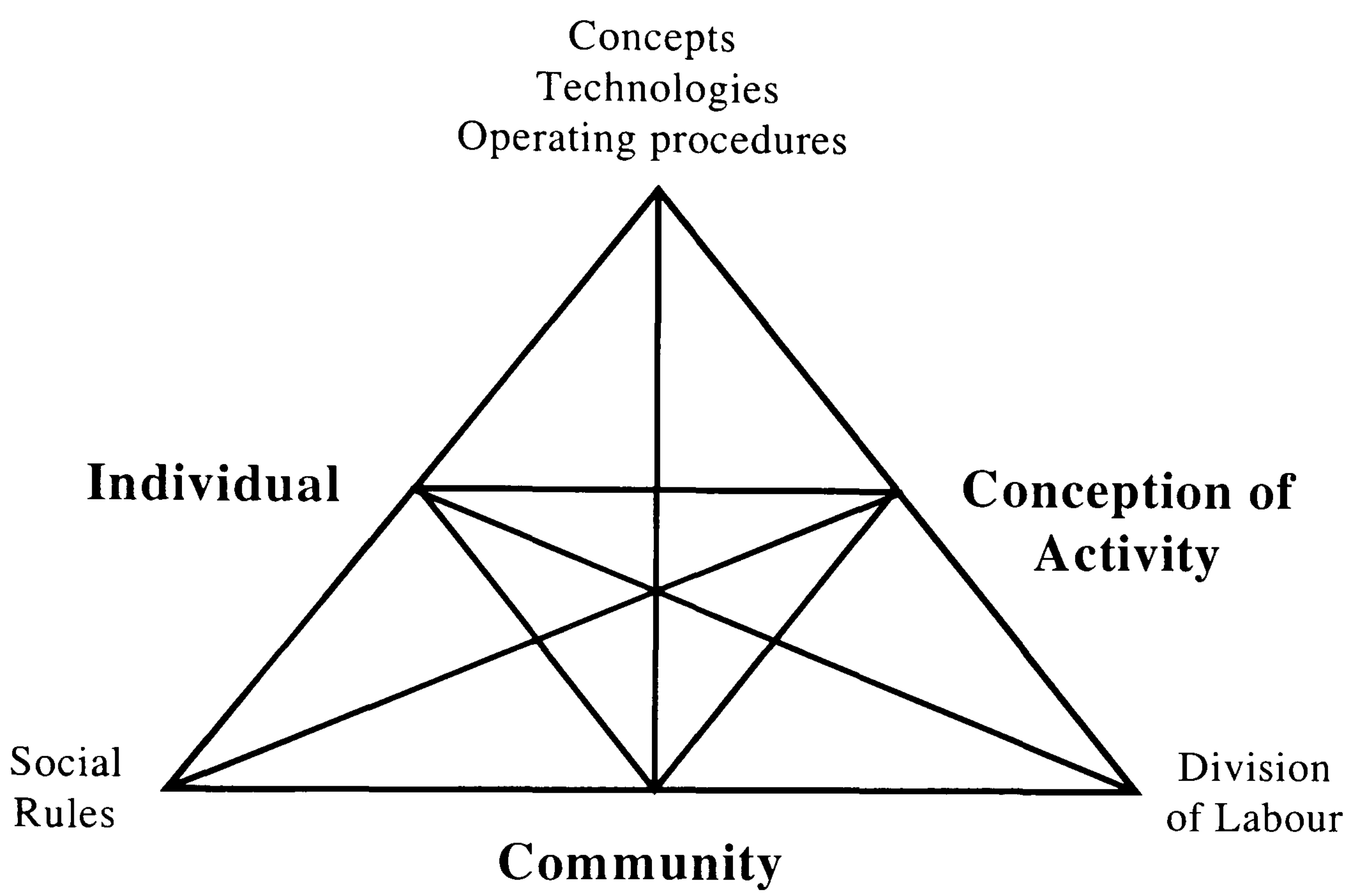

Figure 2: A General Model of Activity Systems (Blackler 1995)

Orr (1990) studied the way Xerox technicians developed their communal identity through story-telling as part of their daily work. In this sense, Orr proposed an understanding of learning based on a theory of social construction that relied on social participation. This learning theory was further developed by Lave and Wegner (1991) and recently by Wenger (1998). In addition to the development of technical skills by sharing information between technicians, these studies highlight the notion of the identity, individual and collective, of professionals and communities of professionals.

Engestrom (1991) studied a Finnish medical practice by applying activity theory and used the *socially distributed activity system* as the main unit of analysis. The author studied the relationships between agents, communities and conceptions in this activity system. Incoherencies and disturbances in this study were observed as counter-phenomena to management attempts to regulate, rationalise and control these organisational systems. Blackler (1995), interpreting Engestrom's findings, suggests that these incoherencies, paradoxes and conflicts in activity systems may provide avenues for change. To Blackler, these paradoxes and conflicts are the opportunities for individuals to develop their skills and learn about their location within the social space in the organisation. It is through participation that learning and expertise development takes place (see also Lave and Wenger 1991).

Criticisms of activity theory mainly focus on the Marxist origins of the theory. It is suggested that an attempt to explain the relations between society's past experience and society's future by stressing the mode of production is too ambitious and unconvincing in today's complex world. Blackler (1993: 874) suggests that 'a non-deterministic, social constructionist conception of incoherency and dilemma in activity systems' will overcome these weaknesses and shortcomings. Sources of tension in activity systems are much more complex than the tensions between use value and exchange value as expressed in Marxist theory. Therefore, further investigation is needed into the origins and manifestations of tension, incoherencies and inconsistencies in activity systems.

In terms of its conception of knowledge, activity theory provides a processual approach (Blackler 1995). Blackler identifies five different images of knowledge (encoded, encultured, embrained, embodied and embedded), but goes on to argue that this conventional view of knowledge, as an entity, is not really helpful since it suggests that knowledge is abstract, individual, mental and static (ibid.: 1040-1402). What is needed, Blackler argues, is an approach that sees knowing as situated, distributed and mediated. In order to achieve this different perspective, he uses activity theory. Rather than studying knowledge as something individuals or organisations 'have', activity theory studies knowing as something individuals or organisations 'do', and he analyses the dynamics of the systems through which knowing is accomplished. Knowing from this perspective is mediated (manifested in systems of language, collaboration, technology and control); situated (located in time and space and specific to particular contexts); pragmatic (purposive and object-oriented); provisional (constructed and constantly developing); and contested. Knowing is a dynamic ever-changing process which cannot be detached from doing. Knowing and doing are situated in certain contexts shaping people's interpretation and influencing their behaviour. They are mediated in the sense that changes in environments may influence both knowing and doing, for example by changing the ways in which concepts within activity theory evolve and change. Knowing and doing are also provisional and evolve mainly through tensions within and between activity systems.

2.6 Conclusion

In this chapter, the body of knowledge on cross-project learning and process innovation has been examined. The existing literature on cross-project learning is largely limited to the Japanese automobile industry, thereby encouraging the study of cross-project learning in other contexts. Furthermore, studies in this field tend to apply the rational-cognitive approach. This calls for the application of other perspectives on cross-project learning in order to enrich the body of knowledge on this relatively young and emerging field.

The present study also seeks to explain the impact of cross-project learning on organisational processes in product development. For this reason we reviewed the body of literature on process innovation, which appears to be prescriptive and fragmented, failing to appreciate the development of different perspectives between communities, and which reveals little about the processes and dysfunctional actions involved in the introduction of process innovations. More specifically, the literature does not discuss the impact of process innovation on other processes within product development. Some authors assume somewhat naively that different processes are able naturally to coexist without any tension or inconsistency.

Therefore, a theoretical framework is needed that compensates for the shortcomings of the existing literature. Activity theory will be applied in Chapter 6 as a lens to examine the product development activity system as the unit of analysis. Furthermore, activity theory demonstrates strong foundations in bringing together the different disciplines and perspectives related to product development in an attempt to present a coherent and integrated theory in this field. Lastly, activity theory avoids the separation between knowledge and action and offers an approach to studying knowing and doing, action and structure, as elements within the activity system, to be analysed through the dynamics that take place in that system.

3 CHAPTER THREE: RESEARCH METHODS AND PROCESS

3.1 Introduction

The purpose of this chapter is twofold: first, to present the research methods, process and data collection techniques; secondly, to highlight research constraints and limitations.

After a brief introduction of the key research interests, Section 3.3 will provide a justification for using the case-study research method. Section 3.4 will discuss the considerations for selecting the case study companies and constraints encountered during the research. Section 3.5 will describe the research process, followed by a presentation of the data collection methods employed in the research process.

3.2 The Key Interests of the Research

This thesis is very much a result of the inspiration provided by the empirical data. The primary aim of the thesis is to capture phenomena which have previously been neglected or perhaps even not reported at all, placing them in their business context and suggesting new explanations of what has been observed.

Intrigued by the empirical data collected in three leading electronic defence companies and by the new horizons for theory development offered by the 'rebirth' of activity theory (Leont'ev 1978; Engestrom 1992; Blackler 1993), this thesis finds its main interests in the area of cross-project learning as a strategy to accelerate product development. In particular, the chief interest of this thesis is to address the challenge of introducing and managing cross-project learning in a product development environment.

3.3 Case-Study Research: The Theoretical Argument

This research is based on an ethnographic multiple case study of cross-project learning innovations in product development that has affected two processes, expertise development and knowledge management, in three large hi-tech companies. A qualitative, retrospective approach is adopted. The research is based on unstructured interviews and the primary researcher's own on-site observations.

The distinctive strength of a case study is its ability to deal with a variety of evidence, documents, questionnaires, interviews and observations. In particular, in exploring an emerging field and its unknown practices, as in the example of knowledge management, the case-study method seems highly appropriate. In other words, the study accepts Laurila's (1997:222-223) view that "the feasibility of the case study approach is thus based mainly on the opportunities it creates for observing and describing a complicated research phenomenon in a way that allows analytical organization" (Eisenhardt 1989; Tsoukas 1993). The case-study approach here focuses on each of the case organisations as a single, universal unit, and may thus be described as 'holistic' (Yin 1989). In Yin's words, this refers to the case study of an institution as opposed to the analysis of the functioning of the separate sub-units within the institution.

The usefulness of the case-study approach is that it allows one to give more attention to the distinctive and typical characteristics of a particular social scene, and can reveal the deep structure of a particular behaviour. Moreover, in Yin's terminology (1989), the case-study design is eminently justifiable because the case serves a revelatory purpose. The observation of, and insights into, issues surrounding intra-corporate knowledge-sharing in the selected organisation(s) should amount to a significant empirical contribution.

Studying a phenomenon within its context usually predisposes researchers to apply the case-study method (Yin 1993). This involves using data-collection methods such as archive-search, interviews, questionnaires and observations

(Eisenhardt 1989:534). Mintzberg (1979) argues that one should go to organisations with a well-defined focus to collect specific kinds of data systematically. Formulating a research problem and identifying potentially important variables with some reference to the existing literature provides a firm framework for systemic data collection. Still, one should carefully select cases in order to facilitate the replication of cases for supporting and extending the emerging theory.

When preparing data-collection methods, Eisenhardt (1989) argues that a triangular approach, i.e. with interviews, observations and archive sources, is the most commonly used combination in qualitative studies.

Though the data collection approach should ideally be decided in advance, one should bear in mind that altering or adding data collection methods is legitimate as long as they are coherent in relation to the overall methodology. Researchers should be receptive to making changes in their collecting methods. Eisenhardt (1989) concludes by saying that changes in the interview schedule might be necessary as a result of the preliminary analysis of interviews.

There are three broad classifications of research methods: pure (or basic), applied and action research (Easterby-Smith et al. 1991). The emphasis of the different research methods is on the relation between the researcher, the studied environment and the studied phenomenon. The pure research method focuses on scientific objectivism and would prefer to see the outcome as a new construct of theory that explains an organisational or scientific phenomenon (Gummesson 1991). Applied research seeks to explain a problem and produce potential solutions, but with no actual intervention in the phenomenon. Action research aims to change a phenomenon by fostering links between theory and practice (Habermas 1972). It is an interactive research process that seeks to explain a phenomenon and implement solutions with a high degree of intervention. As will be explained below, the present study has drawn on the interaction between applied and action research.

3.4 Research Methods and Process

This section will outline the research methods used and some central events during data collection. Section 3.4.1 will outline the process through which the studied companies were selected. Section 3.4.2 will detail some constraints imposed by the studied companies on the research.

3.4.1 Selecting the Companies and Projects to be Studied

The Israeli electronics defence industry has significantly influenced the Israeli economy since the 1970s (Teubal 1993). Major projects such as the Lavi, an advanced tactical fighter made entirely by the Israeli defence industry during the 1980s, attracted government investment and provided employment to a range of sectors within the industry, thereby further developing its knowledge base. During the 1970s and the 1980s the electronics defence industry was considered to be the premier producer of skilled engineers and technicians, and this effect spilled over to the commercial hi-tech and start-up industry in Israel (Teubal 1993).

The researcher worked as a training manager for the Israeli Air Force between 1983 and 1990 and as a system developer for YellowTech[4] between 1990 and 1996. This experience, as a user and a product developer, was instrumental in the choice of the Israeli electronics defence industry as the arena for this study.

The Israeli defence industrial base is by and large owned by the government. Thus, access to financial and employment data has had to rely on popular media reports and other public sources. Particular reference has been made in the research to the Israeli daily newspapers *Haaretz* and *Globes*, the international defence magazine *Jane's*, and studies of the Israeli defence industrial base (Teubal 1983). From this data, the five leading companies were chosen: YellowTech,

[4] YellowTech is a pseudonym; it is one of the studied companies. A detailed description of YellowTech is provided in 4.3.3.

Rafael, the Israeli Aircraft Industries, EL-OP and Elbit. These five account for 95% of the revenue generated by the defence industrial base in Israel, and they employ more than 30,000 workers (Amnon Barzilai, Haaretz, 09/08/1999).

In late 1998, discussions with the senior management of these five companies started. Because of the rules of confidentiality concerning the technologies developed in some of the projects in these companies, the problem of access was a major obstacle to the research. After two months, during which the research plan was presented and in principal a security clearance for the first stage was issued, it was agreed by the five companies to proceed to the pilot stage. During the pilot study it was made clear by all five that the research project would require the security manager's approval. Following the pilot study, two companies, Elbit and EL-OP, decided to withdraw from the project because of security issues.

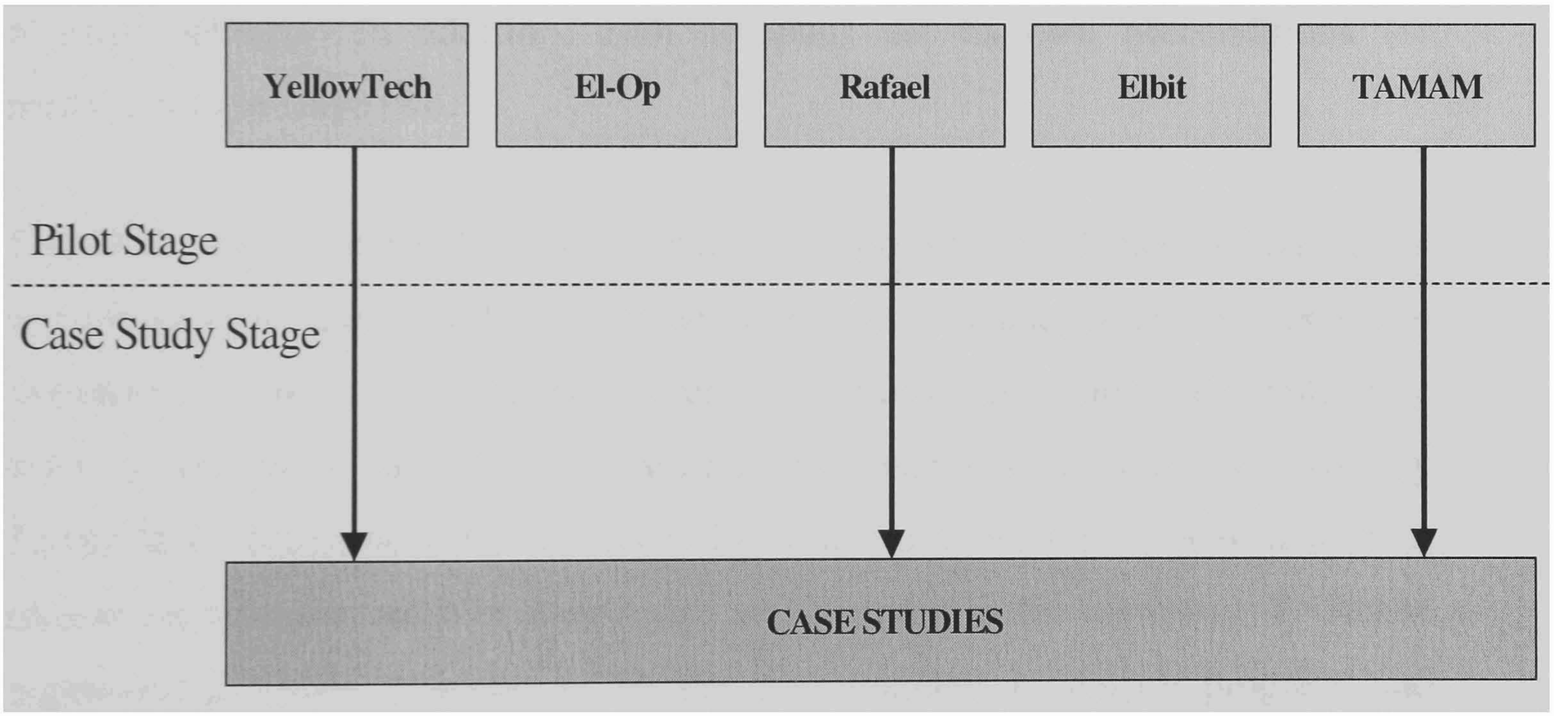

Figure 3: Pilot and Case Study Companies

The three remaining companies (Rafael, Israeli Aircraft Industries and YellowTech), which accounted for 80 per cent of defence-related revenue in 1999, agreed to participate in the second stage of the research project as long as certain conditions were met.

Two product families were selected in each company: a well-established product family and a relatively young product family. Within each selected product family one project was chosen. In total, six projects were studied in three companies. This research design provided the researcher with access to empirical data about projects that have had 'high mileage' and to those that have had 'low mileage' in practising the reusability strategy. Yet the specific selection of the projects was decided by the co-researcher of the company. There were other constraints worth discussing in the study.

3.4.2 Research Constraints

The three studied companies, through the Israeli MoD and based on the rules that govern security in the Israeli defence industry, decided to restrict access to authorised areas and people. In addition, they restricted the discussions to non-technology matters, though in reality this line was not always clear. Lastly, all material that the researcher used during the research project was checked by the security manager. In addition, each company set its own preconditions for participation in stage two.

TAMAM was interested in a consultancy project and hence asked for a consulting-style report and a presentation to senior management. It asked the researcher to focus on three main areas: (i) knowledge centres, (ii) collective learning processes and (iii) unlearning and mistakes. It was expected by TAMAM's management that the researcher would propose some practical steps to improve the management of knowledge and learning in the company. TAMAM nominated a senior manager to be the co-researcher to ensure progress and manage the research project. The co-researcher did not participate in interviews, but was available to answer questions where issues were not clear. This arrangement was helpful for both sides. The researcher validated information through consultation with the co-researcher, while the co-researcher maintained high involvement in the project.

Secondly, Rafael used this research as an element in the power struggle between the Head of the R & D Division, the Head of the Patent Group and the Head of Human Resources. When this research project started, there was a debate in

Rafael about who owned knowledge-management activities. The researcher was brought in to satisfy the HR desire to be more involved in KM activities. Rafael's objectives from this study were similar to TAMAM's, i.e. to study how knowledge and learning evolve and are managed within the company, and to identify areas of dysfunctionality in these processes. In addition, the Head of HR requested the researcher to bring one HR manager up to date with the current thinking on research and theory in the area of knowledge management. For this reason, an HR manager was instructed to accompany the researcher and to take notes during interviews. This situation, which was at first perceived negatively by the researcher, turned out to be a positive move for two reasons. First, the HR manager served as another source of information, clarifying points which were not clear during the interviews. Secondly, the HR manager took responsibility for managing the interview timetable, making sure that all interviewees appeared on time, and reporting back to management on progress. Rafael requested a presentation to senior management as soon as the project ended.

Thirdly, in complete contrast, YellowTech co-operated with the researcher on a scientific interest basis and as an act of good will. YellowTech nominated the Head of the Hardware group as the co-researcher of the research project. Two weekly meetings were scheduled with the co-researcher, aiming to answer questions, clarify unclear issues and monitor progress. YellowTech requested that the researcher would present the research results as soon as the project ended.

3.5 Research Process

The researcher worked for YellowTech between 1990 and 1996. In 1993, he initiated a project that facilitated knowledge sharing across the R&D division. Since then, between 1993-1996, he was involved in promoting KM initiatives at the company. In 1998 and 1999, as an informed outsider, a two-phase study was carried out which examined the process through which project teams participated in KM activities. Apart from interviews, ethnographic research methodology was adopted to allow for capturing, understanding and analysing social relations, social processes and means of management support through retrospective research as an insider in the organisation (Hammersley and Atkinson 1995).

In order to relate our findings to the body of knowledge on product development, cross-project learning and innovations, the researcher decided to approach the research from a wide perspective, engaging with as many elements and factors as possible in a multiple-project environment. However, in order to focus on specific issues, the researcher conducted a pilot study in late 1998 in which the researcher interviewed ten top managers from five leading electronics defence companies in Israel, including YellowTech, Elbit, Rafael, Israeli Aircraft Industries, and EL-OP.

Furthermore, through cooperation with one of the leading consulting firms in Israel, Dr. Edna Pasher and Associates, and via participation in cross-industry knowledge-sharing forums (also known as Knowledge Cafés) organised by Dr. Edna Pasher, information about recent trends in the Israeli defence and hi-tech industry has started to emerge. The main findings from these pilot interviews emphasised that product-development practices have changed since the beginning of the 1990s. A more detailed study of the multiple-project environment at YellowTech, TAMAM and Rafael was then launched in early 1999.

Between January and April 1999, the researcher conducted 87 interviews with top managers, middle managers, project managers, technical managers, engineers, configuration managers, planning and control managers, and technicians (see Appendix 2 for a full list of interviewees and time spent with each interviewee, and Appendix 3 for interview schedule). In addition, the researcher conducted two observations of problem solving in action in each company and participated in one knowledge-management committee at Rafael. Documents and information about the studied companies were collected through various sources, including the Web, *Jane's* magazine, popular media and company publications.

3.6 Data-Collection Methods

The data on the companies were collected by two main methods: semi-structured interviews and documentary analysis. In addition, data were collected from observation and participation in meetings. Each of these methods will be examined to identify the general limitations of the data that were gathered.

3.6.1 Interviews

This was the most effective method of establishing the type of information required for this study. Therefore, this method was chosen to be the primary method of data collection. Through interviews, data were collected about the historical development of the companies and their innovation processes. In addition, interviews provided an opportunity to collect different perspectives on the transformation of the studied activity systems at different levels of the chosen companies. The rationale for interviewing a diversity of professionals from different disciplines was that these professionals could provide different perspectives on the transformation of the innovation process in their company, and together they would cover almost all product development-related activities.

Semi-structured interviews were used as these provided the most flexible format, with the potential for the interviews to develop in areas felt to be relevant by the interviewees (Brenner 1985). The intention was to make the interviews sufficiently open so that issues unforeseen by the researcher could be introduced and developed. For each interview a detailed schedule of issues and questions was prepared. However the interviews were conducted in a flexible way, allowing the interviewees adequate opportunities to pursue the issues they themselves perceived to be relevant. The result of this was that there were significant differences in how each interview developed. This format was deemed to be successful: the character of each interview varied, but the researcher was still able to pursue all the questions and issues perceived to be important, thereby ensuring that the interview data were comparable. In each company, between 25 and 30 engineers and managers were interviewed, thus allowing some triangulation to be done between interviews, and reducing the reliance on the opinion of any single person.

One concern with emphasising the process of change was that the information collected might not provide an explanation of the quality of the decision-making process (Child and Smith 1987) that led to the change process. This was considered a minor concern, as the purpose of revealing the process-related data was to establish an understanding of how systems change rather than studying the decision making involved in the change process.

As Kahn and Cannell (1957) argue, when conducting interviews it is important to reflect on the motivation of the interviewees, as this may influence the information provided. It was therefore recognised that engineers may be motivated to present a certain viewpoint, for example that the change in their practice was greater than what it was in reality, whereas other professional groups such as, for example, sales or marketing staff, might present a different picture. While it was not always possible to verify the accuracy of all data, a number of methods were available for carrying out checks.

For example, interviewing a range of personnel was one method through which data were triangulated. In addition, there was an opportunity to consult documents and talk to informed insiders, such as the consulting firm Dr. Edna Pasher and Associates, before the interviews in a specific company to establish the most significant information about that company. This provided another source of data triangulation during and after the interviews.

The interview schedule was tested at the beginning of 1999 by the co-researchers of two companies, YellowTech and TAMAM. The schedule was sent by fax, and the companies' comments were discussed over the telephone. The research design was not altered drastically following these pilot interviews, as they were generally found to be successful, with the interviews conducted providing data which were more than adequate for the purpose of the research.

3.6.2 Documentary Sources

A wide range of documentary sources was used to provide information on the studied companies. While this information provided a method of triangulating and cross-checking some of the interview data, it was also a rich source of original data itself, providing a great deal of information which could not have been collected from interviews alone. Examples of the sort of information collected from these sources include: revenue and sales figures, ownership information and governmental trade and procurement rules. The range of sources used was extremely diverse and included: Israeli newspapers (on the Web) and specialised journals such as *Jane's Defence Weekly*, *Aviation Week* and *Space Technology*. It needs to be stressed that the Israeli defence industry had been poorly researched, and therefore there were few academic publications about their operations in general, let alone about their innovation processes in particular.

There is always a concern with the possibility of bias in secondary documentary data. Reports can serve the purpose of a specific individual, group or institution to promote their interests rather than providing an objective perspective (Scott 1990). For example, a company brochure may present a picture that emphasises the positive side of working for this company in order to make it more attractive to graduates, whereas in reality this company may suffer from poor management-employee relations. Also, it is common to find discrepancies in national parameters between independent and government sources about employment and spending figures related to the defence industrial base. The reason for these discrepancies is the different definition of the parameters between the two sets of institutions. This does not mean that documentary data should not be used, but simply that it is necessary to consider the motivation of the authors and the assumptions made by them to support their arguments.

3.7 Data Analysis

The data analysis emphasised the unit of analysis -- activity systems. In this research at least three activity systems were studied: product development, expertise development and knowledge management. On the basis of the traditional approach to research suggested by activity theory (Leont'ev 1978; Engestrom 1992; Blackler 1993), the analysis of the data emphasised the following areas: (i) the historical development of the activity system, (ii) the development of mediating artifacts and processes within each activity system, (iii) the subject, community and object of the activity, (iv) the outcome of the activity, and (v) the tensions generated within and between activity systems.

Any researcher conducting qualitative research must acknowledge the presence of ambiguity, since there are very few procedures or instructions to adhere to during the research process. However, there are some steps a researcher can take in order to reduce the ambiguity. For example, in this thesis the researcher analysed and made empirical categorisations from qualitative data to clarify the main themes emerging from the data. Guided by activity theory, the researcher sought to categorise and associate stories and events as an element within an activity system. From this categorisation, an illustration of the elements involved in the studied activity system emerged, allowing the researcher to report on the transformation of the activity system.

3.8 Research Methods and Process: Conclusion

In this chapter a description of the research methods, constraints and process has been provided, highlighting the challenges and dilemmas the researcher has faced in conducting this research.

In the following chapter, an industry background at three levels of detail will be outlined: global, national and company. This description aims to provide the reader with some of the parameters that the studied companies faced before, during and after the transformation of their cross-project learning innovation systems.

4 CHAPTER FOUR: INDUSTRY AND COMPANY BACKGROUND

4.1 Introduction

This chapter provides the context within which the present study was carried out. When one compares innovations systems of two or more companies, understanding the context within which these companies operate is imperative to understanding the differences in their strategies (e.g. Pettigrew and Whipp 1991) and organisational mechanisms (e.g. Collinson 1999).

Thus, the following sections will provide a background description of the defence industrial base, starting with the global defence industry, then describing changes in the Israeli electronics defence industry, and finally providing a detailed description of the studied companies. Lastly, the closing section will outline changes in defence markets in recent years that have affected the organisation of innovation in product development in the Israeli electronics defence industry.

4.2 Trends in Global Defence Markets

The end of the Cold War in 1989-1990 resulted in increased pressure on the major powers' defence budgets. As a consequence, the global defence industrial base experienced a dramatic reduction in the demand for military equipment. For example, arms sales by the largest arms-producing companies in the Organisation for Economic Cooperation and Development (OECD) fell by 15 per cent between 1991 and 1994 (Anthony 1998). Defence procurement markets saw a fall in the value of trade in defence equipment from some $60 billion trade in 1985 to $23 billion in 1999 (Amnon Barzilai, Haaretz, 15/11/1999), and world-wide employment in the defence industry fell from 17.5 million to 11.1 million workers between 1987 and 1995 (BICC 2000). In addition, conventional weapon trade flows have been dominated increasingly by the United States, which recently accounted for at least half of total defence sales (Klieman 1998).

There have been various explanations of the decline in defence expenditures. Wulf (1993) and Walker (1991) argue that the changing political climate in Europe following the collapse of the Soviet bloc is one of the most significant factors. Since 1991, declining European and US threat perceptions have led governments to re-evaluate their defence needs, cut defence budgets and decrease their defence procurement. Wulf (ibid.) suggests two additional causes: (i) the growing pressure on governments and regional organisations to manage their economies with minimum deficits, and (ii) the growing number of arms control and disarmament agreements, particularly in Europe. Despite the significant reduction in global defence procurement, there are some regions, such as the Middle East and the Far East, in which military expenditures have actually increased because of inter-state threats. However, the demand from these relatively small countries cannot compensate defence industries for the lost markets among the major powers.

It must be stressed that the defence industry is by no means homogeneous. It is an amalgam of different capabilities, technologies, products and markets. Furthermore, not all parts of the defence industrial base have suffered to the same extent from the decline in trade during the last decade. Indeed, many states have sought to upgrade their armed forces, thereby generating a growing demand for advanced military systems. Therefore, trade at the high end of defence systems has not fallen but in some cases has actually increased, despite shrinking global military expenditures (Anthony 1998).

4.2.1 Government Policy in Some Regions towards Defence Industries

Some regional economies were severely affected by the reduction in defence expenditures, but others were not (Wulf 1993; Todd 1988; Clark 1995). In some cases -- like that of Israel -- where governments have made long-term commitments, their defence industrial base has retained most of its capabilities. In addition, some governments have chosen to protect regional economies by supporting national defence industries or by providing unique financial support to areas that have suffered from a large number of plant closures related to defence business. For instance, Germany, certain states in the USA, the former Soviet Union mainly in Russia, and China have pursued a protective policy (Clark 1995).

In the USA, a major reaction to change in defence markets did not occur until the US Secretary of Defence, Mr Cohen, stated explicitly in 1994 that firms in the defence industry must merge in order to ensure their survival. As the result of subsequent consolidation, by the end of the 1990s employment in the US defence industry had declined dramatically, with a loss of almost 600,000 jobs (BICC 2000).

The case of Western Europe is different. The West European defence industrial base is relatively small, and hence economic readjustment problems have been less severe. Nevertheless, co-operative defence arrangements between countries in Europe, e.g. in defence production and defence industrial policy, are still largely decided at the national level (Wulf 1993). The ongoing political debate concerning the respective roles of EU institutions and national governments with regard to defence issues remains an obstacle to the attempt to establish a truly European defence industrial policy (Nicoll Alexander, FT, 24/01/2002). Wulf (ibid.: 10) argues that consequently "...European governments have not managed to 'down-size' their large over-capacities. These policy recommendations have never been put into practice on a large scale because of national idiosyncrasies and powerful industrial interests".

The defence industry in Japan has retained only a small proportion of defence R&D and production relative to its large industrial capacity. Therefore, it has not been greatly affected by changes in global defence markets. Indeed, Japan has steadily increased its domestic defence market in the last decade, a trend which stands in contrast to the predominant situation in the Western world.

Changes in global defence markets have also influenced 'third-tier' countries, where, according to the typology proposed by Wulf (1993), five scenarios induced by government policy can be identified: (i) countries that have developed a defence industrial base in the past but have encountered difficulties in keeping up with advanced technology and utilising their capacities (e.g. Brazil and South Africa); (ii) countries that have paid a very high cost for maintaining their defence industrial base by investing a fortune in developing unique technologies (e.g. Israel and India); (iii) countries that have recently started to expand their defence industrial base, and have been willing to upgrade their armed forces following growing external threats (e.g. South-Korea and Taiwan); (iv) countries that have specialised in certain sectors of defence production and have tried to co-operate internationally (e.g. Israel and Singapore); and (v) countries that are known, or claim, to have important defence capacities, but where information is very speculative (e.g. North Korea, Iraq and Iran).

Hence, it can be seen that governments have implemented different policies in relation to their defence industrial base. In many cases governments have regarded the base as a national laboratory which is essential in order to develop adequate defence systems. However, in the 1990s the trends of globalisation and the liberalisation of markets have compelled defence industries to take appropriate responsive measures.

4.2.2 Corporate Strategies in the Post-Cold War Defence Industry

There is little written information that describes how defence industries have coped strategically with changing defence markets (Hougui and Shenhar 1995). Nevertheless, some information from newspapers and other popular media sources can assist in describing the most common strategies taken by defence industries in the USA and Western Europe. There have been three major strategies: (i) downsizing, (ii) concentration on defence products, and (iii) diversification to commercial markets. The largest contractors have practised a mix of the three, but downsizing has undoubtedly been the single most common strategy. Concentration on defence products has taken place in some defence companies through mergers and acquisitions. This strategy has aimed to develop further defence-related production capacities and sometimes to reduce R&D risk.

Consequently, companies following this strategy have developed larger market share, thus allowing them to survive, while smaller contractors have experienced difficulties. For instance, the mega-merger between Lockheed Corp and Martin Marietta Corp in 1995 did not take place before Lockheed had acquired General Dynamics in March 1993 and Martin Marietta had bought General Electric Co.'s GE aerospace division in early 1994 (Harrison 1995).

The diversification of defence-related capabilities to commercial markets, also known as conversion strategy, was implemented by large defence industries in the late 1980s. Over a decade later, it is evident that companies have maintained their defence production capabilities while making more effort to use military-purpose technologies in civilian products. However, the conversion strategy has not always been successful. In many cases, defence companies have realised that they were facing high barriers in their efforts to penetrate civilian markets because of the defence industry's high labour costs, project management style and lack of marketing skills (Dvir et al. 1996).

However, some defence companies in the USA have failed to react to changes even when their business performance has declined. Clark (1995) proposes explanations based on the arguments that (i) the full extent of cuts will be experienced in the industry only after a time lag; (ii) large contractors are sharing the remaining contracts; (iii) other contractors are buying up competitors, thus further reducing competition; and (iv) some companies have specialised in certain niches which were not affected by cuts in defence expenditures.

It is thus clear that the late 1990s saw more consolidation, cooperation and joint ventures between defence industries at the national and international levels.

4.3 The Israeli Electronics Defence Industry: Key Characteristics

The electronics defence industry in Israel is a second-tier world-leader supplier of electronics defence products. Much of its reputation was built on its proven products in the battlefield. During the 1960s and 1970s the Israeli defence industry grew dramatically because of the high level of tension in the Middle East and the weapons-sale embargo imposed by several European countries. These conditions prompted the Israeli government to develop in-house capabilities to produce defence products. During the 1980s and the 1990s, following the fall of the Soviet bloc, the Israeli defence industry experienced a dramatic decline in sales, and consequently the number of employees in the industry dropped from 80,000 in the early 1980s to 18,000 by the end of 1996 (Inbar and Zilberfarb 1998). The forced cancellation of the ambitious Lavi fighter project in 1987, due to prohibitive costs and American opposition, contributed greatly to the reduction in military production labour (Klieman 1998).

4.3.1 Core Technological Capabilities in the Israeli Electronics Defence Industry in the 1980s and 1990s.

The Lavi project led the Israeli electronics defence industry to concentrate on the upper level of defence design and production, and to acquire unique knowledge and capabilities with the financial support of the Israeli government and technology transfer from the US. Amongst the areas developed during the 1980s there was an increased concentration on sub-systems and specialised components. There was a move into the area of 'smart weapons', which combine hardware and software devices in various sub-systems and mainframes: for example, laser sensors, night vision optics, communication equipment, diagnostic systems, air-to-air missiles, air-to-land missiles, pilotless drones, and electronic warfare systems. In addition, upgrading and retrofit data packages were designed and put out for sale on the open market. Amongst the leading electronics companies in Israel is Israeli Aircraft Industries (IAI), with its range of subsidiaries including TAMAM and Elta, Elbit Systems, Rafael, El-Op and Elisra Systems Ltd.

4.3.2 Markets and Financial Results in the Israeli Electronics Defence Industry in the 1990s

Despite the evidence of a global decline in the arms trade, figures published by government officials indicated that Israeli military exports in 1993 were the same in terms of value as in 1992, and that military orders in 1994 showed an increase of 20% (Klieman 1998). This information has been confirmed by sources at the studied companies. For instance, IAI's sales in 1998 amounted to $1.9 billion, and in 1999 to $2.1 billion (Dror Marom, Globes, 22/07/1999). Rafael's backlog broke all previous records in 1999 and was more than $1 billion before 2000 (Dror Marom, Globes, 04/01/2000). Elbit has been awarded a large number of upgrade contracts, bringing its orders backlog to a peak of $670 million in 1998 (Ami Ginsborg, Globes, 07/01/1998).

The Israeli electronics defence industry has benefited directly from the global interest in upgrading defence products. In recent years it has developed specific skills in converting out-dated electronic systems into new ones, thereby improving the performance levels of combat platforms. Elbit Systems was the pioneer in this area, as its General Manager, Yossi Ackerman, explained (Ami Ginsborg, Globes, 07/01/1998):

> *For many years now, we have taken every opportunity to insinuate the notion of 'upgrade', until it finally started to catch on.*

Nowadays, the Israeli electronics defence industry trades with at least 70 countries (Inbar and Zilberfarb 1998). A number of markets, including the Far East, Australia and some European countries, have been widened (interview source). Seeking new markets, the industry has often been associated with controversial clients. However, a rather decentralised and uncoordinated decision by industry leaders to focus on the upper rung of military and dual-use technologies has enabled the industry to reduce its dependence upon marginal third-world countries. Many of the industry's most recent clients are among the prosperous and liberalising Asian 'tigers', which spent some $130 billion on defence in 1995 alone (Klieman 1998). One newspaper report shows that in 1997 25 per cent of orders in IAI originated in the Far East (Dror Marom, Globes, 13/01/1998).

The three following sections will introduce the companies studied in the present research.

4.3.3 A Description of YellowTech

This case study company asked to remain anonymous. Therefore the researcher named it YellowTech. Located in the Tel-Aviv area, YellowTech was founded in 1967 by a group of Jewish-American engineers who believed in Zionism and saw it as their mission to extend the Israeli electronics industry. YellowTech was instituted as a private business, and it was not until the late 1980s that it was sold to a large Israeli communication conglomerate. Since then, YellowTech has been managed as a subsidiary, but has enjoyed considerable autonomy in managing its own affairs.

YellowTech started to develop electronic warfare systems as a three-engineer business, and has since grown to become a leader in domestic and global markets. With some 800 employees, the company has an amalgam of capabilities in the areas of electronic and mechanical engineering. For almost 30 years, YellowTech has researched, developed, produced and marketed electronic warfare systems at the cutting-edge of technology. It enjoys strong relationships with the Israeli Air Force, which has assisted YellowTech in developing broad engineering capabilities. In addition, YellowTech provides technology tailored to the needs of a long list of customers, including some of the world's leading armed forces. YellowTech has three divisions: the Defence Systems Division, the Production Division and the Microelectronics Division. Each division has developed its own distinctive technical capabilities. Specialising in a range of warfare systems and components with customer support -- avionics, ground and sea systems -- YellowTech is also actively involved in the development of commercial applications and technology transfer.

YellowTech, like other defence-related businesses in Israel, is a mature and ageing company. Many of its employees have elected to stay with the company for many years in order to enjoy unique social benefits such as up to 250% night shift pay. Consequently, YellowTech has always had an experienced workforce. Collinson (2001) reported a similar pattern about the career development system in one Japanese chemical company. YellowTech recruitment policy has benefited from close links with the air force. During air-force service, technicians and engineers acquire a unique knowledge of warfare systems, which is crucial for YellowTech.

The Defence System Division at YellowTech operates in a matrix structure. Software and hardware engineers and technicians are assigned to projects but they belong to separate groups. In the Hardware Group the ASIC team (Application Specific Integrated Circuit) is the only team providing services to projects. Other groups that provide service in the matrix structure are the Computing Support Unit, Configuration Group, the Mechanical Group, and the Planning and Control Group.

During the last decade, there has been repeated industrial unrest at YellowTech. Following the market decline of the 1980s, the company downsized its workforce from 1,200 to 800 employees. This led to confrontation between top management and the trade unions, souring a long tradition of co-operative industrial relations. The beginning of the 1990s saw additional problems: the new management introduced further restructuring plans, which required more cuts in employees' benefits. Almost a decade later, YellowTech has become YellowTech Group, made up of YellowTech, Tadiran Spectralink and BVR, three companies in the area of warfare systems, data link systems and pilot rescue systems. YellowTech Group's operations profit in 2000 increased 300% from $4 million in 1999 to $12 million in 2000. The Group's gross profit in 2000 was $50 million, 25% higher than in 1999 (Dror Marom, Globes, 16/01/2001).

YellowTech's technological market is also in upheaval. The company has to cope with rapid changes by acquiring technology and knowledge quickly and applying them directly into systems. In addition, it has to respond to the growing competition in electronics defence markets by diversifying its products and services. Another strategy recently adopted by YellowTech is a strategic co-operation agreement with domestic and global competitors. Recent examples include a marketing co-operation agreement with Elta of Israel (Ora Koren, Haaretz, 08/10/1999) and with Trak of USA (Eli Landau, Globes 06/08/1999) and a joint venture with Northrop Grumman (Dror Marom, Globes, 20/01/1999). Despite operating in markets which are greatly influenced by global politics and economics, and are also regarded as monopolistic and homogeneous, YellowTech remains a business-orientated company and bases its product development strategy on innovative technological solutions according to its clients' needs. As tenders become more and more demanding, YellowTech finds itself in the almost impossible position of having to balance clients' growing demands for sophisticated battlefield solutions and the requirements of shorter projects with shrinking margins.

Two specific projects were studied at YellowTech. The first project is the SPS-1000 product family, which is a light electronic warfare system supplied to clients by YellowTech for more than a decade and having more than a dozen different configurations for various avionics platforms. It consists of more than ten sub-units located in different places in avionics platforms, and is an amalgam of capabilities and knowledge in the areas of physics, electronics, aerodynamics, software and mechanical engineering. The team that worked on this project drew upon established knowledge and skills accumulated through many years of experience.

The second project was first developed as a technology at YellowTech during a period of more than 10 years, and has only recently been offered as a product to clients. The project's technology, which was based on a digital analysis of electromagnetic data, aims to provide high-resolution radar signal detection.

YellowTech has always considered this to be a revolutionary project in its area. Accordingly, the company formed a group of scientists, engineers and software engineers to combine their unique experience and skills in order to meet the challenge. However, between 1993 and 1996 the project was shut down because of the team's poor results and unsatisfactory progress. It was restarted only in late 1996 following a contractual agreement with a client. Another team was given the responsibility for continuing to develop the technology alongside the product.

4.3.4 A Description of Rafael

Rafael, established in 1958 and located in the north of Israel, is a sub-unit of the Israeli Defence Ministry (MoD). It has since gained the title of 'the national laboratory for defence research and development'. During its early years Rafael concentrated on research and development (R&D) activities, and only during the 1960s did it extend its capabilities by starting to produce defence systems in order to avoid quality problems induced by a faulty knowledge transfer process between Rafael and its sub-contractors. Enjoying the financial support of the MoD, Rafael has for many years focused on developing in-house, sometimes double, capabilities in technological areas that consume much of the organisation's resources and create internal competition.

During the 1960s and 1970s Rafael symbolised the traditional Defence Corporation claiming to know better than its clients what products they needed. Marketing activities and co-operation with external R&D institutions were considered to be a waste of time (Rafael Bulletin 1998). Changes in domestic and global markets have pushed the company to readjust its strategies. Hence, after focusing originally on knowledge creation, Rafael has recently redirected its efforts to other areas in order to enhance its understanding of clients' needs (Rafael Bulletin 1998). New markets have been explored -- e.g. Australia, Greece and some countries in the Far East -- in an attempt to attract more clients. Some sections of the organisation have attempted to introduce business-orientated practices. For instance, management have invested in developing Marketing and

Sales teams at different levels of the organisation. Quality Assurance (QA) processes have been transferred from central QA functions to suppliers and employees in order to achieve continuous improvement. Together, these new approaches have been presented as a transformation from 'quality at any price' to 'pricing the quality' (Rafael Bulletin 1998). In addition, Rafael has diversified its technologies, seeking new business opportunities in three commercial markets: communications, medical equipment and semi-conductor testing equipment.

Rafael now has five divisions: Missiles, Ordnance Systems, Electronic Systems, Platforms and Launchers, and the Propulsion and Explosives Directorate. Three quarters of the 4,250 employees are organised on the basis of a collective agreement, while the rest have individual contracts. Some 48 per cent of the workforce hold an advanced degree; 47 per cent of these have first degrees, 35 per cent have second degrees, and 18 per cent have doctorates. The 1998 sales distribution figures showed that Rafael sold 60 per cent of its products to the Israeli Defence Force and 15 per cent to clients in the Far East. Europe and North America accounted for a further 25 per cent of sales. Despite the increase in sales in recent years, Rafael has shown a loss of $375 million since 1994. In 1999 Rafael broke all previous records in recording a $1.1 billion backlog of orders with a loss of at least $42.5 million. The continuous loss is seen by commentators as the result of poor management at Rafael, which has been unable to overcome the problems of hidden unemployment among the workforce and the high salaries paid to research employees (Amnon Barzilai, Haaretz, 26/07/1999).

In recent years it seems that Rafael has developed two different personalities. On the one hand, it has tried to act as a commercial company driven by profit. On the other hand, it has continued to perform the role of a national defence laboratory focusing on R&D and paying little attention to costs. In addition, the future of Rafael has been uncertain for a number of reasons. First, past Israeli governments have sought to change the status of Rafael to that of a government-owned business in order to improve financial results and increase Rafael's concentration on markets (Haim Bior, Haaretz, 02/11/1999). The company's employees have not welcomed this plan, arguing that as long as Rafael retains its autonomy, they would be willing to negotiate. So far, governments have not come to any firm decision about whether Rafael should become more of a commercial organisation. Because Rafael is responsible for 80 per cent of the generic defence R&D, also known as non-project R&D, for the Israeli government, government officials find it difficult to transform the company while also preserving its unique R&D capabilities (Rafael Bulletin 1998). Secondly, the massive financial support provided to Rafael by past Israeli governments has come to be questioned by the Israeli public.

In addition, there are other factors casting a shadow over Rafael's future. The high average age of employees, recently reported as 45, has now become a serious problem. A recent attempt to recruit young engineers on personal contracts has ended in an industrial relations crisis, with trade unions claiming that management was trying to reduce trade union power and replace old and experienced employees with a young, cheap workforce (Amnon Barzilai, Haaretz, 03/10/1999). As a result, the general atmosphere at Rafael has deteriorated. The internal turbulence has been aggravated by the company's tight financial situation, the ongoing debate about its future identity and ownership, and the growing market pressure for better performances with fewer resources.

Two specific projects were studied at Rafael, both from the Missile Division. The latter employs some 1,100 employees and is divided into four different Directorates: Air-to-Ground, Air-to-Air, Electro-Optic and Anti-Tank Personal Missiles. Each Directorate manages a number of projects or programmes. Programmes are managed in the same way as projects, but are different in the sense that they have more clients for the same product. Each Directorate operates in a matrix structure, which distinguishes between two different areas of responsibilities: project managers and system engineers from the administration are responsible for the management of projects, while engineers and technicians from the R&D and Engineering Field are responsible for engineering tasks. These engineers and technicians are assigned to projects according to the workload. Hence, engineers are often involved in more than one project.

The Missile Division has developed distinguished, widely tested solutions for the Israeli Air Force for the last 40 years. The recent exposure to global defence markets has affected the Division's operation. The development of marketing knowledge and the incorporation of product development activities to marketing efforts have become major factors in the Division's strategy. Many of the recent successful marketing efforts were promoted through joint ventures with large American defence conglomerates such as Lockheed-Martin and Northrop-Grumman. However, the Israeli Air Force (IAF) is still the most important client of the Missile Division. The close relations between the Missile Division and IAF have resulted in the development of innovative solutions such as the air-to-ground missile Popeye, which is one of the studied projects at Rafael.

Popeye has gained a reputation as one of the most accurate air-to-ground missiles in the world, developed during almost two decades of improvements and adaptation to different avionics systems. Popeye was developed into a product family, and one of its configurations was recently modified to fit F-16 combat aircraft. This has opened up new markets for the Popeye product family – a success based on a recent joint venture with Lockheed-Martin. As the Head of the Popeye programme explained:

> *Popeye is a leading project in the Directorate, which allows us to cash in on existing properties with only minimum effort by reusing the knowledge developed in so many years of R&D.*

A second project, another flagship product at the Electro-Optic Directorate, is the Litening programme. This revolutionary product, a navigation and attack pod, has established a worldwide reputation. Litening comprises technological capabilities that were developed in the electronics defence industry over many years, inside and outside Rafael; and these capabilities were integrated to one product, offering innovative solutions for recent battlefield problems.

4.3.5 A Description of TAMAM, a Subsidiary of Israeli Aircraft Industries (IAI)

TAMAM Division, located in the centre of Israel, is an integral part of the Israeli Aircraft Industries' Electronics Group, which in turn is part of Israeli Aircraft Industries (IAI), a state-owned business and a global leader in military and commercial aerospace technology, accounting for approximately 50 per cent of Israel's defence exports in 1997. Founded in 1953, and a limited company since 1968, IAI has achieved impressive results, being ranked 30th in the 1998 list of the world's 100 largest aerospace manufacturers, with sales reaching $1.87 billion (Amnon Barzilai, Haaretz, 09/08/1999). Operating as autonomous businesses -- with separate management, research and development and marketing activities – IAI's four Groups co-operate in order to offer their customers solutions under one roof. The four groups are: the Bedek Aviation Group, the Commercial Aircraft Group, the Military Aircraft Group, and the Electronics Group.

The Electronics Group is a world leader in advanced Defence and Aerospace Electronics, with a turnover of some $860 million per year and a backlog of over $1.6 billion in 1999. About 60 per cent of its activities are related to exports. The Electronics Group comprises four divisions, each of which is a player in its respective niche in the global market: ELTA - Electronics Industries Ltd.; MABAT -- Weapon Systems & Space Technology; TAMAM - Optronics and Navigation; and MALAM -- Systems Design and Integration. The driving force behind the diverse and distinguished technological capabilities at the Electronics Group is the 5,300 or so employees, of whom over 65 per cent are engineers and technicians (TAMAM's company profile 1998).

Since its foundation in 1964, TAMAM has specialised in advanced electro-optical systems, navigation and inertial technologies for use in air, land, sea and space platforms. It has developed a close working relationship with the Israeli Defence Force, which has assisted TAMAM in producing solutions for modern military users. Amongst the company's main products are day/night electro-optical payloads for helicopters and fixed-wing aircraft, and night targeting systems for helicopters. TAMAM employs 860 highly experienced personnel, more than 200 of whom are engineers and scientists, while 300 are technicians. TAMAM is organised in five professional-orientated directorates: Optronics, Navigation, Engineering, Operations, and Product Assurance. The company operates in a matrix structure, dividing project tasks between the five directorates. The management of a project is the responsibility of the Optronics or Navigation directorate. The Engineering directorate is responsible for the design of the product. The Operation and Product Assurance directorates are responsible for the production and quality assurance of the product respectively.

Like YellowTech and Rafael, TAMAM faces the problems of the workforce's high average age and low turnover. Because TAMAM is part of IAI, any attempt to recruit newcomers starts within IAI, and only if this is unsuccessful does the company look outside IAI. The practice of transferring employees between groups and divisions has become a company policy, and this has helped IAI to maintain good relationships with trade unions. However, it has not been the best solution for managers and engineers, who have been expected to recruit any available employees to their team irrespective of their skills.

Recent years have seen massive layoffs at IAI. TAMAM released 20 per cent of its workforce during the 1980s and 1990s. Consequently, the strong family atmosphere among employees has declined. In addition, the highly regulated reward system at TAMAM has further complicated management's ability to reward individuals for high-value performance. Rewards at TAMAM have not included any financial benefits. Rewards were in the form of citation in the company's newsletter.

Moreover, confusing information from the media about the government's intention to shut down IAI because of heavy losses in the early 1990s generated further industrial unrest in IAI and its subsidiaries (Dror Marom, Globes, 27/11/1997). In the past, persistent cash flow difficulties in IAI have led to government officials stating that IAI might have to be sold to investors. At the same time, management at IAI have sought to downsize the organisation and seek new markets. In this confusing environment, employees have developed a high level of solidarity with trade unions at IAI and at the national level. For instance, in 1997 IAI's employees joined a one-day strike, demonstrating against the government's intentions to privatise Bezeq, the Israeli national Telecommunication Company (Dror Marom, Globes 17/07/1997). The unstable political system in Israel for the last ten years has generated more unrest at TAMAM. Announcements by government officials about the government's intention to sell IAI to private investors, though these were usually followed by immediate denials, further generated speculations about the future of TAMAM and the possibility of it becoming a private company (Amnon Barzilai, Haaretz, 15/11/1999).

Two specific projects were studied at TAMAM. The first was involved in the development of a Multi-mission Optronic Stabiliser Payload (MOSP). Engineers and technicians involved in this project demonstrated high-level skills and expertise in the areas of microelectronics, mechanical engineering and physics. MOSP is supplied to clients in different configurations for airborne, land and sea applications and consists of two to three sensors. MOSP's technology has matured for more than a decade, thereby minimising R&D workload in exploiting the product's success and making MOSP a well-developed product family.

The second studied project was involved in developing a Plug-in Optronic Payload (POP) technology over a period of nearly ten years. Only recently has POP been offered as a product -- a navigation system based on a Ring Laser Giro (RLG) technology, which has been proven to be more accurate than, but not as reliable as, the mechanical payload technology. For this purpose, TAMAM had to acquire and develop knowledge relating to RLG technology and its application as a POP product.

4.3.6 Similarities and Differences between the Studied Organisations

In many ways the studied organisations are similar (see Table 3). All of them have operated in domestic and global electronics defence markets for the last 30 years. Their combined sales for 1999 accounted for 80 per cent of the industry, and together they employ 68 per cent of the industry's workforce[5].

In terms of competition, Rafael and YellowTech compete in the electronics warfare systems market, while TAMAM and Rafael compete in the Optronics and Payload systems market. YellowTech and TAMAM do not compete on any specific product; however, YellowTech and Elta, a sister company to TAMAM and part of the Electronics Group Division, compete and co-operate in the electronics warfare systems market.

The studied organisations have developed and produced defence systems for more than three decades. In the 1990s they all faced major changes in their environments following a worldwide reduction in defence trade. Consequently, they reorganised their innovation systems by introducing project-management tools and cost-effectiveness concepts. Changes were introduced in their approaches to marketing, sales and contracts. More emphasis was given to the integration of product development teams and their co-operation with sales and contract teams. In addition, changes in organisational structure were introduced, emphasising the need to enhance flexibility and communication using a matrix structure. TAMAM and Rafael now operate under matrix structures with a clear distinction between the management and the engineering functions of projects. A matrix structure was introduced at YellowTech during the 1980s. However, recent organisational structure initiatives have introduced functional teams, such as the ASIC group, which provides hardware design services to projects.

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[5] Because the studied organisations have not published annual reports, these figures were taken from the popular media and were based on interview data.

The studied organisations downsized their workforces significantly during the 1980s and 1990s[6]. Defence industries in general have suffered from a negative image because of poor financial results resulting in low wages, an inability to reward employees, and a lack of resources for innovative R&D projects (Amnon Barzilai, Haaretz, 15/11/1999). Thus, the industries have become unattractive to young graduates. Because the studied organisations have traditionally recruited their employees from the Israeli Defence Forces (IDF), their declining image has led to difficulties in recruiting employees of the highest quality. In recent years there has been more of an emphasis on the need for a flexible workforce, and this has led to electronics defence organisations recruiting employees through manpower companies for shorter periods of time.

In spite of the many similarities between the studied organisations, there are also some differences between them. First, each has a unique structure of ownership. YellowTech is owned by a large Israeli communication conglomerate; TAMAM is a government-owned company; and Rafael is a sub-unit of the Israeli MoD.

Secondly, the financial performances of the studied organisations have also diverged in the last decade. Between 1994 and 1996 YellowTech showed marginal losses, mainly because of compensation packages to redundant employees. YellowTech achieved a marginal profit of $2 million in 1997 and 1998. In 1999 YellowTech purchased BVR, an Israeli company which specialises in rescue systems for pilots. In 1999 YellowTech registered a loss of $9 million, which was associated with the recent purchase. In year 2000, after becoming a group, YellowTech showed a profit of $50 million.

After poor financial results in the early 1990s, IAI is now presenting a profit again. A profit of $30 million in 1997 grew to $52 million in 1998. During the

[6] Official figures were not available. According to interview data, the reductions in workforce were as follows: YellowTech – 20 per cent in 1994; IAI -- almost 40 per cent during the 1980s and 1990s; and Rafael -- more than 30 per cent during the 1990s.

1990s, TAMAM, as part of IAI, constantly presented a break-even balance, but with a marginal profit of $1 million in 1998, $2 million in 1999 and 2000. Rafael has suffered heavy losses totalling $354 million in the last five years. These losses have been covered by successive Israeli governments. In the year 2000 Rafael showed a first-ever $2 million profit.

Thirdly, although the future for the entire industry is unclear, there have been important differences between the strategic approaches to each organisation by past governments and the mother companies. At the present time, the studied organisations are involved in negotiations about their future ownership structures and their identities. In 1999 YellowTech negotiated a potential merger with two other electronics defence companies in Israel in order to achieve an improved position in the electronic warfare systems markets (Ora Koren, Haaretz, 08/10/1999). In February 2000 YellowTech became YellowTech group, consisting of three companies in the area of electronics warfare and pilot rescue systems.

IAI has considered a government plan to privatise the company. In November 1999 a special committee investigating the defence industry in Israel suggested that the industry should be restructured by merging R&D laboratories into one body owned by the government and privatising their production lines (Amnon Barzilai, Haaretz, 15/11/1999). At present negotiations with trade unions and the Israeli government still continue but without conclusion.

TAMAM, as part of IAI, is expected to be privatised if this plan goes ahead. This may mean that TAMAM will become either a private business or a public company. Rafael has considered a government plan to change its ownership status from an MoD sub-unit to a government-owned company (Haim Bior, Haaretz, 02/11/1999). Strong objection from the employees hampered past Israeli government's plans to change Rafael's ownership.

	YellowTech	TAMAM	Rafael
Organisational Structure	Matrix with functional teams	Matrix organised by project management and professional fields	Matrix organised by project management and engineering groups.
Ownership	A Group owned by private company	Government owned	Israeli Ministry of Defence
Identity	Business driven	Business driven with strong roots in research	Research driven with growing business awareness
Profit/Loss ($million/2000)	+50 (Group)	+2	+2
Strategic Development	Seeking to create an Israeli Electronics warfare conglomerate, joint ventures with international companies, diversification to commercial products.	Focusing on core defence-related products, seeking to maintain its present ownership status.	Competing in new markets including Australia, Greece and Germany. Joint ventures with international companies. Seeking to maintain its current ownership status.
Markets	Electronics warfare systems	Optronics and Payload	Air-to-Air/Air-to-Land Missiles, Optronics and Payload

Table 3: Similarities and Differences between the Studied Companies

It is imperative to describe the changes in market conditions that managers and engineers from the studied organisations have faced in the last ten years.

4.4 The Israeli Electronics Defence Industry: Key Changes in Market Conditions during the 1990s

The Israeli Electronics defence industry has experienced a global slow-down in defence systems procurement. In 1993, YellowTech, one of the studied companies, showed a loss for the first time in 30 years. The other two studied companies, Rafael and TAMAM, struggled with shrinking markets and new rules of competition. Two main practices have changed in the electronics defence markets since the beginning of the 1990s. One is a shift from cost-plus contracts to a fixed price contract system. Secondly, there has been an intensification of competition in new markets. The next sections describe in detail these two trends.

4.4.1 From Cost-Plus Contracts to a Fixed-Price Contractual System

The cost-plus contract era dominated the defence industry until the beginning of the 1990s. Sadeh and his colleagues (2000) argue that cost-plus contracts may reduce the uncertainty from the developer's point of view and may lead to better performance; however, cost-plus contracts motivate the developer to stretch the project timetable and consume more money, and are thus less efficient in terms of resources. Cost-plus contracts promise to pay for all development and production costs plus a flat rate of between 5 and 15 per cent. Fixed-price contracts lead to better efficiency in meeting schedule and budget constraints. But, when high levels of technological uncertainty exist, there may be a conflict between economic considerations and design considerations, which in turn may lead to an inferior technological solution.

In the case of the Israeli Defence industry the flat rate was around 10 per cent. The early 1990s saw a shift from a cost-plus contract to a fixed-price system. Sadeh and his colleagues (2000:14) explain that 'when technological uncertainty at the start of projects is high, cost-plus contracts result in better performance. Fixed-price contracts are better suited for projects with lower levels of technological uncertainty'.

Thus, clients in the Israeli electronics defence industry sought to control expenditures in R & D projects and therefore pushed companies to agree to fixed-price contracts. When signed, based on an estimation of the extent of work required in the project, the fixed-price contract guarantees the total cost for the development and production of the system. Cost-plus contracts did not completely disappear and are still applied in some projects in the Israeli defence industry. In particular, cost-plus contracts are common in projects that have high levels of uncertainty in the R & D stage.

4.4.2 Competition in Electronics Defence Markets

The beginning of the 1990s saw growing competition in defence markets. Mega-mergers, such as that between Lockheed Corp and Martin Marietta Corp in 1995, a multi-million dollar acquisition of General Dynamics by Lockheed in March 1993, and of General Electric Co.'s GE aerospace division in early 1994 by Martin Marietta, have put more pressure on second-tier defence companies to maintain their market share (Harrison 1995).

The studied companies have experienced a growing pressure to market their products in new and more traditional markets. Traditional markets include governments in South America and the Far East, which traditionally purchased well tested (preferably in the battlefield) defence systems from the Israeli industry. However, because of political conditions in some of these countries, the Israeli defence industry has sought to extend its pool of clients and enter new markets (interview source, special consultant to the Israeli Ministry of Defence).

Competing in new markets such as Australia, Greece, Canada and Germany or even the US has not been easy. International politics played a major role in decisions about the next generation of defence systems. The pressure that the USA government put on the US Navy to prefer an Air-to-Air missile produced by an American company over the Israeli product is one example of the impact of politics on the defence business (Amnon Barzilai, Haaretz, 26/07/1999).

Competition also means that clients become more sophisticated and demanding. Before the 1990s product performance and technological innovation determined the winning system in the bidding process. Late delivery and overrunning projects were common in the defence industry, and usually the technological complexity took the blame. Since the beginning of the 1990s, clients have put a greater emphasis on project control that includes the proper management of the project, and proper and realistic budgeting, including late delivery penalties (interview source). Clients have become more involved in projects and often request a representative on their behalf who resides in the company and participates in the design process. All studied companies have received such requests from their clients and in most cases have agreed to the conditions.

These changes in market conditions have had an impact on the management of product-development projects. The product-development process has changed and new processes have been introduced. Amongst the changes in product development was the introduction of cross-project learning mechanisms aiming at transferring designs, platforms and components between projects (Cusumano and Nobeoka 1998; Nobeoka 1995).

4.5 Research Background: Summary

The present chapter provided a three-tier description of the defence industry, addressing global, local and company-specific changes in trade and management. In addition, the case for similarities and differences was outlined, demonstrating the high level of heterogeneity of the selected companies and the differences that need to be considered. Finally, recent changes in the Israeli electronics defence industry have been described, thereby providing a background to the introduction of cross-project learning mechanisms.

Chapter 5 will focus on cross-project learning mechanisms in the three studied companies. More specifically, Chapter 5 will analyse organisational and managerial issues relating to the reusability approach that dominated the product development environment in the studied companies. Of particular interest in Chapter 5 is the following question: what were the organisational mechanisms and structures that were introduced in the case study companies which aimed to support a successful cross-project learning and how did cross-project learning enhance product success and market performance?

5 CHAPTER FIVE: CROSS-PROJECT LEARNING IN MULTI-PROJECT ENVIRONMENTS: LESSONS FROM THE ISRAELI ELECTRONICS DEFENCE INDUSTRY

5.1 Introduction

Large manufacturers face a growing need to manage their product line as an environment of multiple development projects; however, they rarely exploit the efficiencies that cross-project learning may offer (Nobeoka 1995: Cusumano and Nobeoka 1998). There is a large number of studies that have focused on the efficient and effective management of new product development projects; however, most of these take a single-project effort viewpoint (e.g. Gupta and Wilemon 1990; Clark and Fujimoto 1991). Only recently has research paid attention to the growing trend in intensive R & D and manufacturing firms to reuse technological platforms and components through the management of product development as a multi-project environment (Cusumano and Nobeoka 1998).

Yet the evidence provided by researchers about the organisational and managerial settings is largely limited to the context of the Japanese automobile industry. This chapter aims to fill this gap by addressing the following question: what were the organisational mechanisms and structures that were introduced in the case study companies which aimed to support a successful cross-project learning, and how did cross-project learning enhance product success and market performance?

The three studied companies have already been introduced alongside a detailed description of the changes that have taken place in the context within which these companies operate. These changes pushed the case study companies to transform their product development environment. Of particular interest is the growing emphasis on the reusability of designs, technologies and products promoted by the three studied companies. Such activities are perceived in this thesis as cross-project learning, referring mainly to the transfer of designs between and across projects.

This chapter explores the organisational and managerial mechanisms introduced and implemented in the companies studied to support a successful cross-project learning process. These organisational and managerial mechanisms can also be perceived as knowledge management practices (Coombs and Hull 1998). This view emphasises the way knowledge activities become core capabilities for cross-project learning through the way they are organised and made routine in R & D environments. In many ways, the findings in this chapter confirm the findings of a recent study carried out by Cusumano and Nobeoka (1998) at Toyota and other automobile manufacturers. Yet the present study also reveals a different pattern of strategies applied in the Israeli electronics defence industry.

After outlining the case for the success factors associated with cross-project learning, Section 5.3 will describe the mechanisms and processes put in place at YellowTech. Section 5.4 will provide the picture of mechanisms for cross-project learning at TAMAM and Rafael. Lastly, section 5.5 will compare the three cases, drawing conclusions with regard to the similarities and differences in implementing cross-project learning.

5.2 Cross-Project Learning and Product Success

Research suggests that cross-project learning may improve product and market success (Clark and Fujimoto 1991). The contribution of cross-project learning to product and market success has mainly been associated with two management contexts: product development (Slappendel 1996; Wolfe 1994; Krishnan and Ulrich 2001) and project management (Kerzner 1995; Stone 1985; Smith 1995; Bergman 1990; Cusumano and Nobeoka 1998). In this section, a brief review of the main success factors in product development and project management is provided in an attempt to highlight some of the main factors in the case study material.

It is not the intention of this dissertation to review the extensive literature on the success factors in product development and project management. Some of the main factors were reviewed in Chapter 2 (see for example; Clark and Wheelwright 1992; Tidd, Bessant and Pavitt 1997; Utterback 1994).

Nevertheless, some factors have dominated the field and are worth mentioning. A flexible organisational structure is considered to contribute to success in product development (e.g. Bart 1986; Nonaka and Takeouchi 1995). Open communication channels between departments through cross-functional teams have also been mentioned as positively correlated with a successful product development effort (For example, Wheelwright and Clark 1998; Saren 1987). External communication with customers has also been indicated as improving product design (e.g. Von Hippel 1988). Lastly, a well-defined product description and a clearly outlined project plan that minimises technical uncertainties were suggested by Morris (1997) as positively impacting on product success (see Figure 4).

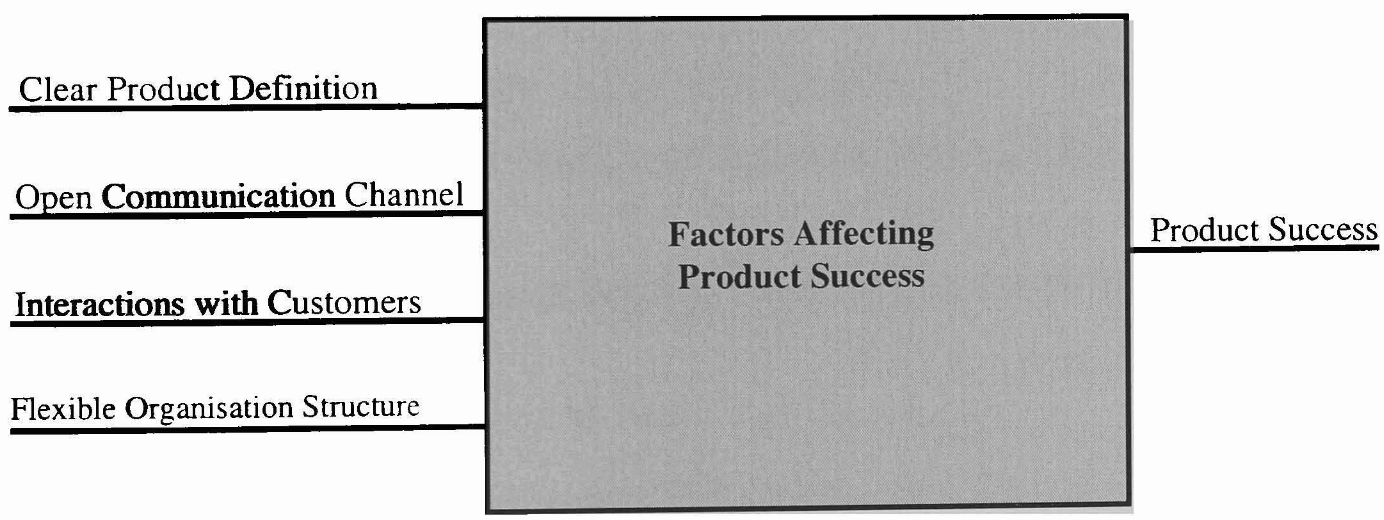

Figure 4: Correlation between Contextual Factors and Product Success

In line with such suggested correlations, the next section will assess the mechanisms put in place at YellowTech, evaluating the contribution of cross-project learning mechanisms to product success.

5.3 Cross-Project Learning: Lessons Learned at YellowTech

5.3.1 Introduction

The lessons learned at YellowTech will be outlined in this section, revealing a set of mechanisms that were put in place in order to facilitate cross-project learning activities. An assessment of the contribution of these mechanisms to the successful introduction of cross-project learning and product development will then be offered.

The analysis of cross-project learning mechanisms at YellowTech will place an emphasis on the contribution of various mechanisms to cross-project learning throughout the different stages of a project. In addition, the analysis will aim to validate the presumed correlation between the implemented mechanisms and product success.

The next section presents the notion of organisational design (Myers 1996) that will be used in this research as the infrastructure for cross-project learning. Following this, an analysis of organisational design elements will be offered.

5.3.2 The Organisational Design and Mechanisms for Cross-Project Learning

Organisational design consists of three critical performance factors: strategy, organisation and motivation (Myers 1996). In line with this approach, these areas will be studied in relation to cross-project learning activities at YellowTech. First, the process of change at YellowTech will be introduced.

5.3.2.1 The Process of Introducing Cross-Project Learning at YellowTech

The process of introducing cross-project learning mechanisms at YellowTech started at the beginning of the 1990s with the introduction of a matrix structure, which aimed to foster knowledge transfer between projects by centralising the pool of expertise under the professional group. Additional formal mechanisms such as design centres and the organisation structure emerged only in the mid-

1990s. However, the reusability of software and hardware components has taken place since the beginning of the 1990s through the support of the matrix structure (Cusumano and Nobeoka 1998).

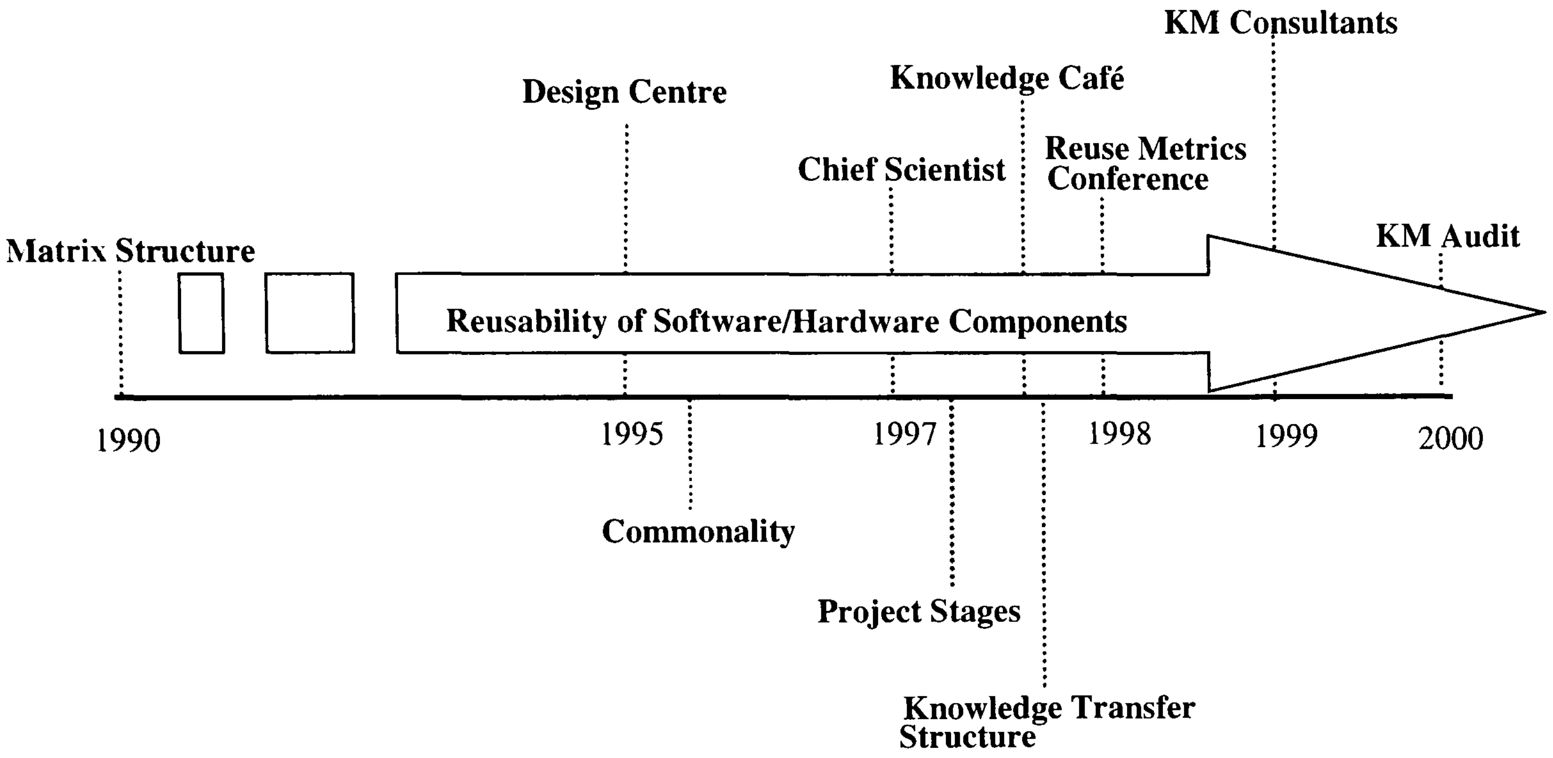

Figure 5: The Process of Introducing Cross-Project Learning at YellowTech

Figure 5 indicates the most distinct instances related to cross-project learning between 1990 and the year 2000. Some of the most significant steps are the introduction of design centres, such as the ASIC group in 1995, the appointment of a Chief Scientist, the reorganisation of project management practices, and the introduction of a new organisation structure to support knowledge transfer during 1997. Since 1998 YellowTech has become further involved in knowledge management initiatives. This includes the participation of the Head of the Hardware Group in a Knowledge Café, a cross hi-tech industry forum for knowledge management, and the presentation of knowledge reusability metrics implemented at YellowTech at conferences, and engineers' participation in reusability seminars. Finally, YellowTech has recently launched a knowledge management project with a consulting firm that still continues as this thesis is being written. This project will map knowledge centres within the company (e.g. R & D Division, Marketing, Sales), and pinpoint critical practices, technologies and system engineers, in order to reorganise activities around the reusability strategy and develop knowledge management capabilities (Victor and Boynton 1998).

Thus, a gradual involvement in knowledge management is evident, fostering the reusability of software and hardware components and supporting cross-project learning. These steps will be described in detail in the following sections.

5.3.3 Strategy, Priorities and Decisions: Cross-Project Learning

To understand the extent of the strategic change of project management at YellowTech, we first briefly review some of the more common models for stages in projects from a project management perspective. Following this, an analysis of the reorganisation of project stages at YellowTech will be undertaken.

5.3.3.1 Stages in Projects: A Project Management Perspective

Researchers associated with project management, such as Kerzner (1995), have attempted to identify the stages that a product development project goes through. Stone (1988) suggested three stages in a project: proposal, authorisation and implementation. Smith (1995) proposed a cyclic process of eight stages: initiate, appraise. define and design, implement, test and commission, deliver products, and use products, records and experience. Bergen (1990) takes a more time-related approach to describe the different stages in projects. A project life-cycle comprises eight stages and starts with a market demand, continues with defining a proposal, conducting a feasibility study, planning and estimating costs, conducting an experimental study, designing and developing a product, testing a prototype, and eventually producing a product. Repenning (2001) offers only two stages; concept development and product design and testing.

While the above categorisations help in understanding the content of project stages, they by no mean describe the organisation of project stages which emerged at YellowTech. Further, these categorisations lack the dimension of managing multi-project environments that were emphasised by YellowTech through the organisation of cross-project learning activities (Nobeoka 1995).

The framework which has emerged from the data describes three main stages in projects from a cross-project learning perspective.

5.3.3.2 Stages in Projects: A Cross-Project Learning Perspective

Managers at YellowTech described stages in projects as divided into three main parts: (i) conception, (ii) development, and (iii) testing and integration of the product (See Figure 6).

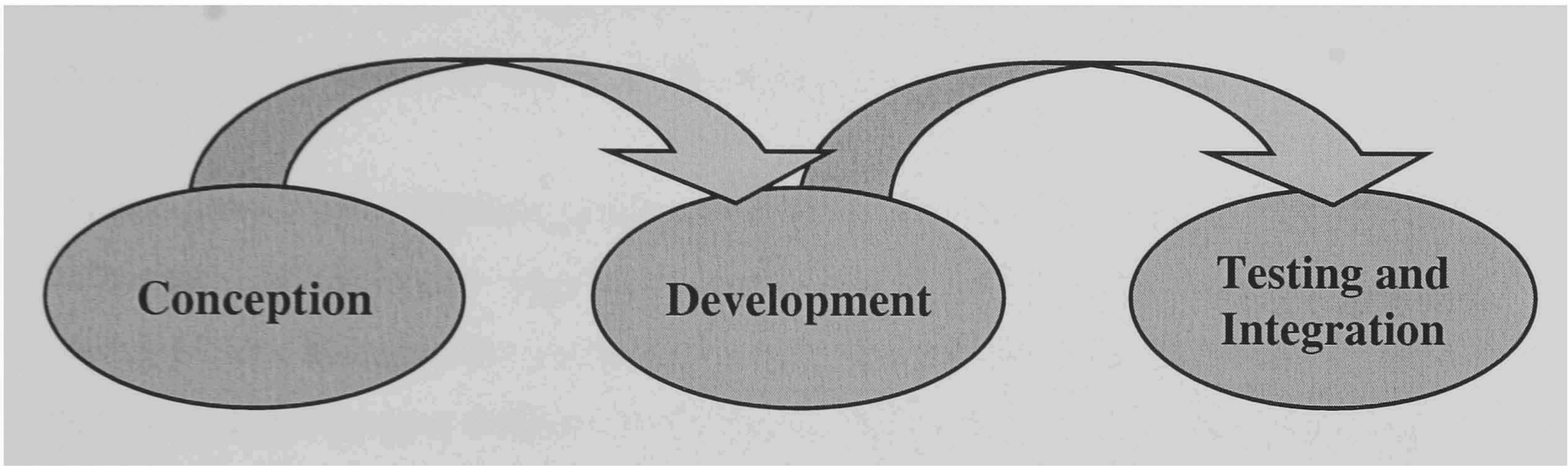

Figure 6: Three Stages in a Project from a Cross-Project Learning Perspective

One Project Manager portrayed these categorisation of stages in projects as stages in a flight:

> *First, there is the take-off stage.[...] If you prepared the aircraft properly for a long flight then the cruising phase should be smooth. The landing, like the take-off, is always risky, but does not necessarily have to be bumpy.*

Each stage represents a different set of activities from a cross-project learning perspective.

The conception stage consists of activities that aim to minimise risk and reduce the uncertainty associated with R & D projects. This is done through careful assessment of resources, scheduling of tasks, and by communicating the necessary resources across the organisation.

The development stage presents activities associated with a high level of coordination and integration of the technical and project management effort within and outside the R & D Division.

The integration stage ends in the testing of the system before the delivery to the customer. This stage is characterised by an emphasis on technical problem solving. In each stage, different mechanisms were put in place to support cross-project learning.

5.3.3.3 The Conception Stage

YellowTech has placed a significant emphasis on effectively utilising cross-project learning mechanisms during the conception stage.

From a cross-project learning perspective, a clear set of priorities and the scope of activities involved in this stage was put forward by management at YellowTech, urging project managers to conclude the conception stage with a clear direction of the product and project (Morris 1997). These activities were aimed at improving the match between the set of activities performed during the conception stage and the environment that YellowTech was competing in (Johnson and Scholes 1989).

The Chief Scientist at YellowTech explained:

> *The way we define the product will determine the success of the entire project. At this point in time, we need to make sure that the project starts on its right leg.*

The Head of the Hardware Group reiterated this approach, claiming that:

> *It is important that project mangers avoid surprises throughout the project. There is not 100% guarantee that there will be no hiccups down the road; however, they (project mangers) can and should foresee what is needed in the beginning and if there is a problem they (project managers) need to raise a flag.*

Project managers confirmed the above, arguing that management has reprioritised processes relating to the execution of projects. One of the distinct priorities put forward was the assessment of the reusability option during the first stage of the project.

The strategy to manage the conception phase includes a five-stage process during which the project manager reviews, assesses, transfers, designs and presents the reusability option (see Figure 7). A decision-making tree was put in place at YellowTech to clearly communicate priorities and guide project managers throughout the process (see Figure 8). This decision-making tree was proposed by the Chief Scientist and, according to project managers, the scheme has been helpful in navigating their way through the first stages of the project.

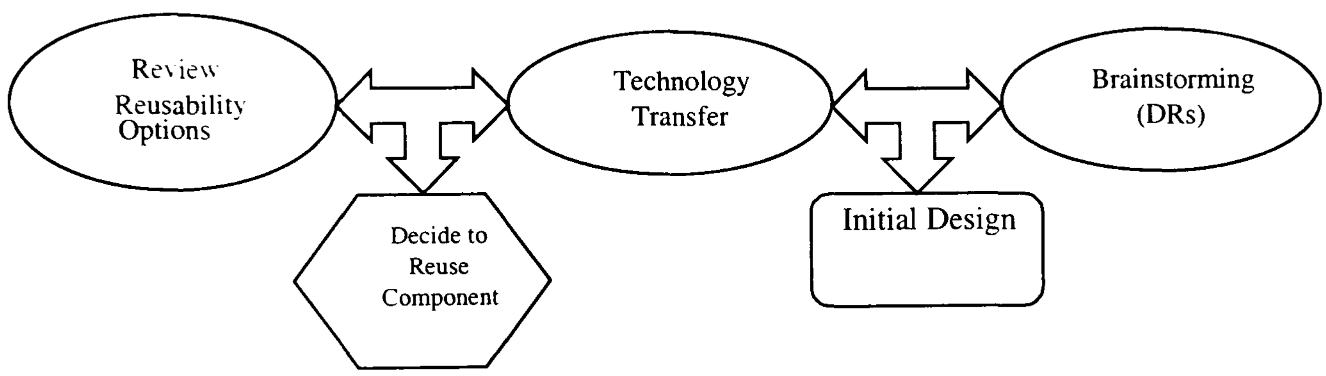

Figure 7: A General Schema for the Decision-Making Process during the Conception Stage

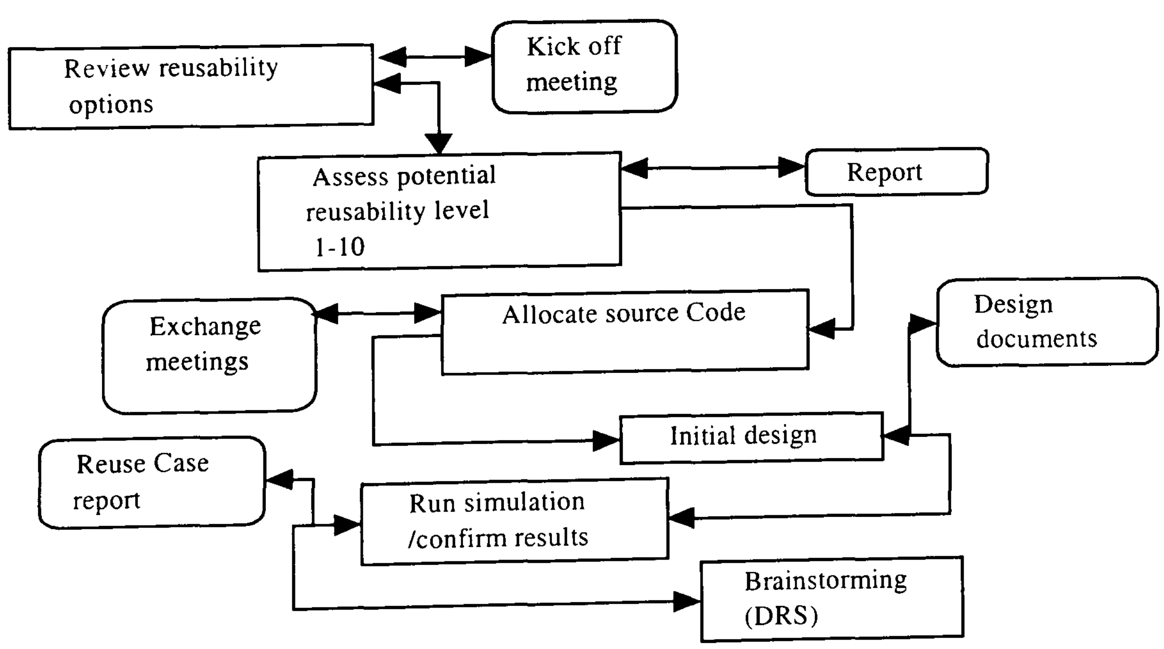

Figure 8: Decision-Making and Action during the Conception Stage

Figure 8 captures the decision making process in one Light Systems project during the conception stage. This process begins with the reusability option phase, in which the reusability option is assessed while potential existing in-house solutions are reviewed. A go/no-go decision with regard to the reusability option is reached by the end of this phase. Following this, a series of decisions is made by the project manager, including the assessment of the reusability process that is summarised in a Reuse Case report.

One project manager from YellowTech explained the objective for introducing the decision-making tree:

> *We have been reusing components for a long time now but in an unsystematic way. These procedures [the decision-making tree] introduced some order to what used to be a messy process, and put reusability up in the priority list.*

The above prioritisation of cross-project learning activities achieved a high level of standardisation in the product development process at YellowTech (Victor and Boynton 1998: Sobek et al. 1998). In addition to spreading designs across different product development projects, YellowTech has also customised the way projects are managed and run for each and every client (Victor and Boynton 1998). Through the documentation of the reusability process and its outcomes, YellowTech has paved the way for continuously improving the process.

From a strategic viewpoint, the emphasis in the conception stage was on ensuring that the development stage started with a clear definition of the technical, operational and managerial objectives and the resources needed to successfully execute the project in order to improve success in product development projects (Morris 1997).

5.3.3.4 The Development Stage

From a cross-project learning perspective, the strategy in the development stage has shifted from an intense knowledge transfer process in the conception stage to a rather high concentration on coordination of projects and technical issues within the matrix structure (Sparrius 1994; Hauptman and Hirji 1999):

Senior managers at YellowTech claimed that the coordination of project activities within the portfolio of product development projects was planned from a multi-project strategic approach. The Head of the Hardware Group claimed:

> *In my mind, the structure we created (the matrix) allows us to manage a pool of projects by using the resources currently available. I don't care whether this project just started or is going to end. All I care is that we will be able to move resources when and where they will be needed.*

This view demonstrates the strategic approach by senior management seeking flexibility in the organisational structures during the development stage (Clack and Fujimoto 1991; McCollum and Sherman 1993).

In order to achieve coordination and yet maintain flexibility, management at YellowTech promoted the work of a cross-functional team which acted as a decision-making group involved in coordinating technical and manufacturing issues inside and outside the R & D Division.

The Head of the R & D Division envisioned the learning in this group as based on problem-solving, involving debates and different perspectives on how resources should be allocated and priorities should be set during the development process (Hauptman and Hirji 1999). Nevertheless, he concluded by saying:

> *This is a group of highly qualified professionals. And despite the differences and politics, they always find a way to overcome problems and work together effectively.*

Thus, autonomy, freedom to act, and coordination through a cross-functional team, were strategically envisioned as stimulators for cross-project learning activities, by promoting the development of problem solving skills that are crucial for a successful product development project (Tushman and Nadler 1996).

5.3.3.5 The Integration Stage

During the integration stage, management conveyed a rather 'fire fighting' (Repenning 2001) or 'crisis management' (Perlow 1999) strategic approach which set up priorities to allocate engineers and other resources to fix problems discovered during the late stage of the project. Usually, these problems impose numerous costs on the project. In addition, problems in the last stage of the project could overrun product delivery deadlines, and hence might risk relationships with clients and bear financial consequences.

The Head of the Hardware Group justified this strategic approach, claiming that:

> *At this point in the project we cannot afford deep and thorough study of the problem. We have to come up with a solution in no time and implement it right away.*

Thus, from a cross-project learning perspective, priorities were diverted towards rapid problem-solving practices by deploying engineers from the matrix organisational structure. It is the combination of flexibility (McCollum and Sherman 1993) and a high level of problem solving (Victor and Boynton 1998) that management sought to promote during the integration stage.

From a cross-project learning perspective, the deployment of experts from one project to another was considered as a learning process across different projects. This action created a mutuality of engagement (Wenger 1998) that serves as a learning mechanism through the ability to engage with other colleagues and enhance participation across projects.

5.3.3.6 Strategy, Priorities and Decisions for Cross-Project Learning at YellowTech: Summary

The strategy, decisions and priorities at YellowTech for cross-project learning revolved around the three stages of projects. Proper project management practices were conceived by management as essential in order to facilitate cross-project learning. In particular, those project management practices that support specific cross-project learning actions needed for each stage of the project; conception, development and integration were given high priority. Indeed, cross-project learning mechanisms have been different for each stage in product development projects. Cross-project learning activities were intense in the conception stage, ensuring that uncertainties and risks would be minimised through the reusability strategy. A high level of learning took place during integration, in which experts from different groups exchanged knowledge while engaging in problem solving, whereas the development stage is characterised by a formal project management with a high level of coordination between different professional groups. Cusumano and Nobeoka (1998) confirm the above findings. Furthermore, in the context of the Israeli electronics defence industry, the present study highlights the importance of project stages which were not reported previously.

Nevertheless, strategic planning tends to be implemented rather differently than envisioned (Johnson and Scholes 1989). Therefore, the following sections will analyse structures put in place to support cross-project learning activities and their impact on cross-project learning and product success. These mechanisms first and foremost demonstrate the experiences learned in implementing cross-project learning at YellowTech and yet also reveal the constraints within which organisations operate.

5.3.4 Organisational Structure

The organisational structure at YellowTech evolved into three forms that accommodated different needs in each project stage.

5.3.4.1 The Conception Stage

YellowTech introduced a network structure, based on a 'hierarchy' of knowledgeable individuals (Nonaka and Takeouchi 1995). This structure, also known at YellowTech as the Knowledge Transfer structure, enhances communications between knowledgeable engineers and project managers during the conception stage of the project (see Figure 9). It was acknowledged that the network structure was not part of the matrix structure but rather a separate entity. The Head of the R & D Division at YellowTech explained:

> *Implementing the knowledge network helped us tremendously in opening communication channels and allocating those who have answers to our most acute problems.*

This network structure, which represents a knowledge mapping directory, does not necessarily represent any means of control (Sobek et al. 1998). Rather, the network structure emphasises the exposure of individuals to organisational knowledge and the channels through which knowledge can be communicated to others (Kanter 1996).

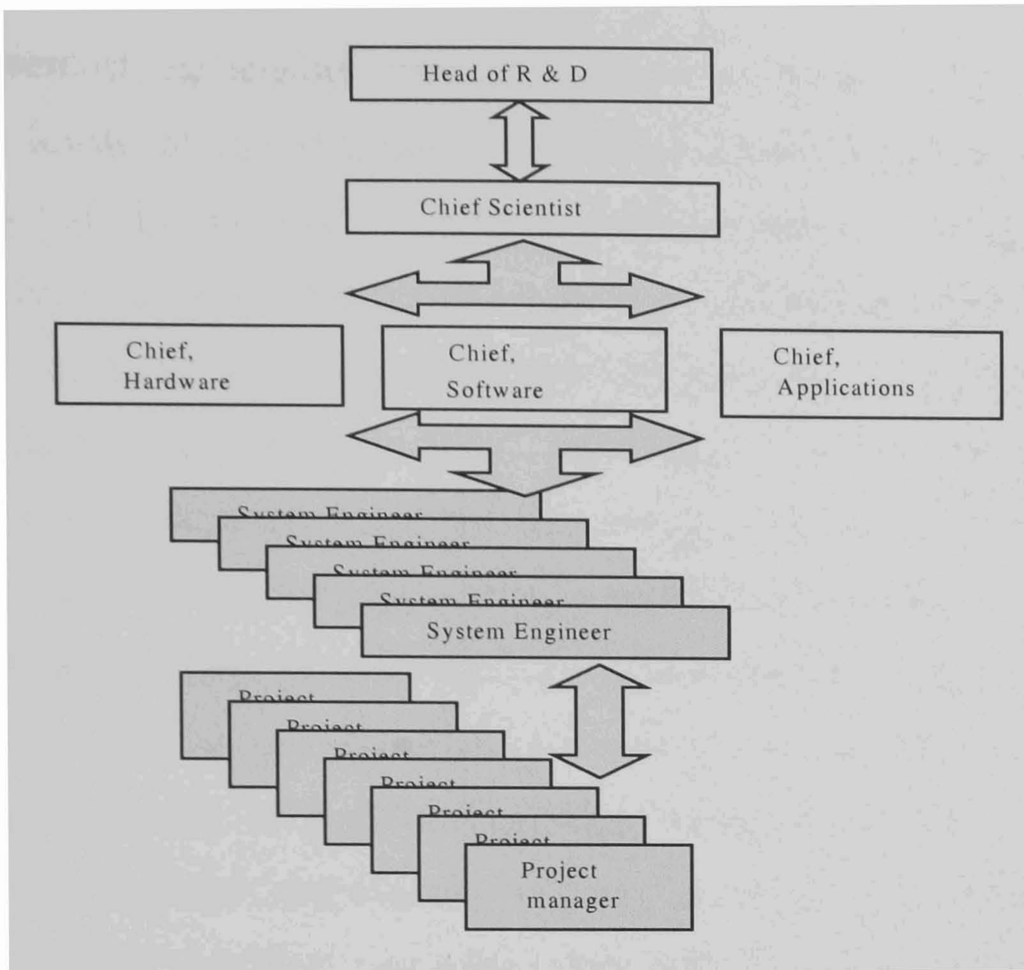

Figure 9: Knowledge Transfer Organisational Structure

One system engineer from YellowTech explained the value in linking these knowledgeable engineers in a network of knowledge:

> *The system engineer has a better overview on projects than the project manager. The Head of the Hardware Group knows more than the system engineer about who is doing what. Therefore, the network of people was defined in such a way that helps project managers to get to the right solutions faster.*

Another system engineer from YellowTech summarised the essence of the knowledge network in three words:

> *Visibility is feasibility*

This slogan suggests that the position of a system engineer within the organisation, metaphorically described as higher than the project engineers', may give system engineers the ability to see the broad picture of products, technologies, and people involved in these projects and thus advise project managers on potential use or reuse of these resources.

First and foremost, the network structure supports the ability of those positioned at the higher levels of the structure to quickly identify existing technological resources within the organisation and offer these resources to project managers while the project is in the conception stage. This helped project managers in the process of assessing and evaluating potential platforms and components for reusability during the conception stage (see Figure 7). It has been argued that, because of the growing trend to reuse technological platforms and components, the network structure has become critical in facilitating a smooth, clear and well-focused conception stage of the project. To demonstrate this argument, the Head of the Hardware Group presented Figure 10 to the researcher. This figure was also presented in a forum of project/programme managers as part of a one-day conference on 'Software and Hardware Design for Re-Use' in Hertzelia, Israel. Figure 10 suggests that there has been a 50% growth in the number of projects based on reused platforms and components between 1995 and 2000. At the same time, the number of generic R & D projects has dropped by 25% in the same period of time and by 66% between 1985 and 2000. Also, 82% of the projects in the R & D Division engaged in reusing either a platform, component or a software module in 2000, in comparison to 55% in 1990.

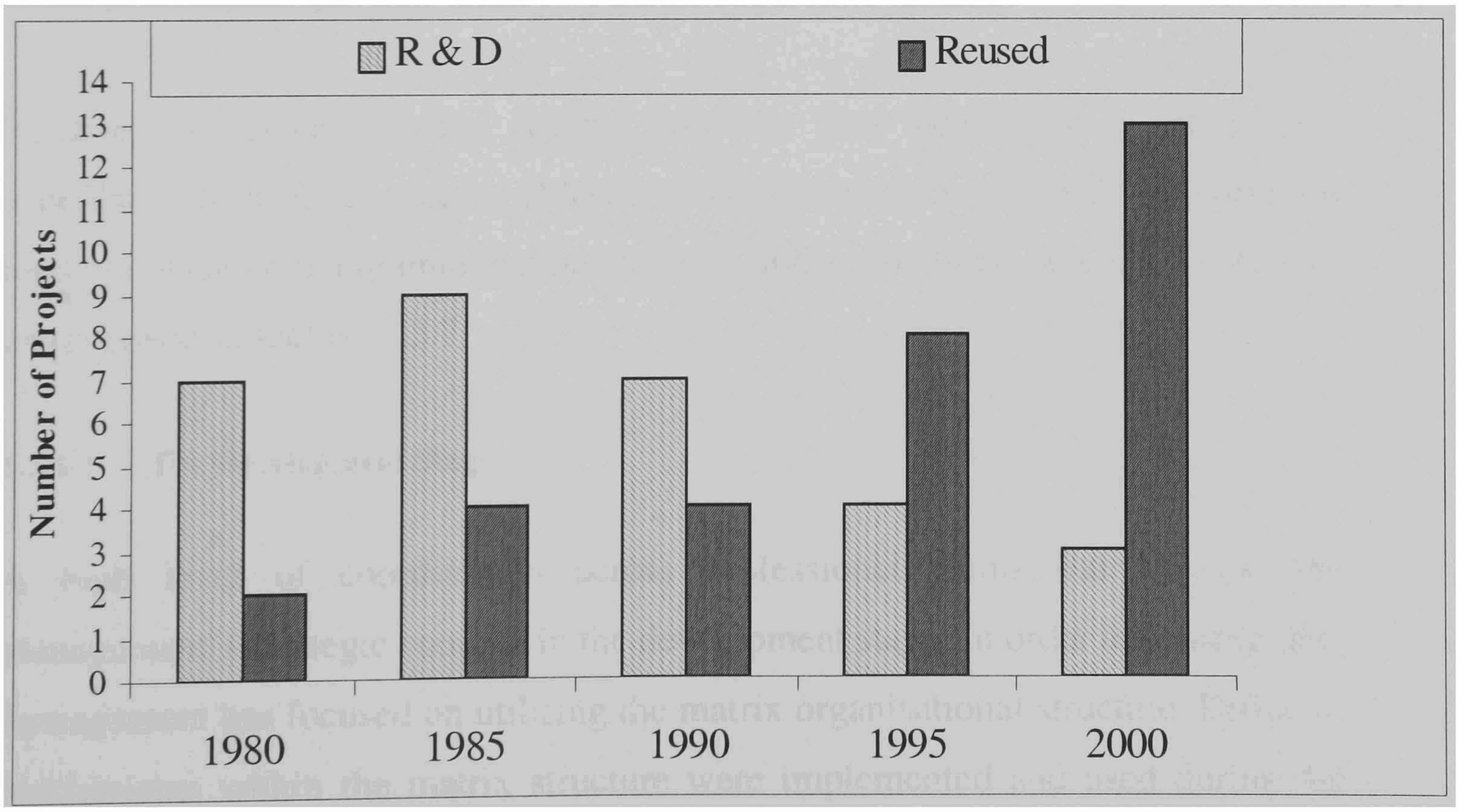

Figure 10: Trend of Projects Characterised as Generic R & D versus Reused Projects

However, the Head of the Hardware Group explained that, though the graph suggests that more recent projects were based on reused technologies, in reality some generic R & D projects in the past have been practising the reusability strategy long before 1995 without 'making a fuss out of it'. Yet, he further indicated that only recently had formal mechanisms to support the reusability strategy been put in place.

In those cases where the reusability option was adopted, it was acknowledged that the network structure helped in allocating the technology and the people involved in the project. This action resulted in a better use of internal resources, which reduced the risk of falling behind deadlines and increased the probability of meeting technological challenges on time (Lester 1998:36; Dyer and Gupta 1999).

Despite various difficulties in transferring a design to another project, mainly expressed by project engineers, and to be described in detail in Chapter 6, the overall results were satisfying. The Head of the R & D Division claimed:

> *The fact is that we are doing more work with fewer people in the last five years and our clients are getting a better product [...] Projects take less time [...] the cost of the development has gone down [...] we are much more focused.*

Focusing on objectives and results from the very beginning of the project contributes to product success (Morris 1997; Bernasco et al. 1999). However, it requires leadership, communication channels and a structured process. These will be reviewed in section 5.3.7.

5.3.4.2 The Development Stage

A high level of coordination across professional teams has become the management's strategic concern in the development stage. In order to achieve this, management has focused on utilising the matrix organisational structure. Different mechanisms within the matrix structure were implemented and used during the development stage, supporting cross-project learning.

From a cross-project learning perspective the matrix structure is seen as a social space within which software and hardware engineers are allocated and then reallocated to different projects (McCollum and Sherman 1993). Through work with members of different project teams, involving debates, discussions, the use of tools and procedures, these engineers share experience, expertise, learning and know-how of the product, technology and organisational systems (Wenger 1998). This process, mainly through debates and discussions, leads to the build-up of collective expertise (Lave and Wenger 1991; Robbins 1987; Engestrom 1999). One system engineer from YellowTech explained:

> *The matrix structure that we put in place back in 1990 allows us to deploy engineers from one project to another. This is one way to keep the learning system going.*

The matrix structure at YellowTech was also structured to contain some design centres that were organised as teams of highly qualified engineers. These design centres maintained their autonomy and were not associated with either the project/programme management field or the professional field (see Figure 11). One of these design centres is the ASIC team which acted as a knowledge centre for ASIC developments (Cusumano and Nobeoka 1998:29). The justification for centralising ASIC developments in one group was to reduce the costs associated with the learning of the ASIC development.

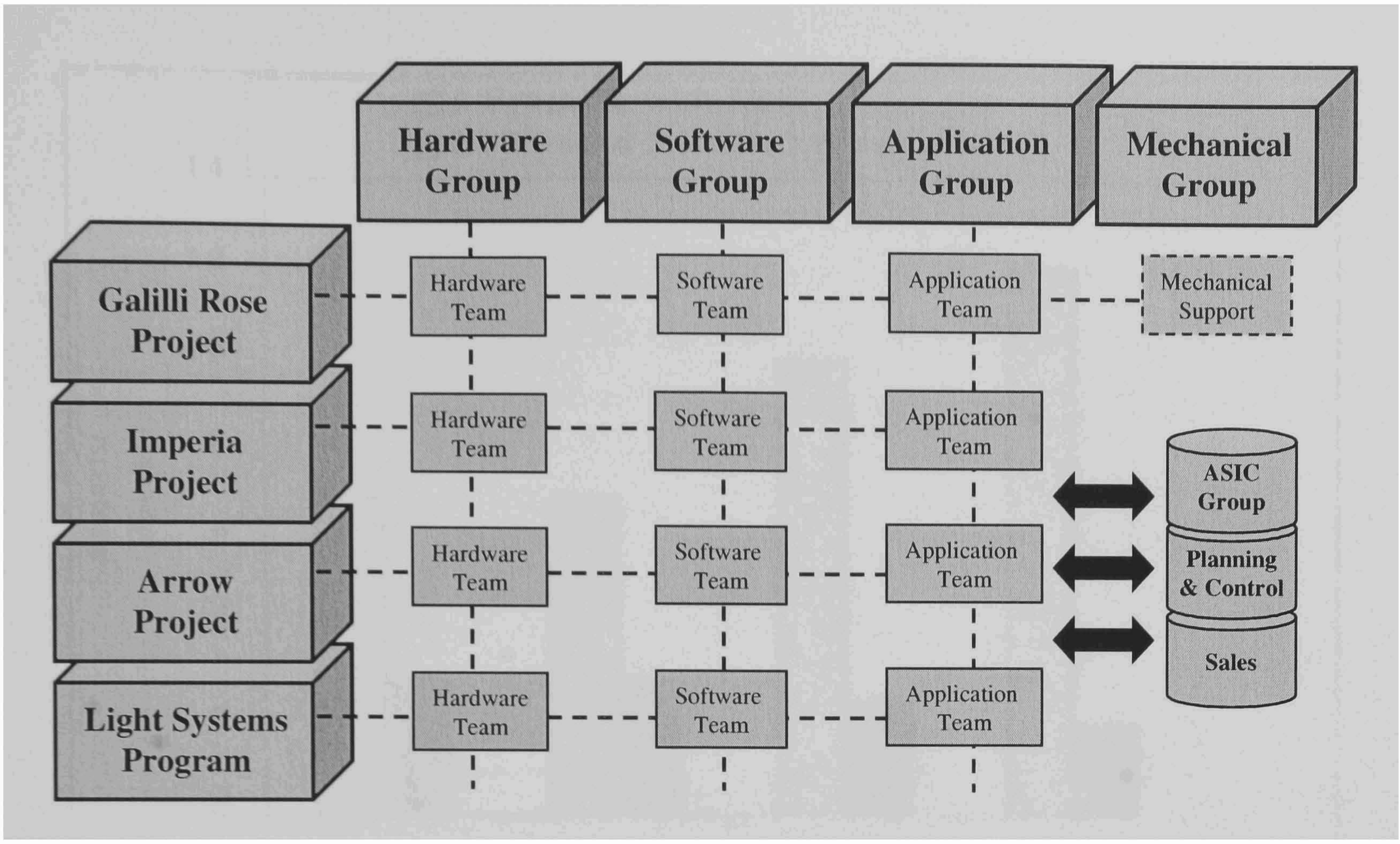

Figure 11: Functional Matrix Structure in the Development Stage

Data about the ASIC group suggest that since its constitution the costs associated with ASIC developments have gone down significantly despite the growing complexity needed in products (see Figure 12). It has been suggested by the Head of the ASIC team that by creating a knowledge centre for ASIC technologies, considered to be one of the most advanced current technologies, the team has in fact preserved knowledge, enhanced learning from their own experience and was able to quickly address projects' needs (Adler and Shenhar 1990). In addition, the team has built a knowledge base for ASIC solutions and was able to reuse solutions for different projects.

Thus, during the development stage, once the team received the specifications of the design from the project manager, the ASIC team reviews the specifications, searches for similar designs in the ASIC knowledge base, and once found, makes the modifications needed to adjust the reused design to the new specifications. Figure 12 shows a major reduction in learning time as the team has become more skilful and experienced with ASIC developments. The Head of the ASIC team suggests that his team spends on average 2 man/months per order in comparison to 2.5 in 1995 (see Figure 12).

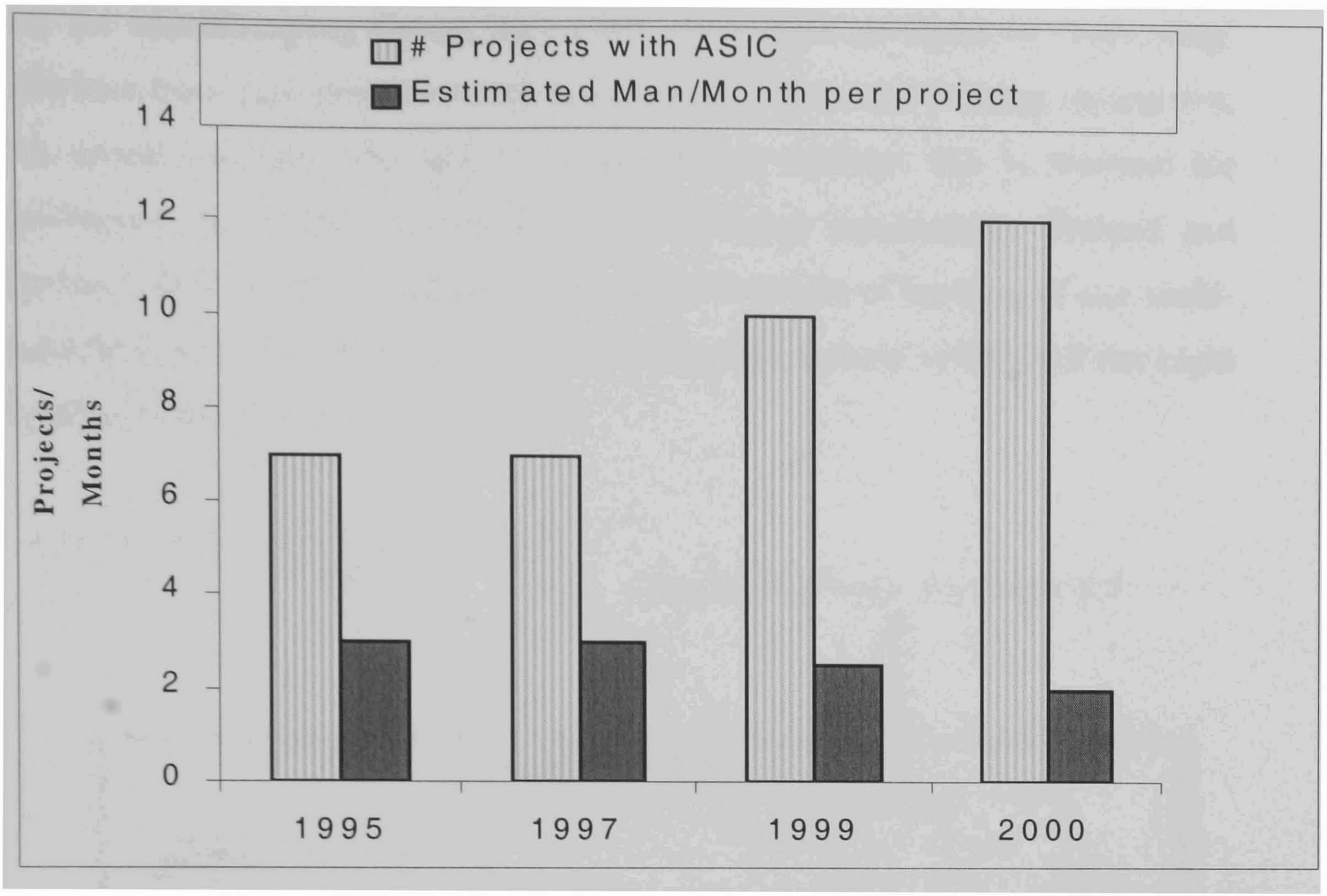

Figure 12: Estimated Man/Months per Project for ASIC Development (based on data provided by the Head of the ASIC team)

Another mechanism implemented in the R & D Division was one cross-functional team that promoted manufacturing activities across YellowTech. This team consisted of middle level managers from the R & D Division and the Manufacturing Group. The discussions revolved around acute and most recent problems in coordinating processes in concurrent engineering. The team focused on problem-solving related to the transfer of the design from the R & D Division to the Manufacturing Group. Though the direct contribution of the cross-functional team to cross-project learning was not central, this group of people has indirectly supported the multi-project management approach.

The multi-functional team consists of managers and engineers who are working on one specific project. More importantly, these individuals are responsible, each in his/her own area, for promoting product development and manufacturing activities of the same product family. This means that when the multi-functional team encounters problems in coordinating activities between the R & D Division and the Manufacturing Group, they often solve these problems by 'borrowing' solutions from past projects of the same family. From the learning perspective, this process supports the notion of 'perspective making' that is essential for developing 'boundary innovation' across different communities (Boland and Tenkasi 1995). Figure 13 describes the shared histories of learning of one multi-functional team. The participants were involved in various versions of the Light Systems product family.

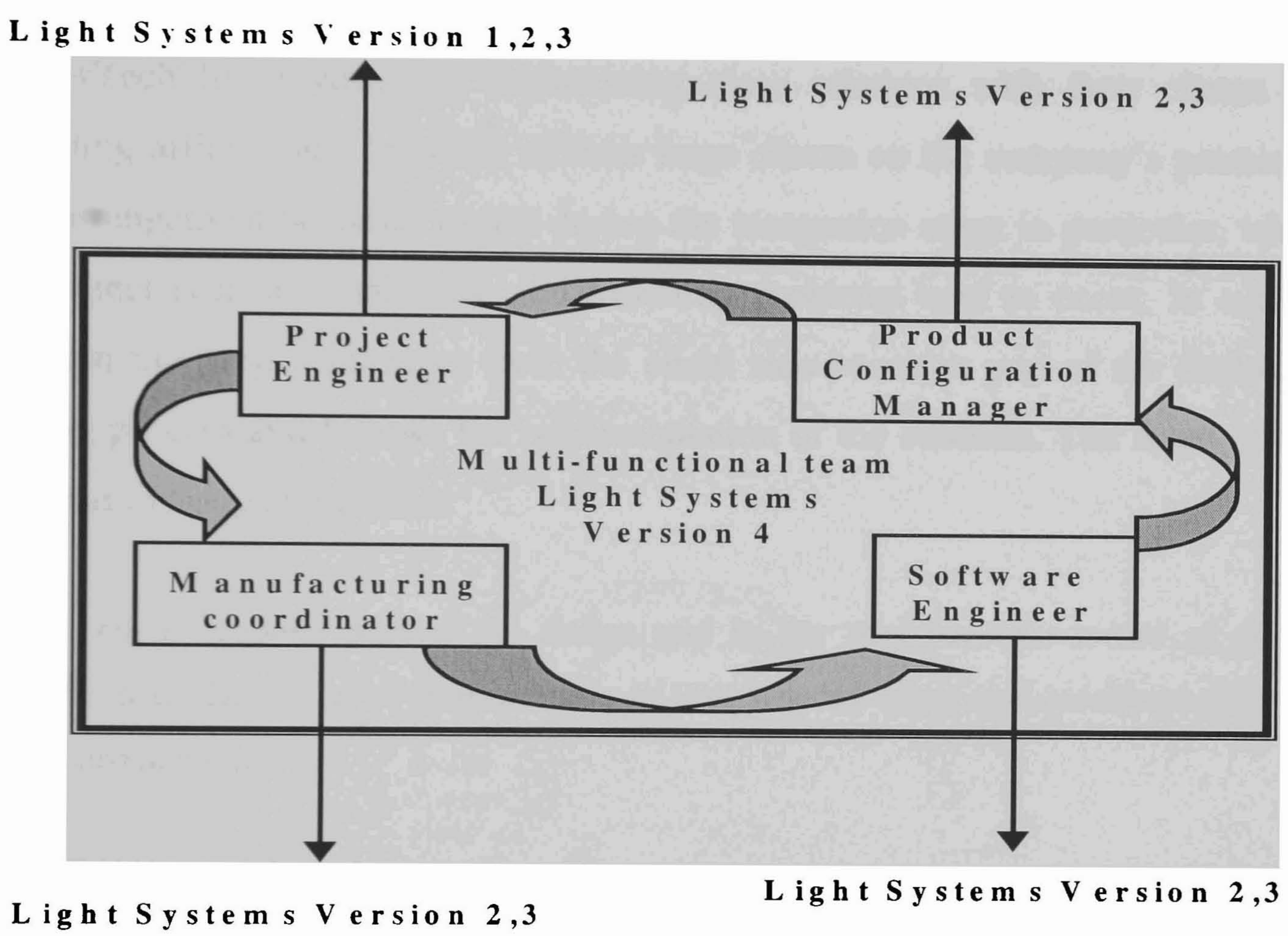

Figure 13: Shared Histories of Learning in Multi-Functional Teams

5.3.4.3 The Integration Stage

Activities during the integration stage revolve mainly around testing and problem-solving activities while the client gradually becomes part of the testing and finally the acceptance process of the product.

The opportunity to learn collectively during this stage is twofold. First, this occurs through learning by working closely with the client, particularly when it comes to the Israeli Air Force, which was considered to be the most demanding and sophisticated client for YellowTech when this study was carried out. The learning from interactions with a client has various sides. Some of the benefits in bringing the client into the last stage of the project were described by the Head of the Hardware Group:

In general it is good to be in touch with the client. It helps to maintain good relations with the client, understand their present and future needs and to be prepared with a solution when they issue an RFP (Request for Proposal).

YellowTech has invested in maintaining close relations with their clients by providing office space for some of their large clients on the company's premises. This arrangement becomes useful during the integration stage in particular, when the project is in its final stage and troubling problems tend to occur. In such a situation the project manager from the client side becomes part of the decision-making process and follows the implementation of the solution. The Head of the Hardware Group argued that:

The client becomes part of the design and he [or she] becomes aware of the difficulties. This helps us tremendously in satisfying the client and quickly pushing the product out.

In other words, the involvement of the client in critical decision making actually makes them part of the decision and therefore makes the delivery of the product much smoother. Working closely with the client has been regularly mentioned in the literature as one of the most significant factors for learning and product success (e.g. Victor and Boynton 1998; Gehani 1998; Crocombe et al. 1991; Saren 1987).

It can also be argued that the learning from interactions with clients becomes collective because of the structure of problem-solving teams during the integration stage.

In line with management strategy to promote flexibility and the deployment of people across the matrix functional structure in order to address problems in the integration stage, the structure of the project team and its relation to other teams becomes more interactive and boundless.

One system engineer from YellowTech described the nature of this process:

> *The malfunctions we get during integration and final testing are often far more complex. Rarely can we immediately understand whether the malfunction is software or hardware related, or which sub-unit is failing. To get the system out to the client ASAP, we get the best brains we have and the client together, get a decision that is within our ability to implement considering the time and resources, and go for it. The client is happy and we are happy.*

The structure that emerged from discussions with engineers and project managers is presented in Figure 14, which demonstrates the close working relationships during problem solving sessions between the project team and other experts, and the involvement of the client in the decision-making process.

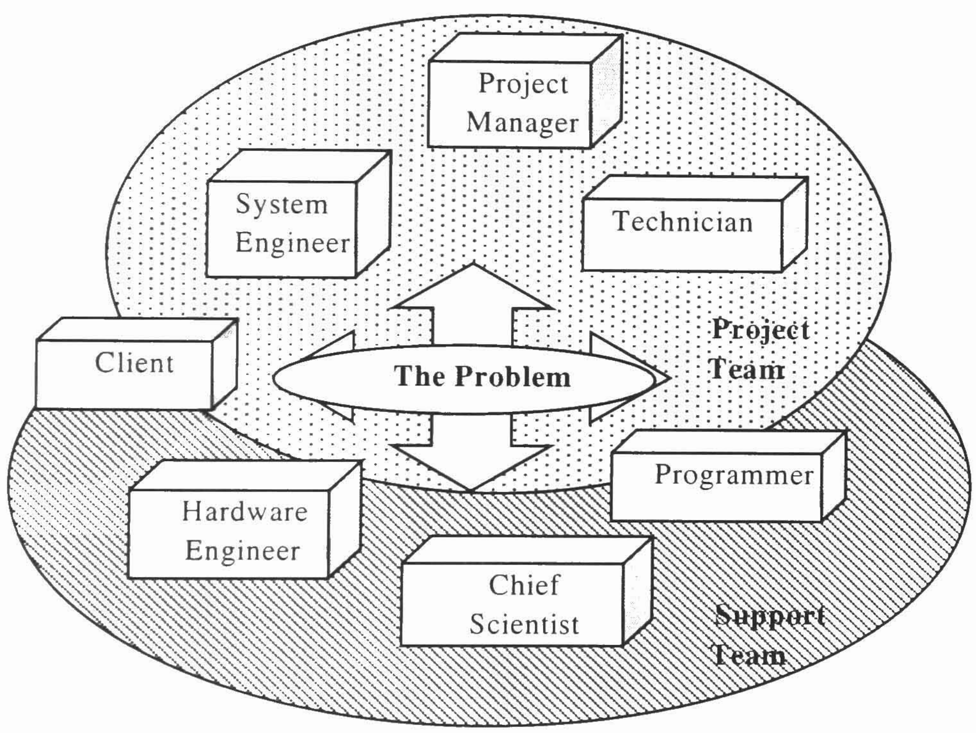

Figure 14: Interactions between the Project Team and other Experts during Integration

To conclude, YellowTech implemented mechanisms that supported the involvement of the client in the last stage of product development and enabled the dissemination of knowledge across the R &D Division through flexibility and by deploying experts from one project to another.

5.3.4.4 Organisational Structure: Summary

Mintzberg (1988) suggests that organisations may implement a number of organisational structures within one setting. As seen above, YellowTech implemented a number of concurrent structures, most of them based on the functional matrix structure, to support cross-project learning and link cross-project learning mechanisms to product development activities.

Of particular interest is the emphasis that YellowTech put on the conception stage. In addition, the inclusion of clients in problem-solving teams and the dissemination of knowledge through the matrix structure is another mechanism supporting cross-project learning activities.

However, the matrix structure, presented above as one of the mechanisms supporting cross-project learning, does have its limitations. Managers suggested that the matrix structure presents staffing complexities, leads to conflicts between the management of the project and the management of resources concerning priorities, and incorporates a dual reporting structure that tends to confuse and create tension between project managers and the heads of the professional fields (McCollum and Sherman 1993). These areas of tension will be further explored in Chapter 6.

5.3.5 Technology Management: Commonality in Hardware and Software Development Tools

In order to enhance the transferability of designs between projects, the Chief Scientist of YellowTech decided in early 1995 to introduce commonality in hardware and software tools. To enforce this practice, the Head of MIS, an experienced engineer, was appointed to manage the technological platform of software development tools. These are software packages that are used by software engineers as the platform upon which the code is developed. For example Borland has a software application that supports developing programmes using C++. Microsoft offers the same type of application. In the case that the code was developed on the Microsoft platform, it will not be transferable to another platform. Since 1995, the Head of the MIS department has been the 'watchdog' at YellowTech concerning the management of software packages. No longer could engineers upgrade their development tools individually.

The Head of the MIS department explained the process:

> *The system for software upgrades has changed. Now the MIS team is doing all the upgrades. We schedule a specific day on which all users will get an update of the software once they switch on their computers.*

Software upgrades were coordinated by the MIS manager to ensure compatibility of software versions across projects. In addition to the benefits associated with cross-project learning, it was commented by the MIS manager that this move has improved the MIS team response to software problems. The team is more experienced in troubleshooting and demonstrates a higher level of skills than before.

A rather similar process has taken place with regard to hardware components; however, with less restrictions and control. The Head of the Hardware Group has indicated that more attention is given to the components used in development. The Head of the Hardware Group argued:

> *There has to be a good justification to purchase a component that offers the same functionality as an existing one.*

However, this practice is not always enforced, as project managers enjoy the autonomy to run project matters with little interference from top level managers.

Lastly, modularity in design (Baldwin and Clark 1997; Sanchez and Mahoney 1997) was introduced, mainly in software development. The Head of the Software Group pointed out that YellowTech has followed this practice for many years. This practice enabled projects to 'lend' sections of software code from one project to another.

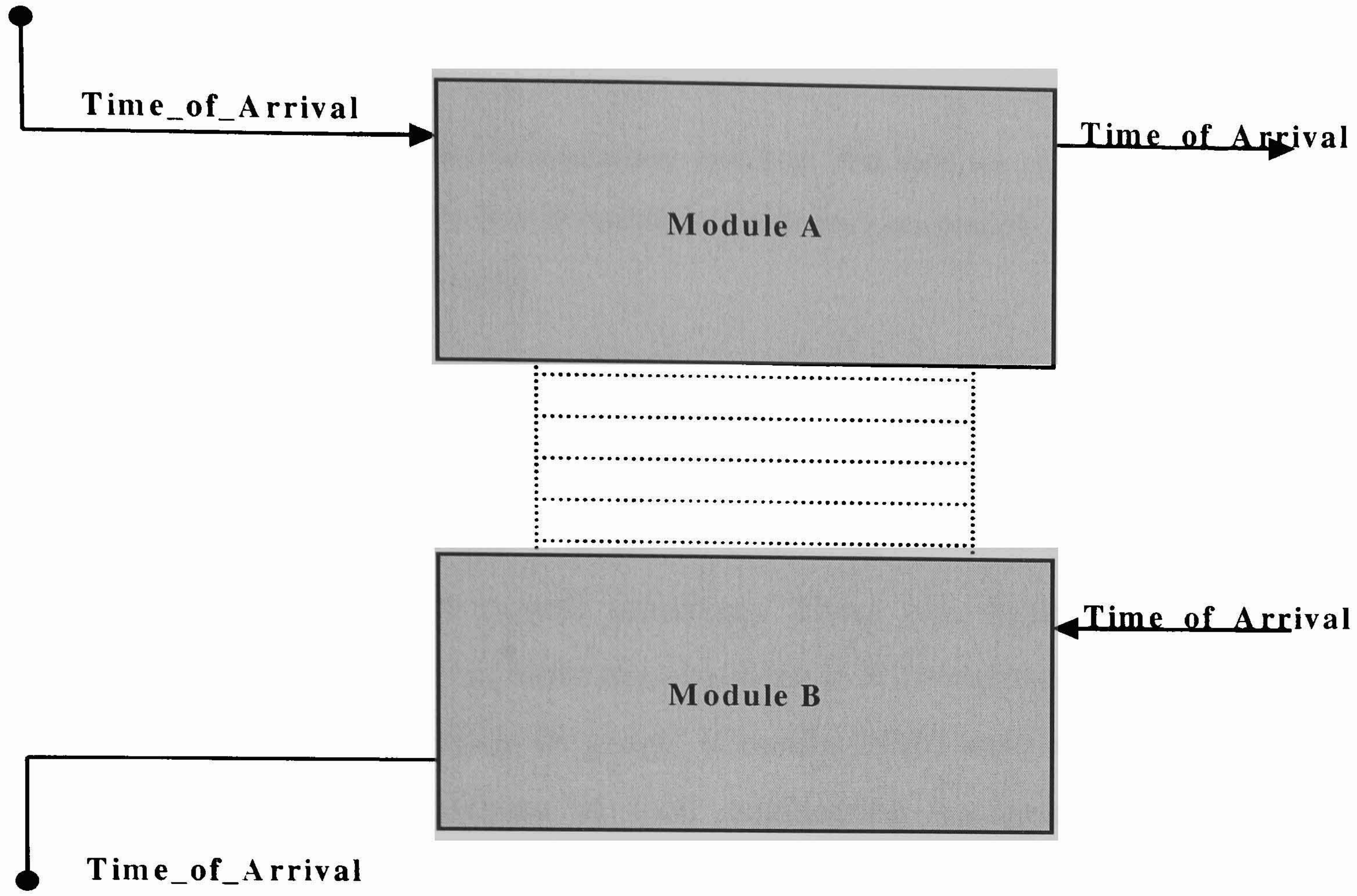

Figure 15: The Concept of Software Modularity at YellowTech

This practice has certain rules. For example software engineers need to clearly define inputs and outputs for each section of the programme and to write the programme in a way that will avoid direct dependency between two sections. Figure 15 demonstrates the concept of modularity in software (Sanchez and Mahoney 1997). The emphasis is on the independence of each stand-alone module and on the clear definition of inputs and outputs, i.e. the Pulse Time of Arrival. This way, projects needing to 'borrow' module B do not have to inherit module A as well. This practice paid off well, according to the Head of the Software Group, because many modules of software become exchangeable with very little work needed to adjust them to client-specific requirements.

5.3.6 Integration with Sales and Clients

The Sales team at YellowTech, consisting of four people, has been fully integrated with the engineering function. This was achieved through physical and organisational positioning of the Sales team in the central floor of the R & D Division (Hull et al. 2000).

The Head of the Sales team explained:

> *We were first located in the headquarters building. But then we realised that we spent most of our time in the R & D building. It was only reasonable to relocate the team to where it really belonged.*

Furthermore, the Sales team, which is relatively young in the company, is made up of talented engineers who have spent many hours designing electronics warfare systems but also have engaged with clients extensively in their previous role as either project engineers or project managers. These two factors have had a tremendous impact on the communication between R & D engineers and the Sales team. Concerns about 'common language' (Coombs 1996) were less an issue for the Sales team mainly because of their engineering background. However, interviewees indicated that sometimes information about recent technological developments in the R & D Division was not always available to the Sales team, mainly because of the frequent travelling that the Sales team was committed to as part of their jobs.

Interactions with clients were intense. Because the products produced by YellowTech were 'made-to-order', consultation with clients about features, systems configuration and malfunctions was essential for the product design process. Thus, in some cases YellowTech accommodated clients on the premises, providing them with office space and other secretarial services. In one case, the chief client of YellowTech has a permanent office close to the R & D laboratory in which the development of this client's systems is undertaken. This geographical arrangement was described by engineers and managers as assisting the transfer of designs between different generation systems (Van den Bulte and Moenaert 1998). However, this process was not systematic and was very much based, we have been told, on informal communications.

The next sections review additional mechanisms and factors, mainly motivational elements (Myers 1996), that facilitated cross-project learning in product development.

5.3.7 Motivational factors

5.3.7.1 Autonomy

The overall impression from the data is that engineers and managers were granted a relatively high level of autonomy when it comes to their area of responsibility. Yet, recent years have seen more discipline in the area of project management, introducing more strict scheduling and planning practices. The tension between knowledge management processes and expertise development, presented in Chapter 6, is one example of the impact that recent changes have had on employees' perception of autonomy. As suggested in Chapter 6, employees felt that the newly introduced project and knowledge management practices have restricted their exploration-related activities and directed their efforts towards exploitation-related activities (March 1999; Cohen et al. 1999).

Yet job design and job description at YellowTech has always been loose and rarely well-defined, a factor that acted as an enabler to pursue innovations (Orr 1996). In addition, engineers rarely moved horizontally between professional groups. Specialisation was mainly vertical and within the same professional group. In some cases, engineers have specialised in one product family for ten years before moving to another. This long specialisation in one product family did not seem to bother the engineering force, perhaps because in any new product there were some new designs to introduce in addition to the reused components.

5.3.7.2 Informal Communications Networks

In addition to the formal communication channels, YellowTech has established through the years wide informal communication networks between experts (Tushman and Nadler 1996: Van Aken and Weggeman 2000). These communication networks have taken place in many forms and through different channels. For example, interviewees claimed that they often discuss work with colleagues while commuting home. Also, chitchats in the corridors were mentioned as another channel through which employees learned about recent developments and other people's work.

Research on the contribution of informal interaction is inconclusive. For example, Kreiner and Schultz (1993), who studied informal networking between two organisations, suggest that informal collaboration needs to be channelled through and monitored by management for the reason that information can be exploited by others (ibid:206). Tushman and Nadler (1996) argue that informal communication is vital for innovation because it improves problem-solving interactions and creates a direct channel of feedback. Victor and Boynton (1998) see the importance of informal communication in story-telling that communities of practice generate, which leads to the development of identity (Orr 1990) and expertise (Lave and Wenger 1991).

Data from YellowTech suggest that informal interactions support the development of individual and collective expertise, as will be demonstrated in Chapter 6. Communications with peers were through the formal channels as well as based on social interactions. This enhanced employees' mobility between projects and stimulated their participation across projects, while they engaged in problem-solving sessions (McCollum and Sherman 1993). The strong presence of informal channels helped in bridging boundaries between different professional groups and facilitated the creation of shared language and histories of learning (Wenger 1998). However, in line with Kreiner and Schultz (1993), managers argued that such interactions would be beneficial to product success only if the interactions were goal-orientated and sought a specific result. On the other hand, engineers and technicians argued that much of their learning took place through informal interactions. They argued that sharing experiences collectively helped them in problem solving (Tushman and Nadler 1996).

Thus, informal communication networks are indeed an integral part of cross-project learning activities; however, the contribution of informal networks to cross-project learning at YellowTech, as was voiced differently by managers and engineers, is inconclusive.

5.3.7.3 Rewards

Against the common belief in recent studies that rewards are essential for the organisational learning system (e.g. Tushman and Nadler 1996), YellowTech lacks a reward system that remunerates either individual or groups for successfully executing cross-project learning activities or any knowledge sharing activity. Nevertheless, rewards for reusability activities are common in a number of Israeli companies, including Motorola Israel. In Motorola Israel, developers may receive a reward if they have properly catalogued a component in a special directory and the component was reused by another project. In 1998 Motorola Israel gave about $25,000 to designers whose components were reused by others (Tal-Or 1999).

When asked why YellowTech is not implementing the same policy, the Head of the Hardware Group replied:

> *We prefer to diffuse reusability as a practice necessary to our business*

In other words, learning and participating in reusability activities is of value to managers. The value of this practice, according to the Head of the Hardware Group, needs to be realised through the understanding of changes in markets and other conditions within which YellowTech operates. According to the Head of the Hardware Group, individuals and groups need to internalise changes in markets and consequently change their values and behaviour (Bandura 1977).

5.3.7.4 Leadership

The Chief Scientist, who took up his position in 1997, was given the mandate to lead the cross-project learning activity. The Chief Scientist coordinated and aligned reusability-related activities from the beginning of the project until the delivery of the product. His leadership was considered essential to the successful diffusion of the reusability and learning strategy (McDonough and Barczak 1991; Starkey 1996).

The Chief Scientist explained his role as follows:

> *Putting me in this position (Chief Scientist) gave me the opportunity to make use of the success we have achieved with Light Systems. All we needed to do then was to exploit success [..] The trick was to get to project managers before they start connecting wires.*

One example of the impact that the chief scientist has had on cross-project learning is the Light Systems program. The Light System (SPS-1000) is a successful product family that has produced numerous systems in different configurations for various clients in the last decade. The Chief Scientist in his previous position managed the Light Systems Programme. During this time he pushed the reuse of software, hardware components and documentation across projects within the Light Systems Programme. In addition and perhaps more importantly, since he entered his new role numerous software modules and hardware components from the Light System programme have been transferred and implemented in other programmes and projects.

The Chief Scientist has been described by his colleagues and sub-ordinates as a pleasant person. His management style has been described by managers as based on human contact and he has always been open to new ideas. His clear vision on the process of reusability, his consistent promotion of knowledge management initiatives and persistent involvement in projects paved the way for the implementation of the reusability strategy (Haque and Pawar 2001). Yet he was demanding and highly involved in almost any detail.

Perhaps the best way to describe his leadership is in the way Starkey (1996:371) describes Petersen's strategic role in the transformation of Ford:

Petersen was responsible for disrupting conventional thinking in Ford, for getting Ford managers to think the 'unthinkable' and for shifting the focus from the functional to the strategic.

In the same manner, the Chief Scientist at YellowTech was one element in the introduction of cross-project learning, contributing to the transformation of the conventional thinking about product development projects from a single-project to multi-project management at YellowTech. His vision that product management starts with the assessment of existing solutions has shifted the conventional thinking of managers that projects are mainly about technological development. Moreover, the shift in paradigm was on the strategic level, as the practice of project management has also changed tremendously.

The Chief Scientist led discussions about knowledge transfer and reusability assessment and made them open to all. This act encouraged technicians and programmers to participate and become involved. The Chief Scientist made occasional visits to the laboratories and engaged in discussions. This has given him appreciation and respect at all levels within the R & D Division.

5.3.8 Summary: Organisational Characteristics and Capabilities for Cross-Project Learning at YellowTech

Organisations have a variety of structural forms from which to choose when implementing a strategy (Olson et al. 1995:51). In the case of YellowTech, a handful of mechanisms interrelate in the activity of cross-project learning including the organisational structure, project management routines, technology management practices, integration procedures of R & D activities with clients and Sales, and various motivational factors.

One way to look at the organisational and managerial issues involved in cross-project learning is by treating them as the capabilities that a company has developed to support cross-project learning (Coombs 1996; Collinson 2001). These capabilities are technical expertise, managerial practices, structural arrangements, and values and norms that YellowTech developed in many years of technological and organisational development (Schilling 1998). Coombs argues that core competencies consist of (1996:346) ‘the bodies of technological expertise (both product and process) and the organisational capacity to deploy that expertise effectively’.

Figure 16 provides a case in point that exemplifies the capabilities developed in reusing the technology of a display card in three different products.

Dynamics of Capabilities and Competencies

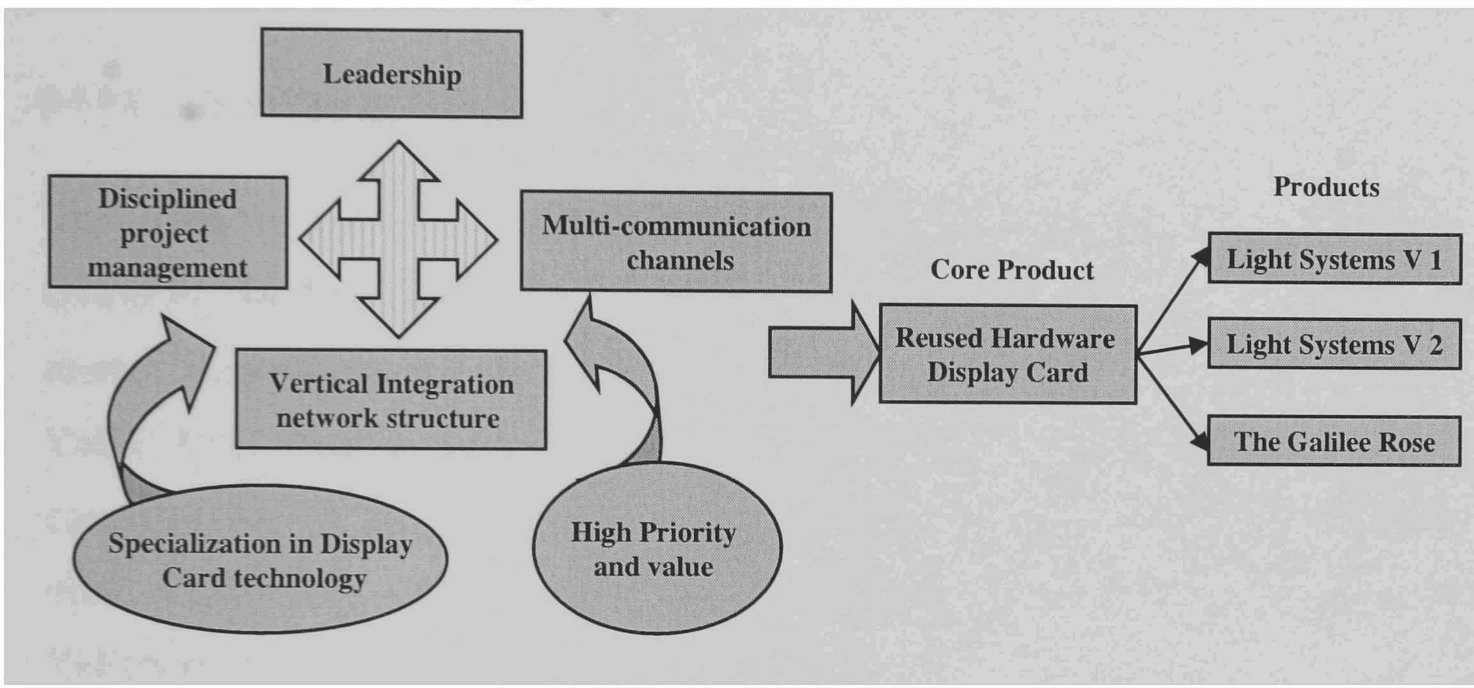

Figure 16: Dynamics and Products of Cross-Project Learning Capabilities at YellowTech (Based on Coombs 1996)

The dynamics of the capabilities described in Figure 16 suggests that the process of reusing a display card technology involves various factors, mechanisms, values and priorities that can all also be perceived as the reusability routine (Nelson and Winter 1982). The term ‘routine’ does not necessarily imply that the process of reusing is systematic, but rather demonstrates the know-how embedded in individuals, groups and systems about the actions associated with, and results expected from the reusability process.

In the following section, business performance from the last five years will be presented, suggesting that these years saw a gradual improvement in market penetration, product marketing and business performance.

5.3.9 YellowTech: Business Performance Indicators

Following the presentation of the mechanisms supporting cross-project learning, this section seeks to address the following question: did YellowTech enhance product success following the implementation of these mechanisms?

In order to suggest an answer to this question some business performance indicators have been analysed, in addition to the objective and subjective factors already presented above. These business performance indicators refer to new market penetration, success in bids, annual revenue, backlog and future growth.

5.3.9.1 New Market Penetration

Very little is known about the Israeli defence industry, let alone about the countries that the defence industry trades with. Figure 17 shows an estimate of market penetration for the last five years provided by the Chief Scientist at YellowTech. Market penetration is considered here as new contracts signed by countries that YellowTech has never traded with before. As mentioned above, these figures are based on a rough estimation by one senior manager at YellowTech and could not be confirmed by other sources.

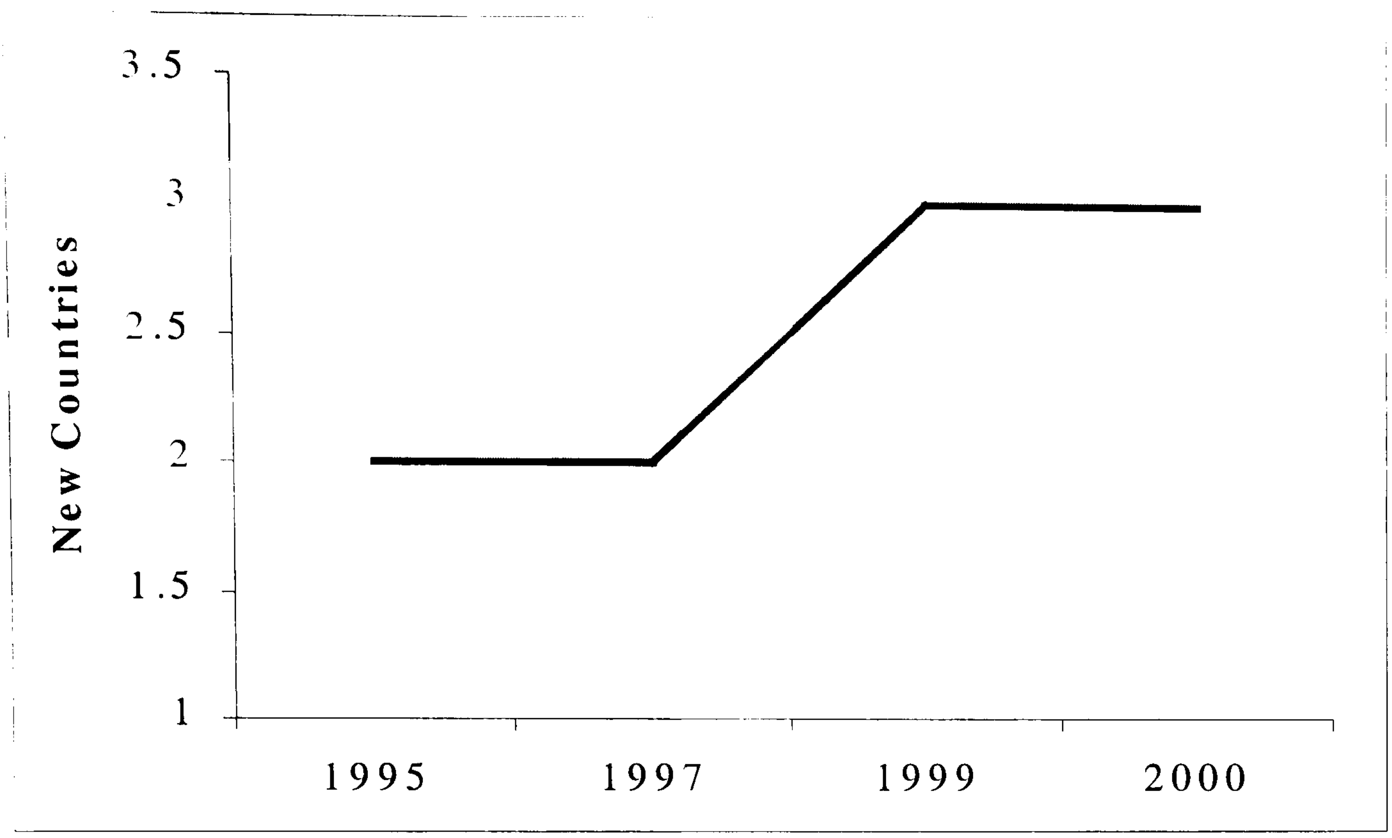

Figure 17: New Opening Markets for YellowTech

Amongst the countries that recently signed a contract for the first time with YellowTech are Germany and Singapore (1995) and Australia (1999) (interview source). Only very recently has it been announced that Greece is in final negotiations to sign a first-ever $500 million contract with YellowTech Group (Amnon Barzilai, Haaretz, 2.12.2001).

Thus, data suggest that YellowTech is constantly improving its market penetration into new markets. This data may suggest that YellowTech has achieved product success in these countries that have made contracts with the company for the first time in the last five years.

Nevertheless, other factors may negate the conclusion suggested above. In particular, the involvement of international politics often affects governments' decisions concerning defence procurement.

5.3.9.2 Success in Bidding

Success in bidding is another indicator of product success. Nevertheless, as mentioned above the involvement of political factors in the decision making process may hinder a clear correlation between these two elements.

Nevertheless, YellowTech has strategically targeted this factor as an indicator of market competitiveness. To accommodate this approach, the company has decided to submit bids more often than before, even in areas that in which the chances were slim, in order to demonstrate its strong presence in defence markets and possibly to be considered as a sub-contractor to the winner.

An estimate of the last five years' success rate was received from the Head of the Sales team, and is presented in Figure 18.

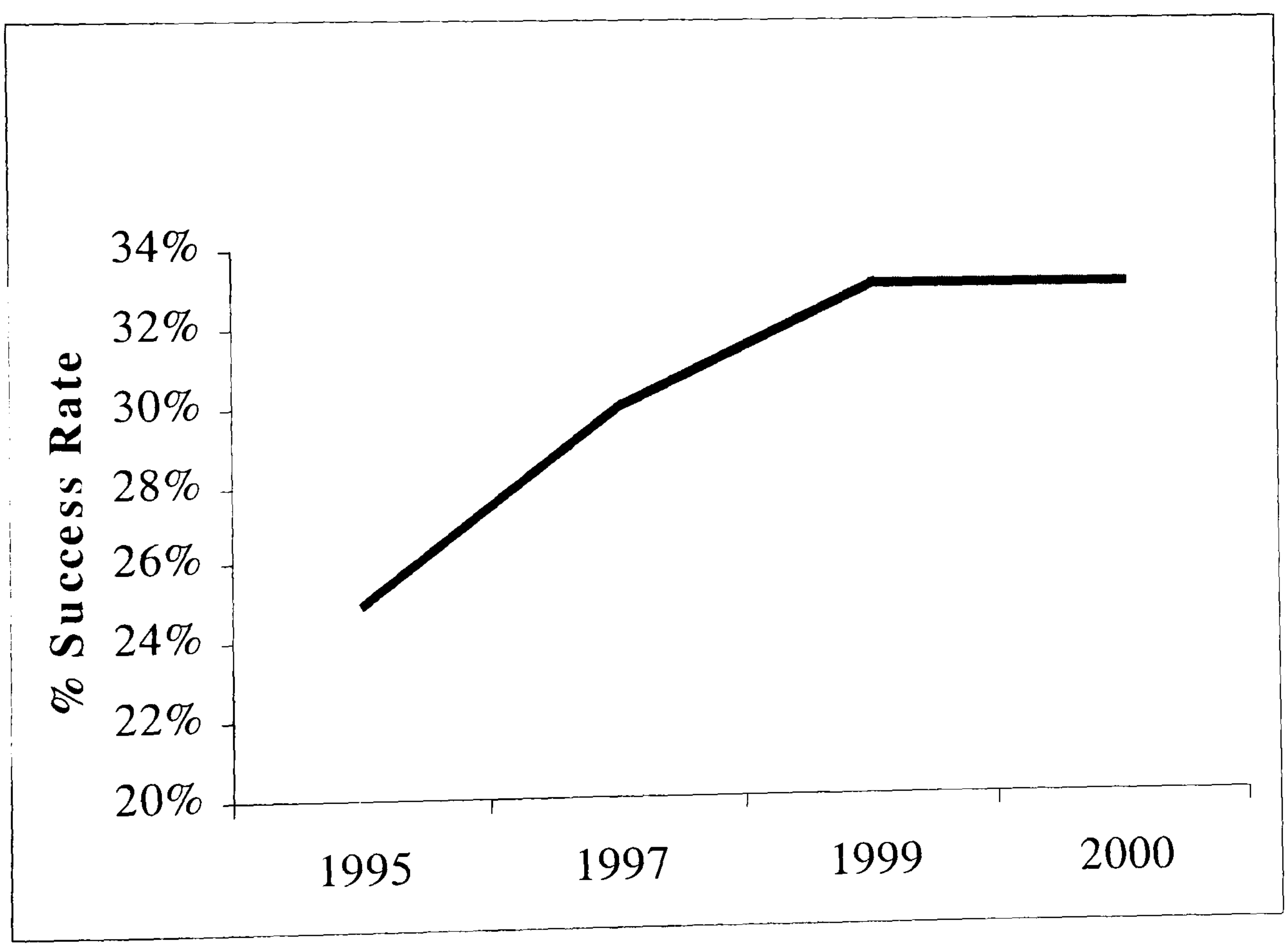

Figure 18: Success Rate in Bids at YellowTech

Data suggest that the company has improved its success rate in bidding from 25 per cent in 1995 to 33 per cent in 2000. Figure 18 suggests that the company has been more successful in competing in the last 3 years than before.

5.3.9.3 Revenue

Based on data from the popular media, Figure 19 suggests that YellowTech has constantly increased its annual revenue and order backlog in the last five years. Yet it has to be noted that the figures for the year 2000 actually represent the results of YellowTech Group, after the February 2000 merger. Nevertheless, a steady improvement in revenue and backlog between 1999 and 2000 was reported for the three companies involved in this merger (Marom Dror, Globes, 16.01 2001).

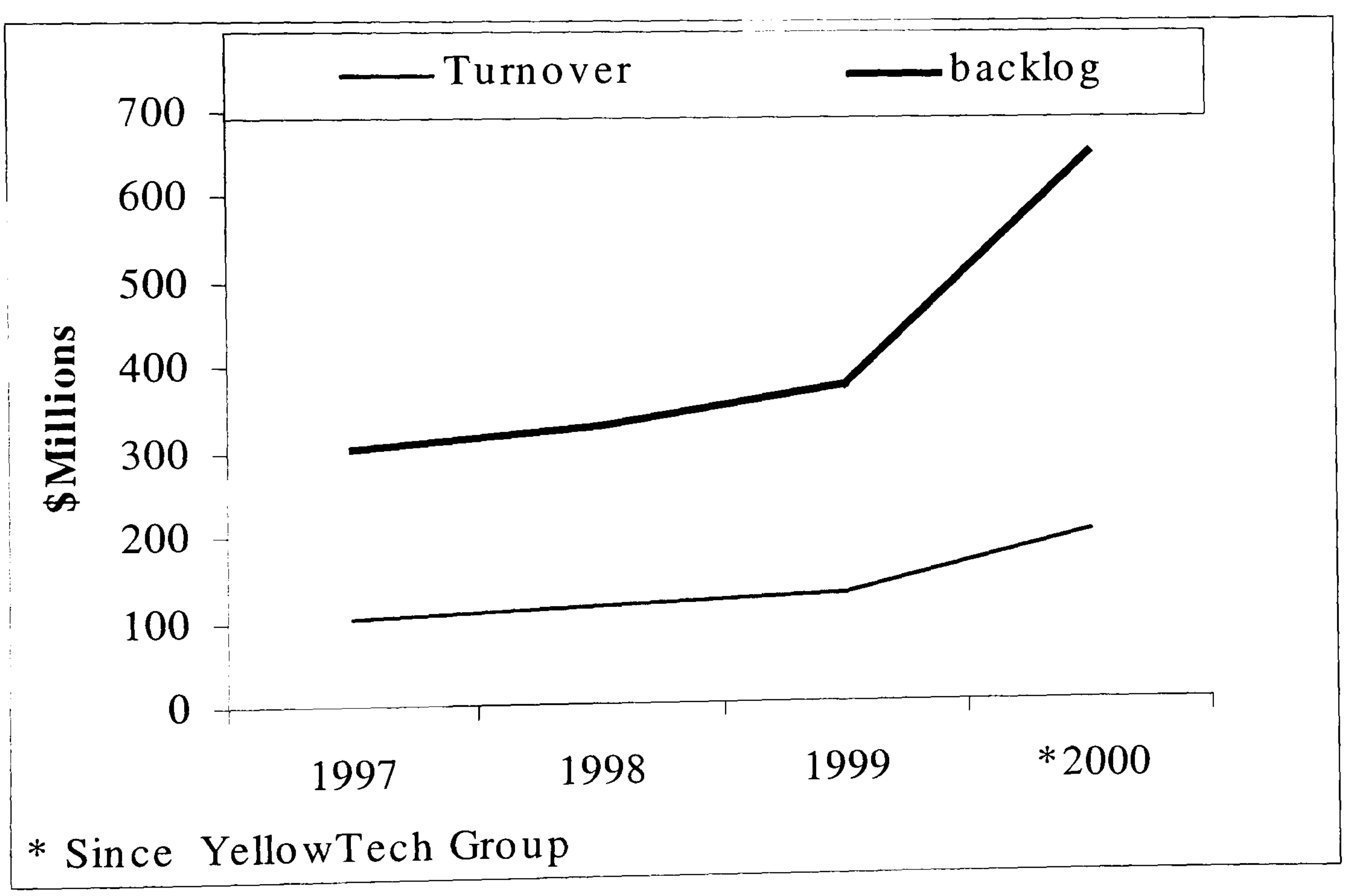

Figure 19: Backlog and Revenue at YellowTech between 1997-2000

Figure 19 suggests that YellowTech has steadily improved its financial performance since 1997. We suggest that the successful implementation of cross-project learning mechanisms played a role in achieving product and market success.

5.3.9.4 Reusability: The Cost Effectiveness Factor

YellowTech introduced a few metrics to evaluate the cost-effectiveness of cross-project learning activities. A case in point, presented by the Head of the Software Group, demonstrates the cost-effectiveness of the reusability strategy, when implemented properly in three consecutive, reused projects.

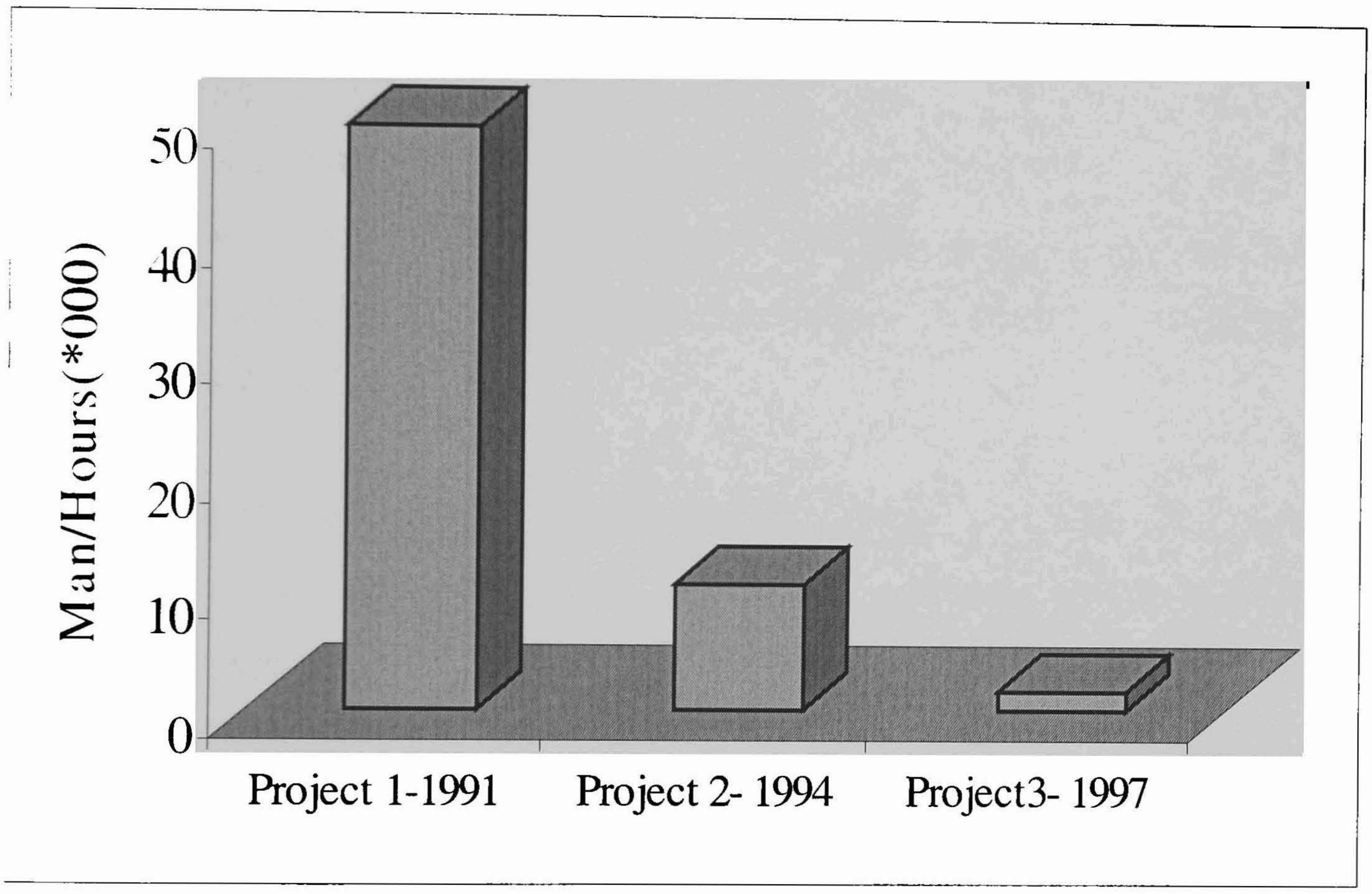

Figure 20: Man/Hours in a Reusability Process at YellowTech

Three consecutive projects between 1991 and 1997 were involved in reusing a specific source code. Figure 20 shows the man/hours invested in each project, indicating that the cost of developing the source code in the third project was only 2% of the first project. The extent of the cost-effectiveness of the reusability process is fully understood when one makes the link between the growing trend to reuse technologies and designs presented in Figure 10 and the tremendous saving in man/hours in three consecutive 'reused' software projects presented in Figure 20. When these two figures (i.e. Figure 10 and Figure 20) are analysed together, the implications for YellowTech's business performance become evident suggesting that the company significantly reduced R & D costs in 'reused' projects, improving its product and market success.

In addition to the cost-effectiveness of the reusability system, the Head of the Software Group claimed that the reusability system helped in getting a better feel for estimating the costs involved in software development before the project starts.

5.3.9.5 Summary: Business Performance at YellowTech

The above-presented business performance suggests that YellowTech has improved market penetration, order backlog, revenue and success rate in bidding in the last five years. Evidence presented in previous sections has shown that throughout the years between 1995 and 2000, the company has aggressively pursued the introduction of cross-project learning mechanisms in the form of reusability strategy.

We conclude this section by suggesting that the recent improvement in product and market success may possibly be linked to the successful implementation of cross-project learning mechanisms. We realise that the variables we use to suggest the above have some limitations; however, the primary purpose in this section was not to develop a comprehensive model to predict product and market success (Cusumano and Nobeoka 1998). Obviously, selling products in defence markets is a complex task. Some of the aspects involved are political and there is a strong political and industrial lobby that promotes purchasing defence systems from the domestic defence industry. Yet doing a better job than the competitors in designing, building and maintaining defence systems would support a long-term successful sales strategy. In this sense, the reusability strategy at YellowTech was aimed at achieving these objectives.

Before moving forward to organisational and managerial issues at TAMAM and Rafael, we acknowledge that further study is needed, in particular with regard to statistical correlation between product success and cross-project learning mechanisms.

The next section reviews cross-project learning mechanisms implemented at Rafael and TAMAM.

5.4 Cross-Project Learning: A Review of Lessons Learned at TAMAM and Rafael

5.4.1 Introduction

Thus far, the above sections reviewed in detail the mechanisms put in place at YellowTech. As seen, data suggest that YellowTech has improved product success and market competitiveness following the introduction of these mechanisms.

This section presents organisational and managerial mechanisms and processes supporting cross-project learning implemented at TAMAM and Rafael, and stresses their contribution to product success.

5.4.2 Lessons Learned from TAMAM: The Strategy for Cross-Project Learning

Despite the similar objectives shared by TAMAM and YellowTech with regard to cross-project learning, a rather different approach has been taken by TAMAM in implementing mechanisms supporting this activity. TAMAM, which has been urged to demonstrate strong financial results by the Israeli Aircraft Industries, its mother company, relied on the centrality of the system engineer in the design process to support cross-project learning activities.

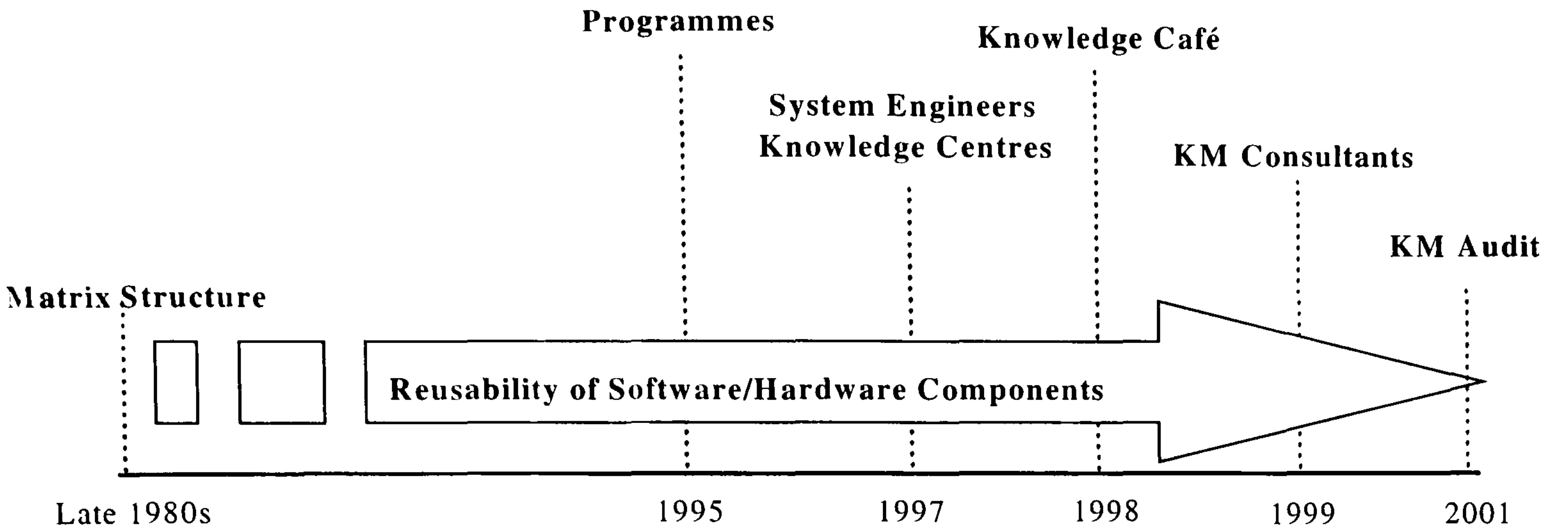

Figure 21: The Process of Introducing Cross-Project Learning at TAMAM

Two major actions were taken at TAMAM between 1995 and 1997 that changed the nature of cross-project learning (see Figure 21). The first, in 1995, was aimed to create product families through the grouping of projects in programmes. The second was the decision that system engineers would be at the centre of the technology transfer process, making a link between the base project and the receiving project. This new role gave system engineers the name 'knowledge centres'.

Nevertheless, managers at TAMAM reported that projects were reusing software and hardware components before 1995 mainly through informal channels. Also, Design Review sessions and other knowledge exchange forums were indicated by managers as helpful in exploring reusability alternatives (Sobek et al. 1998). Indeed, TAMAM has been paying attention to the benefits offered by reusing technologies.

The rhetoric at TAMAM was similar to YellowTech's, peppered with the slogan 'avoid re-inventing the wheel', aiming to promote the reusability of platforms and components across projects. Yet, the implementation of cross-project learning has not always been aligned with present project management philosophy at TAMAM. For example, management insisted on managing projects as profit centres. This practice has directed project teams' efforts towards internal affairs, supporting 'domain innovations' (Boland and Tenkasi 1995). By contrast, management's intention was to promote the reusability of technologies, through 'boundary innovations' (Blackler et al. 1999). In this atmosphere, project managers, engineers and system engineers cooperate in order to reuse technological platforms and components.

In addition to the above-mentioned characteristics, TAMAM also relied on the matrix structure (McCollum and Sherman 1993); however, with an attention to the centrality of the system engineer in the process of transferring designs. In addition, the organisation of projects in programmes has been another mechanism put in place to foster the reusability of components between projects of the same product family. Other mechanisms, mainly informal in nature, were described, yet they portray a similar picture to those presented above and therefore will be briefly reviewed. This mainly refers to informal communication channels, autonomy and the reward system.

5.4.2.1 The Organisational Structure at TAMAM: The Role of the System Engineer

In essence TAMAM implemented the classic matrix structure, which horizontally accommodates the five directorates and vertically the different programmes. A good description of a similar organisational structure that was implemented at TAMAM can be found in Quinn et al. (1988:290).

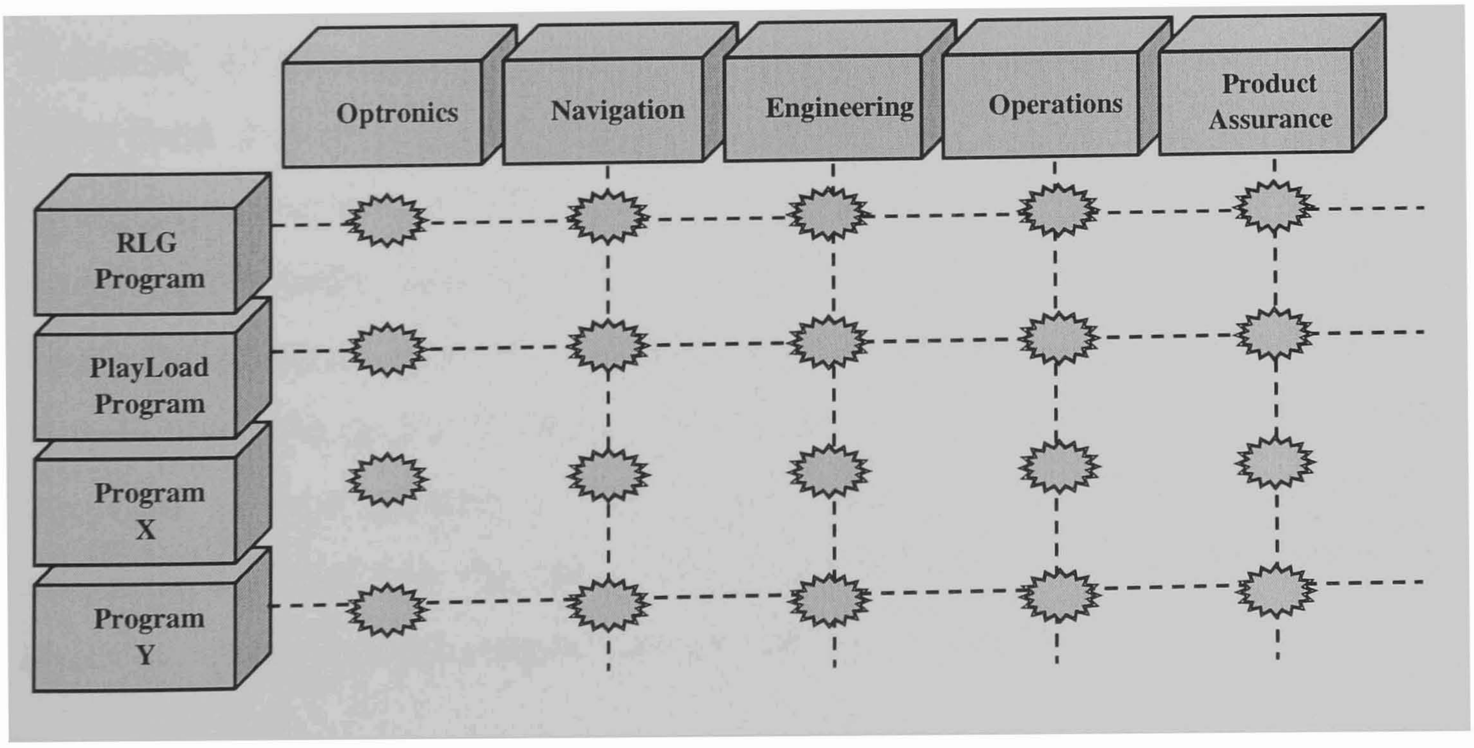

Figure 22: Matrix Structure at TAMAM

The role of the system engineer is central to cross-project learning activities. The system engineer is associated with the vertical integration of technologies that are organised horizontally in the professional directorates (see Figure 22). On the other hand, the management of the programme, i.e. the horizontal integration of different professional teams within the matrix structure, has maintained a clearer picture of current activities across different projects. Yet the management of programmes at TAMAM has lacked the technical knowledge needed to facilitate cross-project learning. This was because the personnel in this section of the matrix structure was project management and Sales orientated, with little or even no engineering background. One project manager explained:

> *There are two dimensions in the matrix structure. One is the professional fields and directorates and the second is project management. [...] project management at TAMAM has two areas of responsibilities. One is about scheduling and coordinating project activities. The second is to work with clients. Project managers at TAMAM don't have an engineering background. Most of us come from project management positions in the Israeli Air Force.*

This situation posed a dilemma to management at TAMAM. On the one hand project and programme managers were most suitable to lead reusability efforts because of their visibility on different projects across directorates and within their own programme; however, they lacked the understanding needed to lead a reusability effort, which might jeopardise the project objectives and goals. On the other hand, system engineers, the experts who hold knowledge about the various technologies and solutions that can be reusable, were located in the professional directorate. Initially, this location of the system engineer was logical because of their engineering orientation. However, from a cross-project learning perspective, system engineers as part of the professional directorate were not effective. Their exposure to new projects, client's requirements in these projects and the technological base that the client would like to see were all limited and often relied on reports that the project management team provided.

Thus, the role of the system engineer has changed, and metaphorically they have been relocated into a space between project management and the professional field. In reality, system engineers become more involved in project management activity.

In a way, system engineers developed a dual identity which allowed them to cross community boundaries (Wenger 1998). System engineers integrated shared histories of learning from the area of engineering with fresh learning from the project management field. However, the system engineer was also put in the almost impossible position in which he or she needed to satisfy both the professional directorate and the programme unit (Sobek et al. 1998).

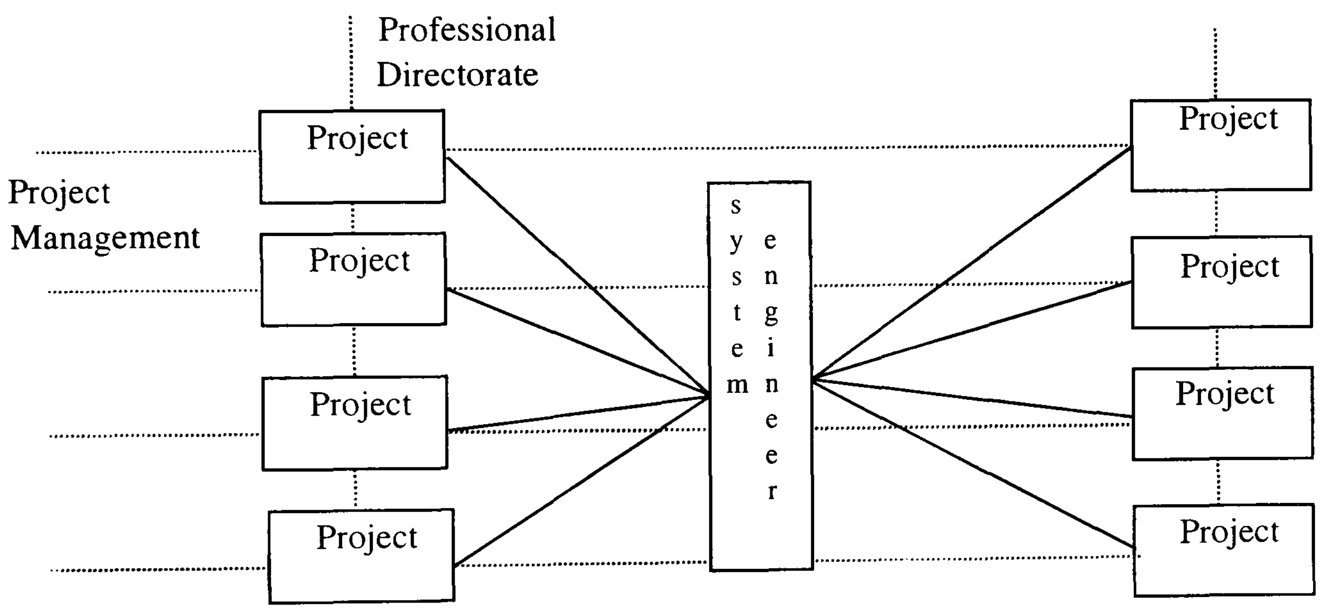

Figure 23: The Role of System Engineer in Vertically Integrating Knowledge

Therefore, the structure and dynamics that emerged at TAMAM demonstrates a high level of participation of system engineers across different project teams (Lave and Wenger 1991; Wenger 1998).

5.4.2.2 The Organisation of Projects in Programme Setting

The organisation and management of several projects in one programme has also supported cross-project learning activities. Projects were clustered together based on their source technology, creating islands of product families within the matrix structure (Meyer and Utterback 1993; Nobeoka 1995; Sundgren 1999). Figure 24 presents the relationships between core technology and a number of projects that may be managed as a programme or perhaps will be treated a product family.

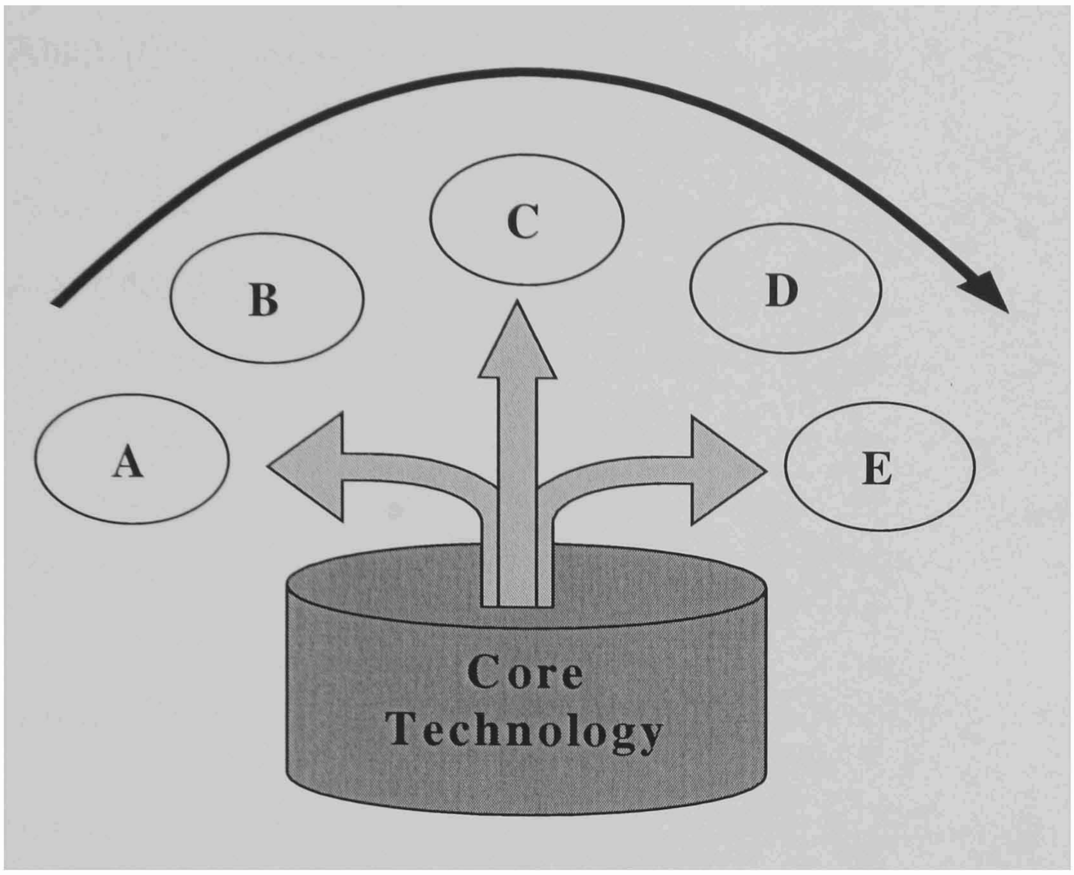

Figure 24: Core Technology and Projects at TAMAM

Figure 24 illustrates the use that five different products (A-E) are having in the same core technology. Figure 25 describes the development of product family from one core technology through time and through different programmes. Mayer and Utterback (1993:32) provide an analysis of these dynamics, suggesting that in the long run product families are the core capabilities of a firm.

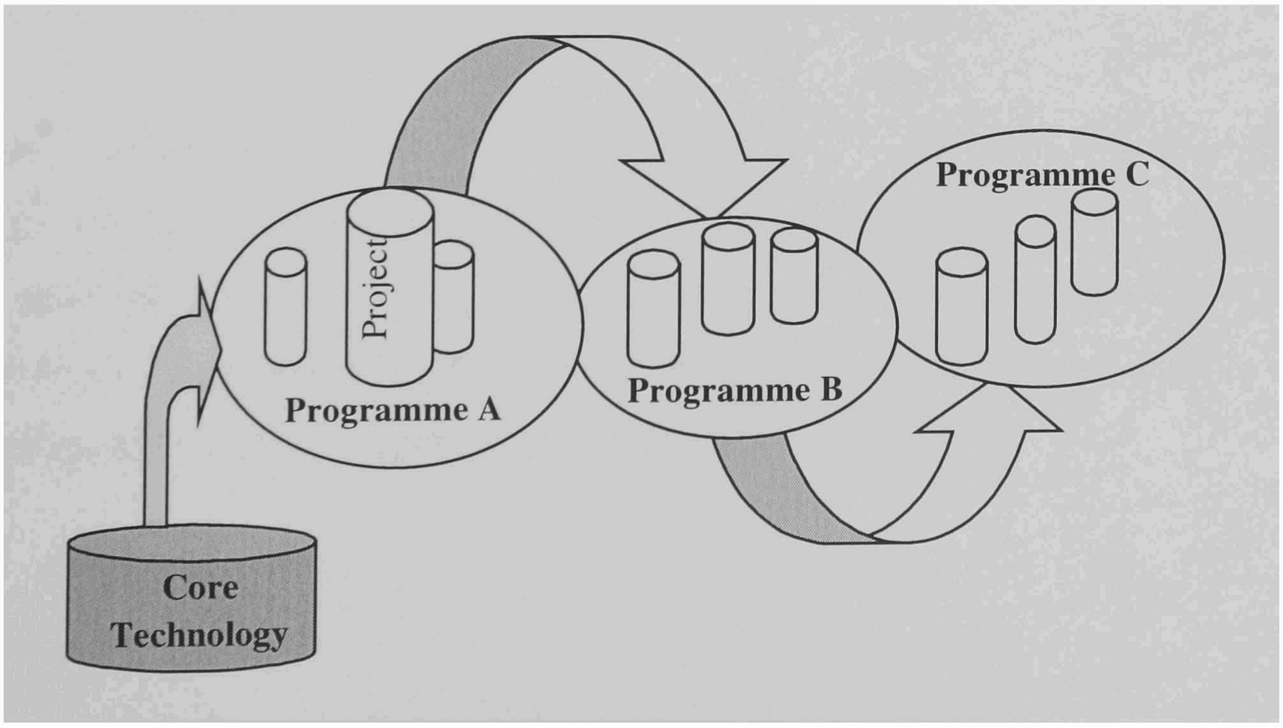

Figure 25: The Development of Product Family

This grouping of projects in programmes is essential for cross-project learning at TAMAM. This organisation provided a better exposure to multi-project activities within one programme for the system engineer. Through this exposure, it can be claimed, TAMAM managed to successfully reuse components within the same programme[7]. The main pitfall in this approach was the lack of a cross-programme learning process. However, it has been argued by managers that a programme would usually specialise in one core technology and transferring this technology to another programme is quite rare and even does not make sense. For example, in the Navigation directorate there are two types of core technologies. One is based on the giro technology and the other one on laser technology. It would be a rare case to see these two share technological platforms or components.

5.4.2.3 The Role of Design Reviews and Knowledge Exchange Meetings

Design Reviews at TAMAM were indicated as a mechanism that supports, amongst other things, cross-project learning. Because of the separation between project management and technological design roles at TAMAM, design reviews have addressed both project management and design issues. One system engineer from TAMAM explained:

> *During Design Reviews we had to discuss design issues as well as project scheduling and coordination matters. Most of the issues were relevant for both project engineers and people from the professional directorate.*

Project management issues were presented by the project manager, whereas design matters were presented by the senior project engineer in the project team. The participants in these sessions, most likely system engineers, the Head of the Directorate, and project leaders from the various directorates, commented on issues regarding the management of the project and the design.

[7] See an example of a successful knowledge reusability process in section 6.5.3

With regard to the management of the project, discussion would revolve around timelines, milestones, resource allocations and coordination. The decisions that were agreed in this session would be crucial to the successful execution of the project.

From the cross-project learning perspective, the presentation of the initial design generates feedback, mainly from system engineers, about existing solutions in-house that can cut short the development process. These existing solutions can be part of the same product family or perhaps reside in another product programme. Yet the linking point, as described in section 5.4.2.1, was the system engineer.

In addition to Design Review sessions, TAMAM also introduced numerous Knowledge Exchange sessions; however, these forums did not have a fixed time schedule and attendance has been reported as low. One forum addresses Sales issues and aims to share 'war stories' between the participants. It has been reported by one project manager who attended this session that only a few Sales people attended; however, they were reluctant to speak up about their experiences. This project manager theorises that the reason for this was perhaps the internal politics between different desks organised by geographical areas.

Engineers and managers from TAMAM actively participated in the Knowledge Café forum, a cross hi-tech industry forum organised by Dr. Edna Pasher and Associates. This forum provided TAMAM with an exposure to recent knowledge management and product development practices in other electronics defence companies in Israel.

5.4.2.4 Technology Management: Commonality and Modularity

Commonality at TAMAM with regard to software packages supporting hardware and software development has emerged as a common sense practice. It has been suggested that there has not been any decision about who would be responsible for this matter. Yet engineers pointed out that the Head of IT Services at TAMAM 'took care of this issue'. One senior hardware technician from TAMAM claimed:

The IT Services department is responsible for upgrading software versions. We are informed once software packages are upgraded.

However, engineers indicated that there are cases in which individuals upgrade their own software, and often this creates problems when versions of software development platforms are not compatible.

Software development practice at TAMAM has followed the Object Orientated practice since the mid-1990s. For a detailed description, see section 5.3.5. Software engineers reported that indeed the Object Orientated practice improved the transferability of software modules between projects.

5.4.2.5 Integration with Sales and Interactions with Clients at TAMAM

The Sales team at TAMAM is part of the programme structure (see

Figure 26). Sales people are allocated to a specific programme and a distinct geographical area within the programme (Van den Bulte and Moenaert 1998). At TAMAM the Sales team lacks any engineering background. Most of the personnel in the Sales team are retired high rank officers from the Israeli Air Force. The integration of the Sales team into R & D has been achieved through the matrix structure. It has been argued that the Sales team participates in almost all project-related meetings. However, because of their lack of technical skills, the immediate contribution to cross-project learning in the sense of transferring specific designs, has not been significant. However, their participation in project meetings has contributed to the effectiveness of communication between R & D personnel and the Sales team. The impression is that gradually the Sales team has started to speak the 'engineering language'. Perhaps more importantly, their participation in some project meeting has contributed to the development of the 'pilot language' by engineers.

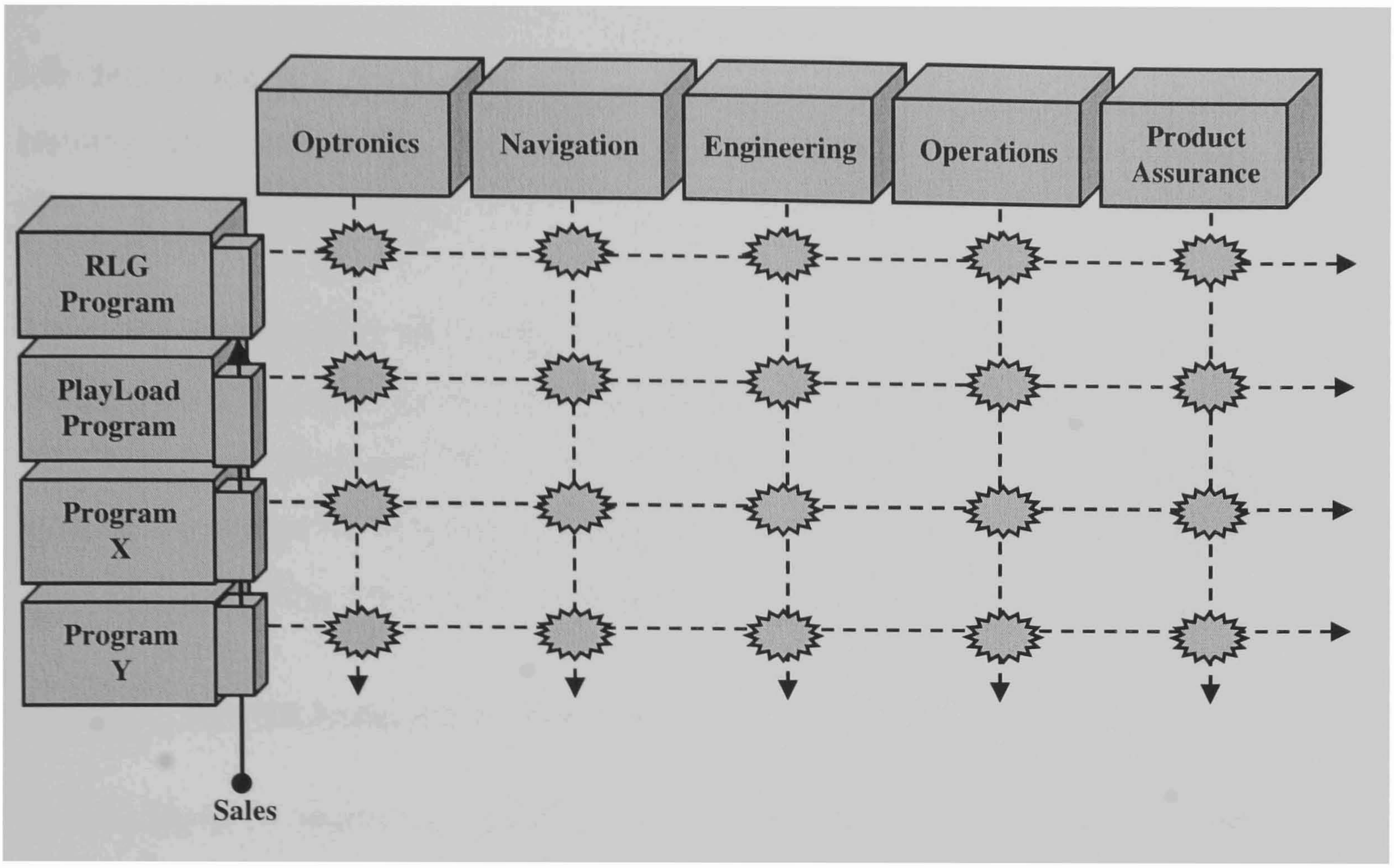

Figure 26: Sales Team in the Matrix Structure at TAMAM

Interactions with clients at TAMAM portrayed the same characteristics as in YellowTech. YellowTech also accommodated some of its clients in the company's premises. Some geographical areas within the R & D space were allocated to specific client projects which created sections of product families. However, despite the impression that the above geographical layout may have boosted interactions between project teams, these interactions were not systematic; nor was it claimed that the geographical arrangement was a chief factor in facilitating knowledge transfer.

5.4.2.6 Motivational Factors at TAMAM

5.4.2.6.1 Autonomy

As in YellowTech, engineers and managers were granted a relatively high level of autonomy within their area of responsibility. However, the move towards the reusability practice has caused some unease with regard to engineers' autonomy, in particular concerning the balance between exploration and exploitation of technologies (March 1999).

Job design and job description was another factor in promoting cross-project learning activities, as this area enjoys a loosely-defined set of responsibilities (Sherman and Nadler 1996).

Thus, the combination of a high level of autonomy and loosely-defined job description stimulated interactions, discussions and participation across projects (McCollum and Sherman 1993). These activities facilitated participative learning leading to collective learning through the development of communities of practice, by creating a sense of belonging and shared language (Wenger 1998).

5.4.2.6.2 Informal Communication Network

Communities of practice at TAMAM were the foundation upon which a wide informal communication network between experts was established (Tushman and Nadler 1996; Van Aken and Weggeman 2000). These communication networks varied in form and objectives, and included such as informal chitchats while commuting home, in the corridors or during lunch. These channels were considered useful although in most cases the results of these interactions did not target a specific problem. A rather more focused and problem-solving informal session was the Café forum every Thursday afternoon. In this session project teams of the same programme gathered to have a cake to celebrate the end of the week. Managers and engineers interacted in discussions about problems and progress in different projects and often learned about common and repetitive problems in design.

As argued above, research on the contribution of informal interaction to learning is inconclusive. Our data suggest that informal interactions supported cross-project learning at TAMAM. In particular, informal interactions between project teams of the same programme were indicated as a source for sharing solutions and becoming aware of potential problems in their design of the core technology.

5.4.2.6.3 Rewards

TAMAM, similarly to YellowTech, lacks a reward system that remunerates either individual or group effort for successfully executing cross-project learning activities.

5.4.2.6.4 Leadership

Data suggest that leadership and sponsorship of cross-project learning was vaguely defined at TAMAM. The co-researcher of this study has been promoting knowledge management and learning activities but without a well-defined budget, resources or the full support of the General Manager. The co-researcher participated in numerous knowledge management forums and was often presented as 'the knowledge management person' at TAMAM. Yet there were mixed signals within the company with regards to the importance that TAMAM has given to knowledge management.

When the results of this study were presented to top management, including a review of most recent knowledge management practices in intense R & D companies, the General Manager of TAMAM summarised this exercise by saying;

> *We will probably never be like Buckman Industries or IBM, but it was a quite interesting exercise to do.*

This statement can perhaps be interpreted as if TAMAM's management would like to see engineers reusing technologies and platforms to cut R & D costs; however, without investing in the organisational infrastructure that would effectively support cross-project learning.

5.4.2.7 Summary: Organisational Characteristics and Capabilities for Cross-Project Learning at TAMAM

The system engineer integrates learning between different projects within a professional directorate by operating in the area between project management and the professional field.

The organisation of a number of projects in one programme formulates a small cell of individuals who transfer learning and experiences within the programme boundaries. However, the same programme entities obstructed cross-programme participation, hence inhibiting cross-project learning across the R & D Division.

Values and norms at TAMAM were characterised by the high level of autonomy; however, with mixed signals from management. Yet market pressure to reduce R & D costs, shorten R & D project times and supply a reliable and yet simple to maintain defence system pushed project managers and system engineers to choose the reusability strategy.

Dynamics of Capabilities and Competencies

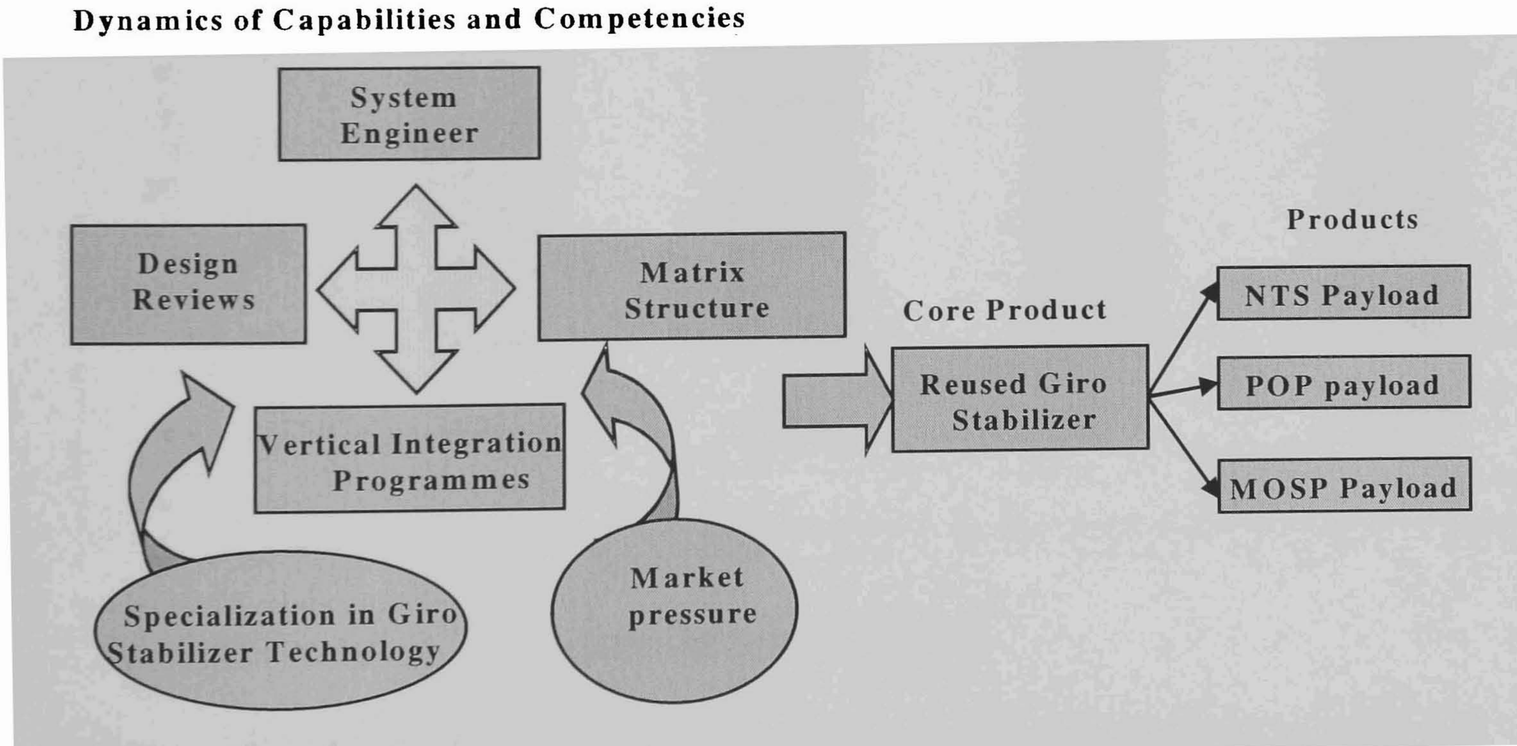

Figure 27: Dynamics and Products of Cross-Project Learning Capabilities at TAMAM (Based on Coombs 1996)

Figure 27 presents a case in point of the Payload family, in which the Giro Stabiliser component was reused across different products.

5.4.2.8 Business Performance Indicators: TAMAM

Data about TAMAM's business performance in recent years was not available from management. Neither had TAMAM monitored or analysed the cost-effectiveness of the reusability strategy. Yet it was claimed by the Head of the Quality Assurance directorate that project development time has been much shorter since attention was given to the management of programmes and since there has been more attention to reuse components.

Data of the last four years' sales performance suggest that TAMAM is improving its positioning in the electro-optic/navigation system markets (Dror Marom, Globes, 28/02/2001). Figure 28 presents a steady growth of sales.

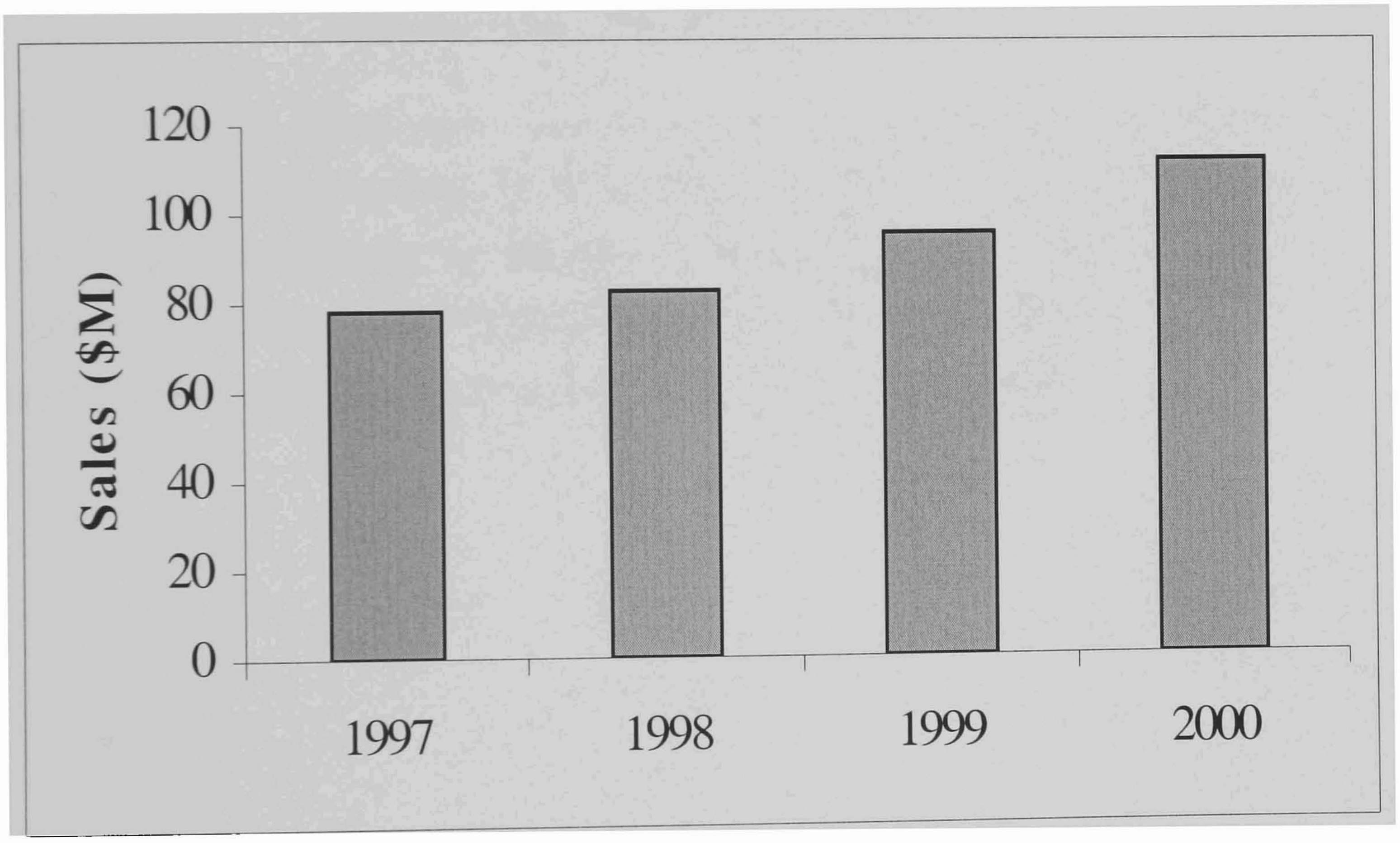

Figure 28: Sales at TAMAM

In terms of profit, TAMAM presented a marginal profit of $1 million in 1998 and $2 million in 1999 and 2000 (see Figure 29).

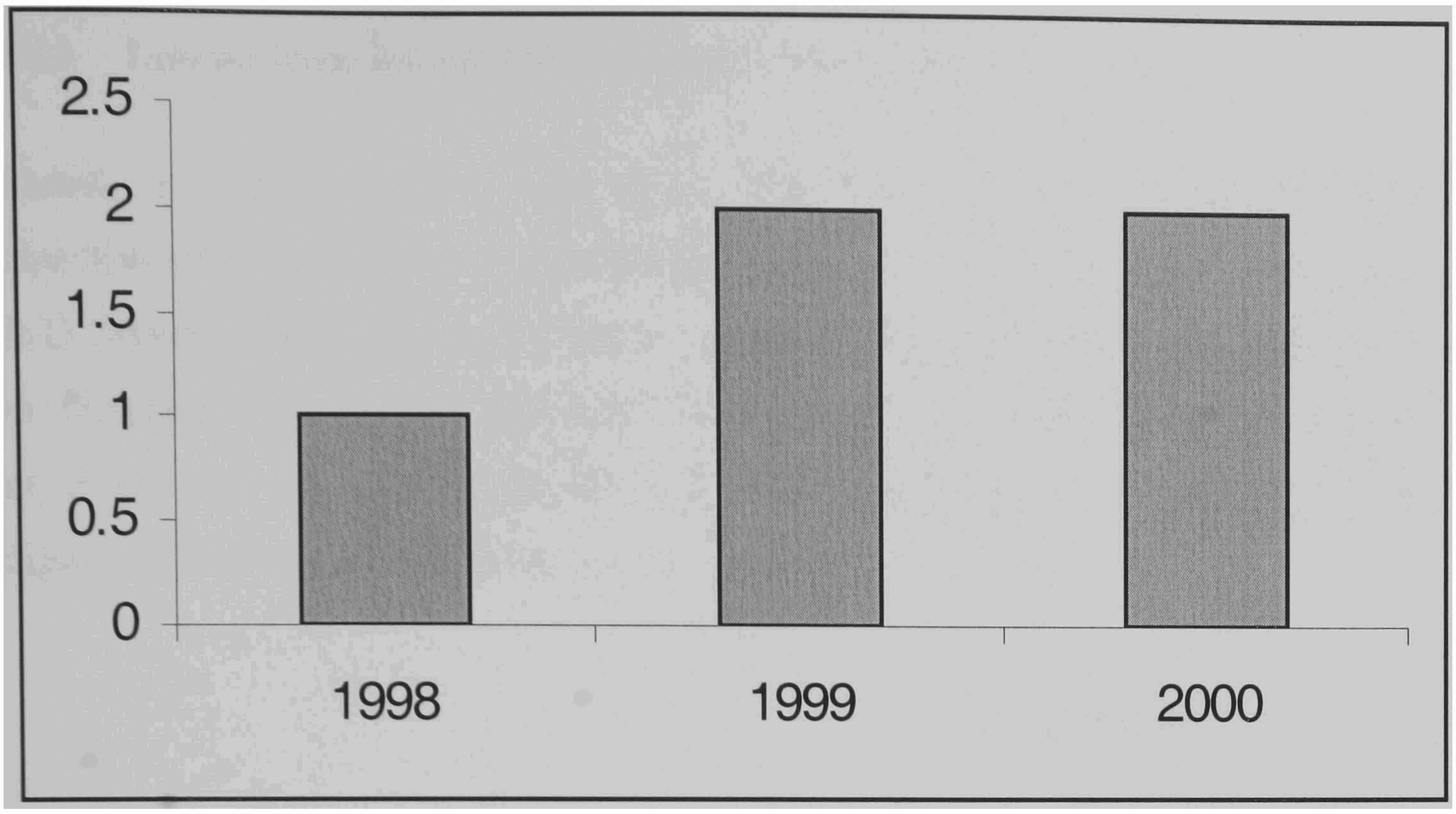

Figure 29: Profit at TAMAM 1998-2000 (in $M)

Thus, it may be argued that, similarly to Yellowtech, TAMAM improved its market success and maintained profitability following the implementation of cross-programme learning mechanisms, with the caveat that the limited success indicators available from TAMAM may blur the true correlation between implemented cross-project learning mechanisms and product success.

5.4.3 Lessons from Rafael: The Strategy for Cross-Project Learning

Rafael, a research-driven organisation that only recently adopted business objectives, has formulated a robust informal communication networks within its R & D Division. Data suggest that Rafael has successfully harnessed social networks to facilitate cross-project learning. This activity was supported by a matrix organisational structure, design review sessions, technology management and the high involvement of individuals in problem solving activities.

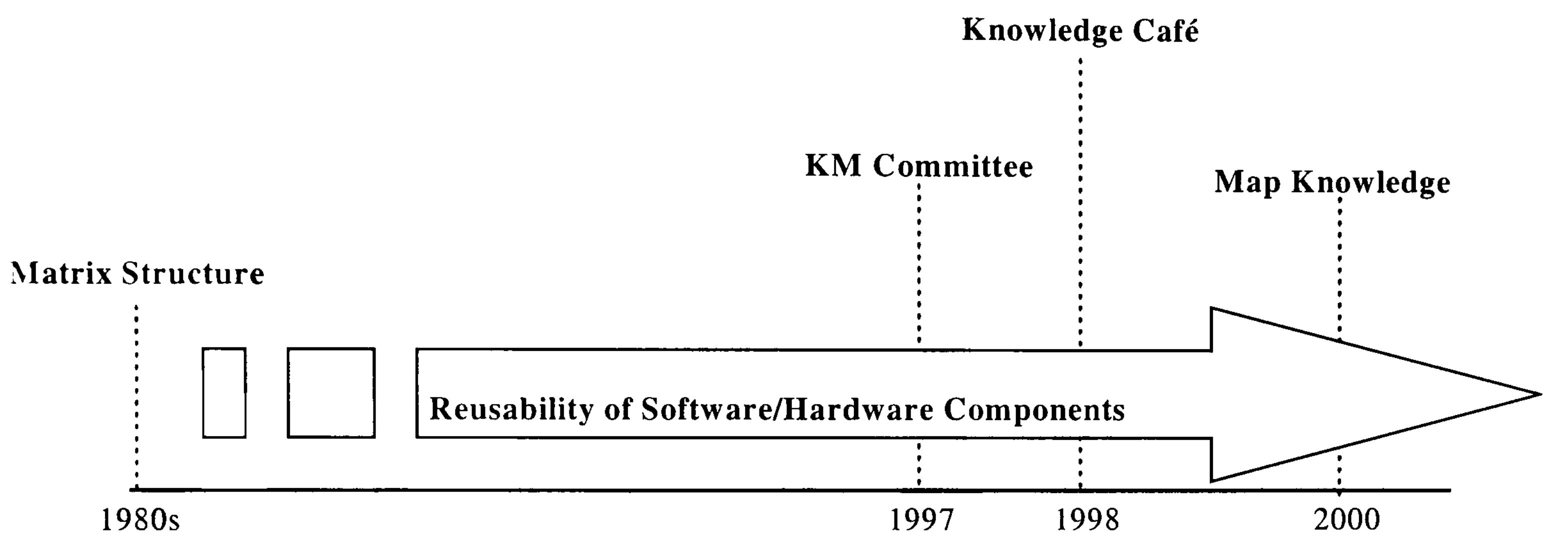

Figure 30: The Process of Introducing Cross-Project Learning at Rafael

Rafael reused software and hardware components well before 1997. However, only recently has Rafael been putting an emphasis on cross-project learning by setting up a committee to explore knowledge management initiatives, promoting knowledge exchange forums, through participation in Knowledge Café activities, and by launching a knowledge management project aiming to map knowledge centres. Nevertheless, the vast majority of cross-project learning activities have relied on social interactions. The following section will demonstrate the nature of cross-project learning at Rafael.

5.4.3.1 Social and Informal Communication Networks at Rafael

The situation portrayed by managers, engineers and technicians suggests that cross-project learning activity has taken place at the lower level of the organisation, meaning that cross-project learning activities were driven by project managers, engineers and technicians. It has been suggested that social networks at Rafael were well-established, developed over many years of shared research interests, of a high level of autonomy (Sherman and Nadler 1996) and of loose job descriptions, which all facilitated informal interactions between individuals and groups (Wenger 1998). A description of the process of cross-project learning at Rafael provided by the Head of the Popeye Administration demonstrates the above:

> *We reused many components from the core technology of the Popeye missile. [...] There is more than one way to ensure that components will be reused and we trust our engineers to find a way that makes sure that we don't waste time and money on reinventing wheels.*

At Rafael, cross-project learning activities were generated at the project level during either the design stage or while the team has encountered a problem in the design.

In either cases, the person who identifies the opportunity to reuse a component from a base project becomes an internal entrepreneur for the cross-project learning process (Nonaka 1994). During this process, this person harnesses more people and creates a network of experts who attempt to solve the problem (Floyd and Wooldridge 1999). Data show that the entrepreneur is usually one of the more experienced engineers in the project, who has been with the company for many years, established network centrality within the professional field (Pfeffer and Salancik 1978), and hence is usually free to pursue his or her own goals and gain structural autonomy (Floyd and Wooldridge 1999).

During the process of creating a network of experts that will facilitate cross-project learning, the entrepreneur engages in discussions with members of the project team, suggesting that a solution to the problem can be found in another project (Nonaka 1994). The entrepreneur has either a specific knowledge of the solution that resides with another project or he or she make an assumption about the potential reusability process based on a generic knowledge he or she possess about the other project (Floyd and Woolridge 1999).

It was argued by the Head of the Popeye Programme that Design Reviews were often the stage in which the build-up of social networks for reusability were formed. However, to execute a reusability process, the flexibility of the matrix structure at Rafael was needed (McCollum and Sherman 1993).

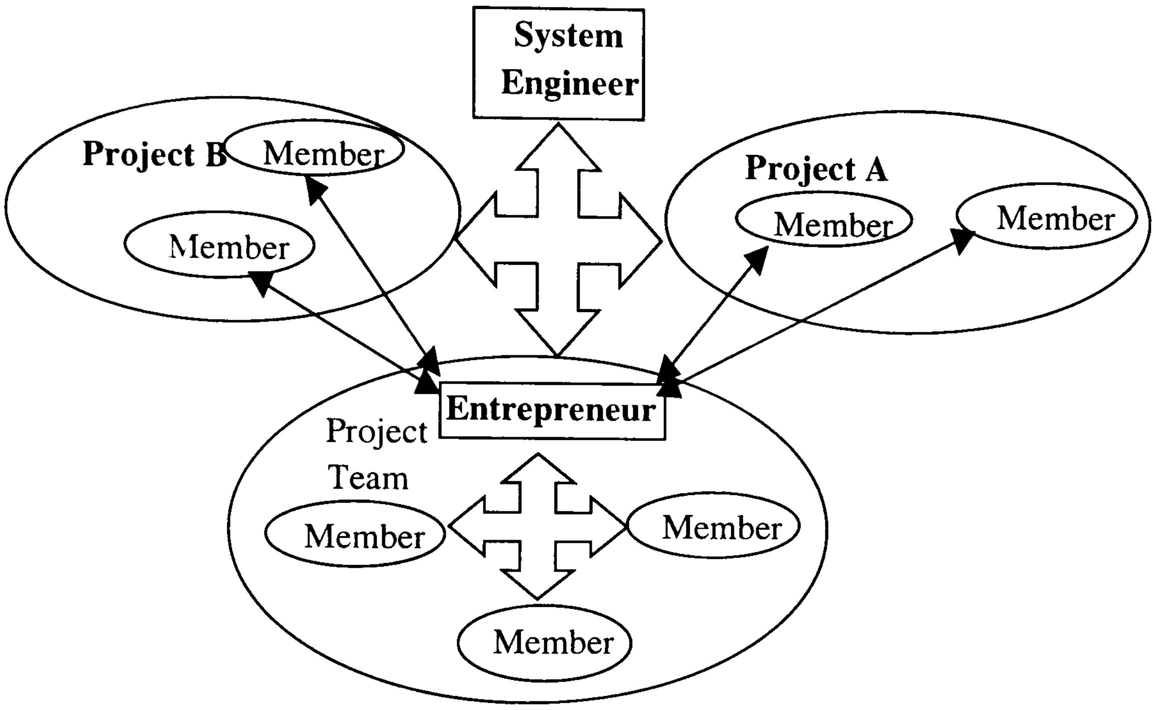

Figure 31: Interactions between the Entrepreneur and Other Members of Projects in Social Network

Figure 31 suggests that the entrepreneur, who can be the project manager, engineer or technician, is central to the cross-project learning activity. The network is created through discussions that the entrepreneur initiates with individuals who are potentially in positions to support the transfer process.

One engineer from the Lightning project at Rafael explained:

When I am facing a problem that I cannot immediately resolve by myself, I will start asking colleagues from the Division, those who should have some knowledge of the technology. Usually what happens is that one engineer brings another colleague and we eventually find a solution.

One aspect of the development of cross-project learning at Rafael is the expansive nature (Engestrom 1999) of the activity, during which more participants join and new themes emerge (see Figure 32).

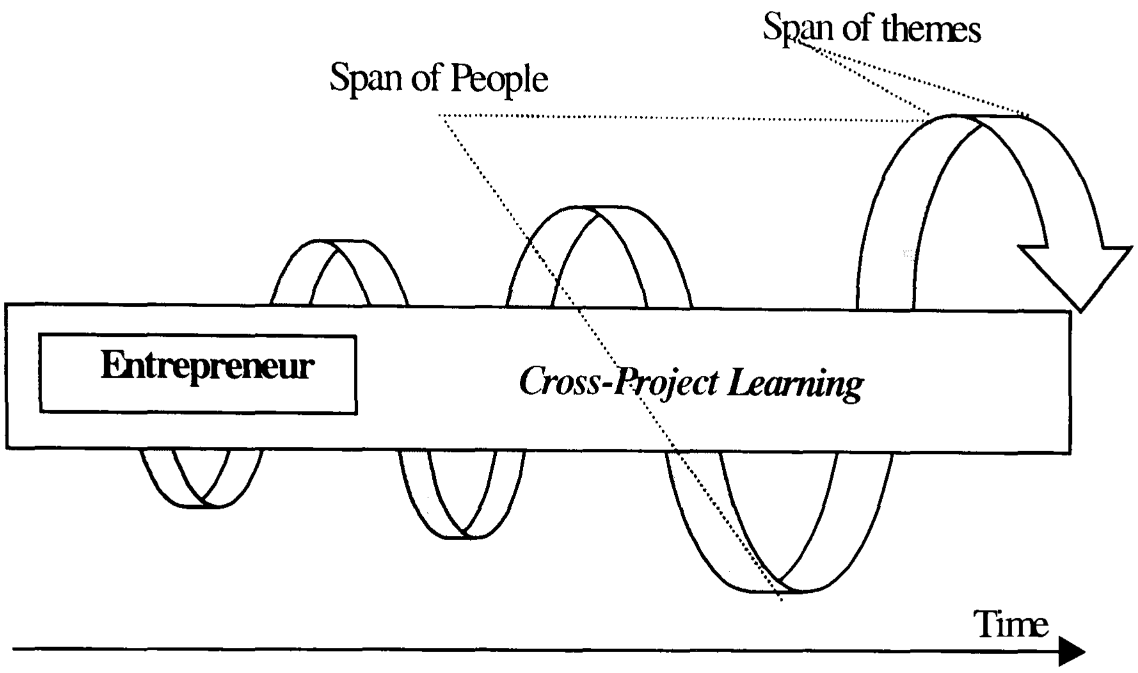

Figure 32: The Expansive Nature of Social Network in Cross-Project Learning Activity

For example, a reusability process of one electronics card from one Popeye project to another started with one system engineer checking the input/output socket of the base component to validate the compatibility of the card. A few days later further tests were carried out, including checking the processing time of some of the functions. As this activity between two projects progressed, the participants raised more concerns and debated the feasibility of reusing the card until the point at which a decision was made by the project manager that 'it was worth bothering'.

One project engineer from the Popeye project at Rafael claimed:

> *Usually when we reuse a component this [activity] starts with a couple of people involved but soon it becomes much bigger. There are activities that need to be coordinated and not always those who are first involved have all the knowledge required to complete the reusability of the component.*

Another aspect in this process at Rafael, which emphasises the informal nature of the activity, is the role of the system engineer. One system engineer reflected on this process, claiming that in fact they are involved in reusability processes because it is their responsibility to approve the design. Yet they confirmed that there are cases in which the initiative to reuse components started in the project level. One system engineer explained:

> *This is the project manager dilemma, whether they want to reuse or not. If a project manager comes to me with a request to help with this [reusability], I will help them as much as I can.*

Thus, the picture which emerges from cross-project learning activities at Rafael emphasises the informal nature of the process (Van Aken and Weggeman 2000), demonstrating rather a process that is entrepreneurial in nature, supported by formal and informal structures such as the matrix structure, design review meetings, system engineers and informal communication channels.

5.4.3.2 The Role of Design Reviews and Knowledge Exchange Meetings

Similarly to TAMAM, Design Reviews at Rafael have become the stage where individuals become aware of their possible contribution to the design effort. The process through which the social network was constituted, leading to the reusability of components, is described in detail in section 5.4.3.1.

Knowledge Exchange forums were another mechanism introduced by management to help the crossing of project boundaries. Two distinct professional areas used this medium in order to transfer knowledge between teams. These were the Sales group at Rafael and the Popeye Programme.

The Sales group maintains a multi-layer structure that is described in Figure 33. In order to maintain consistency in terms of the Group sales strategy, Rafael management promoted Knowledge Exchange forums for the Sales force. These forums were reported as successful, in particular when a guest lecturer was invited to discuss Sales strategies.

The Popeye Programme maintained a monthly knowledge exchange session during which one senior engineer would present recent technological development in Rafael. Because of the specificity of the subject many employees chose not to attend and the value of these sessions to product development and product design was indicated as low.

5.4.3.3 Technology Management: Commonality and Modularity

In many ways the pattern for commonality at Rafael was similar to the one at TAMAM. The Missiles Division has attempted to control the vast offering of software packages and maintain a reasonable pace of upgrades across the division. The responsibility for commonality in software development platforms was associated with the IT manager of the Missiles Division. Engineers and managers who referred to this matter argued that this area should not be subject to financial-related considerations but rather open to project-specific needs to keep up with technological development. One project engineer claimed:

> *There were times when we needed to either upgrade a software package without waiting for the MIS team or purchase a tool that the MIS team did not offer. These cases were rare but they can happen. For example, we had to make our development tools compatible with those of the IAI in one joint-venture project, therefore we purchased and implement a development tool that nobody in the Division had used before.*

In practice, the general impression was that the Missiles Division has followed this practice despite the mix of voices calling for balance between technological autonomy and financial control in this area.

Data suggest that modularity in software programmes at Rafael followed the same pattern of implementation that was present at YellowTech and TAMAM (Sanchez and Mahoney 1997). Because this is a common practice in the software industry, these findings are not unexpected. As in the other two cases, the Object Orientated practice has been indicated as the common sense practice for developing interchangeable software modules.

5.4.3.4 Integration with Sales and Interactions with Clients at Rafael

In the same manner as at TAMAM, Rafael integrated the Sales team into different programmes in the Matrix structure (see

Figure 26 for a similar structure at TAMAM). However, Sales at Rafael maintained a hierarchical structure of three layers; top management, Division, and Programme (see Figure 33). In practice, Sales personnel on the Programme felt disconnected from the Sales team at the Division and top management level. They affiliated their identity with the programmes. This often created knowledge-sharing problems between programmes as well as between the three layers of the hierarchical structure of Sales. Sales personnel often did not report back to either the Division Sales manager or the Director of Sales about their experiences in the field. This information was circulated between members of the programme and was hardly available to neighbouring programmes.

Sales people were allocated within a programme to a specific geographical area. For example, the Sales team in the Litening Programme was divided into four geographical areas: Asia and Middle East, North America, South America and Europe. The group was an amalgam of individuals with various backgrounds, including one person who had worked in the past in the 'white goods' field. Only one person had some engineering background and none of the members was a pilot. These unique and unusual characteristics for Sales personnel in the defence business were portrayed by the Head of the Litening Programme as an advantage. In his words, these characteristics are in favour the Programme because he can 'convert' these individuals to speak the 'Litening' language. Indeed, Litening is considered as the 'flagship' programme in this division, mainly because of its recent market success[8].

The integration of the Sales team into R & D was achieved through the matrix structure and through their participation in project-related meetings. However, the Sales team at Rafael suffered from a lack of technical skills and therefore their contribution to cross-project learning in the sense of transferring specific designs, has not been significant. Yet, their involvement in project meeting was indicated as a significant factor in the coordination of project activities and in managing customer relationships.

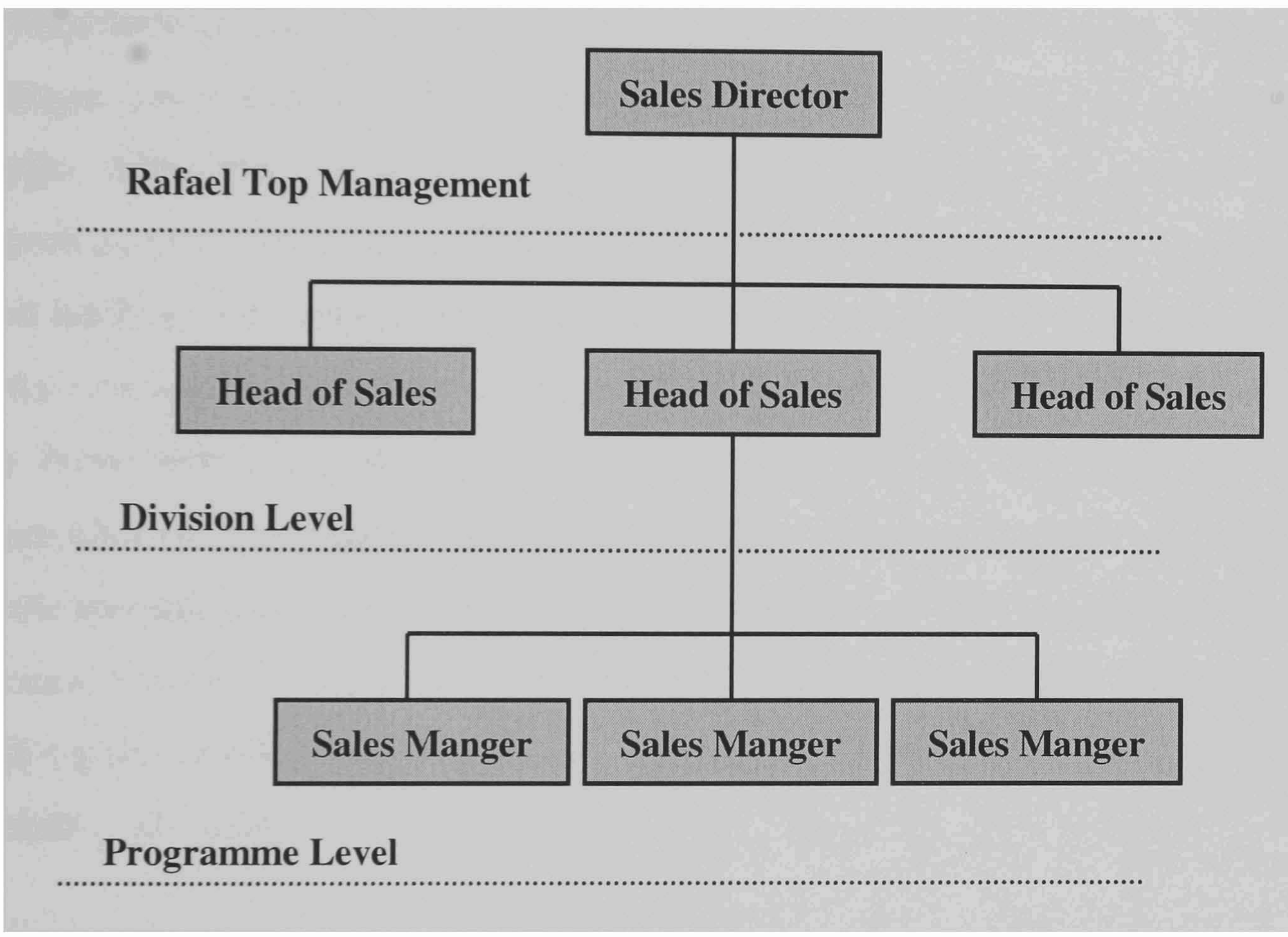

Figure 33: Sales Group at Rafael

Interactions with clients at Rafael followed the same practice as described in sections 5.3.6 and 5.4.2.5.

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[8] Data about sales and clients of the Litening programme are confidential but from interview sources the estimate is that the customer-base of the Litening programme, which is only 7 years old, is wider than that of Popeye's, which is over 20 years old. Amongst the chief clients are the Israeli Air Force, the US Air Force and Germany.

5.4.3.5 Motivational Factors at Rafael

5.4.3.5.1 Autonomy

A pattern of high degree of autonomy has emerged from the data, suggesting that engineers and managers enjoyed a relatively high degree of freedom in their area of responsibility. The first project manager of the Litening Programme explained how flexible the system was and how powerful social networks were in promoting product development activities.

When the first Lightning project reached its production stage after a very troubling development effort with some critical deadlines approaching rapidly, the project manager had a dilemma. He was very concerned that the project might encounter further difficulties during the production stage because of the novelty of the system and the first-time integration of laser and navigation systems. He consulted with his boss and together they decided to physically relocate the project manager to the production plant. In one phone call the matter was resolved and the Head of the Production plant agreed to give the project manager a desk close to the assembly line. The project manager describes how, through having coffee together in the morning and going to lunch together with the production team, he quickly became part of the team and participated in discussions, debates and decisions, making sure that the project priorities are maintained and been properly promoted (Sobek et al. 1998).

5.4.3.5.2 Rewards

Rafael maintains the same approach as TAMAM and YellowTech. TAMAM does not have any reward system for activities related to cross-project learning.

5.4.3.5.3 Leadership

Though knowledge management has attracted the attention of a number of top managers at Rafael, including the Head of the Patent Department, the Head of R & D and the Head of HR Department, none of these top managers has taken the lead and sponsored cross-project learning in particular. Furthermore, the ownership of knowledge management has been at the centre of a long dispute between these top managers and often the impression that was given to the researcher was that part of the effort towards knowledge management and cross-project learning was driven by power games rather than by professional interest in promoting efficiency and learning.

5.4.3.6 Summary: Organisational Characteristics and Capabilities for Cross-Project Learning at Rafael

Cross-project learning activities at Rafael revolved around social networks and the matrix structure. These two mechanisms are based on intense participation within and across communities of practices, generating an expansive learning activity each time a new reusability process begins.

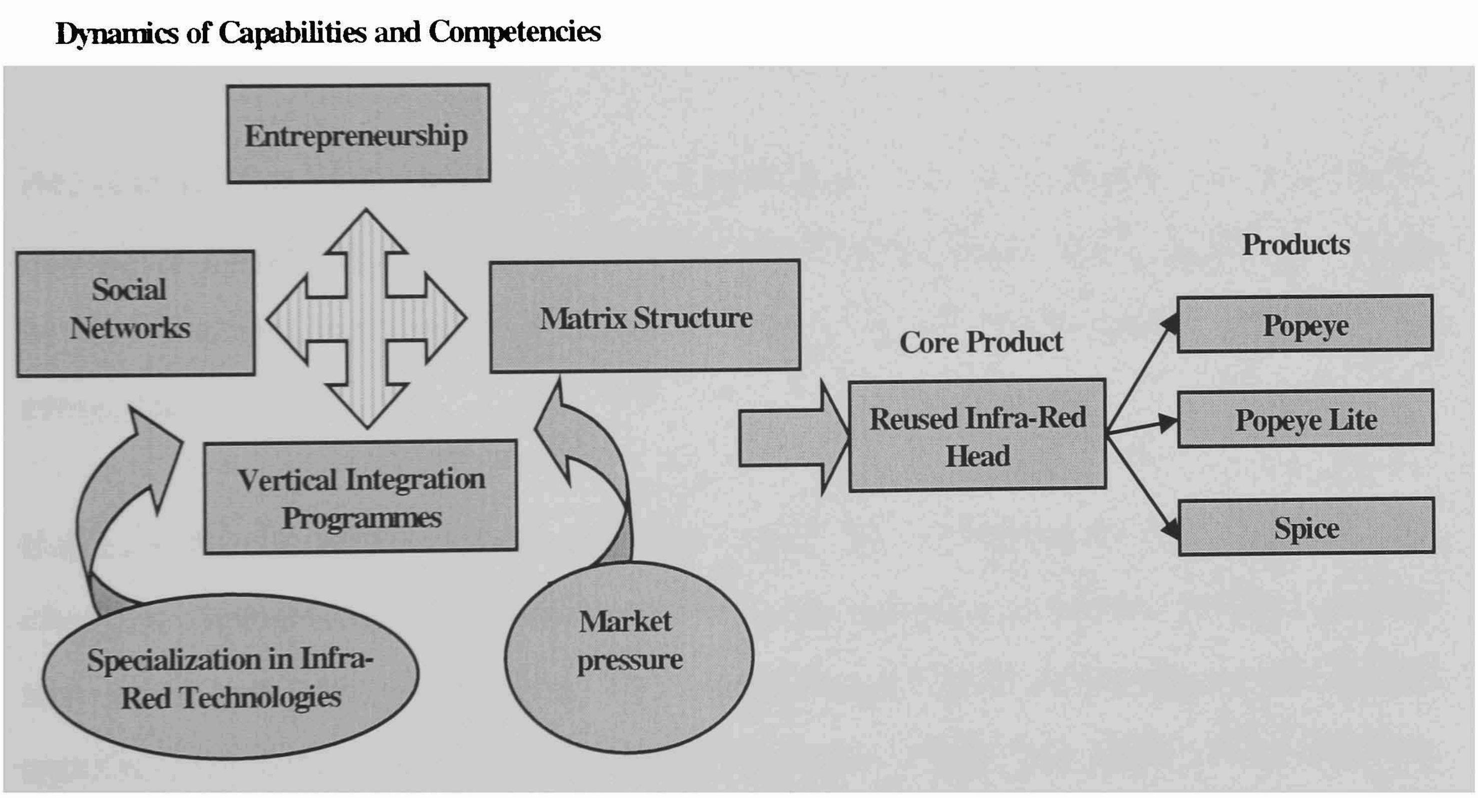

Figure 34: Dynamics and Products of Cross-Project Learning Capabilities at Rafael (Based on Coombs 1996)

At the heart of the social network activity there is the entrepreneur who starts a new cycle of cross-project learning each time the solution cannot be found within the group.

Figure 34 provides a case in point in which the head sensor of an air-to-land missile, based on infra-red detection technology, was reused by three different product families at Rafael.

5.4.3.7 Some Success Indicators: Rafael

Managers at Rafael claimed that the company has extensively reused components in the last five years. Indeed, in the same manner as in YellowTech and TAMAM, the phrase 'avoid reinventing the wheel' was used by mangers, engineers and technicians as a guideline to their project and product management philosophy.

However, Rafael did not apply any methods to measure return on investment with regard to the reusability process. In addition, data about recent new market penetration by Rafael has not been released for confidentiality reasons. Yet data from interviews suggest that Rafael has penetrated a few new markets between 1997 and 1999 including Greece, Australia, India and Holland.

Because of the subjectivity of this information, which impedes any conclusive statement about the correlation between the mechanisms put in place for cross-project learning and product success, some objective indicators will next be presented.

Rafael's recent performance indicators will be evaluated in the light of the changes implemented in product development aiming to enhance product success and improve market positioning. These performance indicators suggest that Rafael significantly improved its performance between 1998 and 2000 (Dror Marom, Globes, 04/01/2000; Dror Marom, Globes, 28/03/2001). Thus, it may be argued that, similarly to YellowTech and TAMAM, Rafael may have improved its product and market positioning following the implementation of cross-project learning mechanisms.

5.4.3.7.1 Profit

Rafael has posted a first-ever annual profit of $2 million in 2000, compared with a $30 million loss in 1999 and $80 million in 1998.

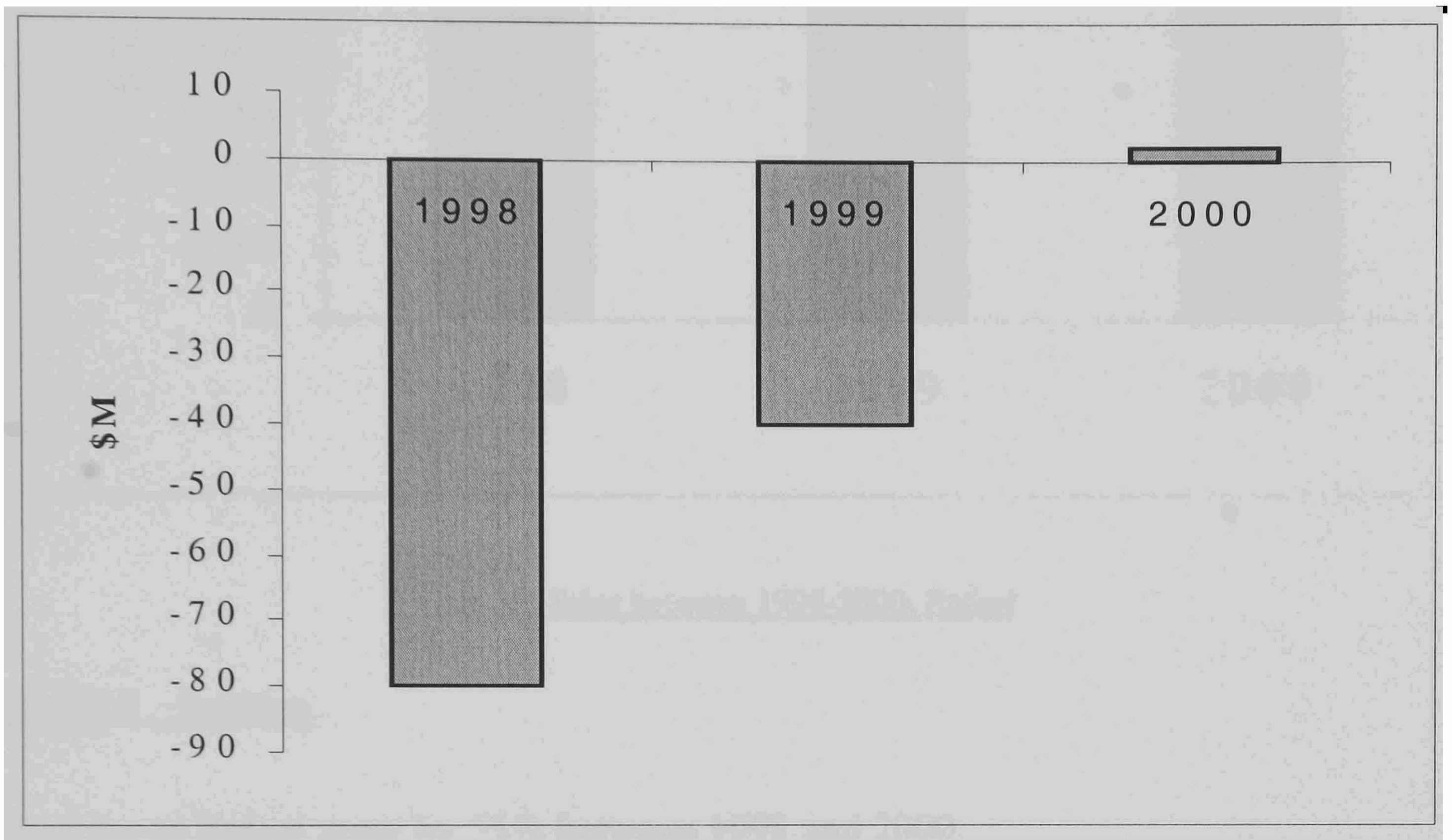

Figure 35: Loss/Profit Figures between 1998-2000, Rafael

5.4.3.7.2 Sales

Data suggest that sales at Rafael steadily grew, presenting a 50% growth in three years (1998-2000).

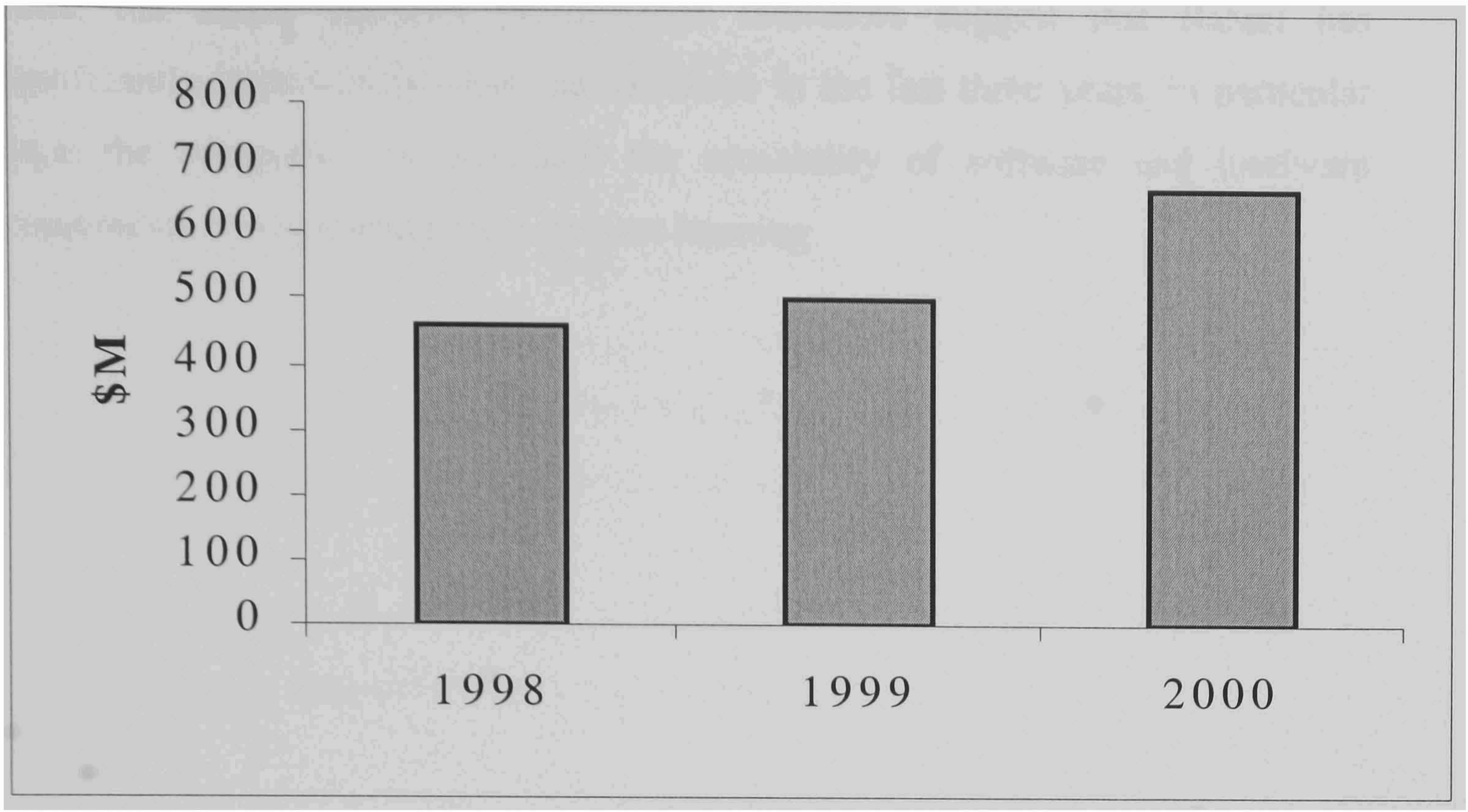

Figure 36: Sales between 1998-2000, Rafael

5.4.3.7.3 Backlog

Backlog at Rafael grew by 55% between 1998 and 2000.

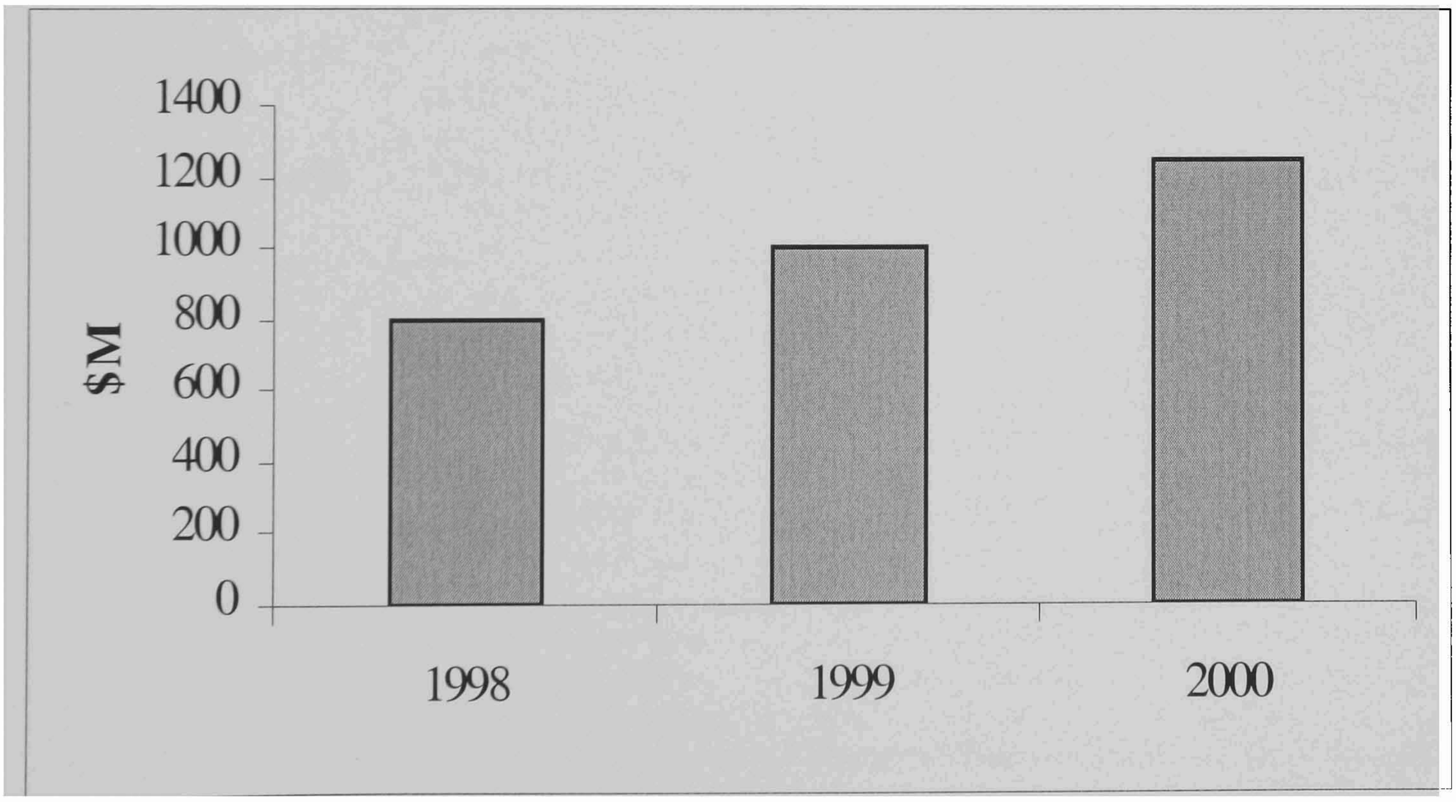

Figure 37: Backlog between 1998-2000 Rafael

Thus, the above business performance indicators suggest that Rafael has significantly improved business performance in the last three years, in particular since the company has promoted the reusability of software and hardware components by supporting cross-project learning.

5.5 Patterns of Cross-Project Learning Capabilities

The above analysis examined organisational and managerial issues related to cross-project learning in three companies. The impact of cross-project learning on product and market success was also assessed, suggesting that the studied companies significantly improved revenue and sales. Also, in some cases the cost-effectiveness of the reusability practice was evident.

The next section will seek common organisational and managerial patterns for cross-project learning between the study companies.

5.5.1 Overlapping Cross-Project Learning Capabilities

Table 4 captures the main similarities between organisational mechanisms supporting cross-project learning in the three studied companies.

	YellowTech	TAMAM	Rafael
Organisational structure	Matrix/Functional	Matrix	Matrix
Integration with Sales	Physically and structurally integrated	Physically and structurally integrated	Physically and structurally integrated
Interactions with clients	Physically integrated, highly involved	Physically integrated, highly involved	Physically integrated, highly involved
Autonomy	All levels with emphasis on project manager	All levels	All levels
Job description	Loose and undefined	Loose and undefined	Loose and undefined
Multi-functional teams	Cross R & D and Manufacturing	Cross R & D	Cross R & D
Communication channels	Social networks, Design Reviews, multifunctional teams	Social networks, Design Reviews, multifunctional teams	Social networks, Design Reviews, multifunctional teams

Table 4: Similar Organisational Mechanisms for Cross-Project Learning across the Industry

It appears from Table 4 that there are many similarities between the studied companies. For example, the matrix structure has dominated the studied environments. This confirms Cusumano and Nobeoka's (1998) findings, that indeed the matrix structure is perhaps the most useful for cross-project learning. Also, multi-functional teams were involved in providing solutions based on the participants' experience and work in the same product family. This contribution of multi-functional teams is in addition to their horizontal coordination of concurrent engineering activities.

Furthermore, the three companies invested in linking the Sales team to R & D activities by relocating members of the team from the headquarters to the R & D area, and by positioning the Sales team within the matrix structure either as a functional group or associated with project management. Also, the case study companies invested in maintaining close relationships with their clients. Representatives of various air forces were allocated to offices within the premises of these companies and become involved in the decision-making processes in cases where the project team faced acute and troubling malfunctions during the last stages of the project.

A high level of autonomy has been reported in the three case study companies. And a web of communication channels, formal and informal, has been described by interviewees from YellowTech, TAMAM and Rafael. This area will be further analysed in Chapter 6, though in a different theoretical context.

However, despite operating in a similar context, i.e. the same country, industry, and markets[9], the studied companies have shown great diversity in other organisational aspects.

5.5.2 Company-Particular Cross-Project Learning Capabilities

Table 5 illustrates those organisational mechanisms supporting cross-project learning which are particular to each company.

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[9] See Chapter 4 for a detailed analysis of global, domestic and company-specific defence markets

The management of projects at YellowTech has included processes relating to cross-project learning. In particular, the emphasis on knowledge transfer during the conception stage stood out as a distinct feature supporting cross-project learning. In addition, YellowTech implemented learning centres (Cusumano and Nobeoka 1998:29) within the matrix structure in the form of Design Centres (e.g. the ASIC team). Lastly, data suggest that different levels of individuals were involved in leading the knowledge transfer process. Furthermore, the role they were playing in the knowledge transfer process has varied significantly, from leadership to entrepreneurship.

	YellowTech	TAMAM	Rafael
Project management practices	Three distinct stages: Conception, Development & Integration		
Learning centres	Design Centres		
Reuse metrics	Mainly in software projects		
Technological commonality	Structured and centrally controlled	Unstructured, centrally controlled	Unstructured, loosely controlled
Modularity in design	Hardware and software, highly controlled	Software, highly controlled	Software, highly controlled
Projects organised in programmes (product families)	Mixed, both project-based and programme-based organisation	Programme-based organisation	Programme-based organisation
Leading role in transferring knowledge	Chief Scientist (Leadership) Project manager (Operations)	System Engineer (knowledge centre)	Project member (entrepreneur)

Table 5: Organisation Mechanisms Supporting Cross-Project Learning Distinct to a Specific Company

Yet, in addition, there are variations in the way the studied companies implemented some organisational mechanisms. For example, the matrix structure at YellowTech also accommodates functional teams such as the ASIC team (Cusumano and Nobeoka 1998:29). The grouping of projects into a programme has been observed in all the three companies; however, YellowTech did not maintain a consistent structure of programmes. Also, the level of control in the commonality practice introduced at TAMAM and Rafael falls short of YellowTech's standards. Lastly, though modularity was practised by the three studied companies, only YellowTech attempted to enforce modularity of hardware components, which are far more difficult to control.

Perhaps one should wonder what would explain these variations and differences? How can they be interpreted?

5.5.3 Competing Interpretation of Differences and Variations in Cross-Project Learning Capabilities

There are numerous competing explanations that may address the above question. This debate between strategy approaches cannot only be limited to internal organisational matters. It has to embrace the context within which the studied companies operate. Hence, the following paragraphs debate the present study's findings using some of the leading strategic thinking, in an attempt to produce an explanation for the differentiation and variation in organising product development for cross-project learning.

5.5.3.1 Classical Approach

Classical strategists would argue that these differences are the result of different long-term goals and objectives, courses of action and allocation of resources aiming at achieving higher profitability (Chandler 1962). Accepting the classical approach argument would mean that YellowTech, TAMAM and Rafael have had different short- and long-term objectives, because each company believed that the organisation of its capabilities for cross-project learning would be sufficient to enhance profitability. In essence they were right. Indeed, the three studied companies improved their financial results in the last four years despite the different implementation of cross-project learning.

Yet the present study may raise one uncertainty about this explanation. The premises in the classical approach that individuals plan the future strategic direction of the company (see Cusumano and Nobeoka 1998) has not been the case for TAMAM and Rafael. Data suggest that in these companies, especially at Rafael, the process was rather loose, and emerged from the bottom of the organisation. How would classical theory explain this? If strategy is a matter of careful planning, then any bottom-up cross-project learning management style perhaps results from poor strategic management?

5.5.3.2 Bounded Rationality Approach

We turn to the 'bounded rationality' view to explain the latter phenomenon. Bounded rationality would argue that it is in human nature to create different solutions. Managers are only able to consider a handful of factors at a time and tend to choose the first satisfactory option that presents itself, rather than the best solution (Cyert and March 1963). Thus, the differences between YellowTech, Rafael and TAMAM are the result of managers' bounded rationality decisions; that is, not necessarily the best or perhaps the worst cross-project learning practice, but just the first satisfactory practice that they have found. Theoretically, this argument sounds convincing; however, evidence supporting this argument was not found in the studied companies. Instead, data suggest that changes in markets were the driving force behind the introduction of cross-project learning. Thus, if strategic planning and managers' incompetence do not explain the differences in the organisation of cross-project learning capabilities, perhaps the environments within which the studied companies operate would produce an explanation?

5.5.3.3 Evolutionary Approach

Evolutionary strategists would argue that these differences do not matter because 'whatever methods managers adopt, it will only be the best performers that survive' (Whittington 1993:17). Environments, not managers, dictate the winning strategies within a particular context. Hence, the different mechanisms and strategies between the studied companies, according to the evolutionary approach, matter only in the context of the environmental fit.

Thus, according to evolutionary strategists, YellowTech's careful planning is in vain. Despite the leadership of the Chief Scientist who carefully planned the cross-project learning strategy, evolutionary strategists would argue that applying methods to measure the cost-effectiveness of the reusability process is irrelevant, because competition is not about these calculations but rather about a constant battle for survival. It is a long process of *adaptation* to the new game rules in defence markets that the three studied companies are experiencing, and they are still taking steps to achieve a fit with the environment. At the same time, YellowTech's approach would be explained by evolutionary strategists as the only approach for survival. Instead of focusing on a single rational strategic plan, YellowTech, the evolutionary strategists would argue, has spread its strategic options by launching various strategic initiatives to support cross-project learning. So, if YellowTech realised these game rules for survival, why have not the other two companies?

The concept of strategies of differentiation introduced by Henderson (1989) suggests that it is better for companies competing in the same environment to adopt different strategies, such as in the case between TAMAM and Rafael. This concept may explain the case of these two because of their competition in the Optronics and Payload markets. Coexistence is impossible if organisms make their living in an identical way (Whittington 1993). This biological rule may explain the differences between TAMAM and Rafael; however, it does not explain the differences between these two and YellowTech.

In Chapter 4 we outlined the case that changes in defence markets pushed the studied companies to pursue the cross-project learning strategy. Suppose that the degree of competition that each company encountered was different: would this lead to differentiation in organising cross-project learning capabilities?

Penrose's (1952) argument that large oligopolistic corporations, such as defence conglomerates, have 'buffered' their structures from the influence of market because of their monopolistic power in these markets, would rule out the case for market influence. Furthermore, this study proposes another argument against this explanation: how can evolutionary theorists explain the case of markets that become part of the managerial process?

Our findings suggest an intensive involvement of various air forces representatives in product development work. Can one therefore draw a boundary between markets and managers, in this case? What would be a market decision or a manager decision, when clients and product developers work together to solve product problems?

Thus, perhaps the differences are not the result of market competition as we proposed in Chapter 4. These differences could be the product of other markets, such as the market of corporate stakeholders. The three companies present three different ownership schemes: private, government-owned and a sub-unit of the MoD, which may suggest that these stakeholders present different levels of tolerance to the development of the organisation. This raises the possibility that the dynamics of the development of cross-project learning is related to the impact that ownership has had on the organisation. We turn now to competence-based approach to propose an explanation to the observed differences.

5.5.3.4 Competence-Based View

Competence-based theorists (Hamel 1994; Prahalad and Hamel 1990) would argue that YellowTech, TAMAM and Rafael have integrated some specific capabilities that (i) make a disproportionate contribution to customer-perceived value, (ii) are competitively unique, and (iii) provide an entry into new markets. By integrating these capabilities, YellowTech, Rafael and TAMAM identified their core-competencies. These are integrity-related competencies 'like quality, cycle time management [...] which allow a company to do things more quickly, flexibly or with a higher degree of reliability than competitors' (Hamel 1996).

YellowTech's core competence is in its ability to integrate market knowledge into decision-making in the design process through project management practices that allow the vertical integration of knowledge about technological platforms. This process builds series of product families which are the core capabilities of the organisation (Meyer and Utterback 1993). Product families support the build-up of specialist knowledge which is essential for the innovation process (Collinson 2001), and further reinforce the notion of 'avoid reinventing the wheel'.

TAMAM on the other hand integrated market knowledge around the activity of the system engineer. The mobility of system engineers as knowledge centres on the axis between project management and the professional directorate generates opportunities to realise market opportunities and hence to offer more reliable, cheaper and yet customised products. These are the integrity-related competencies that TAMAM developed during the years. The continuous investment in product families through programme entities only strengthens the value of reusability as a competence.

Rafael developed social networks and a sense of entrepreneurship support by a high level of autonomy that was integrated with market knowledge, to realise that the reusability approach would give a competitive edge over competitors. The autonomy to create a network of individuals from different projects, to deploy experts when needed, is a capability that is unique to Rafael. Because of this capability, Rafael is responsive to its clients and is able to quickly address their needs.

Thus, differences in organising capabilities are associated with three 'conditions' for core competencies. In other words, as Hamel (1996) says to top managers: whatever satisfies these three conditions is your core competence. According to the business performance analysis undertaken above, the results of the integration of core capabilities in each company has been satisfying. As seen, YellowTech, TAMAM and Rafael penetrated new markets, significantly increased their turnover, and are profitable again. YellowTech, TAMAM and Rafael invested in developing capabilities that were essential for the fit between their core competence and the environment. Yet the notion of 'developing capabilities' would suggest that this process is lengthy. How would theory explain the differences in cross-project learning in the time-dimension?

This thesis argues that these differences exist because of the starting point of these companies, which is different and depends on the very first shared histories of learning in each company (Wenger 1998). Mintzberg (1987) would argue that the cross-project learning capabilities in 2000 were the result of an incrementalist approach, in which a *continuous and adaptive* process has taken place through small steps and actions, gradually changing shared histories of learning. These steps are in fact an 'emergent' strategy (Mintzberg and Waters 1985), to be realised only after a series of events. The learning at YellowTech, TAMAM and Rafael emerged as these companies realised the results of previous steps that led to the gradual adaptation of the so-called cross-project learning 'strategy'[10]. In line with Grant's (1995) 'resource-based' theory, the internal resources at YellowTech, TAMAM and Rafael, which include tacit (e.g. know-how of product families, autonomy) and tangible assets (technologies, equipment), skills and patterns of co-operation (matrix structure, multi-functional teams), will gradually transform themselves and change because of the learning process. Perhaps the latter proposition would mean a shift in the core competencies (Prahalad and Hamel 1990) of an organisation as the changes in its contexts are realised by the internal organisational process.

5.6 Conclusions

This chapter opened with the following question: what are the mechanisms and conditions for the implementation of a successful cross-project learning?

[10] This argument will be further developed in Chapter 7.

The above analysis presents three different approaches to cross-project learning implemented in the case study companies. In addition, an analysis of recent business performance of the case study companies has been undertaken, suggesting a successful implementation of cross-project learning. Though each case study company has introduced a rather different approach to cross-project learning, by and large the three case study companies have significantly improved their market and product success since they have pursued the cross-project learning 'strategy'.

Following this, an analysis of the differences and similarities between the three studied companies has been provided, suggesting that there are differences in the way these companies organised their cross-project learning activities. A set of competitive explanations has then been introduced to conclude that differences and variation are the result of the different unique resources that a company possesses and considers as core capability. Also it has been suggested that these capabilities change and evolve over time during the course of learning and adaptation that take place in organisations.

The process through which core capabilities change during the course of learning is at the centre of Chapter 6. Very little is known about the impact that process innovation has on interrelated, interdependent organisational processes. Thus, Chapter 6 aims to address the following question: how did the introduction of cross-project learning and the acceleration of product development impact the organisation of product development and other organisational processes?

6 CHAPTER SIX: CROSS-PROJECT LEARNING AS A DISTURBANCE-PRODUCING SYSTEM: AN ACTIVITY THEORY PERSPECTIVE

6.1 Introduction

Thus far, Chapter 5 has provided an analysis of the mechanisms and structures that supported cross-project learning activities in the Israeli electronics defence industry. The analysis presented in Chapter 5 suggests a great diversity in the approaches to cross-project learning between the case study companies. Yet, despite this diversity, the analysis of the case study companies' recent business performance suggests that the 'strategy' of cross-project learning has significantly enhanced product and market success in all three companies.

The transformation of the innovation system in the studied companies was intended to speed up product development processes (Coombs 1998). New tools and structures were introduced at YellowTech and TAMAM, and the value of reusability as a strategic cross-project learning process to competitiveness has grown tremendously across the industry (Markus 2001).

However, how did cross-project learning and the acceleration of product development impact the product development environment?

To anticipate our conclusions, data suggest that cross-project learning activities and the acceleration of product development, which emphasise the reusability of designs, have had a significant impact on expertise development, gradually eliminating the historical mentoring system. In contrast to the diversity in approaches to cross-project learning, the data suggest that the three case study companies have experienced a similar change in the way engineers and managers develop their expertise and share knowledge.

Furthermore, the focus on knowledge management and expertise development processes provides a unique opportunity to examine the nature of the relationships between two activity systems central to product development. The account reveals new tensions between these activity systems that have not been reported before, and offers an opportunity for further developing situated learning theory to take account of the process of learning in unexpected directions.

Through the lens of activity theory (Leont'ev 1978; Engestrom 1992; Blackler 1995), the impact that cross-project learning and the acceleration of product development activity have had on the organisation of work in product development will be analysed. The gradual shift in the organisation of innovations will be analysed, with an emphasis on tensions and contradictions between two concurrent though interrelated organisational processes: expertise development (ED) and knowledge management (KM).

Section 6.2 proposes a theoretical framework to analyse the transformation of product development from an activity theory perspective. Section 6.3 is devoted to the innovation process prior to the transformation of product development, providing a historical context of the studied organisational processes (Engestrom 1992). Section 6.4 provides an activity theory perspective on the transformation of the innovation system, highlighting the centrality of cross-project learning initiatives in this process. Section 6.5 analyses the impact that cross-project learning and the acceleration of the innovation process have had on product development, expertise development and knowledge management processes. Lastly, section 6.6 highlights tensions and contradictions between these organisational processes and engages in discussion of the process through which activity systems are transformed.

6.2 An Activity Theory Perspective on Multi-Activity Environments

The transformation of an innovation system can be studied from numerous and various angles. Previous studies have mainly emphasised several chief factors essential for the successful transformation process[11]. Nevertheless, there is little known about the impact that the re-organisation of innovation systems might have on other organisational processes. Perhaps the reason for this neglect is embedded in the pursuit of superior performances and extraordinary skills with which Cartesian approaches are obsessed (Engestrom 1992). For example, the study of expertise by Ericsson and Smith (1991) sought to present a rather stable picture of skills and performances involved in innovation work, ignoring inconsistencies and contradictions which are often inherent in expertise systems (Engestrom 1992).

The application of some aspects of activity theory enables the present study to investigate disturbances and tensions in product development and thus address the question that opened this chapter: how did cross-project learning and the acceleration of product development impact on the product development environment?

Through the analysis of the historical development of the innovation system in the case study companies, this chapter will examine disturbances and conflicts generated throughout the change process within and between the two activity systems under investigation (Blackler et al. 1999).

[11] See Slappendel (1996) for a useful organisation of the literature on innovation and factors for a successful change process. Two distinct studies that emphasise factors contributing to a successful organisational transformation are Pettigrew and Whipp (1991) and Walton (1987).

6.3 Multi-Activity System Development in Product Development : Phase 1

6.3.1 Introduction

Figure 38 illustrates the relationships between expertise development and knowledge management as two activity systems that coexist within the product development activity system. In order to distinguish old from new practices, some kind of historical perspective is necessary (Kuutti 1999). Further, activity systems change because artifacts, procedures and rules have changed internally (Engestrom 1992). Tensions and disturbances are generated because of the continuous self-movement of the innovation system towards a culturally more advanced activity system, as new procedures, rules, technologies and structures are introduced, creating contradictions within the activity system and between the activity system and neighbouring systems (Engestrom 1992).

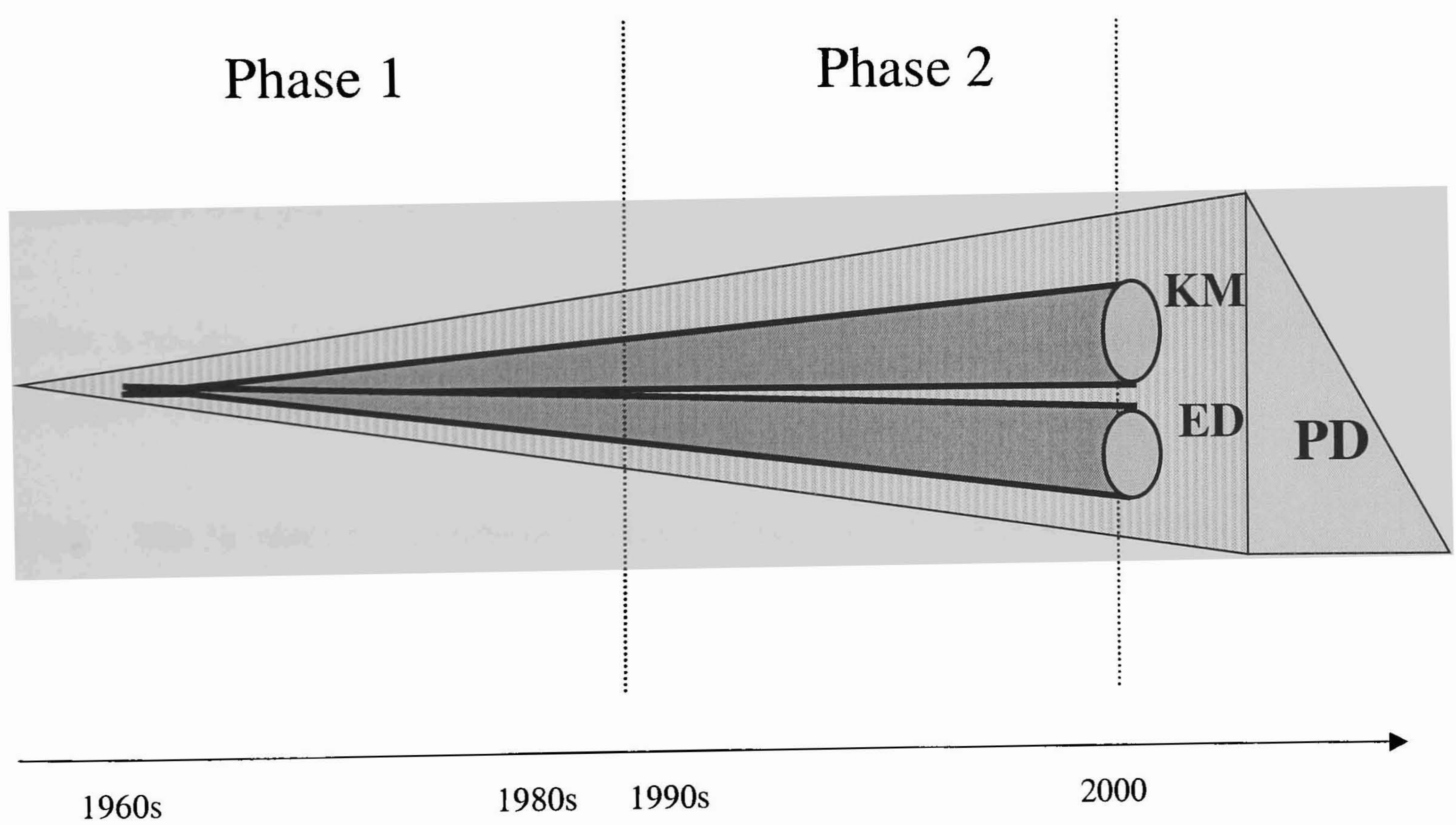

Figure 38: The Development of an Innovation System

Two phases will be discussed (see Figure 38). In terms of the time dimension, Phases 1 & 2 cannot present a clear break between specific years. This is because the implementation of cross-project learning took place in different forms and times in each case study company, as described in Chapter 5. Yet broadly speaking, Phase 1 describes the years prior to the 1990s, before the collapse of the Soviet block that was followed by major changes in defence procurement, as described in Chapter 4; whereas Phase 2 covers the years after this.

The relations between three activity systems -- product development (central activity system), expertise development and knowledge management (two neighbouring activity systems) will be analysed. Product development is defined as the process through which market opportunity and a set of assumptions about product technology are transformed into a product available for sale (Krishnan and Ulrich 2001). Expertise development is the learning process through which individuals and groups develop skills, know-how, identity, and meaning that facilitate their participation in organisational activities (Wenger 1998). Knowledge management is the practice through which the exchange and sharing of technological knowledge and learning between individuals and groups is facilitated (Wenger 1998; Lave and Wenger 1991).

Thus, a review of the historical development of PD, ED and KM during the years of phase 1 will follow.

6.3.2 The Product Development Process in the Israeli Electronics Defence Industry During Phase 1: The Scientific-Inventor Process

Product development during Phase 1 was characterised by a heavy concentration on developing a mastery and cutting-edge design of technology and products (Blackler et al. 1999). Engineers enjoyed a high degree of autonomy to pursue their interests. An idea to improve or develop a product starts when there is a need to find a technological solution to a new battlefield problem. The process of new product development starts when clients request such a solution or need to replace their old system. In some cases, a new product development cycle starts with the company launching self-financed or government-sponsored research. Having decided to respond to the client's request, engineers start to design the product.

Often, the company allocates engineers to their tasks without knowing whether it has won the contract. During the tendering process, the company will present a concept of the complete product design, preferably ready to be tested by the client. Electronic defence companies believe that a 'Fly Before Buy' strategy -- which means having a testable system ready during the tender -- gives them a distinct competitive advantage over their rivals. In order to maintain this competitive edge, the bidding company will offer one of their existing off-the-shelf products, to demonstrate the technology and features available at present time. Based on this product, the bidding company will ensure the client that any additional features requested by the client will be built into the final product.

In the event of the company winning the bid, it might still be a year before the contract is signed. This is because of the complex process of approving the contract in the client's directorate. Both military and government officials must approve contracts. On both sides there are committees that examine the contract carefully before the Ministry of Defence approves it. During this time, the client negotiates financial arrangements with a view to reducing the final cost of the project. The client also further audits the technological specifications and adapts them to the stipulated requirements.

The full project activity actually starts only after signing the contract. Only on rare occasions, for example when the product is an upgraded version of a previously supplied system, does the company launch a project without signing a contract. When a contract is signed, the project team is quickly staffed with hardware and software engineers who are readily available. At this stage the conception of the product is revised and an updated revision is proposed. This is mainly because products in this industry have to be tailored to each client. Rarely will the concept of the revised product be similar to the product demonstrated to the client in the bidding stage. The reason for this is twofold. Firstly, projects during Phase 1 enjoyed a cost-plus contract system which guaranteed the winning company the full cover of their R & D costs plus a 10% minimal margin. For this reason, the winning company often launched a generic R & D effort as there were no financial constraints against doing so. Secondly, engineers advocated the use of cutting-edge technologies in new products. The implications for using cutting-edge technologies in airborne systems are tremendous, mainly because of the continuous improvement in semiconductor technologies offering much smaller-sized components, although more condensed in functionality, that allow engineers to implement more features without needing to physically enlarge the system.

The picture emerging from the stories told by engineers is of a scientific process that involves a trial-and-error learning mechanism in order to match the system to the client. Individuals pursue this approach to development mainly because it gives them the opportunity to explore new technologies or to experiment with new applications of existing technologies. Thus, in the case study companies designs often went through endless iterations that changed the original design of the product. Some of these changes were because of mistakes in the original design. However, in many cases engineers made changes in order to improve product performance and add 'bells and whistles' features (Blackler et al. 1999). Hence, each product was unique and was often developed from scratch, even those from the same product family.

The phases of system retrofit and the maintenance of software and other parts of the product are part of the late stages of projects. During these stages, members of the project team no longer work together but are allocated to other projects. Hence, ad hoc teams are allocated to missions, usually in parallel to other activities in which they are involved.

During the course of the project -- which can be anything between two and fifteen years in this industry, the project team maintains interactions with other groups outside product development. Sales are involved in negotiations with the client to agree on the pricing model, while Marketing provide the pricing model.

Procurement and Production are involved in this process in two simultaneous stages: when the product design is approved by the client in principal and the component list is issued to Procurement for purchasing; in parallel, the component list and detailed assembly instructions are issued to the assembly team in Production.

It is rare for projects to be regarded as officially finished. Often they are resumed because clients and companies introduce retrofits, upgrades or a second generation of the system. However, although a project may stay active for a long time, its engineers will be allocated to other projects.

Figure 39 suggests that the activity object of product development during Phase 1 was realised as a problem-solving design process resulting in a novel product each time a project starts, leading to cutting edge technologies and products, although embodying high costs and often late deliveries.

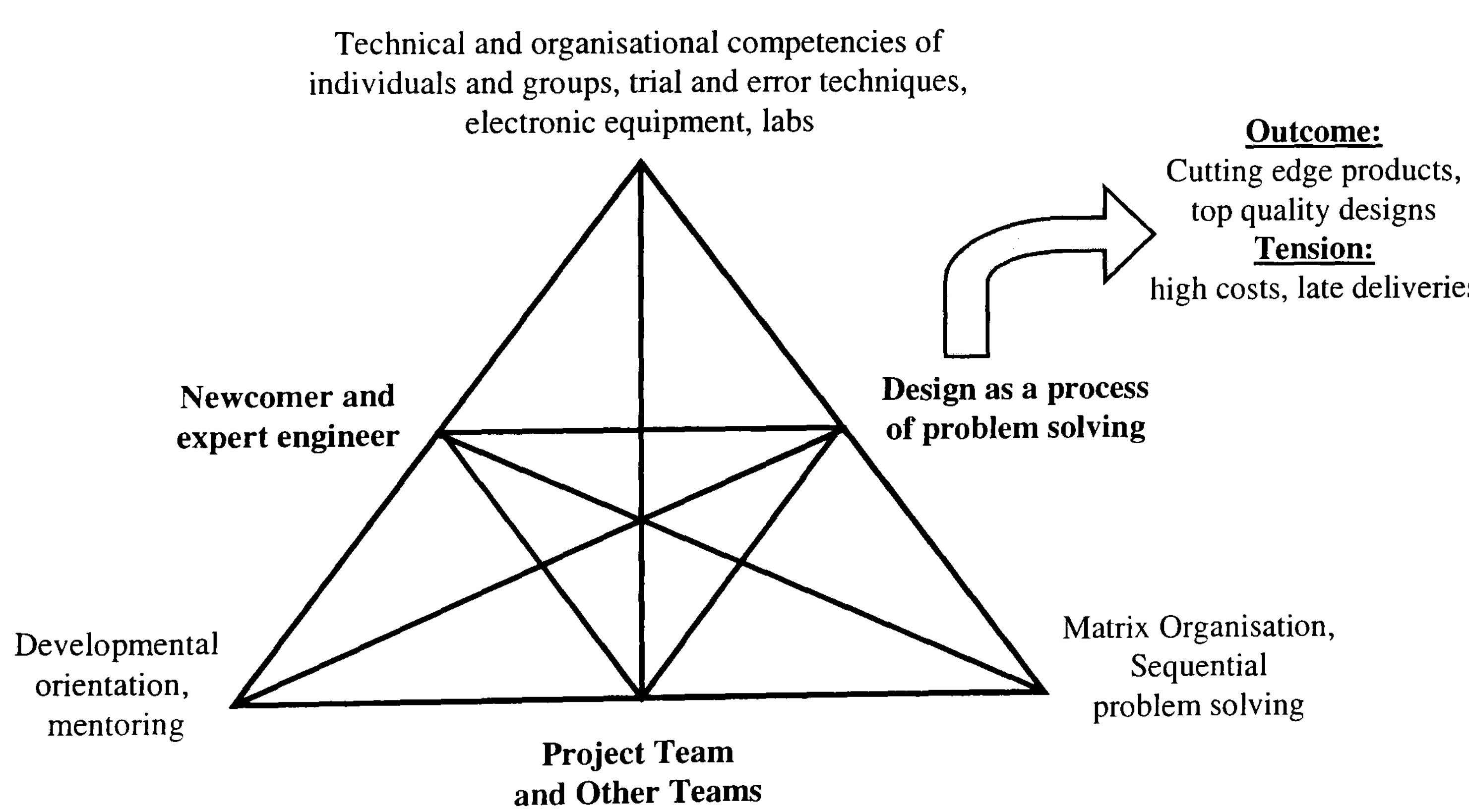

Figure 39: Product Development Activity Phase 1

Though Figure 39 suggests a harmony between individuals, groups and the object of the activity system through the use of technology, organisational structure and language, in reality there is internal tension between the elements of the activity.

For example, the contradiction between use value and exchange value is a particular problem (Engestrom 1992). In the case study companies, engineers wanted to spend time on solving problems and innovation but were restricted by management, who were concerned with deadlines and markets. Nevertheless, market conditions that saw highly unsophisticated and very forgiving customers who were willing to pay the cost of the R & D effort, combined with the relatively loose management of projects in the years of Phase 1, led to a greater focus of engineers on the innovation process. This resulted in a habitual pattern of late delivery of projects and high costs associated with R &D projects in this industry (Blackler et al. 1999).

6.3.3 Expertise Development During Phase 1: The Historical Development of Legitimate Peripheral Participation and Mentoring Processes

In the years during Phase 1, the expertise development process was based on mentoring. Learning in the studied companies mainly meant the development of *scientific-invention skills*. Engineers were considered as scientists-inventors and were given the right to pursue their scientific interests (Blackler et al. 1999). This scientific interest was driven through many years of technology development, exploration and experiments. As the Head of the Hardware Group at YellowTech explained:

> *You cannot teach electronic warfareology at school; neither can you teach it formally in the organisation. It is something that one understands and develops during many years of work and experience.*

Another manager from Rafael added:

> *Experience is still the most important learning mechanism through which we developed expertise. Other means of training were not practical for us because they did not focus on those outcomes we would like to see from our employees.*

And one project manager from TAMAM reinforced the above remarks, stressing that expertise evolved during the course of time through involvement in projects:

> *Doing and experiencing is a key issue in developing expertise and knowledge. The longer we are working on projects the more we know. During this time, technicians and engineers upgraded their knowledge and got a better understanding about technologies and system configuration.*

Though it is not the only learning process that took place in the studied companies, interviewees tended to emphasise the process through which newcomers were introduced and encouraged to participate in activities. To understand the processes involved in developing expertise through a mentoring learning mechanism, a situated learning view developed by Lave and Wenger (1991) and also known as Legitimate Peripheral Participation (LPP) was adopted. This theory offers an alternative view to the cognitive perspective (e.g. Argyris and Schon 1978) on learning. Lave and Wenger (1991) argue that individuals develop their knowledge and expertise primarily through participation in activities within communities to which they belong. In linking their view on learning to other schools of thought, Lave and Wenger suggest that situated learning offers a bridge between 'a view according to which cognitive processes (and thus learning) are primary and a view according to which social practice is the primary, generative phenomenon, and learning is one of its characteristics' (ibid.: 34). Legitimate Peripheral Participation, according to Lave and Wenger, is perceived as a 'descriptor of engagement in social practice that entails learning as an integral constituent' (ibid.: 35). Gherardi and Nicolini (1999: 5) point out that 'peripheral' indicates the route that the novice needs to follow in order to gain the respect of the community, while the idea of 'legitimate participation' stresses the actual and relevant stages in learning that the novice has to go through in order to achieve the community's esteem.

Thus, the theory of Legitimate Peripheral Participation helps to explain the process through which expertise development evolved in the studied organisations in Phase 1. Engineers and technicians developed their expertise mainly through participation in what Kuhn (1970) described as 'social practices', gradually becoming part of the organisation by assuming more responsibilities and accomplishing more tasks.

The Head of the Software Group at YellowTech explained:

> *The tasks we gave new software engineers in the beginning were simple. It could be either to write a short programme, just a patch to the code or maybe to re-programme an existing sub-programme. We wanted them to study the system rather than to achieve results.*

This kind of learning gives newcomers the time to acquire knowledge about products, tools, organisational systems and organisational procedures that facilitate product development processes (Lave and Wenger 1991). Engineers at YellowTech described how they developed programming skills for a specific chip called Xilinx[12]. This chip functioned as a signal processor that captured the time of arrival of the radar pulse, its width, angle of arrival and certain other parameters. Initially, newcomers were given simple tasks to design only one function of the Xilinx, such as the block that captured the pulse's time of arrival. For the newcomers it was a do-able challenge that allowed a rather relaxed learning process and comfortable introduction to the technology and processes. In these cases, it was claimed, a veteran engineer would walk the newcomer through the requirement documentation, explaining the meaning behind each requirement. Furthermore, the newcomer was given specific instructions on how to proceed and was often mentored upon completion about the next steps. In one case, one engineer from YellowTech recalled that when he had been in the company for only one month and was working on designing one function in an analog card, his mentor, now the Chief Scientist of the division, reviewed with him the state of his

[12] Xilinx is the brand name of the component producer. The technical term for the above chip is either Gate Array or Programmable Array Logic (PAL).

work and sympathetically told him to scratch the card. This engineer argued that the mentor simply justified this by saying:

At least you've learned how not to design this function.

Progress in becoming an expert was gradual. Usually in the next stage, newcomers were given tasks that required them to design a number of functions linked together within the Xilinx. This task required their understanding of the product in terms of knowing the integrated unit. Further stages in the learning process challenged engineers to link different electronic cards in one unit and later on to integrate different units into one system mastered by the software.

The art of designing a sophisticated unit was considered to be highly complex and to require a deep and thorough understanding of various scientific areas including physics, electronics and mechanical engineering. Engineers and managers from the studied companies emphasised the long and slow learning process for newcomers. One engineer from TAMAM recalled that as a newcomer he worked with an experienced engineer for almost a year before he was allowed to design one part of the system. He commented:

We took the time to learn technologies and our line of products.

Problem solving, which lacked any reference in the theory of Situated Learning by Lave and Wenger (1991), was at the centre of newcomers' learning experience. Blackler (1999:14) reports that:

[in] order to be able to continue to solve more and more difficult (and interesting) problems the engineer as scientist inventor needed to develop his or her professional excellence.

Thus, problem solving and expertise development were joined together in the studied companies. Highly developed unique expertise contributes to solving difficult problems in this field, and the engagement in solving complex problems assists in developing expertise and a better understanding of the tools and concepts needed for the task (Engestrom 1999). Data from the interviews reinforce this argument. One project manager at YellowTech explained:

We encouraged learning through work and in teams. The guys here developed their knowledge while working and solving problems.

The Head of the Popeye Programme at Rafael articulated the contribution of problem-solving sessions to the learning process:

Information is not transferred unless there is a problem. We learn only when we are involved in problem solving [...] then we need to consult with someone or check what we already know about the problem. This is what makes it a learning process.

Thus, newcomers learned about becoming a master via interaction with others and through problem solving. Learning also evolved as newcomers acknowledged their responsibilities and achievements (Lave and Wenger 1991). Following this, newcomers extended their participation by becoming part of the community's discourse and by generating achievements and stories (Orr 1990). Identity as 'negotiated experience', 'community membership' and 'learning trajectory' (Wenger 1998) has also become central to the process through which engineers and technicians develop their mastery and expertise.

The researcher heard a number of stories that demonstrated this ritual. One engineer said that he had joined YellowTech after working for Intel for several years. Obviously he was under the impression that since he was not a new graduate, he would join the design team fairly quickly. Nevertheless, when he joined, the first task he was given was to tune an analog-receiving component, a relatively simple and boring task. This engineer felt insulted that his experience with Intel was not valued. When he asked his boss about the low-tech task he was given, he was told that at YellowTech 'we prefer the step-by-step approach. You will get to design digital cards soon'. He recalled that at first he felt depressed about doing this task, but he was determined to succeed. He said that he felt envious when he saw others working on digital cards, and to keep his morale high he engaged in conversations with them. To his surprise, he learned that all of them had been through the same process that started with the same analog-receiver component. He even learned a few tricks from these colleagues about how to improve the tuning accuracy. After a relatively short time his manager assigned him to a project that involved working on a digital system. Later he learned that some of the people he was having discussions with put in a 'good word' about him.

Despite its informal role in the Israeli electronics defence industry, mentoring has become the main learning mechanism to support the inclusion of the newcomer in the studied companies (Wenger 1998:100), to introduce the newcomer to procedures, and to create a dynamic involvement in multi-functional work that enhances outcome-orientated entrepreneurial work and the development of collective expertise (Engestrom 1992). This ritual was integral to the culture in the studied companies in Phase 1. As the Head of the Litening project claimed:

> *First and foremost it was important for us to have the best people in the business. We invested months in bringing these guys up to speed and it [mentoring] paid back well. Most of them stayed with us for many years and helped us to be successful.*

A similar line of argument was expressed by the Chief Scientist at YellowTech, who compared the current attitude to learning to the approach in the past:

> *Then [Phase 1] we could spend time mentoring people. The situation was completely different. I admit that mentoring was good in past times. We would not be where we are without investing in our people.*

In the studied companies mentoring was greatly supported by the shared attitude and atmosphere of a 'small village' where people knew each other and hence perceived mentoring as a ritual that everyone goes through. Making mistakes was never an indicator of a lack of fitness of the novice. Rather, experienced engineers and managers accepted mistakes and tolerated failure and sometimes even supported it (Tushman and Nadler 1996). Mistakes were justified by the opportunity they provided to learn how to do things properly, despite the costs involved in recovering from them.

Thus, mentoring in the studied companies, from the perspective of legitimate peripheral participation theory, is perceived as the mechanism through which individuals develop expertise. From the engineer's viewpoint, the object of this activity is to form identity, develop mastery and participate in the innovation process.

An activity system model presents the components of expertise development activity in Phase 1 (Figure 40).

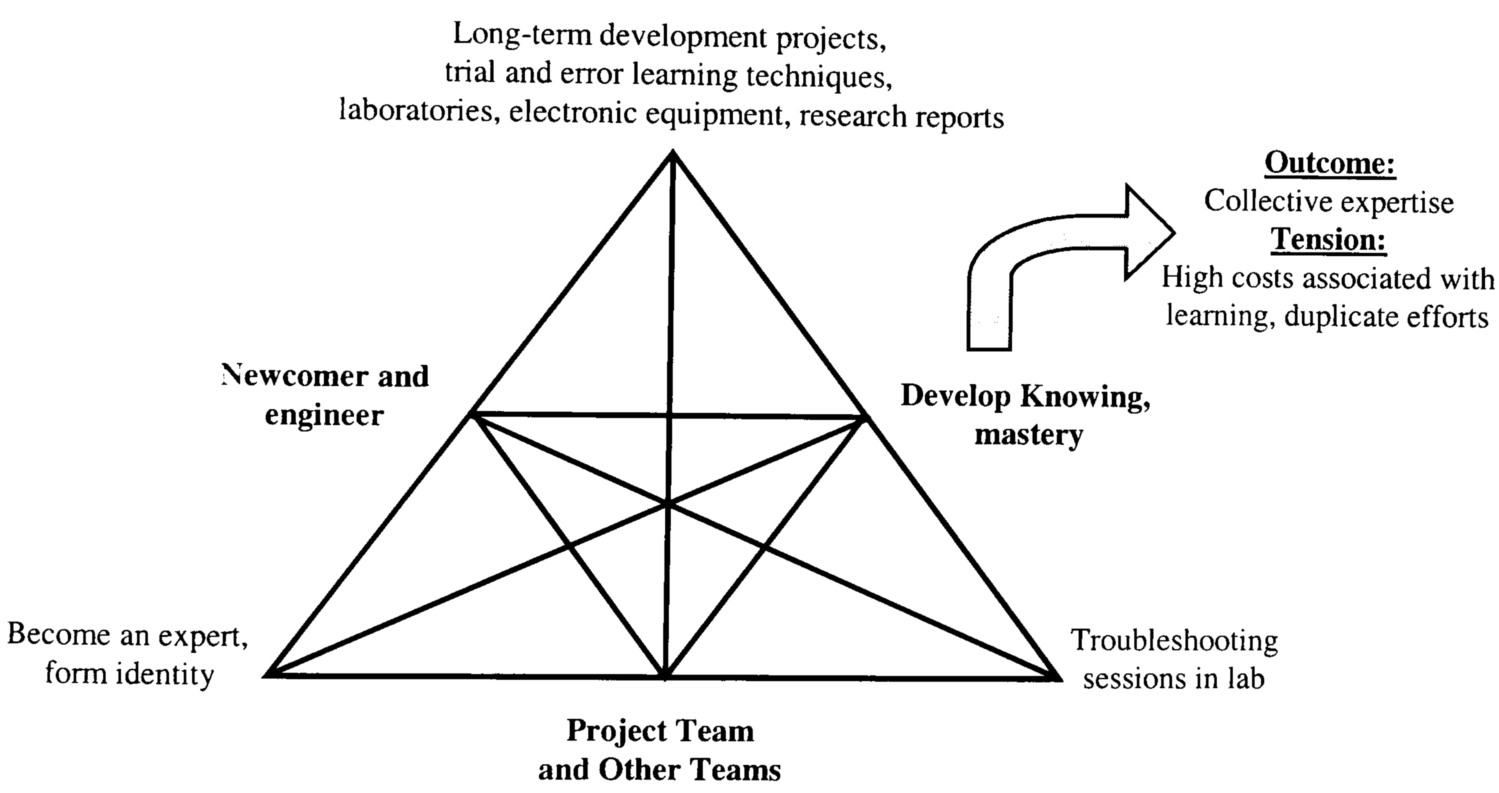

Figure 40: Expertise Development Activity During Phase 1

The expertise development activity was by no means free of internal contradictions and tensions. Expertise development in its form in Phase 1 involved high costs associated with the learning process. In addition, the loose management of technology and the desire of individuals to learn and experiment with new technologies drove them to develop solutions that already existed in the company. The tension between exploration and exploitation presented by March (1999) is one factor that may explain the internal contradictions in the expertise development activity.

In the next section, knowledge management as an organisational process will be reviewed and analysed.

6.3.4 Knowledge Management in Product Development During Phase 1: The Historical Development of Knowledge Sharing

Knowledge management processes in the Israeli electronics defence industry during Phase 1 were unplanned and informal in nature. Furthermore, engineers and managers described those processes as related mainly to knowledge sharing; however, closely they were associated with expertise development and learning. Possibly one reason for this is that Information Systems (IS) had just started to emerge in this industry, which also meant that knowledge systems (such as GroupWare systems) and repositories (such as knowledge base for specific domain information) had not yet been developed (Markus 2001). Therefore, knowledge sharing based on social interactions (Tushman and Nadler 1996) and participation (Lave and Wenger 1991) in problem solving took place between individuals and projects during Phase 1 as an informal, unplanned practice. As one engineer from YellowTech explained:

> *Sharing knowledge was something we used to do every day. We were excited about our products, the cutting edge technology, and wanted to be involved and help. Sharing knowledge allowed us to be involved.*

Another project manager from TAMAM added:

> *The day I joined TAMAM I realised that here you don't keep secrets. You cannot work together if you do not share your knowledge with others.[...] You get to the point where you might risk the product [if you do not share knowledge].*

The Chief Engineer at Rafael also referred to this point:

In research-driven organisations such as Rafael, sharing knowledge is essential. Designing systems is a complex task and requires everybody to pull together.

One enabler of knowledge sharing was the autonomy (Handy 1976) that engineers were granted by management in the years of Phase 1. One project manager at TAMAM observed:

Back in those days, pressure to finish projects on time was mild. To be honest, sometimes we did know when the deadline of the project was. All we cared about was that the design worked in the field.

Engineers and managers were given the autonomy to explore solutions and engage in work and discussions with others in order to ensure that the best solution would be applied in the product. By these means, knowledge was shared. One project manager from Rafael explained:

If it were needed, we would have spent days with other teams, working together to help them solve problems with their project.

Another project manager from YellowTech described how he spent time working on another project and contributing his experience:

[...] because I had run testing before, the project manager of the other project approached me and asked whether I could join them to do testing. At that time I was responsible for another project but I knew that these guys needed me. I decided to spend two weeks helping these guys in the testing site in the south of Israel, showing them how to run testing. Nobody made a fuss of it.

The Chief Scientist at YellowTech justified the autonomy engineers were granted in those years, saying that:

Time and money were not the issue for most of our clients. The conception was that our systems have to be smarter than those of the enemy's. [...] It was just about technology. Nobody bothered then whether the project would take another six months or would cost a few more millions.

He went on to suggest that:

Back then engineers could easily have spent a couple of weeks working with other teams in order to overcome a specific problem. That [working with other groups] was the way we shared knowledge.

This was explained by one engineer from Rafael:

You have to understand the atmosphere in those years. People did not hold information mainly because of that atmosphere. We were doing something different from the rest of the industry. We were at the cutting edge of technology, doing national projects, working in secrecy. Like a special task force for the Israeli Defence Forces.

Motivation was another enabler of participation in knowledge sharing. It was indicated that the level of motivation was high in the studied companies in the years of Phase 1. The image of being a 'special team' helped to boost engineers' motivation. In addition, salary, job security and working conditions were reported as satisfying employees during the 1980s and the early 1990s (Herzberg et al. 1959). The Human Resource Manager at YellowTech referred to the motivation issue, noting that:

The company was doing fine then (during Phase 1). Negotiation with trade unions used to take a couple of days and every couple of years we compensated employees with a rise that exceeded the average in the market. We had a training budget and a special budget for social events. People were highly motivated then.

Expectancy Theory (Vroom 1964) explains the individual's motivation in organisations. Motivation, it is argued, is based heavily on people's expectations.

However, these expectations do not take place in isolation. It is suggested that expectations evolve based on the individual's interactions with the environment (Fudge and Schlacter 1999). Therefore, the high motivation in the Israeli electronics defence industry during Phase 1 was based on the personnel policy of promoting and rewarding individuals and investing in their personal development.

Some interviewees kept mentioning the relationship between power and knowledge in the context of knowledge sharing (Pfeffer 1992; Kirkbride 1992). Some argued that power games and politics existed from day one, mainly because of personality clashes and the personal ambitions of individuals that were not always fulfilled and sometimes frustrated these individuals (Myers and Briggs 1962). A few cases were described of some team players who were labelled non-cooperative individuals. However, it was agreed by all interviewees that power games in terms of individuals holding information related to a project were rare. For example, the Head of the Popeye Programme at Rafael claimed that there was a good atmosphere around knowledge sharing in his programme:

> *I cannot remember politics and power games at Rafael as we have now. I think we started to see political games at Rafael only when the Israeli government started to talk about changing the company's orientation and turning Rafael into a profitable business [around 1995].*

To conclude, sharing knowledge in the studied companies emerged as an activity system which realised its motives in both product development and expertise development. Through this organisational process engineers mentored others while solving problems, and shared with others their understanding of the organisational procedures and rules. Engineers were motivated by their desire to reinforce their identity, to gain accreditation for their mastery by demonstrating their knowledge, and to mentor others. In addition, engineers were motivated to share knowledge in order to extend their participation in the innovation process.

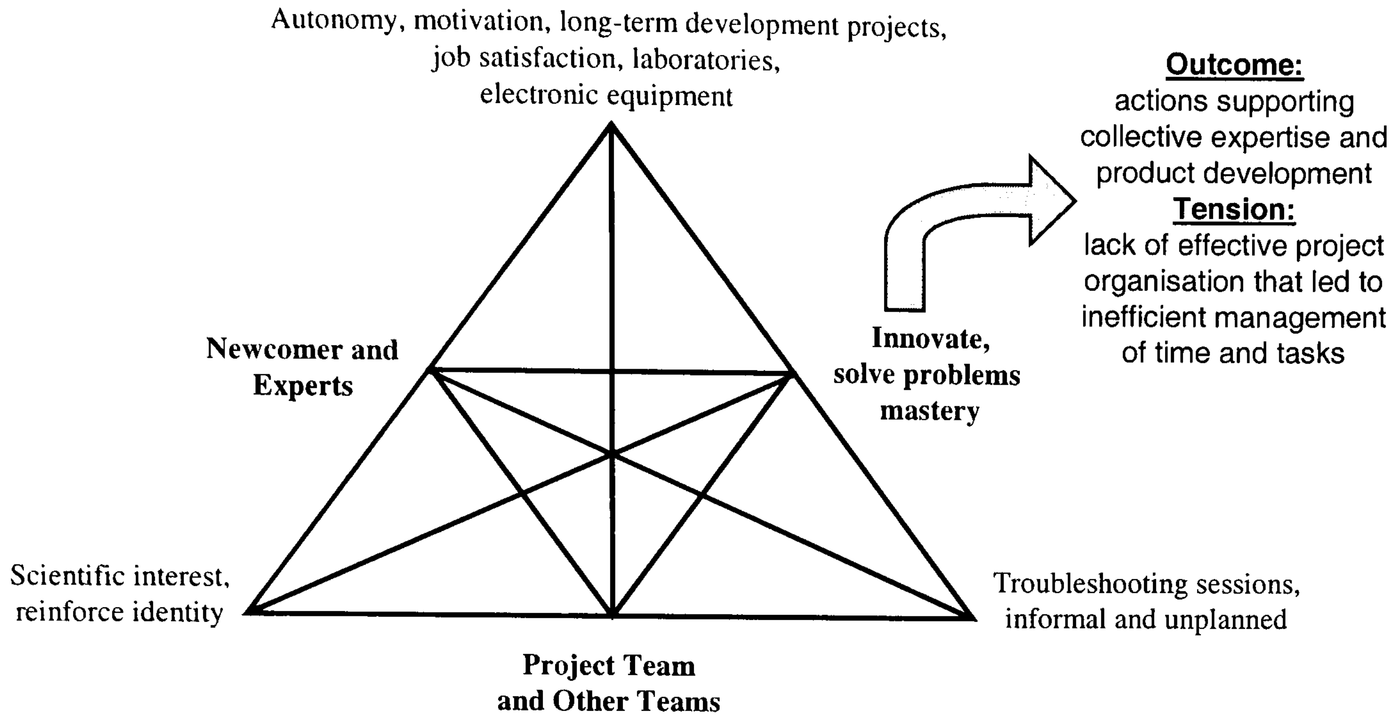

Figure 41: Knowledge Management Activity during Phase 1

There were some sources of tension in the knowledge management activity. The contradiction between use value and exchange value was especially problematic (Engestrom 1992). For example, the practice of time management and task management by engineers suffered from a very loose approach. In particular, management was rarely involved in the prioritisation of tasks and people, and they left this terrain for the engineers.

Thus far three activities have been reviewed from a historical point of view. In the next section, an analysis will be presented to show that during Phase 1 expertise development and knowledge management coexisted in harmony within product development.

6.3.5 The Coherence between Expertise Development and Knowledge Management During Phase 1

In contrast to the evident tension *within* expertise development and knowledge management, tension *between* these two organisational processes was not evident (see Figure 42).

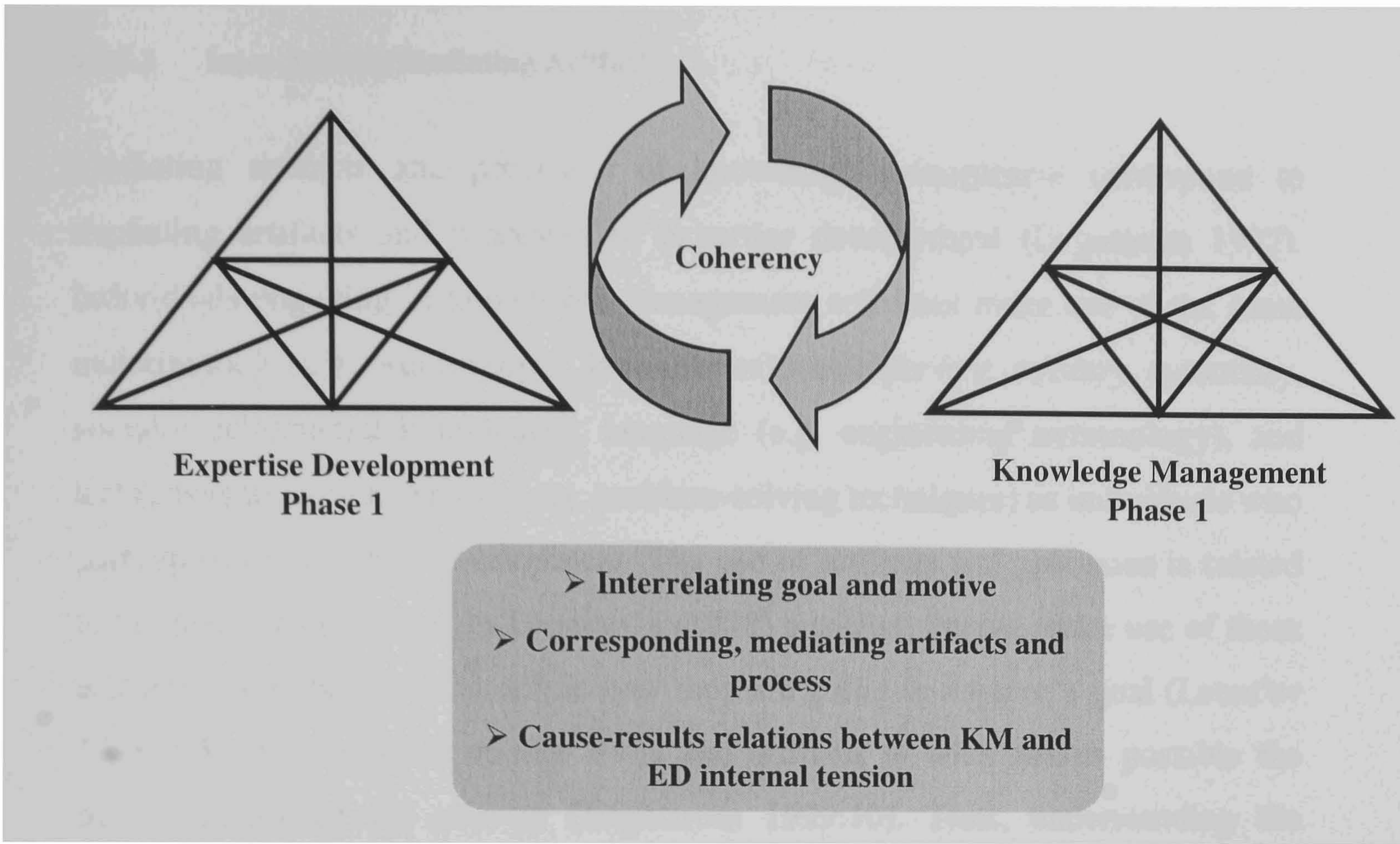

Figure 42: The Sources of Coherence between Expertise Development and Knowledge Management during Phase 1

It seems, then, that expertise development and knowledge management coexisted in harmony and maintained coherence within product development in the years of Phase 1. We can identify a number of elements that support our observation.

6.3.5.1 Inter-Activity Goal/Motive

There were interrelations between the goal of knowledge management and the motive of expertise-development activity (Leont'ev 1978). Experienced engineers shared knowledge with newcomers in order to mentor them, to include them in the socialisation process and to upgrade their technical mastery. Newcomers sought mastery and appreciation of their social position within the organisation and of their technical capabilities in problem-solving sessions. These two dimensions went hand in hand and were complementary. One way of explaining this observation is to use Weick's and Roberts's (1983) conception of how individuals and groups pursue a shared objective through the constitution of a collective mind.

6.3.5.2 Inter-Activity Mediating Artifacts

Mediating artifacts and processes of knowledge management correspond to mediating artifacts and processes of expertise development (Engestrom 1992). Individuals engaging in knowledge management activities make use of the same material tools (e.g. oscilloscopes, laboratories), concepts (e.g. mastery, autonomy, socially constructed knowledge), language (e.g. engineering terminology), and techniques to learn and share (e.g. problem-solving techniques) as individuals who participate in expertise development. The use of artifacts and processes is related to the level of operations in Leont'ev's (1978) analysis. People make use of these artifacts when they need to define how they are going to achieve a goal (Leont'ev 1978: 65). The creation of new tools and artifacts is what makes possible the transformation of the activity (Engestrom 1999:10). Thus, understanding the transformation of an activity is intimately associated with the use of artifacts at the operations level of human activity. The use of artifacts in knowledge management seems to be linked to two activities: expertise development and product development. Leont'ev (1978:64) explains this by arguing that 'one and the same action may accomplish various activities and may transfer from one activity to another, showing its relative independence in this way'. According to Engestrom (1999), this transferability of action across activities takes place at the operational level through the change in material tools.

6.3.5.3 Inter-Activity Outcome and Tension

The outcome and tension generated following knowledge management actions corresponds to the tension introduced by expertise-development activity. We observed that such activity generated tension around issues relating to the high costs of learning, and often led to excessive technology development. Complementarily, the tension arising from knowledge-sharing activities demonstrated a rather loose organisation of people and tasks, leading to inefficient management of tasks and time. These tensions represent the inefficiencies that the studied companies had to bear during Phase 1.

We sought an explanation of this in Activity Theory, which would explain the meaning of corresponding interactions between the outcome and tension of two concurrent activity systems. Blackler (1993: 871) theorises about the relationships between activity systems, arguing that 'activity systems do not exist in isolation one from another: the outputs of one system provide the input to another'. Yet Blackler and his colleagues (1999) tend to focus on the sequential development of one activity system, the engineering system, over time, attempting to include themes related to knowledge management and expertise development under the engineering activity system umbrella. The present study sympathises with their proposed analysis of the transformation of a single activity system over time and with the intention to enlarge the unit of analysis to comprise a network of multiple activity systems; however, the researcher is in favour of understanding the 'internal systemic connections' (Leont'ev 1978) between concurrent activity systems (Engestrom 2000).

Engestrom (1992), in addition, does not provide assistance in explaining the systemic connections between outcome and tension of concurrent activity systems. Engestrom (1992) suggests four levels of interactions, which are in fact contradictions, between activity systems: (i) inner contradictions, within each constituent component of the central activity system; (ii) between the constituents of the central activity system; (iii) between object/motive of the dominant form of the central activity and the object/motive of a culturally more advanced form of the central activity; and (iv) between the central activity and its neighbouring activities. Despite this useful mapping of the contradiction network that may arise in a multiple activity environment, Engestrom (1992) does not interpret the meaning of systemic interactions between concurrent activity systems, in particular with regards to the meaning of corresponding tension between two activity systems.

Thus, this leaves the present study with an unresolved theme needing further investigation. Perhaps, this theme raises the following questions: *how can one interpret data suggesting that the tension of two concurrent activity systems* *correspond? And what are the implications for future transformations of these activity systems?*

6.3.6 Conclusion: The Dominance of the Expertise Development Process

The data presented above suggest that expertise development and knowledge management as two concurrent activity systems coexisted in harmony within product development. Furthermore, these two activity systems evolved based on *social interactions*, developing knowing and learning as socially constructed phenomena.

The corresponding goals, artifacts and tensions between expertise development and knowledge management demonstrate the close interactions between these two activity systems. These two activity systems were imminently interconnected and interrelated to the point that perhaps separating them would be almost impossible. Engineers shared knowledge to develop expertise and they developed expertise as they were sharing knowledge.

Yet, activity theory fails to explain the empirical data observed in this study. The meaning of corresponding internal tensions of concurrent activity systems, observed in the present study, has been ignored by activity theorists so far. Before an explanation is offered, there is a need to complete the picture of these systematic interactions between activity systems during Phase 2. Only then perhaps, will this study be able to draw a conclusion.

In addition, the learning theory associated with activity theory is based on Lave and Wenger's (1991) Peripheral Legitimate Participation concept. Though we sympathise with Lave's and Wenger's (1991) situated learning theory, we have to acknowledge that the theory is one-dimensional and in one direction, i.e. from novice to expert. It does not provide any reference or explanations of learning in unexpected directions when individuals and groups, sometimes novice but often experienced, encounter unknown situations -- situations that require novices and experienced individuals to get up to speed with new knowledge, propose solutions in no time and sometimes improvise, without having a clear understanding of the motive that drives the activity of which they are a part.

In many ways Phase 2 symbolises a rather new era in the case study companies, characterised by new values (market-driven instead of research-driven values) that are diffused in the studied companies, by the introduction of new concepts to manage product development (reusability instead novelty) and by new processes and tools that facilitated this change process. Thus, the following sections will provide empirical data suggesting that individuals and groups generate learning in unknown and unexpected directions. It will be argued that the introduction of cross-project learning and the acceleration of product development processes in the Israeli electronics defence industry produced new and unknown situations for both the skilled and novice workforce in the studied companies, in particular with regard to knowledge management practices. Thus, the following sections will focus on analysing the impact of cross-project learning on expertise development and knowledge management. The question that will be addressed here is: how did individuals and groups respond to the transformation of the innovation system?

6.4 Cross-Project Learning Initiatives and the Acceleration of Product Development Processes in the Israeli Electronics Defence Industry

Since the beginning of the 1990s there has been a growing pressure to regulate and accelerate product development processes. From the perspective of activity theory, it is argued that some rapid changes were introduced in the predominant object of product development activity (Blackler 1993). The motivation for these sets of changes will be discussed in the following section. The succeeding section will discuss the changes in product development from the viewpoint of activity theory. Then, expertise development and knowledge management during phase 2 will be examined. The concluding section will consider the implications of the main changes during Phase 2 for the study of the transformation of activity systems.

6.4.1 Reinventing the Wheel: The Motivation for Change

Eldred and McGrath (1997) discussed in two consecutive papers the challenges facing product-development and technology-development teams in trying to build a coherent process that integrates both sets of activities in extensive R&D organisations. One of the areas that they considered as especially challenging was the perception by the technology development groups that the product-development team (ibid.:30) 'was either not technically capable of receiving the incoming technology or was trying to "reinvent the wheel"'. As seen above, the latter perception, i.e. duplicate technological development efforts by horizontal teams, became a common practice in the Israeli electronics defence industry during the years of Phase 1.

There is more than one factor which led to the evolution of the 'reinventing the wheel' practice in the Israeli electronics defence industry[13]. Stories from engineers demonstrate the breadth of the 'reinventing the wheel' phenomenon. Similar technologies were developed simultaneously, sometimes in two nearby laboratories, but the teams did not know about each other's efforts. One project manager at YellowTech explained:

> *All these years (Phase 1) we were driven by the concept of providing 'the best': the best technology, the best quality, and the best solution. Clients were willing to pay and we focused on developing technologies. In some cases, some projects reinvented the wheel. Management did not care much because the company was doing well at that time.*

Another engineer from Rafael argued that this practice evolved mainly because of internal competition. He explained:

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[13] See section 4.4 for a detailed description of changes in defence markets

Rafael is the Israeli Defence R & D Laboratory. You get this title only if you have been proven to provide top quality, sophisticated technological solutions. Our people were expected to excel and were even evaluated based on their 'sophistication'. To prove how good they were, they developed from scratch solutions that we already had in house.

The case in TAMAM was no different. Engineers and managers provided similar examples when speaking about duplicate efforts in technologies, often referring to the phenomenon as 'reinventing the wheel'. As one software engineer observed:

In software it is much more difficult to reuse the base code. And yet, now we see that ten years ago we did not even bother considering an approach to reusability.

As seen in Chapter 5, since the middle of the 1990s the Israeli electronics defence industry has urged its engineers to reuse concepts and technologies. For example, in the six studied projects, interviewees stated that now they extensively reuse concepts and technologies in their final product. In one project at YellowTech, the project manager described how after six years of development, the team decided to scrap their microprocessor and use one that was developed by a different project. One interviewee estimated that 80% of total development has been based on reused concepts and technologies since 1995.

6.4.2 Context in Activity Theory

In activity theory, context is a process and not a set of factors. Furthermore, as Lave (1996:17) argues 'activity is its own context', reiterated by Engestrom (1996:67) who suggests that 'contexts are activity systems'.

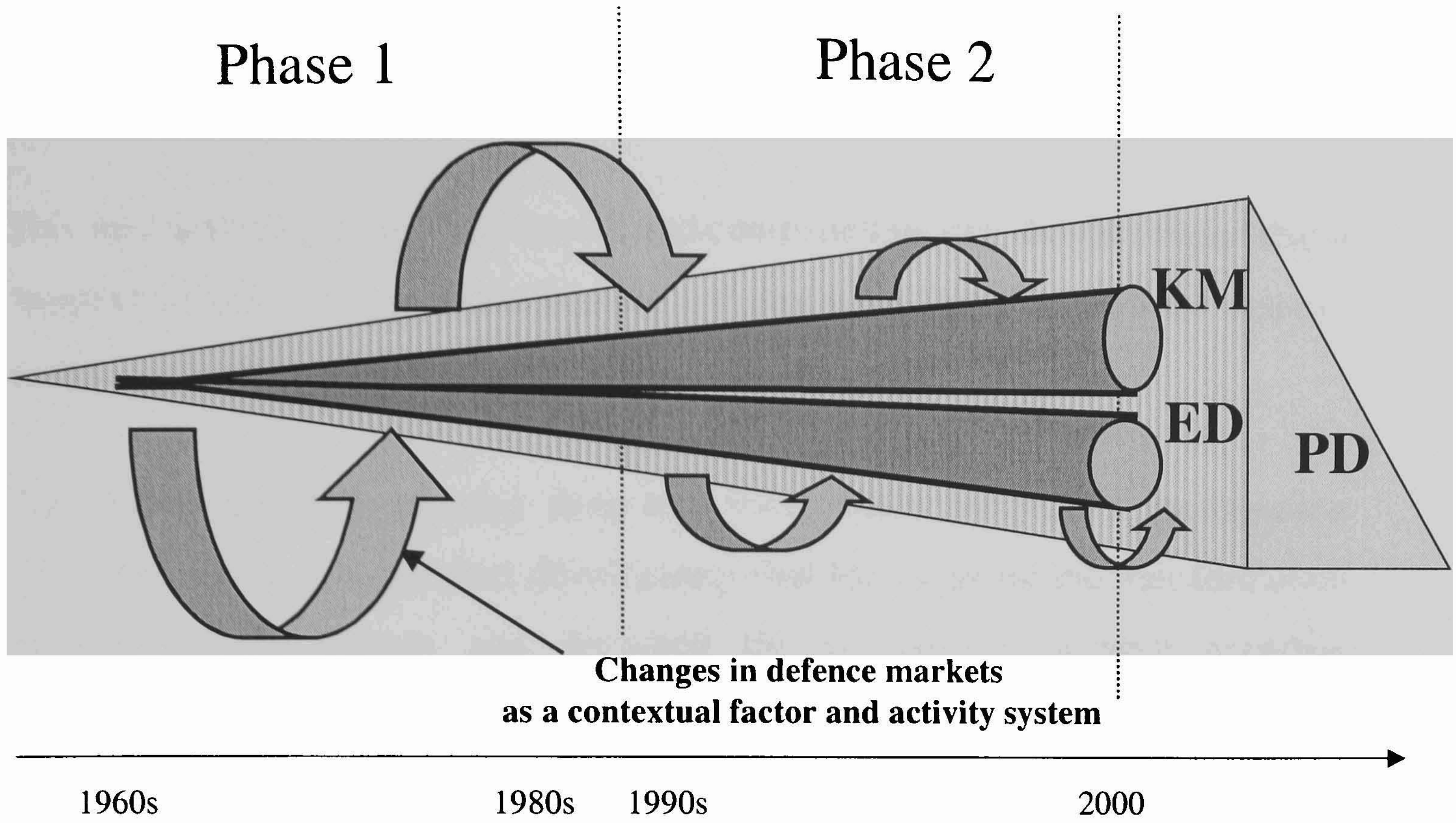

Figure 43: Contextualism in Activity Theory: The Internalisation of Market Changes

Thus, from the activity theory perspective, changes in defence markets need to be realised as an activity system that interacts with product development activity (see Figure 43). Contexts are neither containers of given problems and knowledge domains nor are they situationally created experiential spaces. Rather, contexts integrate the subject, the object and the instruments involved in an activity system (Engestrom 1996).

However, accepting the notion that a context is an activity system, one has to wonder how such an activity system, which is often external to the organisational activity system network, is internalised, diffused and turned into action?

Activity theorists (e.g. Blackler et al. 1999; Engestrom 1996; Lave 1996) suggest that any activity system is connected to other activity systems through all its components. It is also argued that the injection of a strong new factor into one of the activity system components will emphasise the contradiction between that component and other component of the system, leading to further disturbances within the 'injected' activity system. Innovations will follow tension and disturbances as individuals attempt to overcome 'persistent mistakes', resulting in the transformation of the activity system (Engestrom 1996).

This means that by observing tension and contradiction, one should assume that a 'contextual' activity system has injected a strong novel factor into another activity system, gradually transforming the latter.

The following section explains, from an activity theory perspective, the injection of a strong factor into product development that has triggered the transformation of this activity system and disturbed the coexistence between expertise development and knowledge management activity systems.

6.4.3 Avoid Reinventing the Wheel: The Change Process

The studied companies set about their task not just to eliminate technological duplication but also to use and reuse existing technologies and products from the same family in future products. The chief objective was to accelerate product development cycles and reduce costs, goals that aimed to enhance their competitiveness. Many of the changes were in the areas of organisational structure, project management practices, communications and the redefinition of the roles of managers and engineers in the innovation process. In addition, new technologies were also introduced, such as Computer Aided Design (CAD) applications, Computer Integrated Manufacturing (CIM) applications, and Project Management applications. However, changes in organisational structures and processes were reported as the most aggressive and effective in targeting the above objectives. These changes were widely described and analysed in Chapter 5.

The metaphors used by engineers and managers to describe technological development were strongly associated with the chief problem these companies were experiencing (Bradshaw 1992). For example, almost all interviewees referred to the issue of excessive and duplicate technological development as the 'reinventing the wheel' syndrome. The solution to this problem was coined by these interviewees as 'avoid reinventing the wheel'. Using this metaphor made it clear to engineers what they were expected to do and what were the desired results from this change process (Weick and Roberts 1993).

Thus, the realisation of changes in markets was injected into product development in the form of a metaphor suggesting that the solution to excessive technological development was the efficiency that the slogan 'avoid reinventing the wheel' had to offer. Obviously, the scope of the actions involved in 'avoid reinventing the wheel' is far more broad than just reusing technological platforms and designs. As seen in Chapter 5, numerous and various mechanisms were implemented in order to satisfy management's slogan 'avoid reinventing the wheel'.

Of particular interest in the following sections is the impact that the introduced mechanisms have had during Phase 2 on three concurrent, although interrelating, activity systems: product development, expertise development and knowledge management.

6.5 The Impact on Product-development, Expertise-Development and Knowledge-Management Activity Systems during Phase 2

Solutions to past problems may themselves become the source of future difficulties (Blackler et al. 1999: 28). In the Israeli electronics defence industry the introduction of the above initiatives triggered a transformation chain reaction of organisational processes within product development. Of more interest is the directions that expertise development and knowledge management have taken following the above initiatives. However, because expertise development and knowledge management take place in the context of product development, it is first necessary to describe the impact on product development.

6.5.1 The Product-Development Activity System during Phase 2: An Accelerated Development Process

The product-development activity system experienced a growing pressure to change its object of activity during Phase 2. Project teams were urged to accelerate the product-development cycle, reduce costs and rapidly address client requirements by applying such solutions as reusability. These processes and the impact on product and market success were extensively reviewed in Chapter 5, undermining a rather successful contribution of these initiatives to business performance.

However, as argued before, rapid changes in the conception of the activity system often generate tension between the elements of the system (Blackler 1993).

Reservations were also expressed by a number of interviewees with regard to the new conception of the activity system. In particular, some areas were identified as problematic, indicating the complex situation that individuals and teams ran into when they were required to cope with new, often interrelated, processes.

For example, project managers and engineers were not comfortable with the approach of 'tying up all loose ends' in the first stages of the project (Kerzner 1995). They argued that product development by nature requires an approach that is receptive to continuous changes in design. Engineers argued that now they get the feeling from management and Sales that project teams should not make changes and should 'stick' to the design agreed in the conception phase. Changes, engineers argued, have been and will be introduced after the conception phase because of interactions with clients and recent technological development. Blackler and his colleagues (1999:22) explain this situation by stating that 'the design process is by nature a journey of discovery'. However, Sales and top management argued against this perspective, saying that changes after the conception phase jeopardise deadlines and increase costs. The Head of the Hardware Group at YellowTech provided his view on last-minute changes:

Modifications to inventory and electronics design sheets will be required and the instructions to the assembly line will have to be updated. These are, in many cases, unnecessary costs.

Because of changes in hardware-generated overheads within the studied companies, often problems in hardware found their solution in software changes. Hardware engineers justify the handover of design problems to the software domain by arguing that changes in software are less tangible and do not require changes in inventory, design sheets or assembly- line instructions. Hence, to avoid negotiations with Sales, who tend to bring last-minute changes to projects, project managers (who are usually hardware engineers) tend to push these changes on to the software team.

In return, software engineers expressed their frustration with this situation, claiming that Sales tends to agree to implement software changes because they do not understand what is needed. By taking this approach, Sales in fact legitimises project managers' attitudes to meeting any new requirement or sometimes dealing with poor system performance through software changes. One software engineer from Rafael claimed:

These changes are quite major for us. You change one place and the entire performance of the system might be impacted.

The Head of the Software Group at YellowTech reiterated this view:

Everybody is pointing fingers at us as the reason for delays in projects. They do not understand that making changes in software is like making changes in hardware. Any patch has a tremendous impact on the system.

The tension between those involved in product development reached the point that software engineers at TAMAM requested the Head of the Division to consider them for the role of project manager. One software engineer at TAMAM explained that part of their motivation to become project manager was:

[Their] desire to control the development process.

He explained that the software in his project accounts for more than 50% of the total man-hours invested in the project, and yet a hardware engineer is 'running the show'.

On the other hand, project managers argued that they were left with no other choice but to make changes in the software. They put the blame on management and Sales, who were pushing them to get the specification of the product to the client in a very short time. One project manager at TAMAM explained:

The most important stage (of the project) is the beginning of the project, during which 5% of the project time defines the remaining 95% of the project.[...] this stage has shrunk tremendously in recent years.

Lastly, project managers claimed that they were now spending more time on numerous meetings and design reviews that aimed to transfer knowledge and ensure that the project teams were reusing concepts and technologies. They felt frustrated because it seemed to them that the primary goal was now 'to reuse' concepts rather than develop products. Project managers also claimed that they felt trapped in the 'reusability' circle, meaning that they often chose to reuse components because of the excessive time they spent on discussing this option. In fact, some claimed that in some cases, having reused some components, they realised that their decision to do so in their project was not necessarily wise and did not save them time.

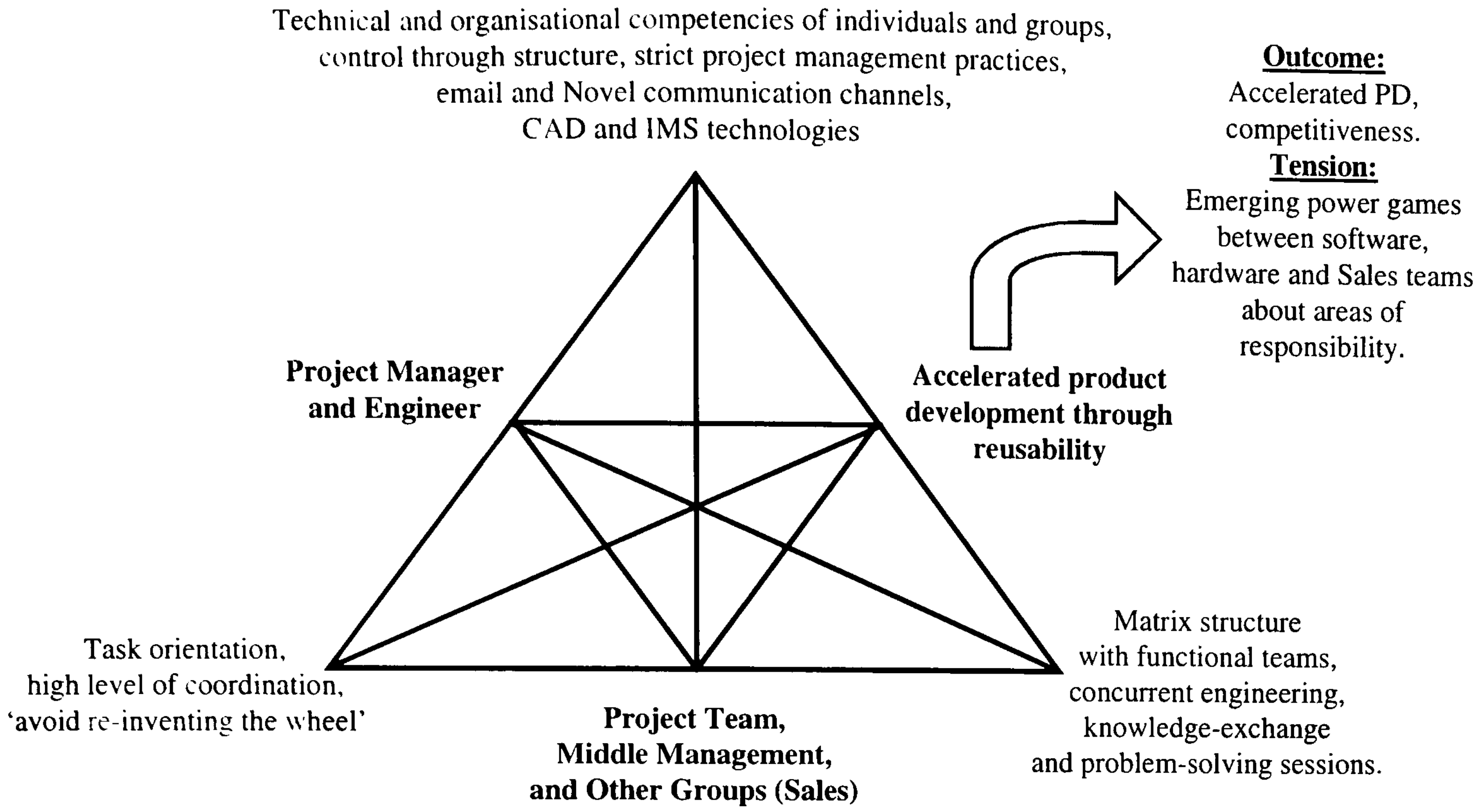

Figure 44: The Product-Development Activity System during Phase 2

Figure 44 presents the emerging interactions between individuals and groups during Phase 2. It is noticeable that the activity of product development has changed. New tools and mediating artifacts have been introduced, making the transformation of the activity possible (Engestrom 1999). The object of the activity, often described as enhancing product development processes, has introduced an orderly process in which individuals, through language games and the use of the metaphor of 'reinventing the wheel ', have become aware of the collective motivation of the activity (Leont'ev 1978; Weick and Roberts 1983). Actions directed towards reusability have helped to achieve the complex task of enhancing the product-development process for new products. However, tension is evident in particular between software and hardware engineers, mainly in terms of their accountability for last-minute changes.

In addition to the changes in product-development activity, there has been an impact on expertise-development and knowledge-management processes. The two following sections will describe these organisational processes during Phase 2.

6.5.2 The Expertise-Development Organisational Process during Phase 2

The acceleration of the innovation system has reduced mentoring and changed the conception of the expertise-development process. Interviewees described a learning process still mainly based on situated learning rituals[14] (Lave and Wenger 1991), although also strongly associated with the emerging product- development motive.

Newcomers who have joined project teams during Phase 2 report that they have learned the system they were working on fairly quickly. Most of them have become involved in design from the early stage of working with the company and were asked to take design decisions after a relatively short time. For example, two young engineers from YellowTech described their first days with the firm. They said that they were given a task to design one specific feature after a couple of days in the company, and were told by their boss that if they did not understand what they were asked to do they should ask for help. Both argued that this was the best way to learn the system. They acknowledged that part of this approach was because of the tremendous pressure that the project was facing to meet a major deadline.

One experienced engineer from the Popeye project at Rafael explained the difference between the present and the past:

> *When I arrived at the company, I was given guidance on the job and had the time to digest my role and my responsibilities. Today we have less time to devote to mentoring. We are busy with our work and focusing on daily results. The new guys are thrown into the deep end and need to learn how to swim quickly.*

Five interviewees from the studied companies were newcomers whose projects were involved in reusing technological components. They report that their

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[14] Described in detail in section 6.3.3.

familiarity with the reused technology has been acquired fairly quickly. They describe the process through which they have learned about the technology. Usually, according to two interviewees from Rafael, they would join a senior engineer who led the reusability effort at meetings with other project teams to discuss the compatibility of the design, system performance and the technological platform used to develop the design. The other three interviewees, two from YellowTech and one from TAMAM, describe a rather different approach during which they joined Design Review sessions during which the option to reuse components or a technological platform was raised by senior managers or system engineers.

When asked about their understanding of the system after these sessions, they reported that the sessions were important in helping them to become educated and to engage in discussions and debates about the specific design on the table. These discussions revolved around a specific problem, and the analysis of the solution was also specific and problem-solving orientated. It is also necessary to mention that none of the interviewees was involved in modifying the design to fit the new system configuration. One project manager explained this as follows:

> *Not everyone can do this work [modify the design of a reused technology]. You really need to understand the history of the system. One touches one place and the rest of the system can be affected. We cannot afford these mistakes.*

The development of gaining knowledge of reused components for experienced engineers has also revolved around meetings and Design Reviews. Only when the reused component was from the same product family did engineers prefer to proceed in their product family laboratories[15]. Experienced engineers also reported that the introduction of a solution was very focused and aimed at the potential

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[15] See section 5.4.2.2 for further elaboration about the organisation of projects according to their product family.

application of this solution in a new design. One project engineer from YellowTech described the process:

> *Often before the meeting we would exchange some material to make sure that the other project [base project] understood the system requirements and for us to have a clue about the components that they had used in the card. Then, we would meet in the 'sanctuary' [the small conference room at YellowTech] and go over the design sheets. Usually the first 30 minutes was for the base project to describe the functionality and then 15 minutes were for us to ask questions. In my case there were four meetings before we started to make modifications in the design.*

These actions were mainly directed at the achievement of successful and enhanced product-development activity, though they were in essence making use of tools and artifacts related to expertise development. The growing emphasis on quick results has raised concern among engineers and technicians with regard to their personal development. A few engineers at YellowTech argued that following the growing concentration on reused components and products, in particular within the product family, they feel that they get fewer opportunities to learn about new technologies. In particular, technicians and engineers who were previously involved in R & D expressed concern that they were excluded from the design work because of the excessive reuse of technologies. One technician at YellowTech expressed this anxiety:

> *We don't have time to learn new developments any more. We just deliver systems. We have become the blue-collar workers of the company.*

His boss, the Head of the Hardware Group at YellowTech, justified the approach, saying that:

> *We cannot afford the luxury of everybody being part of the learning process in the organisation. It is too expensive. We had to take some tough decisions about who would be up-to-date with technologies and who would be more on the production side.*

A similar frustration was expressed by an engineer from TAMAM, who stated bluntly:

> *Everybody here is telling me 'don't reinvent the wheel', check what we have and use it. It is always like that when we start a project. My boss [system engineer] asks me to 'borrow' applications from other projects. We all use the same microprocessors and write in the same program language so it is easy to 'borrow'. The thing is that I learn very little from this.*

Solving problems and engaging in troubleshooting, which used to be the stage for the mentoring of newcomers and experienced engineers, was described as a 'war against the clock' by one engineer from Rafael. He explained that:

> *Troubleshooting should not take long these days. We have deadlines to meet and in many cases the technology is not new.*

Furthermore, engineers and technicians stated that management and Sales push them to provide '*a solution*' rather than '*the* solution' to problems in design. As one system engineer at YellowTech commented:

> *We never get to the bottom of problems. Instead, what we do here is 'put out fires'. Management breathe on our necks, asking us to finish the development when we are still working on problems. No wonder that we always end up having many 'stitches' [corrections] on our cards and always have to go through a retrofit stage.*

Written research reports, which were another avenue to develop expertise for young and experienced engineers, were replaced by product configuration documents in the three studied companies between 1995 and 1997. Research reports were written by engineers in order to document their experiments and results. These reports served an internal audience who were curious to understand the development process of the technology. The work on research reports has received less focus in recent years, and project managers are more concerned about delivering product-specification and product configuration documents, which are part of the delivery package to clients.

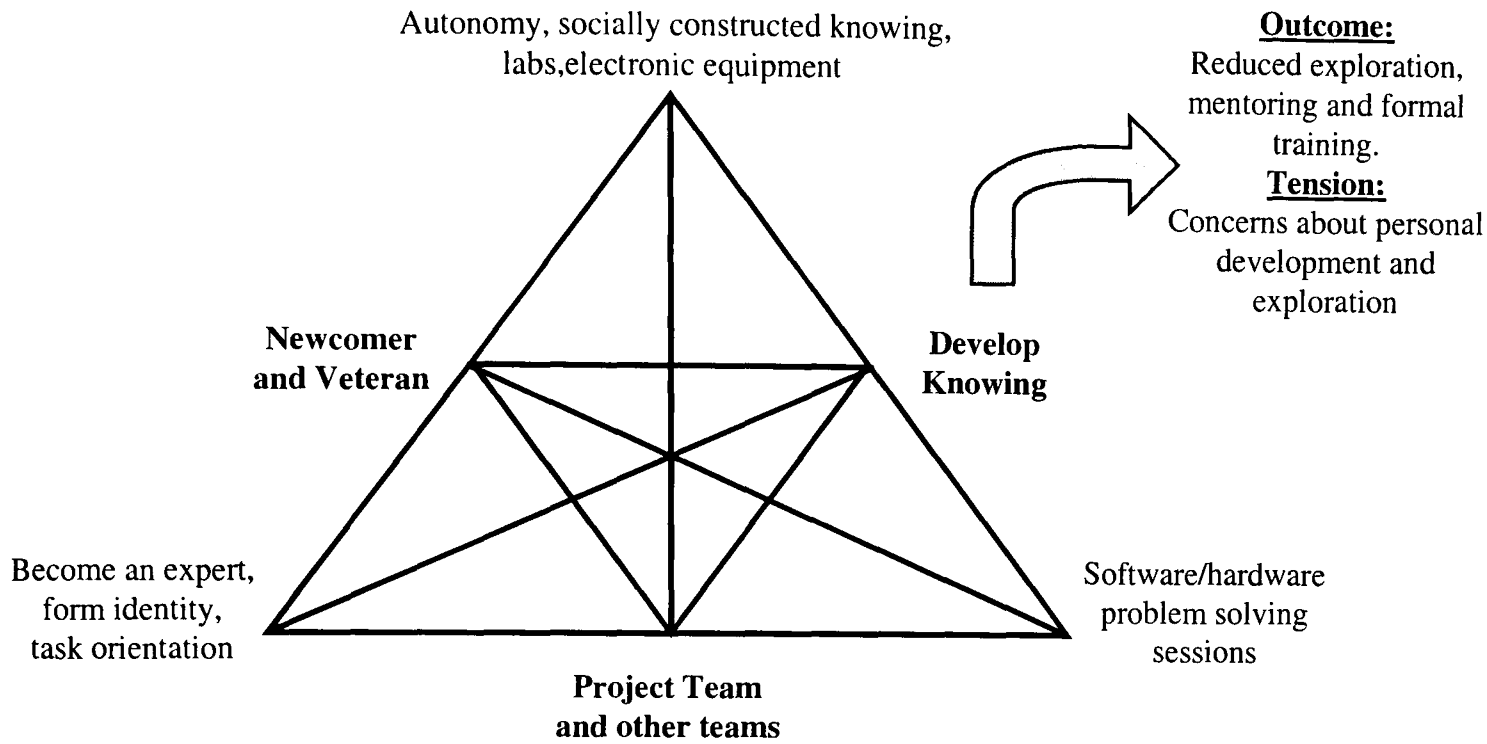

Figure 45: The Expertise-Development Activity System during Phase 2

The paradigm shift in the product-development activity system has impacted on the expertise-development activity system. Speeding up the product- development processes has resulted in reduced mentoring (Blackler et al. 1999). Also, concerns about personal development are one of the key results of the transformation of expertise development. Another area in which confusion was expressed was the lack of guidance for new and emerging groups, such as Sales, Marketing and ASIC. Areas such as job definition and the definition of responsibilities for new groups were elusive and created confusion and frustration. Individuals lacked the necessary tools and did not even know about the need for specific tools to do their job properly, which often generated debates within groups and across the entire organisation. It seems that expertise development has now shifted towards individual effort rather than group endeavour.

To conclude, expertise development as an evident process has become a set of actions realising the product development motive. New mediating artifacts (e.g. product configuration reports), concepts (e.g. reusability) and processes (e.g.

learning by doing) have been introduced to allow the transformation of the previous expertise development activity from an object-orientated activity to a goal-directed set of actions.

Changes in product development have also affected the knowledge- management process. In the next section we will review this impact.

6.5.3 The Knowledge-Management Organisational Process during Phase 2

The enforcement of the reusability strategies in product development has affected knowledge-management processes in the studied companies. As described above, individuals and groups were expected to engage in knowledge exchange sessions which would facilitate the transfer of concepts and technologies between project teams (Cusumano and Nobeoka 1998; Nobeoka 1995). A set of new actions involving new mediating artifacts and processes was introduced by individuals and teams to enable the transformation of knowledge management. However, according to the field data, the motive for these actions was somewhat confusing. On the one hand, engineers saw the motive as closely associated with the reusability strategy. On the other hand, management saw knowledge transfer actions as associated with the enhanced product-development process. Despite this uncertainty, knowledge management has changed from a collection of actions and artifacts associated with knowledge sharing in Phase 1 to a more orderly knowledge-transfer process during Phase 2.

As seen above, new processes and mediating artifacts were introduced in knowledge-management processes during Phase 2. Yet the experience of individuals participating in knowledge transfer has varied.

Two different routines emerged from the field data for knowledge-transfer processes. One is the transfer of technology between projects of the same product family, and the second is that between two projects of two different product families. The following examples took place at YellowTech; however, similar patterns were observed at TAMAM and Rafael.

The routine for the first case is based on the experience acquired at Light Systems Programme. The transfer of designs was considered successful by members of the team and management. The project manager estimated that the entire activity, involving the understanding of the problem, seeking a solution within the group, and, once it was found, completing the action by making some changes, did not take more than a couple of weeks. In addition, the transfer of the design from one team to another provoked only a few debates about some specific features and their application in the new design. These were resolved quickly. The project manager summarised the experience as follows:

> *It was a good experience. The fact that the solution came from our 'family' made it very easy to implement. We know each other's work and have already worked together on problems in the past.*

The second example is from The Galilee Rose Project, where the design of this project was transferred to another project from a different product family. This process experienced more difficulties, though it was still considered as successful by management. The project engineer of the receiving project described the process of knowledge transfer that he was involved in with another project. The emphasis in his description was on the ambiguity of procedures for knowledge transfer, the lack of clear definition of responsibility, the role that each party plays in the process, and the priority that this process is given by both parties:

> *[I} had to chase this guy for a couple of weeks before we could sit down and start nailing down some issues. But even then we ran into arguments about almost any issue. First he got defensive when I asked him why they designed the TOA [Time Of Arrival] function this way. Later on he had to run to another meeting, and finally he asked one of the junior engineers to walk me through the design sheets.*

In the end the project engineer from the receiving project was asked to work out the design by himself and raise any questions if he did not understand specific areas in the design. The project engineer from the receiving project complained:

I was left alone with a document that did not say much about the design but rather gave me the general spec of the system. I managed to go over the missing bits and eventually understood the electronics card completely. Looking back at this experience I am not sure I would like to do it again.

The system engineer from the transmitting project provided his view on the same event:

How can I transfer knowledge that was developed in three years of problem solving, debates, decisions and sometimes without any systematic methodology? The trouble is that we are asked to reuse components but they [management] do not understand what it means.

He went on to suggest that transferring a product design is not really the transfer of the knowledge that is embedded in the product. In fact, the engineer's knowledge of the product (Blackler 1995) or the tacit knowledge (Polanyi 1967; Nelson and Winter 1982) that he or she possesses about the product is at the centre of the transfer process. Other engineers suggested the same and implied that the transferability of knowledge was not trivial. They did not explicitly refer to the implicit side of knowledge but repeatedly stated that 'it is not enough to go over the design sheets in order to understand the design' (interview source).

Thus, the knowledge about a skill which has evolved as a socially constructed process as part of learning and knowledge-sharing in the years prior to Phase 2 has changed meaning and lost the context within which these skills have evolved (Blackler 1995). Suddenly, skills and information have been seen by management as a pragmatic object that can be moved from one place to another, like a ball (Hosking and Morley 1991). The practicality of transferring a design from one project to another seemed attractive and simple to management. This transferability of knowledge as a concept was also promoted by the diffusion of CAD technologies, which made it possible to store and easily retrieve design sheets from one central point. The field data provided three examples of knowledge transfer, and in all of these examples a rather technical process was illustrated, putting the transfer of the design sheets in the middle of the process.

Management and the Sales team in the studied companies perceived the reusability strategy as a generally positive move. The Head of the Popeye Programme at Rafael did not see any problem with the process. Furthermore, he argued that management should only provide a general direction for the strategy and let engineers plan the necessary actions in detail. He put this idea in very militaristic language:

> *We put a circle around the target we want to hit and let the guys decide on the tactics to get the job done with no injuries.*

In reality, engineers who were reusing concepts and technologies found that they needed to *define* tools and *set* rules and procedures, as this area of activity was new and different. Individuals reported that often, in order to 'get the job done' and to ensure the complete process of knowledge transfer, they needed to define simple rules for the knowledge-transfer process. For example, project engineers often did not stay until the end of meetings related to the reusability strategy. One project manager from YellowTech described how after three meetings with the project manager of the base project, he felt frustrated because of the low priority that the other side was giving to this activity. With the Chief Scientist it was decided that after each meeting a summary of the issues discussed and agreed would be circulated by email in the R & D Division. The impact was tremendous for two reasons. First, more people became involved in the reusability strategy of a specific project, and these emails enhanced their understanding of the process and the reasons for reusing a specific solution. Secondly, both sides involved in the reusability process had to be more committed to the results each time they met. Nevertheless, rules and procedures often changed, depending on the dynamics between participants.

Additionally, project managers sought tools to ease their struggle with the reusability strategy. Some started to preserve and share information through repositories and knowledge bases. These were very basic tools that were usually created by one project team and were rarely shared across the division. Two examples of such initiatives illustrate the new trend.

The ASIC group at YellowTech created a repository of designs. The Head of the ASIC team claimed that the repository would help members of the team to quickly deploy solutions from one project to another. Project teams in all three studied companies started to log solutions on the Intranet. A search engine was installed on the database to assist others to find solutions to reoccurring problems in designs. These improvisations were initiated and managed locally by either the project team or the functional team in an attempt to preserve their knowledge in the form of content stored in databases, and to make it available to others in order to speed up the development process.

One Sales manager at Rafael described how he created a repository of presentations for the Litening Sales team. He identified this need when the group was bidding for contracts in a number of countries at the same time. He explained that it was obvious that the members of the team duplicated effort, and hence proposed to the Sales team that he would create a database of presentations, and that this would be accessible to the members of the Sales team. When he was asked about making the concept available to other Sales teams within Rafael, he bluntly replied:

> *I do not want to run in the corridor and shout 'I invented the wheel'. I could make myself a fool if I find out that someone has already 'invented the wheel'.*

One more action worth mentioning was initiated as part of the knowledge-management process in the studied companies. This was an attempt to map knowledge centres based on the expertise that individuals possessed at that time.

This process pushed individuals and groups to form new rules and procedures, and in one case to seek advice outside the organisation.

Mapping expertise was a new process for the studied companies. Rafael and TAMAM started the process in late 1998 and both abandoned the idea soon after. YellowTech started mapping expertise in 1999 and is still updating the 'Yellow Pages' system, though the real usage is reported to be low.

The justification for mapping their knowledge was expressed by one engineer from YellowTech:

> *How do you know who knows what? Some of us have worked in the same product family for the last five years and we don't really know what other project teams are working on.*

This argument was expressed by many interviewees. They made the point that organisational knowledge is not necessarily known and accessible. Bahrami and Evans (1995) studied 37 hi-tech firms in the USA and identified some organisational features that supported communications and enhanced knowledge sharing. These were mainly associated with information system technologies such as email systems and shared databases. As seen above, these tools have just started to emerge in the studied organisations. For example, at TAMAM some employees did not know how to use the email system. At Rafael and YellowTech, it was claimed that security issues prevented employees from having access to the Internet, and that there were restrictions on the usage of email outside the company.

Hence, management was decisive in its approach of mapping organisational knowledge and became involved in setting the direction of mapping expertise. However, in order to reach an agreement about the criteria of expertise and who would be considered as a 'knowledge centre', a committee was formed, chaired by the heads of the R & D Divisions for both Rafael and TAMAM. At Rafael the committee met once a month and its work was terminated after four months. At

TAMAM the committee met once every six weeks and their work was terminated after five months. Both committees failed to complete their tasks. In theory, the emphasis in committee work is on sharing information among all the committee's members, a joint decision-making process, and the rational examination of proposals and their alternatives (Barber 1966). In reality, interviews with managers involved in the committee and others suggested that the committee had spent time debating other topics. In many cases, issues related to problems in specific projects, which were sometimes related to lack of expertise or lack of resources, were raised in the committee. In other cases, some members used this forum to complain about the lack of formal training in their company. One system engineer, a member of the committee at Rafael, described a meeting that took place a couple of weeks before the interview:

> *A debate about who was accountable for one specific bug was carried on from a morning meeting to the knowledge management meeting. Since all the people involved in the problem were in the KM forum, we spent these two hours discussing this bug.*

YellowTech, on the other hand, preferred to give the task of mapping knowledge to one person, the Head of MIS. He was responsible for defining and categorising expertise and coding the tree of expertise of the R & D Division. Helped by two members of the MIS team, this person conducted a number of interviews with the heads of professional fields and after this stage submitted a proposal to follow up this activity by contracting with a consulting firm. In 1999, KnowledgeWare ROM was chosen as consultant to YellowTech on how to proceed with their project. A two-phase project was conducted. The first phase aimed to identify and map core knowledge assets within the R & D Division. A second phase of the project mapped 'knowledge centres' by linking knowledgeable workers to knowledge assets. The entire exercise was concluded in 1999. Since then YellowTech has maintained the system, and once in six months it updates the knowledge assets and knowledge centres. Despite the resources put into this project, interviewees reported that they rarely use the 'Yellow Pages' knowledge-management system.

Project managers and engineers at YellowTech argued that the 'Yellow Pages' system has contributed little to accelerated product development. They added that the system has mainly tagged individuals as 'experts', and those who were not included were tagged as 'non-experts'. They felt that actually the 'Yellow Pages' system led to more confusion. Instead of accessing knowledge, they often felt they were pulling knowledge from the 'experts'. Those who were tagged 'experts' in the 'Yellow Pages' system became extremely busy and it was hard to work with them anymore.

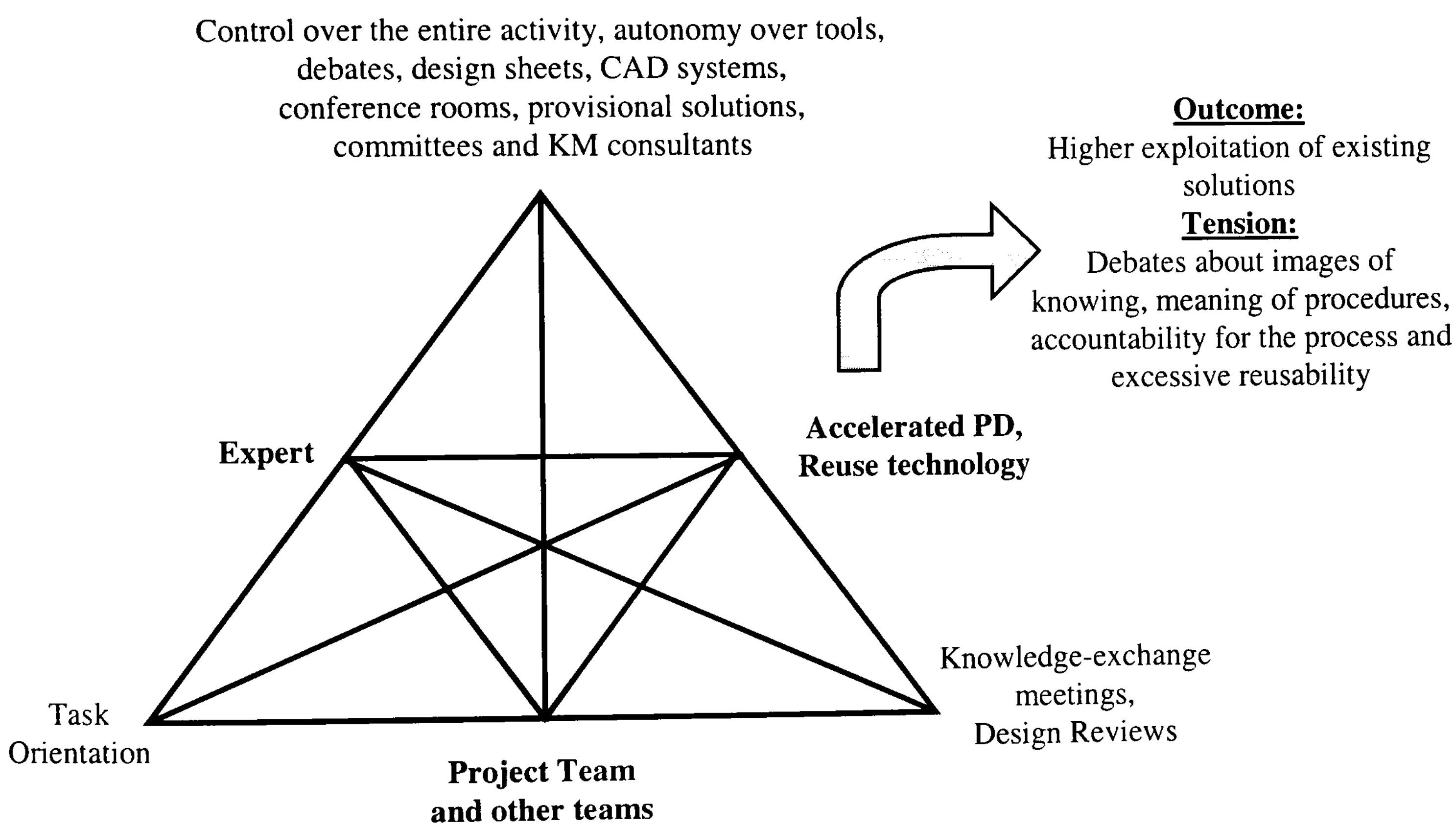

Figure 46: Knowledge-Management Activity during Phase 2

Figure 46 describes the knowledge management activity system during Phase 2, showing that this activity system has become more orderly and regulated in terms of the objective of the activity. However, it remains very loose with regard to the tools and processes needed for the accomplishment of the knowledge-transfer process.

Concerns about the process of knowledge transfer were raised as individuals debated the different perceptions of knowledge and its transferability. Also, different tools emerged within different groups as management left engineers to decide how the reusability strategy would be executed. Thus, the diversity of formats and type of data stored in knowledge bases and other Information System tools have added to the disagreement between project teams during the knowledge-transfer processes.

Thus, knowledge management has emerged as an activity that realises two motives: accelerating product development by management, and reusing hardware and software components by engineers. New artifacts and processes have been introduced which allowed the transformation of this organisational process. Tension between individuals and groups has emerged because of new work practices which lack any means of organisation. Contradictions with regard to tools and procedures during the knowledge- transfer process were described as breakdowns in the process of transferring knowledge. However, these were in fact avenues to learning (Bodker and Gronbaek 1996).

Thus far we have described the transformation of the expertise-development and knowledge-management organisational processes following the acceleration of product development mainly through the introduction of cross-project learning and reusability process in the studied companies during Phase 2. In the following section, the tensions between expertise development and knowledge management will be analysed to examine the breakdown of the collective expertise activity.

6.6 Discussion

6.6.1 Introduction

This chapter opened with the question: how did cross-project learning and the acceleration of product development impact the product development environment?

The above analysis suggests that expertise development and knowledge management have significantly changed following the introduction of cross-project learning and the acceleration of product development. If Chapter 5 has emphasised the conditions and value added in cross-project learning, this chapter highlights the difficulties and perhaps caveats for those companies wishing to follow the road taken by the case study companies. These pitfalls become evident through the application of an activity theory lens (Engestrom 1992), revealing systemic tensions within and between each activity system. Sections 6.6.2 and 6.6.3 will briefly recap the main areas of transformation in expertise development and knowledge management activity systems.

6.6.2 The Transformation of Expertise Development: Phase 1 – Phase 2

Expertise development has significantly changed. The notion of mentoring which supported the participation and identity formation of engineers and technicians has gradually faded. The recent trend to reuse software and hardware components also has impacted the notion of exploration for engineers and technicians, reducing the time spent on exploring and implementing new technologies and thus directing the learning of design towards a rather goal-orientated task. Instead of these two fundamental concepts in R & D work, i.e. mentoring and exploration, a learning by doing, goal-orientated expertise development activity has emerged raising concerns about future personal development for engineers and technicians (see Figure 47).

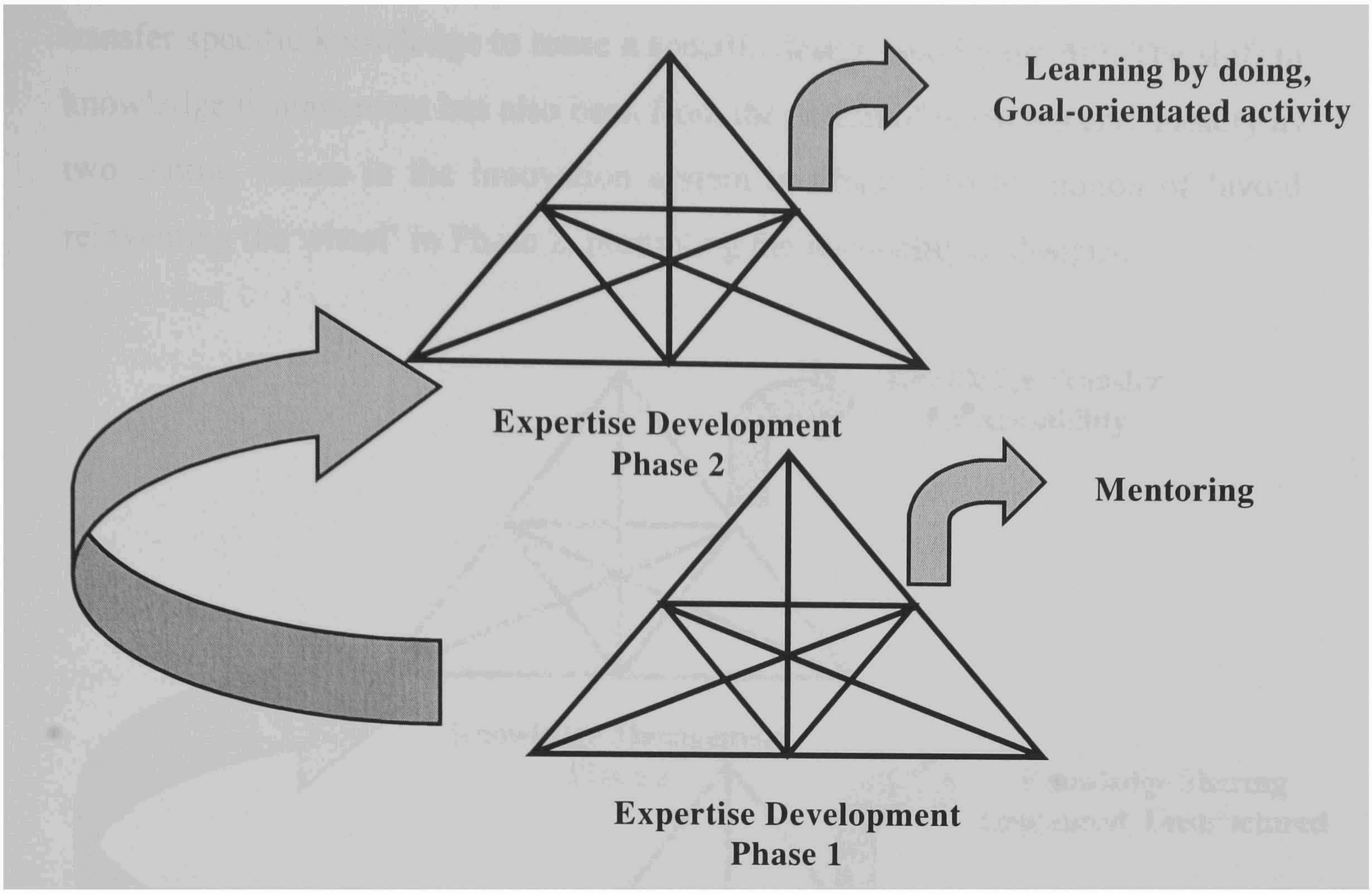

Figure 47: The Transformation of Expertise Development

In addition, changes in the way engineers learn and develop their expertise were also detected. Previous concepts and modes of operation have changed, often replaced by processes that ensure high effectiveness from the R & D process (Coombs 1998). For example, trial and error has been completely eliminated by the recent use of simulation software packages that provide a clear picture of mistakes in the design and in some cases even automatically correct man-made errors. The average project life has shrunk dramatically to three years in Phase 2, cutting the lengthy periods of time that engineers and technicians previously used to study new technologies in a relaxed mode. Lastly, the practice of writing research reports was replaced by on-demand configuration documents.

6.6.3 The Transformation of Knowledge Management: Phase 1 – Phase 2

Knowledge management has shifted from knowledge sharing to knowledge transfer activity. Knowledge management has gradually been transformed from a set of actions aiming to share knowledge often without a specific goal, to become a rather goal-orientated activity that includes designated participants who aim to transfer specific knowledge to reuse a specific design (see Figure 48). The shift in knowledge management has also been from the notion of invention and mastery as two central values in the innovation system in Phase 1 to the notion of 'avoid reinventing the wheel' in Phase 2, promoting the reusability of designs.

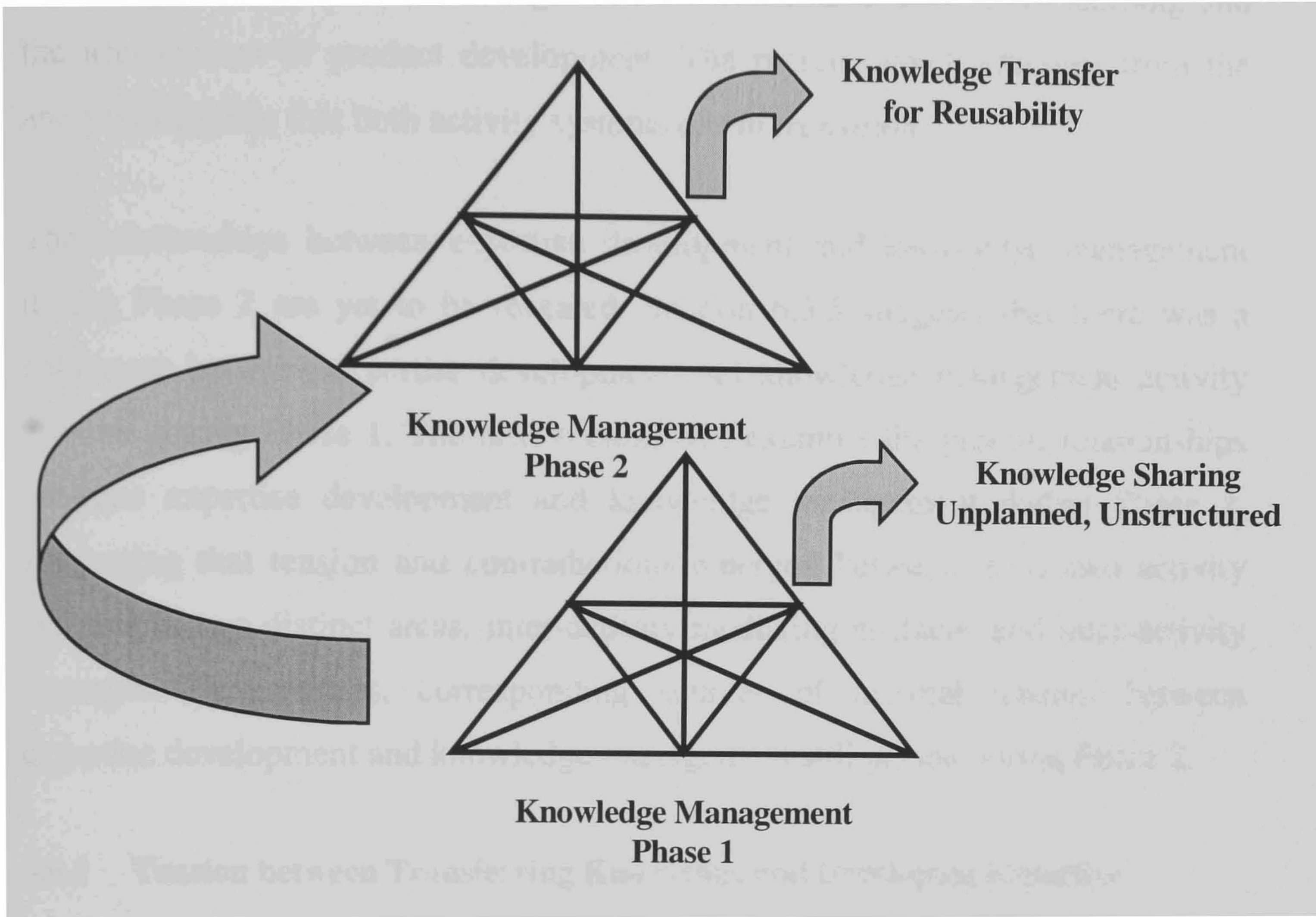

Figure 48: The Transformation of Knowledge Management

Other notable changes in knowledge management have been, for example, the shift in the social spaces within which knowledge management has taken place. From a laboratory-based activity in Phase 1, knowledge management in Phase 2 has taken place mainly in conference rooms, during Design Review sessions involving debates about knowledge management procedures, the meaning of knowledge under transfer and the areas of responsibilities of those involved in the transfer process. In addition, it is evident that individuals and groups have invented solutions addressing their very immediate needs to preserve and 'manage' knowledge and also to quickly retrieve knowledge. In a way, a new cycle of 'reinventing the wheel' has started, in which, for example, rules relating to the management of knowledge transfer have been introduced, along with repositories storing the content of different groups, sometimes shared but often isolated (e.g. ASIC, Sales, project teams).

Thus far, the above sections have addressed changes in expertise development and knowledge management following the introduction of cross-project learning and the acceleration of product development. The picture which emerges from the analysis suggests that both activity systems *are in transition*.

The relationships between expertise development and knowledge management during Phase 2 are yet to be revealed. Section 6.3.5 suggests that there was a coherence between expertise development and knowledge management activity systems during Phase 1. The next section will examine the present relationships between expertise development and knowledge management during Phase 2, suggesting that tension and contradictions emerged between these two activity systems in two distinct areas: inter-activity mediating artifacts, and inter-activity concepts. Nevertheless, corresponding sources of internal tension between expertise development and knowledge management still persist during Phase 2.

6.6.4 Tension between Transferring Knowledge and Developing Expertise

In contrast to the previous observation suggesting that expertise development coexisted in harmony alongside knowledge management during Phase 1[16], it is argued that the above activity systems, during phase 2, presented incoherence and inconsistency, in particular in two distinct areas: the different interpretation of the meaning of knowledge, and the use of different artifacts in these activity systems during Phase 2[17].

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[16] described at length in section 6.3.5

[17] see Figure 45 and Figure 46 for a detailed illustration of the differences

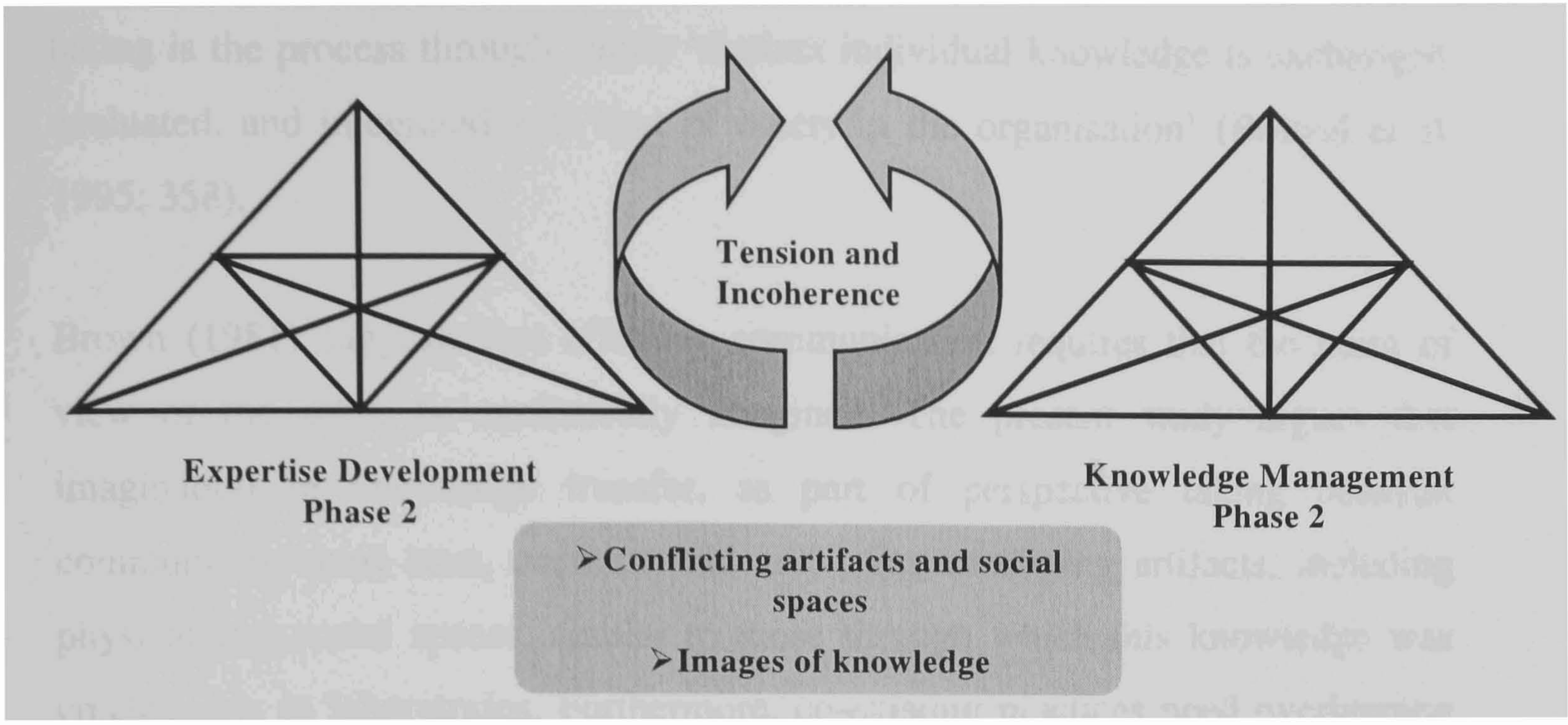

Figure 49: The Sources of Tension between Expertise Development and Knowledge Management during Phase 2

Figure 49 describes the tension and contradiction between expertise development and knowledge management activity systems. These will be described in detail below, in an attempt to address the following question: what are the sources of the tension and why have they emerged between expertise development and knowledge management?

6.6.4.1 Inter-Activity Mediating Artifacts: Contradicting Mediating Processes

Tension has emerged because of the different 'social spaces' accommodating the knowing and doing in knowledge transfer and expertise development activity systems.

The different mediating processes and artifacts in knowledge management and expertise-development activity systems have presented further challenges to the co-existence of these two systems. The communication channel through which knowledge becomes visible and accessible -- as in the designed 'knowledge management' activities -- has been based on project meetings, Design Reviews and informal conversation in corridors. These artifacts have created a social space facilitating the activity of knowledge transfer, which is needed for the process of 'perspective taking'; a term that was originally coined by Boland and Tenkasi (1995) and was later further developed by Blackler et al. (1998). Perspective taking is the process through which 'distinct individual knowledge is exchanged, evaluated, and integrated with that of others in the organisation' (Boland et al. 1995: 358).

Brown (1981) suggests that effective communication requires that the point of view of the other be realistically imagined. The present study argues that imagination in knowledge transfer, as part of perspective taking between communities, must start, continue and end using mediating artifacts, including physical and social spaces, similar to those through which this knowledge was created, e.g. in laboratories. Furthermore, co-existing practices need overlapping areas, such as mediating artifacts and physical and social spaces, in order to allow the build-up of perspective taking. At the studied companies, expertise development has thrived on intra-community interaction and participation, whereas knowledge management has focused on inter-community activities, lacking any active participatory dimension in product design. *Moreover, the present study shows that the knowledge-management activities introduced did not really encourage perspective taking, and in fact have failed to understand the importance of it.*

6.6.4.2 Inter-Activity Concepts: Contradicting Images of Knowledge/knowing

Tension between knowledge management and expertise development has emerged because of the different images of knowledge developed within the two activity systems.

The expertise development practice has thrived on images of knowing and doing as described above; it has been contextual, situated and mediated (Blackler 1995). Knowing is specific and requires the participation of individuals and groups in the process through which this knowing is created.

On the other hand, the knowledge management activities treat knowledge as a commodity, i.e. as generic, accessible, codifiable and context-independent (Smith 1995). For example, the project management practice at YellowTech has encouraged the perception of knowledge as an object by promoting management concepts such as cost-effective design, design centres, profit-centred projects and minimum learning costs.

Lam (1997) describes a similar case in a study of a collaboration effort between a Japanese and a British hi-tech company. Amongst other reasons for the difficulties in this collaboration project is the different way these companies organise, structure, apply and transmit knowledge, which is an integral element of their social settings.

Scarbrough (1999:6) suggests that this conflict is between 'the social conditions that promote the formation of knowledge and the economic conditions that allow the appropriation of its value'. Scarbrough (1999) goes on to suggest that many of the sources of conflict are outside the control of management, proposing that 'conflict may be either stimulated or attenuated by changes in the institutional, organizational and individual contexts for knowledge work'. This study, taking an activity theory perspective, argues against Scarbrough's proposition. Indeed conflict is inherent in activity systems (Engestrom 1999); however, it is argued that contradictions and tensions are stimulated because of the introduction of new artifacts, social rules or perhaps a new division of labour. These innovations are in management control through the set of capabilities put in place to encourage creativity and innovations (Coombs 1996).

Having analysed the sources of contradiction between expertise development and knowledge management, this study must examine the systemic interactions between the tensions of these activity systems.

6.6.4.3 Inter-Activity Tension: Corresponding Concerns about Reduced Exploration and Excessive Exploitation

The outcome and internal tension generated in expertise development corresponds to the internal tension introduced by knowledge management activity. In the case of expertise development, internal tension has revolved around issues relating to reduced opportunities for exploration and degraded personal development. Complementarily, the tension arising from knowledge-transfer activities as demonstrated above, is concerned with excessive reusability and over-exploitation of technologies, resulting in reduced exploration.

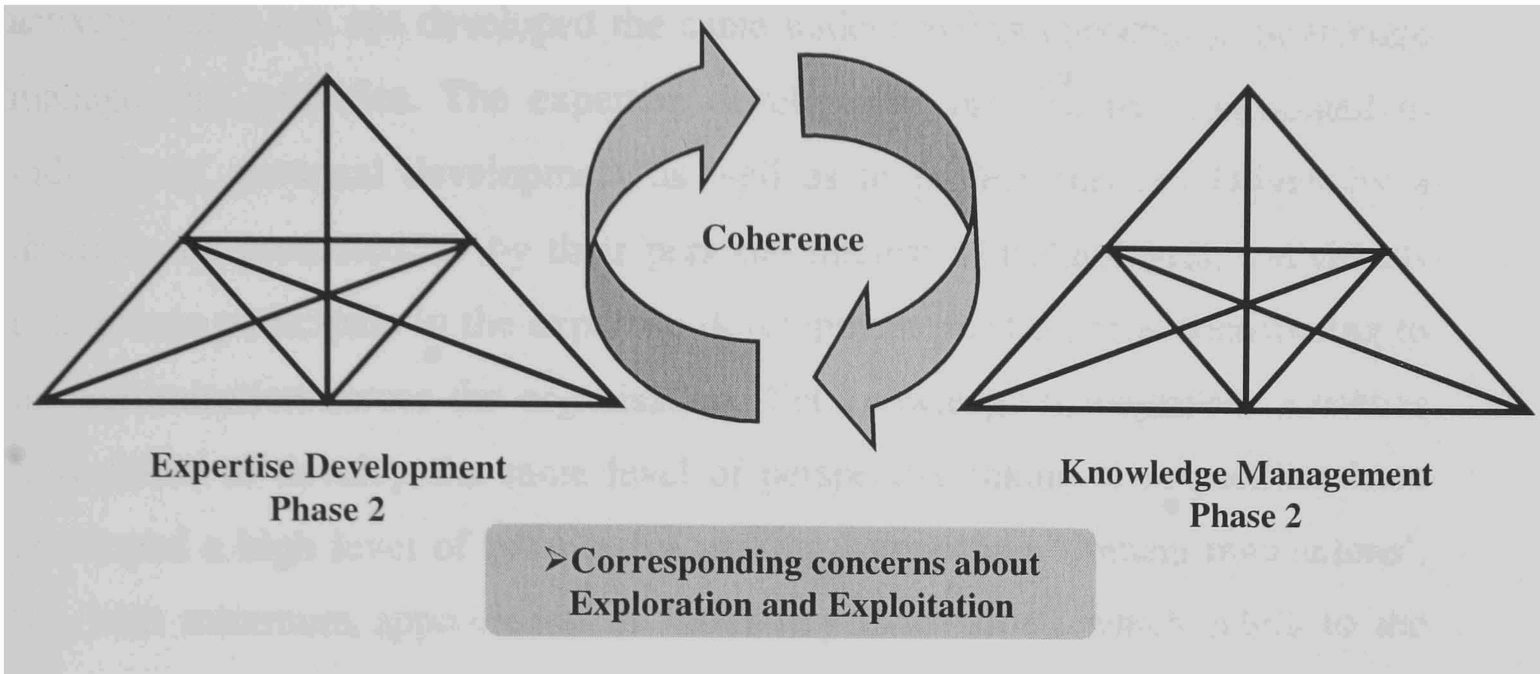

Figure 50: Corresponding Concerns about Exploration and Exploitation

March (1999) argues that tension may exist in organisations between exploration and exploitation. Excessive exploitation of internal capabilities to the exclusion of exploration may lead to a trap where organisations will be operating in 'sub-optimal stable equilibria'; whereas systems that engage in exploration to the inclusion of exploitation may find that 'they suffer the costs of experimentation without gaining many of its benefits' (March 1999: 114). Similarly, tensions of knowledge management and expertise development interact according to the tension between these two concepts, i.e. exploitation and exploration. Knowledge management as a knowledge transfer process has now emerged by aggressively promoting the exploitation of technologies within an environment that was traditionally based on technological exploration.

This scenario has emerged perhaps because project managers understood the multifaceted nature of their collective expertise (Engestrom 1987) but were unable to accommodate 'complex, perhaps competing priorities' (Blackler et al. 2000) or to develop an understanding of 'the adequacy of existing approaches to perspective making and perspective taking and perspective shaping for the self-regulation of the network'.

The product management practice has urged project managers and engineers to appreciate the development of expertise as a multi-project socially-constructed activity, but it has not developed the same understanding concerning knowledge management activities. The expertise development practice has contributed to individuals' personal development as well as to project success. Driven by a desire to be promoted, or by their personal interest in technologies, individuals and groups participate in the expertise development practice, thus contributing to its legitimisation across the organisation. Yet knowledge management activities have failed to develop the same level of perspective taking. Communities have developed a high level of perspective making, supporting 'domain innovations', but with minimum appreciation of 'boundary innovation', which refers to the alignment processes across communities of activity (Blackler et al. 2000).

6.6.4.4 Sources of Tensions between Expertise Development and Knowledge Management: Summary

The above analysis suggests that the shift from the knowledge sharing activity-motive in Phase 1 to a knowledge transfer activity-goal in Phase 2, and the acceleration of product development, was accompanied by changes in concepts and shared social spaces.

Engestrom (1996:73) suggests that ' [...] contradictions of the activity are the moving force behind disturbances and innovations, and eventually behind the change and development of the system. They cannot be eliminated or fixed with separate remedies, they get aggravated over time and eventually tend to lead to an overall crisis of the activity system. In this process, practitioners may experience them as overwhelming "double binds", dilemmas where all available alternatives are equally unacceptable'.

According to Engestrom, the aggravation of contradictions in product development would lead managers to the point that all available alternatives would not be worth pursuing. This means that managers participating in the activity system that is 'in crisis' will, at some point, stop pursuing alternatives that could ease present contradictions. Instead, managers will abandon traditional concepts and tools and introduce new concepts that will unavoidably bring the activity system to 'crisis'. A 'crisis' in the activity system would mean a change in the predominant conception of the activity, for example from knowledge sharing to knowledge transfer activity system.

Engestrom (1992) confirms our findings that managers and engineers endeavour to ease present contradictions by presenting new tools and concepts. However, in the context of this study, data suggest that the knowledge management activity system did not change its predominant conception during the introduction of new tools and concepts, neither were there any signs of a 'crisis' during Phase 2.

Rather, the knowledge management activity system presents an incremental innovative process in which managers introduce new tools and concepts to ensure the *survival* of the activity system by gradually easing present contradictions; however, generating new tensions. A 'crisis' does not occur overnight in activity systems, but rather there is an *evolutionary* process during which activity systems change their identities.

This weakness of activity theory restricts the researcher to seeking a certain point in time in which presumably the activity system has been metamorphosed. Having applied a similar concept in the above analysis which suggests that expertise development, knowledge management and expertise development have metamorphosed between Phase 1 and Phase 2, this study would like to present a rather different view on how activity systems metamorphose themselves in the context of the present study.

6.6.5 Is the Knowledge Management Activity System in Crisis?

To answer this question an Activity Systems Transformation model is proposed. The terminology of 'perspective making and taking' suggested by Boland and Tenkasi (1995) is borrowed, and a rather different interpretation of 'perspective shaping' (Blackler et al. 2000) is offered for the model presented below (see Figure 51). In addition, a new concept central to the continuous transformation of an activity system is introduced and will be coined here as 'proximal innovations'.

6.6.5.1 The Continuous Transformation of Activity Systems

6.6.5.1.1 The Lingo of Continuous Transformation of Activity Systems

Perspective taking and perspective making refer to the meaning of domain innovations and boundary innovations respectively (Boland and Tenkasi 1995; Blackler et al. 1999).

Perspective Shaping refers to the management of the capabilities (Coombs 1996) that are required to bridge the tension between domain innovations and boundary innovations (see Figure 51). In a way, perspective shaping can be understood as the innovation that drives the organisation towards its vision (Senge 1996). These capabilities can be seen as the organisational structure, vertical integration mechanisms, horizontal coordination structures and groups.

The invention of new artifacts, social rules and technologies will be coined here as 'proximal innovations'.

A few researchers referred to the notion of 'proximal' in the context of innovation and knowledge (e.g. Vygotsky). Polanyi (1966) suggested that tacit knowledge has two distinct properties: proximal and distal. The proximal term is the part that is closer to us, while the distal is further away. Polanyi describes how the police help a witness who is unable to describe a perpetrator to create a phantom image by selecting pictures from a large selection of human features as eyes, noses and hair. By attending from the first, closer image that resides within, to the second, more distant picture collection, the witness is able to communicate her awareness of the face. Polanyi (1966) argues that we become aware of the proximal term only in the presence of the distal term but remain unable to communicate the former.

Applying Polanyi's approach here, we suggest that the distal is the object of the activity system, i.e. to transfer knowledge, and the proximal is the small step innovations that individuals make to overcome 'normal but persistent accidents' (Blackler et al. 1999) and to ease tension between domain innovations and boundary innovations. Proximal innovations can be new tools, procedures, rules, technologies, division of labour etc. Proximal innovations are injected into activity systems and affect the perspective shaping of the activity through negotiations, discussion and the application of these innovations in other settings. Gradually, proximal innovations become part of the organisational capabilities (Schroeder et al. 1989). Proximal innovations are not trivial and they depend on the facilitation of the autonomy to act, the creativity and improvisation in the organisation.

6.6.5.1.2 The Transformation of Activity Systems

Figure 51 describes the dynamics of transformation by suggesting that there are three forces involved in transforming an activity system: perspective making, perspective taking, and perspective shaping. It will also be emphasised that activity systems do not break down neither they are in 'crisis', but rather suffer mini-breakdowns which eventually lead to their further development in line with the perception of the object of the activity.

There is an inherent tension between perspective making and perspective taking. The manifestation of this tension can be described as the inherent contradiction between exploration and exploitation (March 1999), or between intra-community and inter-community interests, or between knowing as a socially constructed phenomenon and knowledge as an object. These tensions lead to mini-breakdowns in the knowledge management activity system, as described in section 6.5.3. This can be metaphorically expressed that domain innovation and boundary innovations pull in two different directions. This may create inconsistency and un-coordination with regard to priorities, responsibilities and procedures, as seen in section 6.5. For example, the concept and application of a project as a profit centre may collide with the desire to shift attention to cross-project practices. Or perhaps the expression of frustration by one project manager when the transmitting project has not co-operated to transfer knowledge according to their expectation indicates sources of miscommunications and mini breakdowns of the procedures system in this specific company. Concepts, such as ownership of ideas, associated with small but effective project teams may clash with the aspiration to facilitate cross-project learning. But how is this tension between these two vectors being resolved?

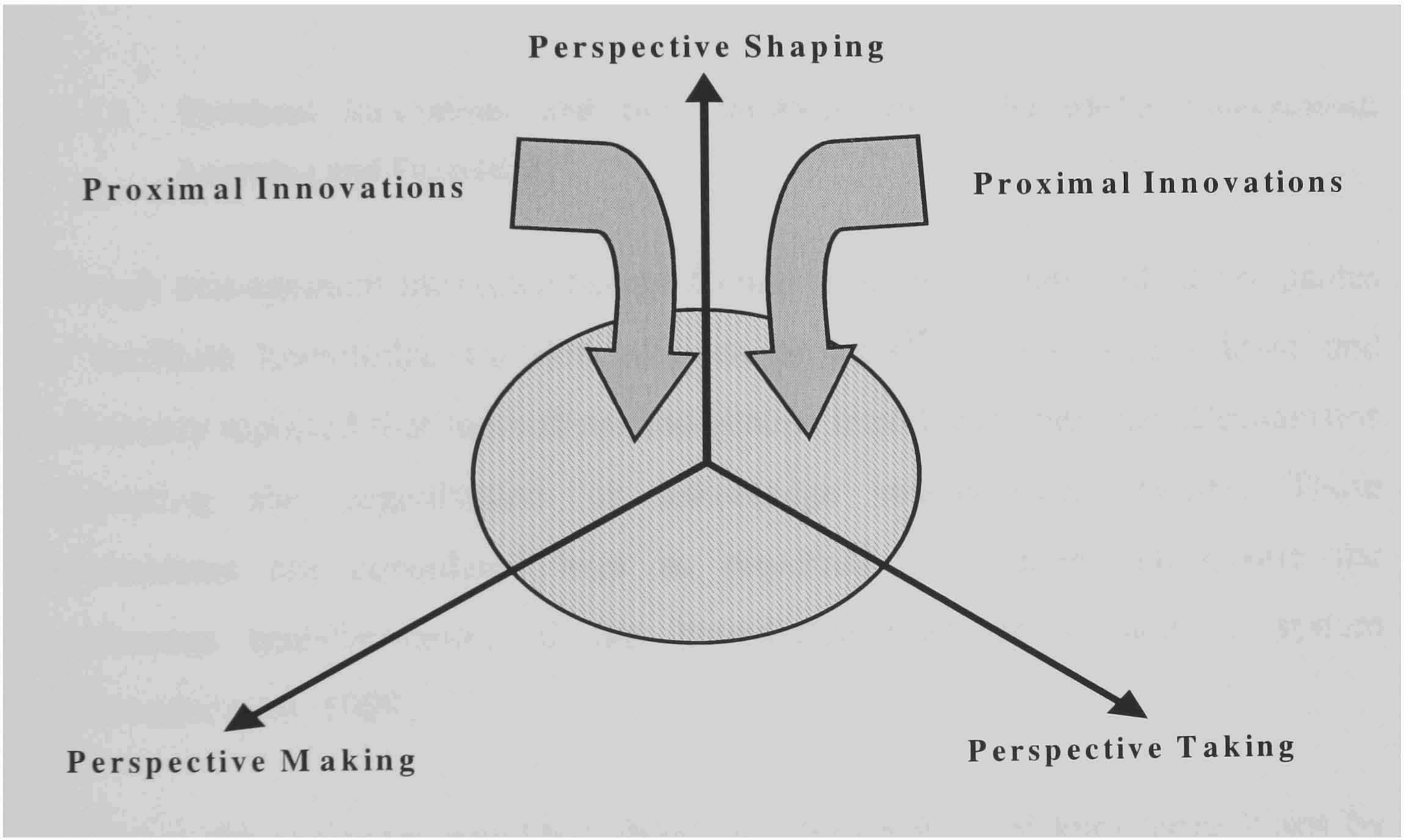

Figure 51: Activity System Transformation

Proximal innovations are the key to resolve these inconsistencies and tensions. Yet, and this is where our argument departs from Engestrom's, proximal innovations are also the source of future tensions without 'breaking down' nor bring the activity system to a 'crisis' mode. An on-going interaction between domain and boundary innovations continues, which represents both cooperation and contradiction between the elements of these processes. However, through 'skill, determination and creativity' (Blackler et al. 1999:8) individuals overcome 'normal accidents' and inconsistencies in activity systems.

Furthermore, this process expands the span of artifacts available in the organisation to maintain and enhance the organisation's ability to organise innovations in accordance with the context within which the organisation operates (Schroeder et al. 1989).

Having said that, there might be collective forgetting in an activity system, which refers to the process through which communities lose touch with their intellectual and practical heritage (Engestrom 1991). Collective forgetting takes place because of the silence and solitude involved in the application of tools, skills and concepts (Blackler et al. 1998).

6.6.5.2 Proximal Innovations and the Transformation of Knowledge Management: Learning and Forgetting

Though management introduced some formal structures in the studied companies to facilitate knowledge transfer between projects[18], it has been evident and previously reported that individuals and groups introduced additional mechanisms supporting the organisation of knowledge management activity. These mechanisms are considered here as proximal innovations that ensure the continuous transformation of the knowledge management activity system (Schroeder et al. 1989).

Amongst the examples provided above are the creation of knowledge bases by individuals in the Sales team at Rafael, a knowledge base for ASIC solutions at YellowTech, a repository for malfunctions at YellowTech, TAMAM and Rafael, the constitution of rules with regards to responsibility and accountability of individuals during the knowledge transfer process, the invitation of the researcher

[18] See Chapter 5 for detailed description

to study knowledge management processes, the attempt to map knowledge and expertise, the work with knowledge management consults, and more[19].

These proximal innovations were a source of debate, disagreement, and sometimes even failure, such as in the case of knowledge mapping at Rafael and TAMAM or the knowledge committee at Rafael as a source for power games. Nevertheless, these proximal innovations generated discussions and participation, in particular across different communities, such as in the case of knowledge management consultants who interacted between R & D, Human Resource and top management at Rafael.

Yet evidence for collective forgetting has been observed in the case study companies as well. For example, engineers at Rafael were reluctant to share with colleagues their idea about creating a repository for presentations. The exclusion of project members from becoming involved early in the design stage at YellowTech is another example. And at TAMAM, knowledge management committees spent their time discussing software bugs instead of knowledge management matters. These instances and others hinder the development of discussion and cross-community participation essential for the development of capabilities, and in fact stimulate collective forgetting through silence and solitude.

Thus, it will be argued not only that the knowledge management activity system *is not facing a breakdown*, it is actually changing fast, seeking solutions for present tensions within the activity and between the activity and others by applying often 'separate remedies', small step innovations that gradually become part of the organisational capabilities through use, discussion, and negotiation.

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[19] These innovations were reported in section 6.5

With regard to the transformation of expertise development we argue that this activity system has lost touch with its mentoring practice, but has introduced rather, a goal-oriented problem-solving learning practice. Therefore, expertise development is also changing, demonstrating both collective forgetting and collective learning experiences.

6.7 Conclusions

This chapter addresses the question: how did cross-project learning and the acceleration of product development impact the product development environment?

The analysis of the historical path through which expertise development and knowledge management activity systems have evolved in the case study companies, has demonstrated that the past coherence between expertise development and knowledge management has broken down following the introduction of cross-project learning and the acceleration of product development. The analysis revealed that the source of tension between expertise development and knowledge management is embedded in (i) the different artifacts and social spaces used by these activity systems, (ii) the different images of knowledge that emerged between management and engineers, and (iii) the managers' inability to strike a balance between the concept of exploitation and exploration.

Knowledge management processes have seemed to suffer from continuous disturbances with regard to the entire process, manifested by 'normal accidents' such as lack of coordination, misinterpretation or lack of procedures.

Against the proposition that such disturbances would lead to a total crisis of the activity system (Engestrom 1996), we theorised and then demonstrated, supported by empirical data, that inherent tension is resolved through the introduction of proximal innovations. Furthermore, we showed that proximal innovations are negotiated to become part of the organisational capabilities and in fact they are the driver of future transformations of the activity system. These proximal innovations require management support for creativity and improvisation. These characteristics were found to be manifested in the studied organisations through autonomy and loose job description.

We would like now to pause and recap some of the arguments in this thesis. In Chapter 4 we reviewed some central characteristics of the defence industry and of each case study company separately. It was argued that amongst the characteristics that vary between these companies was ownership. In addition contextual factors were presented, demonstrating the growing pressure by stakeholders (past and present Israeli governments, the Israeli MoD, Koor) to improve financial results, increase market share, and stay competitive. In addition we outlined the case for changes in defence markets as another driver of the change in product development practices, resulting in a series of actions aiming to accelerate product development through, amongst other steps, the reusability of hardware and software components.

Chapter 5 addressed the organisation of, and conditions for cross-project learning. Three different approaches to cross-project learning were identified in the studied companies. It was suggested that the game rules imposed by the natural *evolution* of the firm were amongst the reasons that can be taken into consideration when one proposes explanations for the differences in cross-project learning approaches.

This chapter launched an investigation into changes of two central activity systems in product development: expertise development and knowledge management. It was demonstrated through a historical-path analysis that the past coherence between these two has collapsed following the acceleration of product development and introduction of cross-project learning. Yet these activity systems did not break down, but rather changed direction, disconnecting from their historical practice and gradually generating new collective historical learning.

One more question is still unanswered: what can other companies learn from the journey of the Israeli electronics defence industry?

The next chapter analyses and draws conclusions from the development path of cross-project learning in the Israeli electronics defence industry. The proposed model attempts to position the set of cross-project learning capabilities in the context of present strategy and future strategic direction.

7 CHAPTER SEVEN: THE DEVELOPMENT OF CROSS-PROJECT LEARNING STRATEGIES

7.1 Introduction

Three different approaches to cross-project learning were presented in Chapter 5, suggesting variations in the way the case study companies pursue cross-project learning. Yet it was suggested that each approach has contributed to product and market success.

Chapter 6 has suggested that the past harmony between expertise development and knowledge management activity systems has been replaced by contradictions and conflict following the introduction of cross-project learning and the acceleration of product development.

This chapter attempts to conclude the analysis of the lessons learned in the Israeli electronics defence industry by addressing the following questions: is there a strategic pattern to cross-project learning from the data presented above? If so, under what conditions are these cross-project learning strategies subject to change?

It will be argued that the most relevant literature on cross-project learning that also presents empirical data (Nobeoka 1995; Cusumano and Nobeoka 1998) is limited to the Japanese and U.S. car industry context, which has unique and specific characteristics. This thesis suggests that though we value the latter study, the strategies for cross-project learning offered by these scholars are irrelevant to the case study companies. Instead, two main strategies will be offered, based on the empirical data presented above. Our analysis suggests two strategies that companies can undertake: *exploit product success* and/or *design to reuse.*

An analysis that combines path development and contingency theory will be offered, built on the Right Path model for organisational development (Victor and

Boynton 1998). The analysis will suggest that cross-project learning strategies evolve in the studied companies subject to two factors: *present identity/strategy* and *future strategic direction.* These variables represent two values: (i) research orientation, and (ii) business/market orientation. With this approach we build upon and extend previous work by Coombs and Hull (1998) and Hull et al. (2000).

Lastly, the future of the Israeli defence industry will be outlined, suggesting that cross-project learning in the three companies studied will produce further tension between present identity/strategy and future strategic direction.

In terms of the outline of the chapter; Section 7.2 will present two strategies for cross-project learning identified in the companies studied. Section 7.3 will discuss the theme of best practices. Sections 7.4 and 7.5 will outline the rationale for choosing present identity/strategy and future strategic direction as the conditions for the development of cross-project learning practices. Section 7.6 will analyse the dynamics of present identity and future strategic directions, followed by an examination of the dynamics of cross-project learning in the studied companies subject to the above factors. Lastly, the future of the Israeli electronics defence industry will be reviewed and the implications for cross-project learning development will be outlined.

7.2 Two Strategies for Cross-Project Learning

The model that Cusumano and Nobeoka (1998) provided presents four types of strategy for cross-project learning: new design, sequential technology transfer, concurrent technology transfer and design modification. They conclude their analysis of cross-project learning in one main statement, arguing that *concurrent technology transfer is the better practice for companies* (ibid.:189). Thus, in the context of their study, companies should plan in advance situations where two projects of the same product family overlap in order to maximise the technology transfer effect.

In the context of the Japanese and U.S. car industry it seems that their conclusion is appropriate. However, their conclusion excludes a large number of companies operating under different conditions and contexts, such as the defence industry. Companies in the defence industry rarely launch generic R & D projects, in particular since the significant reduction in defence R & D budgets in western countries since the beginning of the 1990s (BICC 2000). In addition, the nature of the defence business, as explained in Chapter 4, dictates different game rules, unlike those in the car industry. In the defence industry, and perhaps in other manufacturing and service industries, companies cannot arrange or plan two concurrent projects to start at the same time. It is even more complex to ensure a two-year overlap between two projects of the same product family (Cusumano and Nobeoka 1998). This is because the process of launching a project is subject to winning a tender in a long bidding process and getting all the contract documents signed, as explained in Chapter 4. In a complete contrast to Toyota, Nissan and other car manufacturers, YellowTech, TAMAM and Rafael respond to tenders and rarely initiate their own self-financed R & D projects.

Thus, according to Cusumano and Nobeoka's (1998) cross-project learning strategies, companies such as YellowTech, Rafael, and TAMAM are inevitability obliged to use a less effective sequential technology transfer process. Yet business performance indicators suggest that the companies studied have improved business performance since they have pursued the cross-project learning path.

Thus, another explanation is needed. Based on the research data and the context within which the defence industry operates, we propose two main strategies for cross-project learning. These strategies refer to the vertical integration of technologies, components and knowledge which resides in projects. These strategies target either long- or short-term competitive advantage but can be also integrated. The strategies proposed here are:

⇒ *design for reusability*. This strategy aims at designing platforms and components for potential reusability in the future. The organisational capabilities supporting this strategy are aimed at setting standards to guide engineers to design components with a thought in mind that the base design will be reused in the future. For example, modularity and commonality supports product design for potential reusability in the future. Another example is a Design Centre (e.g. at YellowTech), which produces ASIC solutions with a view to sharing these components between projects. These capabilities aim to improve the process of reusability by introducing technological platforms that have been designed in line with some reusability procedures, tools and metrics. Our data suggest that these organisational mechanisms are located outside the matrix structure (see Figure 52). In contrast to Cusumano and Nobeoka's (1998) proposition, which argued that in the case of new design the potential for technology transfer is low, this strategy suggests that a new design actually paves the way for an effective reusability strategy. However, we confirm that new designs, particularly for reuse, require the longest lead time (ibid.:116; Clark and Fujimoto 1991).

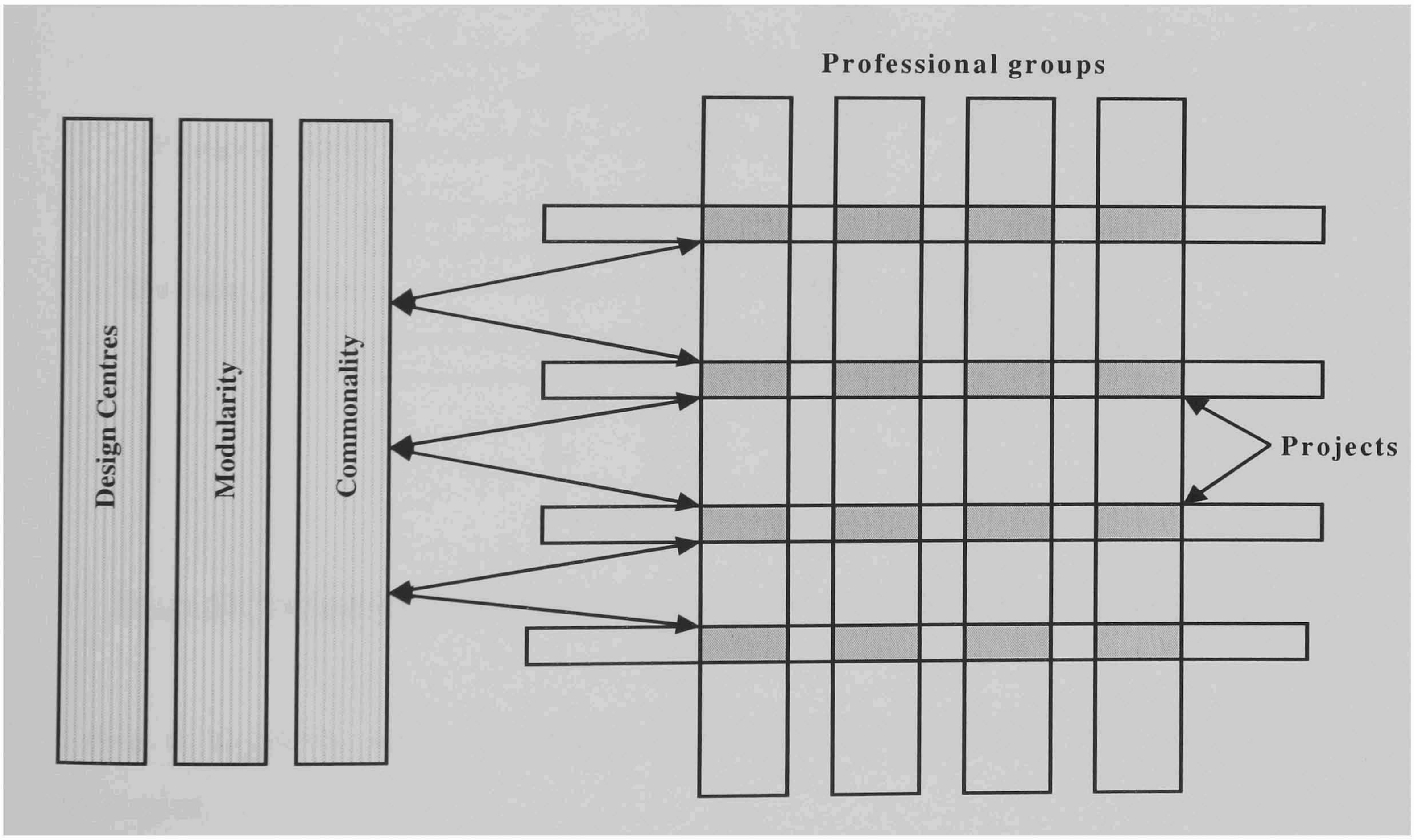

Figure 52: Mechanisms Supporting the *Design to Reuse* Strategy outside the Matrix Structure

⇒ *exploit product success.* This strategy aims at exploiting product and technological platform success by transferring components from the base project to others. In this case, the process can be either sequential or concurrent (Cusumano and Nobeoka 1998). The organisational capabilities that support this strategy are aimed at opening communication channels between projects, making existing solutions and technologies visible to others, and creating links between projects. Some of these capabilities are, for example, the matrix structure, knowledge transfer structure at YellowTech, interactions with clients, integration with Sales, and the horizontal coordination of concurrent engineering activities by cross-functional teams. These organisational mechanisms are within the matrix structure (see Figure 53).

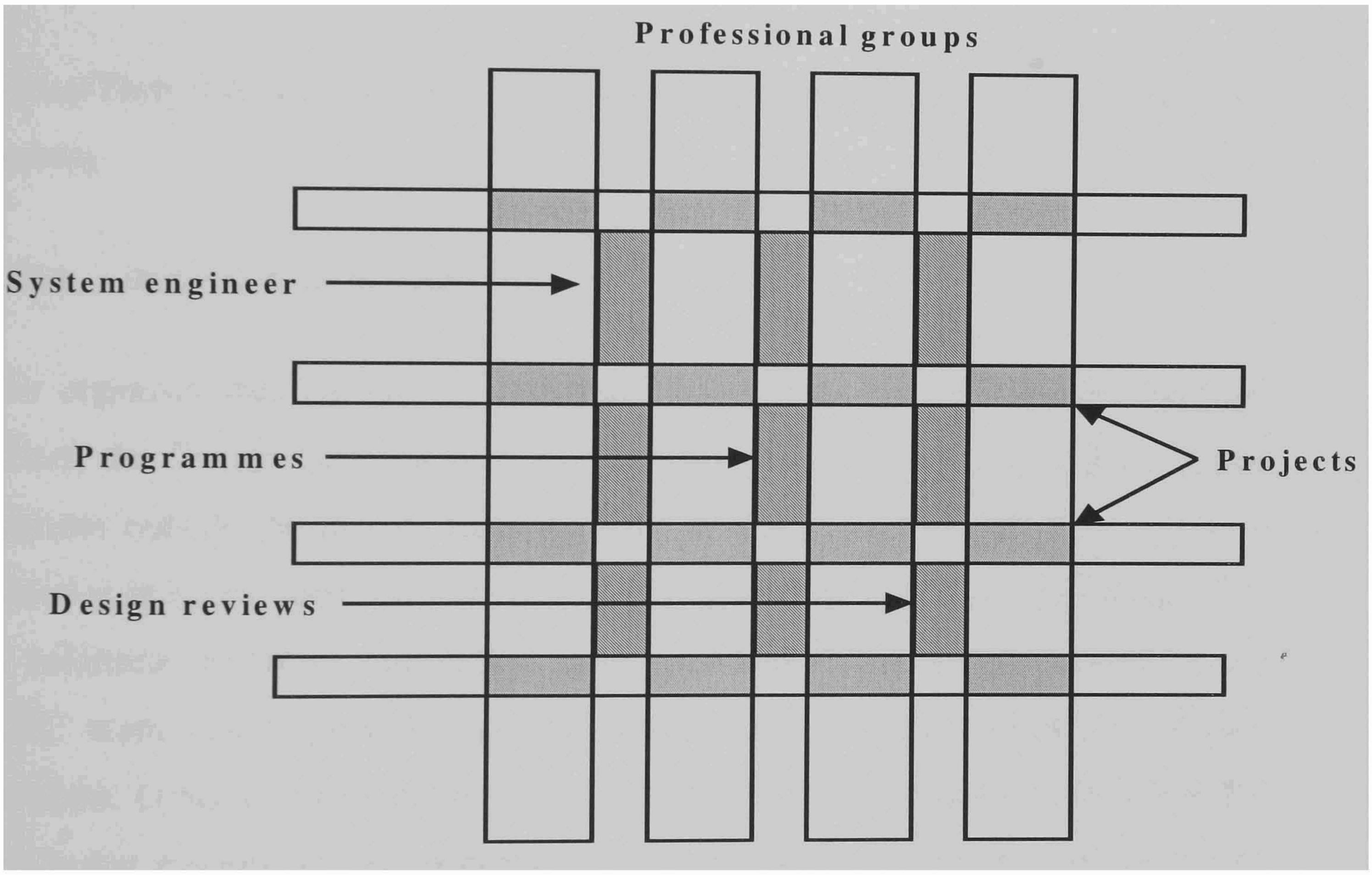

Figure 53: Mechanisms Supporting the *Exploit Product Success* Strategy Inside the Matrix Structure

Table 6 suggests some capabilities that may be associated with the above strategies.

Design for Reusability	Design centres, commonality, modularity, metrics for reusability, PM practices for reusability
Exploit Product Success	Matrix structure, programmes, system engineers, cross-functional teams, interactions with clients, integration with Sales, Design Reviews, Knowledge Transfer structure, Knowledge Transfer forums

Table 6: Capabilities According to Cross-Project Learning Strategy

Based on this categorisation we now analyse the strategic approach in each company studied.

7.2.1 Cross-Project Learning Strategies at YellowTech

YellowTech has taken up both strategies, *design to reuse* and *exploit product success.*

7.2.1.1 *Design to Reuse* at YellowTech

The organisational capabilities integrated for *design to reuse* include, amongst others, the Design Centres, such as the ASIC group, a team of engineers that operates outside the matrix structure. This design process in the ASIC group is aimed at reducing learning costs but more importantly creating a knowledge base of solutions for future reusability. Data presented above demonstrated how the ASIC team has improved lead-time despite the growing complexity in new products. Other Design Centres were mentioned by interviewees, such as the RF group that designs RF components for the entire R & D Division; however, this group has not been included in the scope of this study.

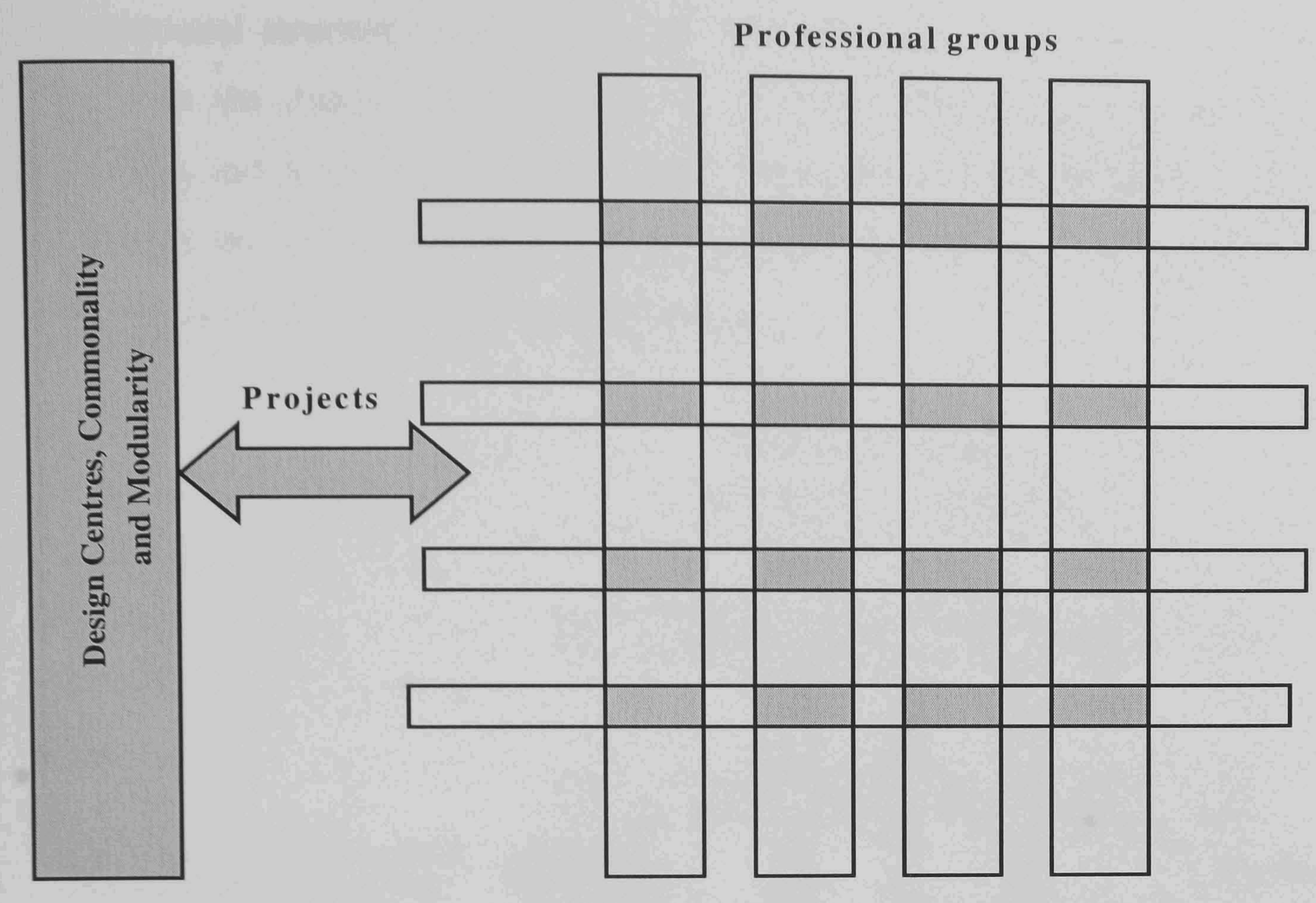

Figure 54: *Design to Reuse* at YellowTech

YellowTech also introduced modularity of (Baldwin and Clark 1997) and commonality in hardware and software components. Modularity and commonality are two central development practices that integrate parallel projects (see Figure 54). The concept behind these practices from a cross-project learning viewpoint is to establish the foundation upon which future shared platforms will evolve. The technological development platforms are the enabler for sharing technologies, mainly because of the required compatibility of development tools between two projects in order to implement changes in the transferred component, in particular in the case of sequential technology transfer (Cusumano and Nobeoka 1998). One simple example that demonstrates the problem when commonality is avoided is the past difficulties in transferring files between a Macintosh computer and an IBM computer because of the different operating systems.

7.2.1.2 Exploit Product Success Strategy at YellowTech

YellowTech also applied the second strategy; exploit product success. To achieve success in this strategy the company introduced a modular knowledge transfer organisational structure, as an additional vertical module to the organisation of projects in the matrix structure (Gold et al. 2001). Multi-Project management procedures and practices have been introduced to include a reference to potential technology transfer. Interactions with Sales have been enhanced and clients have been integrated into the development process.

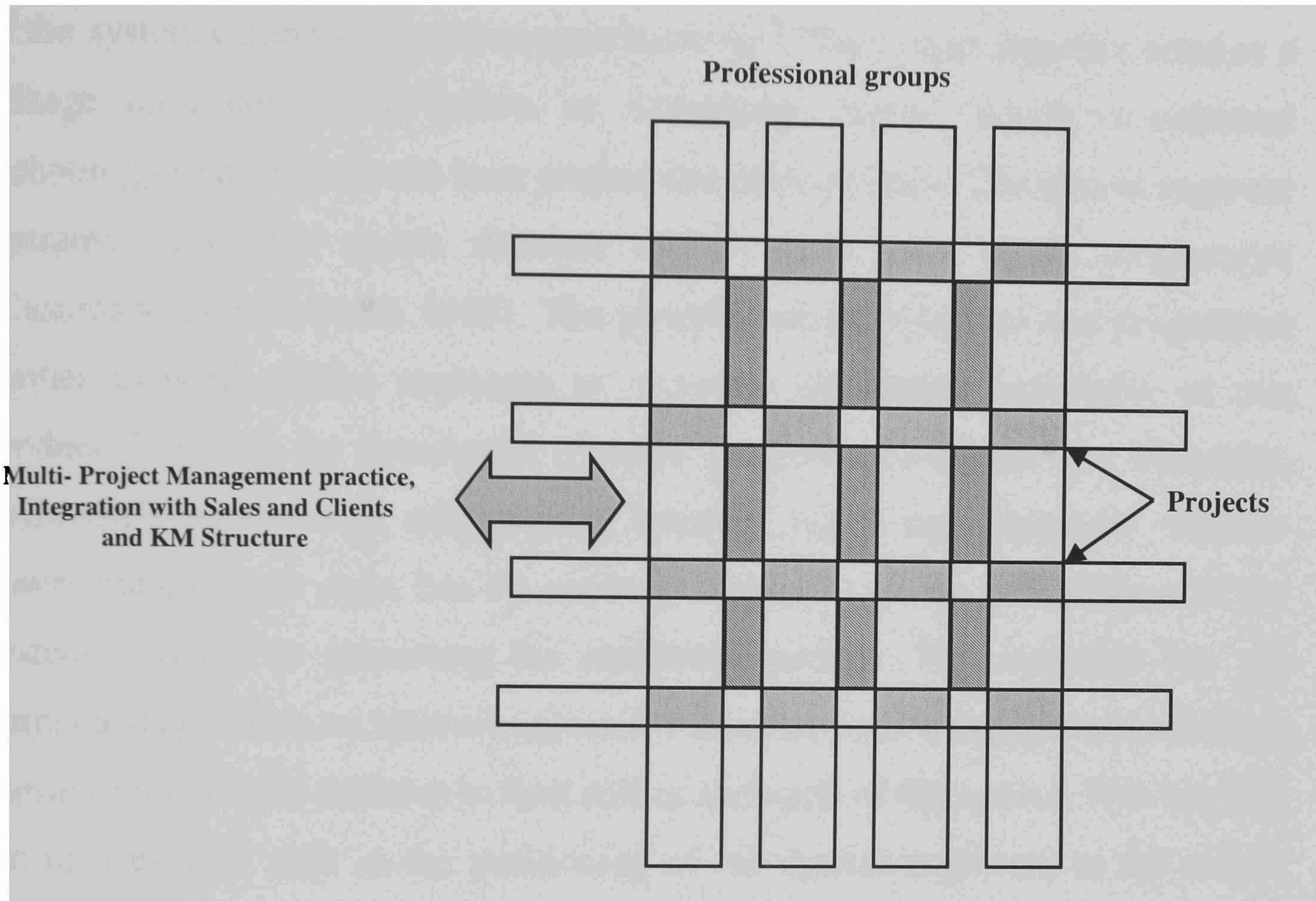

Figure 55: *Exploit Product Success* at YellowTech

These capabilities were integrated into one system through the leadership of the Chief Scientist, and because of the high priority that the theme of cross-project learning has been granted at YellowTech (see Figure 55).

7.2.1.3 YellowTech's Cross-Project Learning Strategies: Summary

The above analysis suggests that YellowTech has positioned the strategy of *design to reuse* at the centre of its strategic vision while operationally YellowTech has been pursuing both directions: exploiting present success and improving reusability processes for the future. Also, YellowTech has introduced methods to measure the quality of the cross-project learning product and sought ways to improve the results of this process.

7.2.1.4 Cross-Project Learning Strategies at TAMAM: Exploit Product Success

TAMAM has mainly focused on the *exploit product success* strategy, though some steps towards the *design to reuse* strategy were observed.

For the *exploit product success* strategy TAMAM has promoted the involvement of the system engineer in cross-project learning[20]. The system engineer acted as a linkage unit, commonly known as 'knowledge centre', which co-ordinated technology transfer between base project and other projects. The system engineer operated within the matrix structure and in some cases across programmes (Cusumano and Nobeoka 1998). The grouping of projects into one programme further assisted system engineers in vertically integrating knowledge of one product family to be transferred to other projects (see Figure 56). However, TAMAM's approach to cross-project learning, which was based on 'middle-down' management style, has by and large depended on the commitment of the system engineer to promoting the reusability process. This approach has put tremendous pressure on system engineers, who often need to engage in technology transfer processes in addition to their role as architects of the system. This has also led to a gradual shift in the positioning of the system engineers in the matrix structure, from the vertical professional group towards the more 'desired' and glamorous horizontal project management.

[20] For a detailed description see section 5.4.2.1

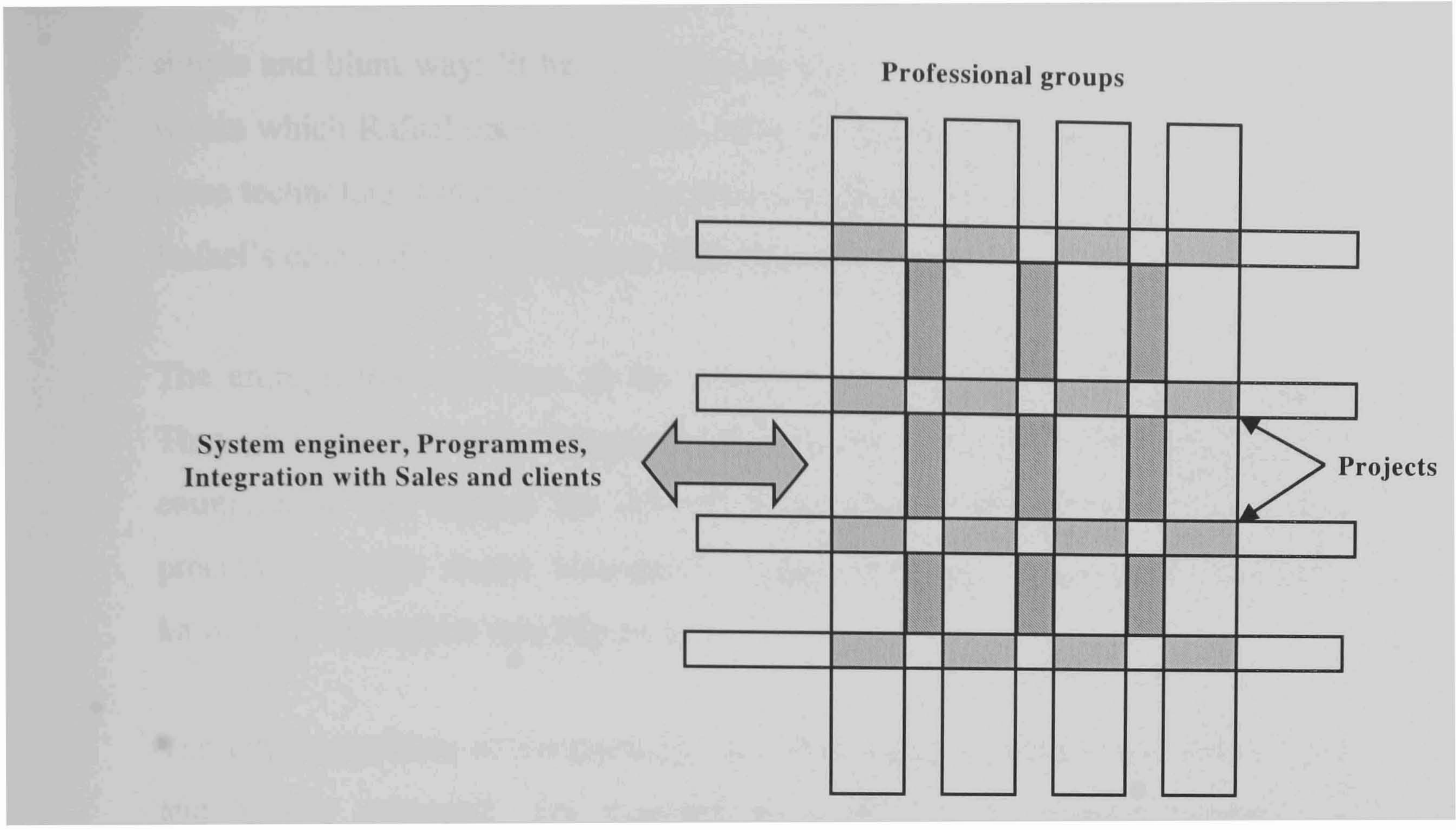

Figure 56: *Exploit Product Success* at TAMAM

There are indications that TAMAM is shifting towards the *design to reuse* strategy. The issue of commonality, though it has yet not been managed centrally, has attracted management attention. Also, the advantages of the Object Orientated methodology, as a modularity practice for creating transferable software modules, have started to emerge. Yet data presented above suggest that TAMAM has not integrated the capabilities necessary to leveraging the *design to reuse* strategy.

In conclusion, the above analysis suggests that TAMAM has positioned the *exploit product success* strategy at the centre of its cross-project learning operations and has taken some first steps towards the *design to reuse* strategy. Yet TAMAM has not introduced methods to control the quality of the cross-project learning, but rather has focused on generating more opportunities for reusability through the centrality of the system engineer in the matrix structure.

7.2.1.5 Cross-Project Learning Strategies at Rafael: Exploit Product Success

Rafael has focused on the *exploit product success* strategy. One system engineer at Rafael referred to the reasons for reusing technology, and put his view in a simple and blunt way: 'it has to be the default'. In another words, the conditions within which Rafael operates lead to the unavoidable conclusion that only if they reuse technologies and components they will maintain their competitiveness. Yet Rafael's case is different from the other two companies.

The entrepreneur has been at the centre of the reusability strategy at Rafael. Through social networks, Design Reviews and the structure of programmes, the entrepreneur has created the dynamics needed for leveraging the reusability process. Through social networks[21], Rafael managed to integrate horizontal knowledge in projects (see Figure 57).

The implementation of commonality and modularity at Rafael was unstructured and loosely managed. Yet management interest in knowledge management practices in general, and in facilitating cross-project learning in particular, may suggest that the company has started to shift towards enhancing its *design to reuse* process. Yet this evidence is not conclusive enough to determine the present position at Rafael with regard to moving towards the *design to reuse* strategy. However, it is evident that Rafael has not pursued the *design to reuse* strategy.

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[21] For detailed description see section 5.4.3.1

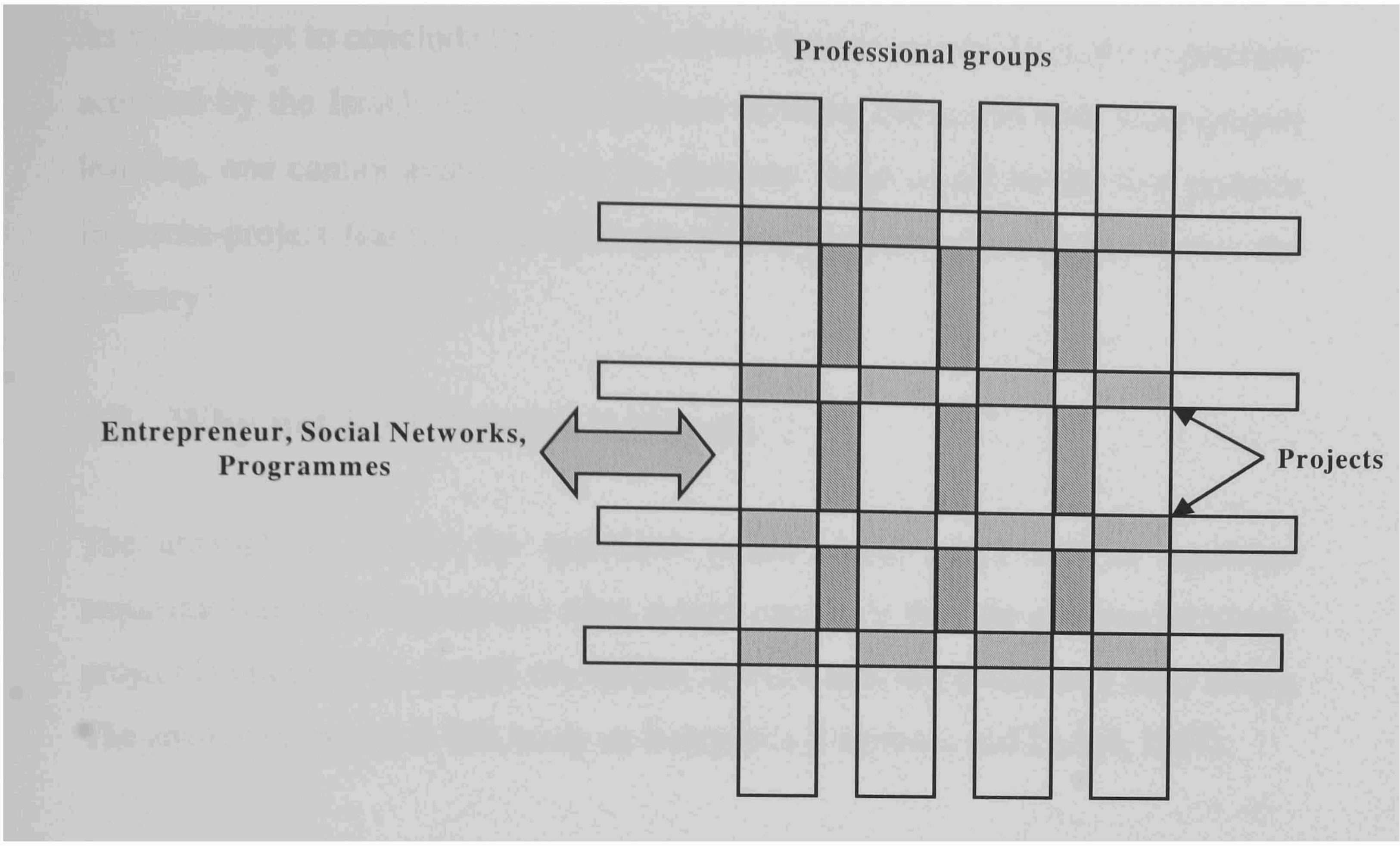

Figure 57: *Exploit Product Success* at Rafael

To conclude, Rafael has focused on the *exploit product success* strategy by facilitating the conditions allowing the development of strong social networks and a sense of entrepreneurship. Rafael did not introduce methods to control the quality of the cross-project learning. Furthermore, Rafael's management expected that through social networks, engineers would be able to reuse technologies. The above analysis suggests that the results from the reusability process were satisfying from Rafael's management viewpoint, yet the process was described as unstructured, unplanned and based on entrepreneurship.

7.2.1.6 Summary

The above analysis suggests that YellowTech has taken a different strategy to cross-project learning from the other two companies by facilitating the conditions to pursue both the *design to reuse* and *exploit product success* strategies. TAMAM and Rafael have been focusing on the *exploit product success* strategy with a gradual yet not significant or conclusive shift towards the *design to reuse* strategy.

As we attempt to conclude the analysis of the lessons learned from the experience acquired by the Israeli electronics defence industry associated with cross-project learning, one cannot avoid raising the question: what would be the best practice for cross-project learning and how can a best practice be transferred across the industry?

7.3 Why not Best Practice Analysis

The attempt to answer the questions posed above raises another argument requiring further investigation: what would constitute the best practice for cross-project learning in the Israeli electronics defence industry (Jarrar and Zairi 2000). The answer proposed in this study is: it depends (Lawrence and Lorsch 1967).

In assessing what would constitute a best practice for cross-project learning, it will be claimed that practices for cross-project learning in the Israeli electronics defence industry are contingent to the context within which they have evolved (Pettigrew 1987; Wenger 1998). Furthermore, context-dependent practices offer a major challenge for the transfer of context-specific practices, assuming that one company does not operate in the exactly the same manner as, and rarely within the same contexts as, others.

Hence, against the vast literature on best practice and benchmarking (e.g. Raval and Subramanian 2000; Jarrar and Zairi 2000), this study challenges the notion of best practice transfer that may suggest that a practice is a static body of knowledge that can be transferred across an industry. Rather, practice is a dynamic process, a way to organise innovations, which is contingent to the context within which the practice has been created, evolved and transformed (Wenger 1998; Lawrence and Lorsch 1967; Olson et al. 1995; Collinson 1999).

Thus, perhaps the question which needs to be addressed in this chapter is: is there a path that would explain the development of cross-project learning strategies in the studied companies and, if so, what are the factors that shape this path of development?

7.4 The Justification for Present Identity and Future Strategic Direction Analysis

One can find many factors that may have shaped different forms of organising cross-project learning capabilities in the Israeli electronics defence industry. Amongst the factors studied in the past and which may relate to the context of the present study are: the age and size of the organisation, technical systems, environment and power (Mintzberg 1983). Yet studies in the field of contingency-structure relations have shown contradictory evidence as to the direction of the relation between organisational structure and contingency variables (Tayeb 1987).

Thus, in this contested terrain, instead of seeking correlation between contingent variables and structures, this thesis, based on our findings, proposes to explore the dynamics of the development of cross-project learning based on two contingent factors. One is the *present identity* of the studied companies (Wenger 1998; Whetten and Godfrey 1998). The second is *future strategic direction* of the studied companies (Victor and Boynton 1998). These two factors will be located on the horizontal and vertical axes in a 2x2 matrix (see Figure 58).

Present identity, in this study, is a socially and symbolically structured notion intended to lend meaning to experience (Whetten and Godfrey 1998:27). Wenger (1998) adds that identity is the formation of a dual process: (i) identification, which is the process 'through which modes of belonging become constitutive of our identities by creating bonds or distinctions in which we become invested' (ibid.:191); and (ii) negotiability, which 'refers to the ability, facility, and legitimacy to contribute to, take responsibility for, and shape the meanings that matter within a social configuration' (ibid.:197). Identity is a trajectory of learning and adaptation that defines *who we are* (Wenger 1998:153). In a way, present identity is the 'emergent strategy' that led us to where we are now (Mintzberg and Waters 1985).

Future strategic direction represents the notion of *who we would like to be.*

Thus, the development of cross-project learning is assessed here subject to two simple questions: one, *who (where) we are;* and the second is *who (where) we would like to be.*

Senge (1996) suggests that there is a natural, creative tension between these two concepts, though he coined them *current reality* and *vision.* Creative tension can be resolved in two basic ways, Senge argues. First, by raising current reality towards the vision. Second, by lowering the vision towards current reality.

We assume that Senge's suggestions may help managers to simplify the world within which they operate. Yet Senge's (1996) conceptualisation of current reality is based on the structuralist approach in which reality is objective and independent of human affairs (Browing 2000). On the other hand, the present study suggests a socially constructed view, in which reality, or perhaps current identity, is multi-faceted, dynamic and rarely expressing one voice and opinion.

We argue that the answer to the question; 'who we are' would provide a short description of the role we hold in society; however, the meaning behind this description is often diverse and multiple. Our role in society may represent the identity we have at work, in our family or perhaps in the football team we play in every Sunday. These are different identities, representing the historical development of learning that we have accumulated throughout the years at work, home and play. These various identities are rarely coherent and often they are in tension with each other (Engestrom 1992; Blackler et al. 1999). To understand who we are today, one has to understand the historical development of the identities of an entity, either a person or a company (Blackler et al. 1999).

Thus, instead of seeking to locate the notion of current identity in a specific time, we propose to treat current identity as a continuum, a dynamic process that reflects on past and present experiences (Engestrom 1992).

7.5 Present Identity/Future Strategic Direction Model

Figure 58 presents a 2x2 matrix that suggests four possible modes:

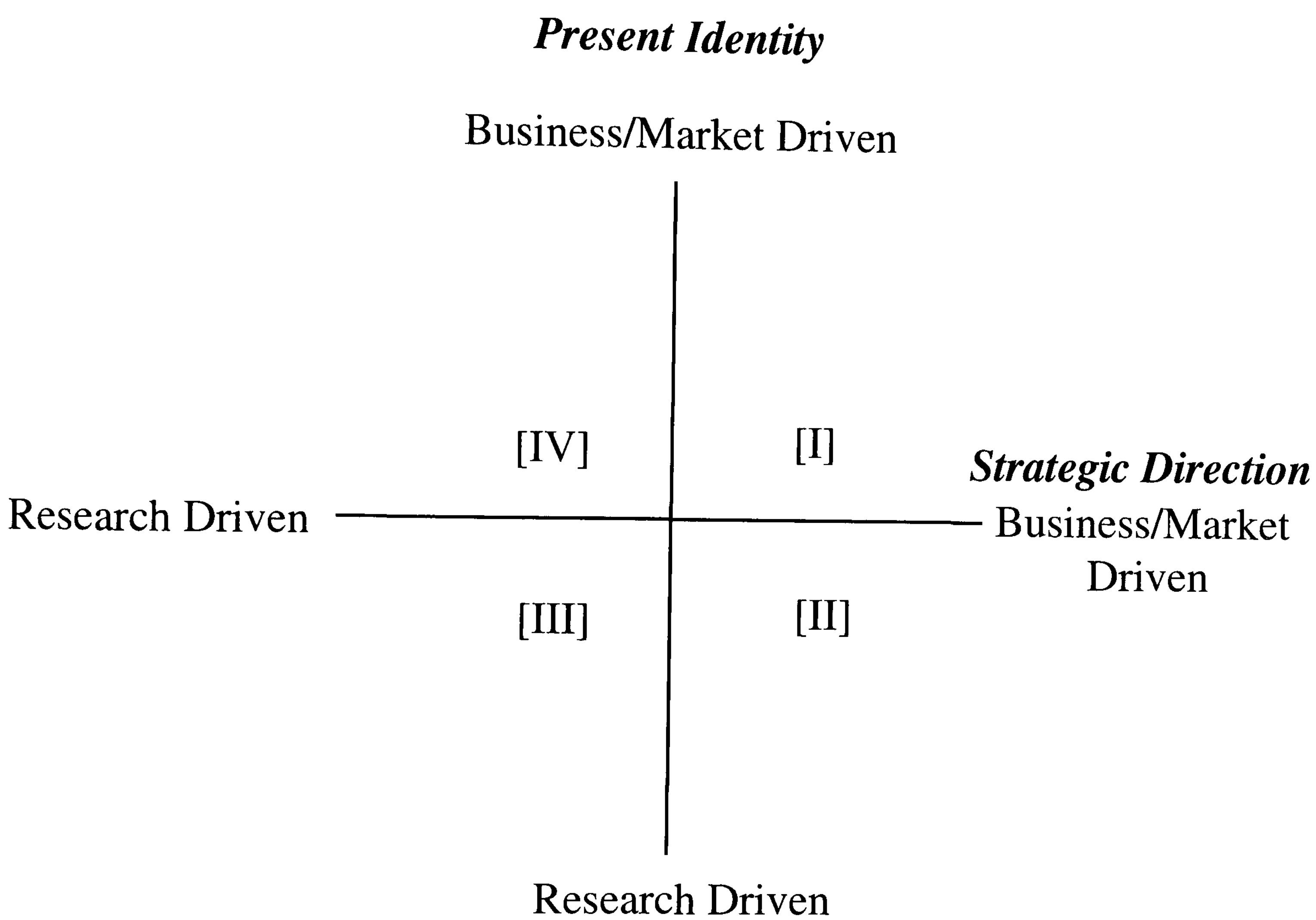

Figure 58: A 2X2 Matrix: Present Identity and Future Strategic Direction

Quadrant [i] represents a state in which the present identity and future strategic direction are business driven. Most profit-orientated organisations will be located in this quadrant. The most obvious example in the 1990s is Microsoft.

Quadrant [ii] suggests that the subject organisation has a research-driven present identity but is seeking business-driven strategic direction. One example of this scenario would perhaps be higher education institutions in the UK, which are experiencing shrinking research funds and hence gradually introducing market-orientated practices.

Quadrant [iii] portrays a state in which the subject organisation is research-driven both in its present identity and future strategic direction. Any fully sponsored R & D institutions would fit in this quadrant.

Quadrant [iv] characterises another state in transition in which the subject organisation possesses a business-driven identity; however, it is moving towards a research-driven strategic direction. This case is rare in the business world; however, one example of this state could be an organisation that changes the objectives and activity of one team within Engineering from product design and development to become an R & D activity.

Because of the simplicity of the proposed model, it may suffer from some drawbacks that need to be considered.

First, individuals and groups may produce conflicting identities as part of their engagement in different activity systems that pursue various objectives. Engestrom (1992) demonstrates how one Medical Doctor (M.D.) engages in both administrative and medical activities at work, suggesting that our attempt to associate a group of people with one single identity might not represent well the complexity and often 'two hates situation' that reality often dictates.

Secondly, this model represents a rather specific case, built upon the learnt experience in the Israeli electronics defence industry. Thus, practical implications from this model would be most suitable to the studied industry or perhaps companies with some similarity. The applicability of this model to other industries in other contexts has yet to be considered.

The next section proposes an analysis of the dynamics of present identity and future strategic direction in the three studied companies.

7.6 The Dynamics of Present Identity and Future Strategic Direction at the Studied Companies

Figure 59 presents the dynamics of change in present identity and future strategic direction at YellowTech, TAMAM and Rafael. The situation which emerges from Figure 59 suggests that these dynamics of change represent not only the future of the companies but also their bodies of shared historical learning. In this sense, past, present and future identity cannot be separated (Engestrom 1992).

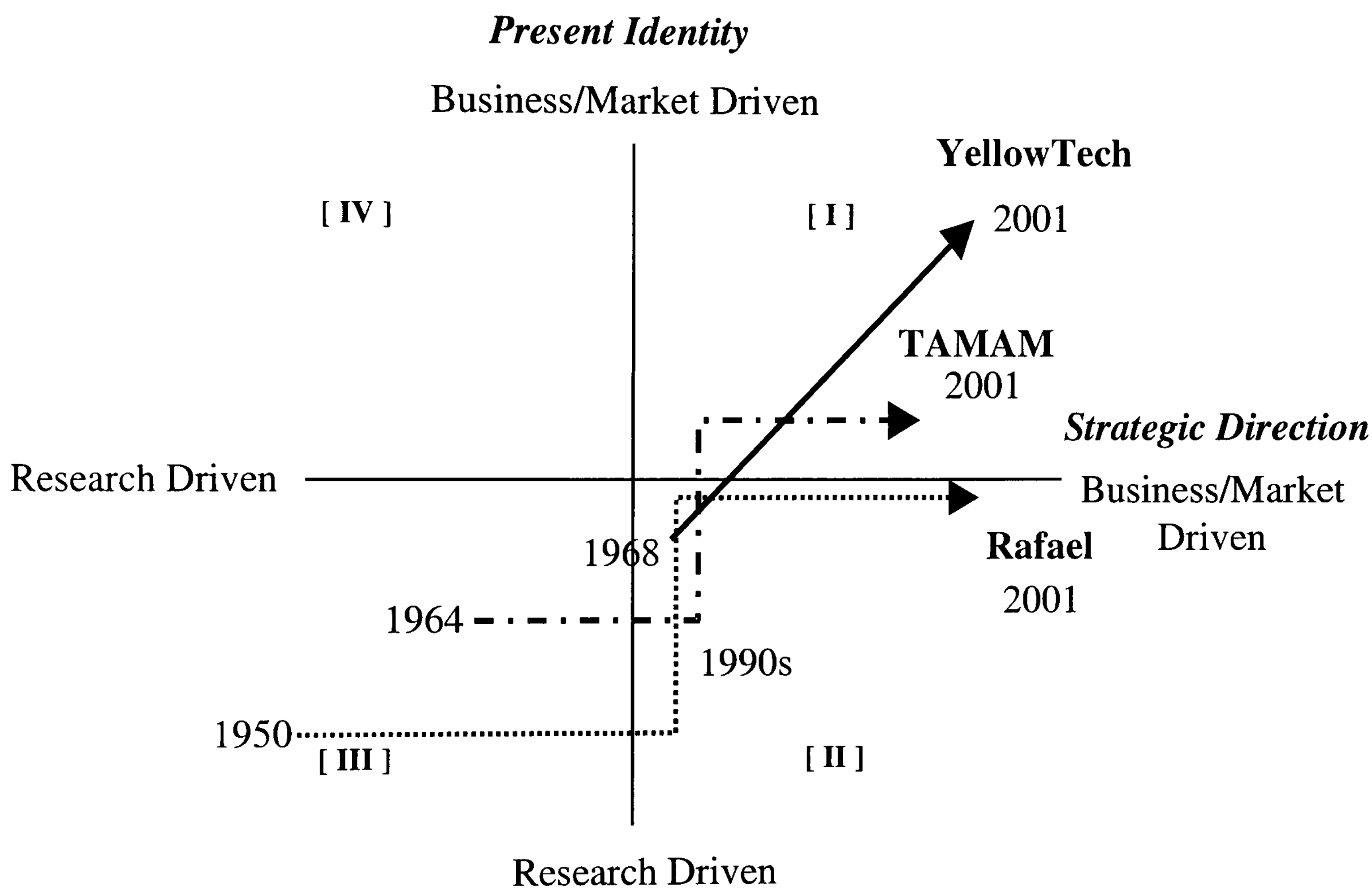

Figure 59: The Dynamics of Present Identity/Strategic Direction in the Studied Companies

YellowTech was established as a business-driven entity and maintained a business-driven focus to its objectives through growth in revenue, profit, mergers and joint ventures and recently through acquisitions (Dror Marom, Globes, 16/01/2001). YellowTech is positioned in quadrant (iii), representing strong business/market orientation that also grew throughout the years. Yet, though positioned as a business-driven organisation, YellowTech's roots are in R & D, which represents some research-driven orientation from its past.

TAMAM was formed in 1964 as a government owned company and enjoyed a generous R & D budget subsidised by Israeli governments. The late 1980s saw a major reduction in government R & D defence budgets, which impacted its operations. TAMAM gradually shifted from a research-driven to a business-driven paradigm, yet with strong ties to its historical roots as a research institution. Voices within the company still debate the identity of the company, seeking the recognition of TAMAM as the Israeli Navigation and Optronics laboratories by Israeli governments. Thus, TAMAM is in a transition mode from a research driven to a business driven identity.

Rafael, a sub-unit of the Israeli Ministry of Defence, known as the Israeli defence laboratories, has for long established an image and identity of a research-driven institution. Recent years have seen change in past governments' resilience towards inefficiencies and continuous losses at Rafael. Past governments sought to change the ownership of Rafael to a government-owned company, in attempt to introduce more strict financial practices and control over defence projects. Rafael is also in transition, gradually shifting from its past historical roots that were strongly linked to research to a rather more business-orientated approach[22]. However, debates and confusion about the present identity and future strategic direction of Rafael still dominate the political agenda in both the Israeli MoD and Rafael's top management.

Figure 59 describes the dynamics of change during the course of the last 30 years, implying that both TAMAM and Rafael are moving towards business identity/business strategic direction entities. Another way to illustrate these changes is presented in Figure 60.

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[22] See Smith (2000) for a similar case in Canada.

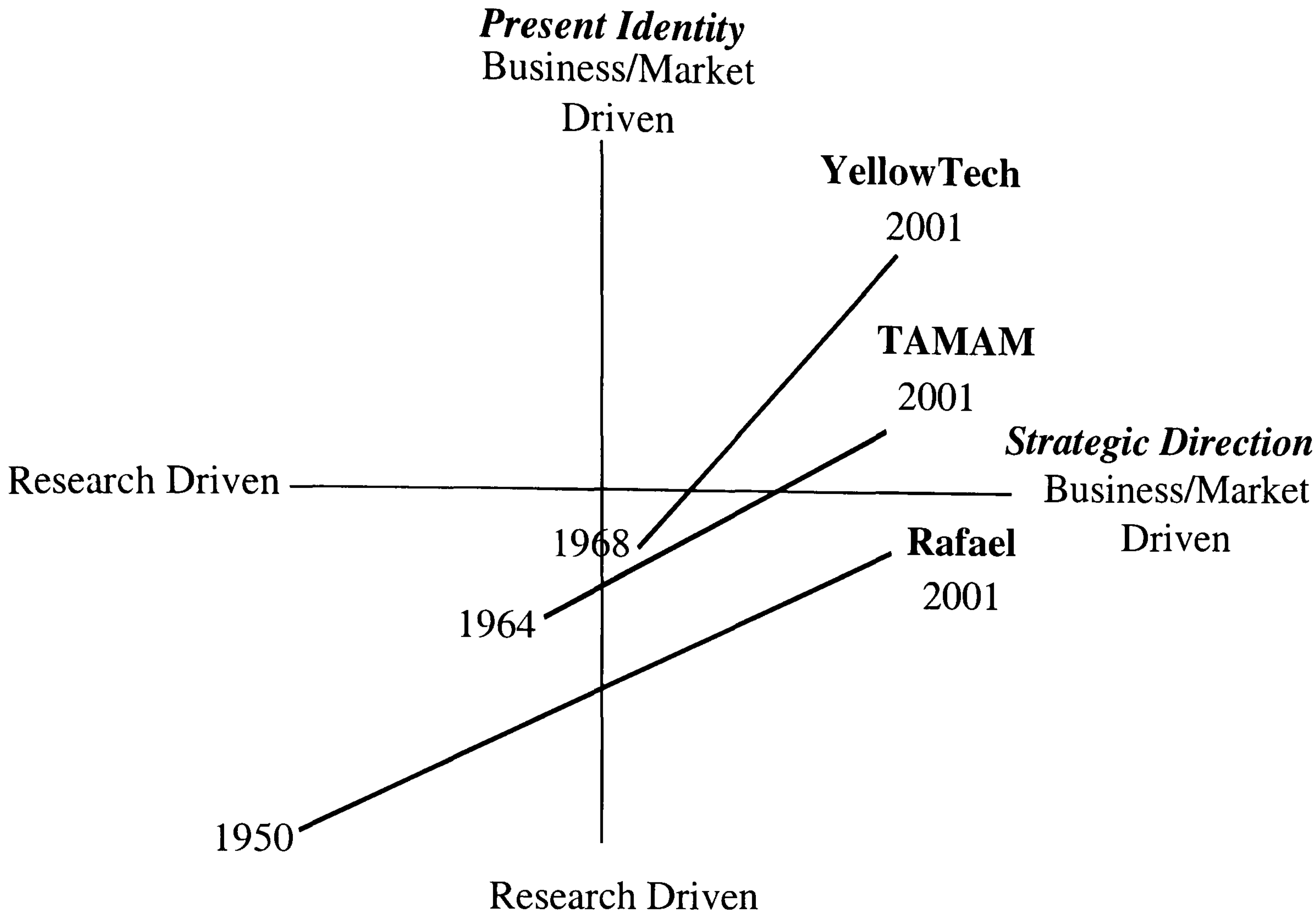

Figure 60: Towards Business/Business-Driven Identity/Strategic Direction at TAMAM, Rafael and YellowTech

Based on the above analysis, we now seek to integrate our findings from previous chapters into the above framework, by introducing the findings on the strategies undertaken by the studied companies and locating them in the proposed framework. However, before integrating the framework of cross-project learning strategies into the above framework, we would like to briefly introduce the concept of the Right Path proposed by Victor and Boynton (1998).

7.6.1 The Concept of the Right Path

In their 1998 book 'Invented Here', Victor and Boynton suggest that a company can create a market value by acquiring a core capability necessary to compete more effectively in a particular market at a particular time. There are four stages for a company to progress through: each stage targets a rather different market, client's needs, organisation of work, and core capabilities.

Victor and Boynton (1998:7) describe these stages and capabilities as follows:

> Craft is strong in inventing and creating high-priced *novel* products that make strong, unique impressions on customers. Mass production is strong in discipline and achieving value through predictable, standard, 'no-surprise', low-price *commodities*. Process enhancement is strong in thinking and doing, and wins by creating products that customers perceive as having superior *quality*. Mass customisation is strong in modular configuration and can dominate a market with *precision*, providing made-to-order, affordable, tailored products and services. (*italics in the source*)

They suggest that the Right Path progresses from craft to mass production, process enhancement, mass customisation and back to craft via renewal (see Figure 61). Development is the process that transforms craft to mass production. It involves a set of actions such as: codify processes, train people, analyse process, select best process, automate process, build controls over the process and output, and create ability to replicate consistent quality, volume and delivery (ibid.:139).

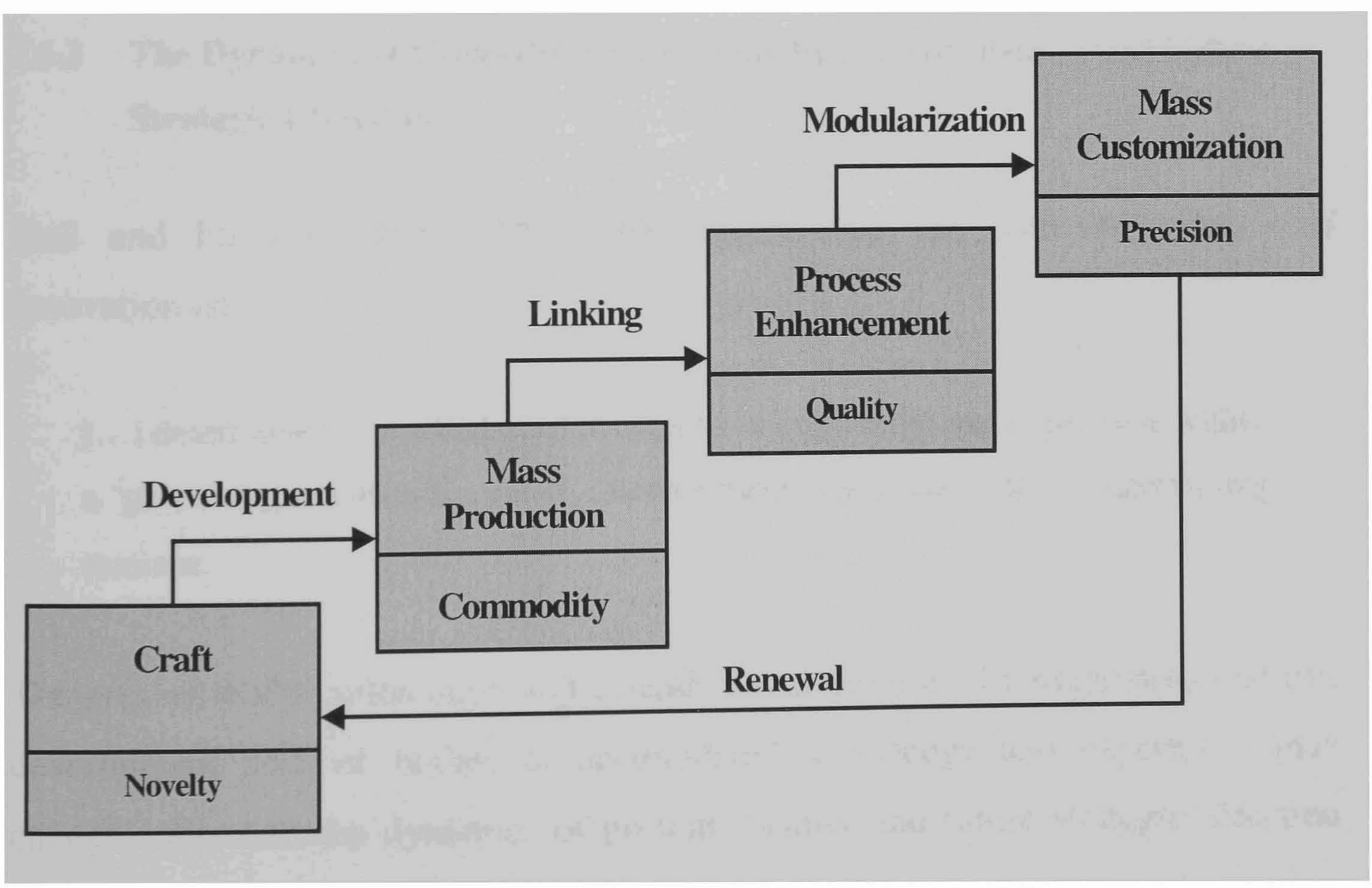

Figure 61: The Right Path (Victor and Boynton 1998)

Linking takes mass production to process enhancement and involves, amongst other actions, creating overlapping know-how, building broader skills, creating teams that swap innovation and efficiency, dropping manager's 'command and control' mentality, and designing controls for output control.

Lastly, modularization drives process enhancement towards mass customisation by introducing the following steps: identify reusable process resources, modularise resources, link resource capabilities directly to markets, and implement information technology for efficiency and control.

Because this thesis concerns the development of cross-project learning in an organisation, which is the chief interest in Victor and Boynton's (1998) study, we would borrow their model and apply it to the framework proposed in Figure 58. In particular, the present study will address two issues: (i) the development stage of cross-project learning for each company; and (ii) the stage of transformation for each company.

7.6.2 The Dynamics of Cross-Project Learning by Present Identity and Future Strategic Direction

Hull and his colleagues (2000:636) suggest that the path dependency of innovation is:

> [...] determined by the bodies of accumulated knowledge and experience within a given organisational culture, management style and set of operational routines.

The present study builds upon and extends the above view by suggesting that this development path of bodies of accumulated knowledge and experience may change subject to the dynamics of present identity and future strategic direction shown in Figure 60. In other words, as seen in Chapter 6, organisations may change the organisation of innovation and start creating new experiences disconnected from past practices (Engestrom 1996).

Figure 62 presents the development path of cross-project learning strategies subject to present identity/future strategic direction.

The main conclusion from the proposed analysis is that the *more an organisation is market-orientated the more it will seek a high quality result from its cross-project learning strategies.*

Another conclusion from this analysis suggests that *the more an organisation is research-orientated, the greater is the likelihood that its cross-project learning processes will be based on craftwork.*

The following section will analyse the present stage of cross-project learning strategies in each company.

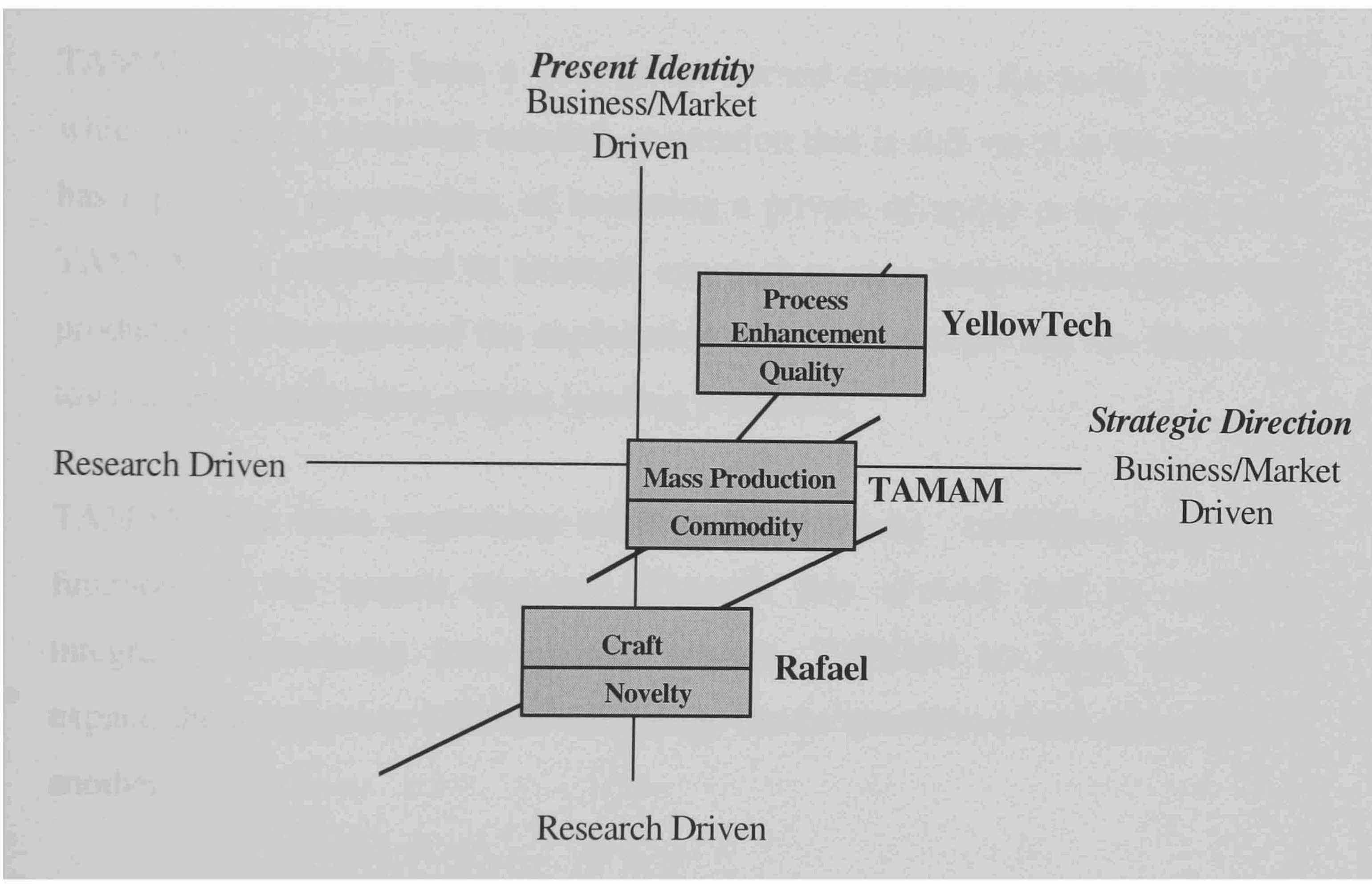

Figure 62: Cross-Project Learning Strategies by Present Identity/Future Strategic Direction

7.6.2.1 Rafael: Craftwork and Novelty

Rafael, which maintains its research-driven identity and still debates the recent trend towards markets and business orientation, has based its strategic approach to cross-project learning on craft. In line with Pelz (1985) and Rogers (1983), we argue that the cross-project learning strategy which emerged at Rafael was unplanned and unstructured, mainly because it originated from a bottom-up management style. This led the company to pursue the *exploit product success* strategy, a rather short-term solution that has maintained the company's competitive edge.

The process of reusability has been 'reinvented' each time such a process starts. The novelty in the process is manifested by the result of the cross-project learning. The product of the cross-project learning varies in quality and depends on the quality of the communication in the social network involved in the process.

7.6.2.2 TAMAM: Mass Production and Commodity

TAMAM, which has been a government-owned company for many years, and which presents a historical research orientation that is still vocal in the company, has a prospect, nevertheless, of becoming a private company in the near future. TAMAM has established its strategic approach to cross-project learning on mass production. It has pursued the exploitation of product success but has taken steps towards enhancing cross-project learning processes.

TAMAM has been organising cross-project learning capabilities around the function of the system engineer. Through this channel and by vertically integrating knowledge from parallel projects, TAMAM has been seeking to expand the instances in which a technology can be transferred from one project to another.

7.6.2.3 YellowTech: Product Enhancement and Quality

YellowTech, which has always been a business, market-driven company, has pursued a process enhancement strategy for cross-project learning.

YellowTech introduced a variety of mechanisms for short- and long- term strategic development and methodically measured the cost effectiveness of its cross-project learning activities.

7.7 The Conditions for Cross-Project Learning

The model presented in Figure 62 suggests an alternative approach to the rationalist view offered by Cusumano and Nobeoka (1998) to understand the conditions for cross-project learning. The present approach, based on contingency theory, argues that the organisation of capabilities for cross-project learning is subject to the trajectory of present identity and future strategic direction, as seen in Figure 62.

Having said that, it would be of particular interest to explore how an organisation can *change* its development path. In other words, if in section 7.6 we had addressed the question: *how did we get here?*, the following section would debate propositions appealing to the no less important question: *how can we get to where we would like to be?*

7.7.1 Competing Propositions for Changing the Development Path

The classical theorists will argue that in order to change the development path of cross-project learning, TAMAM and Rafael need to focus further on market orientation (see Levitt 1960). The voices within these companies that still associate the identity of the company with the notion of invention and research orientation restrain these companies from building the capabilities and competencies needed to achieve consistency with markets (Levitt 1960). Rafael should invest more resources in taking the social network-based cross-project learning practice to the stage that cross-project learning maximises profit. Marketing at Rafael needs to be further integrated in product development, and knowledge about markets should be integrated with product development decisions. By getting closer to markets, companies like Rafael would be able to rationalise strategic decisions about allocating resources towards the *exploit* *product success* strategy, based on the sophistication of the client and by addressing clients' unique needs. TAMAM should follow the same strategic decision, by tying up links between Sales and product development and ensuring returns on investment from cross-project learning strategies based on market knowledge. YellowTech is on the right track, according to Gupta and Wilemon (1990). YellowTech has built its marketing and Sales group based on talented engineers. Communication about market knowledge at YellowTech is being translated into product development strategic choice. For example, YellowTech has practised a technology 'lockout' strategy (Schilling 1998), based on the practice of commonality across electronic warfare systems. YellowTech upgrades electronic warfare systems by adding 'bells and whistles' to the functionality of the system in each generation; however, it keeps the compatibility of the system to the aircraft platform and other electronic systems unchanged. In this way, according to classical theorists such as Schumpeter (Whittington 1993), YellowTech enhances its competitive edge over rivals by utilising market knowledge that suggests that aircraft platforms change every 20 years whereas airborne system platforms would be upgraded every 7 years (interview source).

Thus, to classical theorists the recent engagement of the studied companies in knowledge management projects is irrelevant unless these activities assist in turning market knowledge to profit maximisation.

Evolutionary theorists will argue that in order to change the development path, perhaps the only thing the studied companies should do is to launch as many 'strategic initiatives' as possible. After all, managers do not decide on the winning strategy but rather environments do. Rafael perhaps will learn more about its markets, if one follows the classical argument; however, would this mean that, by investing in a long-term cross-project learning strategy, Rafael will be able to survive, in particular considering the $375 million total loss that the company reported between 1995 and 1999? Would Rafael enjoy the same sympathy towards losses from the Israeli MoD in the years to come?

Thus, Rafael can only survive and change the development path of cross-project learning by launching knowledge management initiatives in different directions in the hope that one will be successful (Henderson 1989). However, launching such initiatives should be relative to the costs involved in this strategy. Williamson (1991) suggests that leveraging cross-project learning beyond the costs that Rafael can bear would only hurt the company. There are 'transaction costs' in pursuing the classical approach: for example, the financial investments associated with introducing design centres, or perhaps the costs associated with training engineers to use reusability metrics to evaluate the cost-effectiveness of modularity. However, there are also other types of costs involved, such as those associated with detaching activity systems from their shared histories of learning, i.e. disturbances and tensions between expertise development and knowledge management, as analysed in Chapter 6. Introducing a profit-maximising system is not the way to change the development path, Williamson (1991) would argue. Rather, managers need to ensure that the associated costs from knowledge management initiatives are bearable to all stakeholders. This includes, for example, ensuring that knowledge management initiatives will not enforce control over social network-based cross-project learning practice at Rafael. This will be an unbearable cost that may bring political unrest to Rafael (Pfeffer 1992). In this sense, TAMAM and YellowTech are no different.

Micro-politics is already part of the path development of cross-project learning at Rafael, the processualists would argue (Pettigrew 1973). Power games between the members of the knowledge management committee are setting the agenda for future development of cross-project learning. Power struggles, perhaps latent in nature, are likely to exist at TAMAM and YellowTech as well (Lukes 1974). Also, changing the development path of cross-project learning cannot take place in one great leap; after all, managers are incapable of considering more than a handful of factors and their rationally is bounded (Cyert and March 1963). Rather, processualists will argue that taking small steps would be a better strategy for Rafael, TAMAM and YellowTech. According to the processual theory, Rafael, TAMAM and YellowTech are already changing their development path. In the processual theory, it is not the Chief Scientist who shaped the cross-project learning strategy. Rather, it is the adaptation process that creates a 'strategy'. In this process, participants introduce mini-innovations that are relatively small and their impact seems minimal (Whittington 1993), perhaps similar to the concept of proximal innovations that was introduced in Chapter 6. This concept of innovations may ease the tension between perspective making and perspective taking and between intra- and inter-community interests.

This thesis concludes by arguing that the above competing theoretical arguments are the present reality at YellowTech, Rafael and TAMAM.

Debates about where the focus of knowledge management should be within the organisation were part of the experience that these companies acquired in the last five years. YellowTech has decided to invest in two areas: R & D and Sales. TAMAM and Rafael decided to enhance the knowledge management practice in the Sales team. It is too early to predict whether these strategic initiatives will narrow the differences with regard to the organisation and the applied strategies of cross-project learning between the studied companies.

These recent strategic initiatives in the studied companies will continue to accumulate the bodies of knowledge and experience necessary for the development of cross-project learning at YellowTech, TAMAM and Rafael. Yet the dynamics of present identity and future strategic direction will continue to dominate the change in the development path of cross-project learning. Therefore, one has to ask: what may the future bring to YellowTech, TAMAM and Rafael?

7.7.2 The Future of YellowTech, TAMAM and Rafael

The Head of SIBAT, the R & D body at the Israeli Ministry of Defence that is also responsible for approving technology transfer to foreign countries, predicts that market competition is only going to intensify for the defence industry in the future (interview source).

Reports in the media, and data collected in a number of interviews with officials from the Israeli MoD, with top mangers in the studied companies, and with informants from the Israeli Air Force portray the following picture.

The Israeli electronics defence industry has suffered from substantial cuts in Israel's defence R & D budget (BICC 2000), which fuelled in past years the development of cutting edge technologies (Sadeh 2001). On the other hand, data presented above suggest that revenues and backlogs are in a steady growth, mainly from foreign clients.

The Israeli electronics defence industry has started to consolidate and further talks are underway (Sadeh 2001). The first merger in this industry took place in February 2000 between YellowTech, BVR and Tadiran, creating the YellowTech Group (Dror Marom, Globes, 16/01/2001). In July 2000 Elbit and El-OP, two companies that participated in the pilot stage of the present study, followed YellowTech and merged, creating the largest group for radar systems in Israel (Elbit Web Site). Government-owned companies, including TAMAM, are planned to be privatised, and Rafael, a sub-unit of the Israeli MoD, is expected to change ownership and become a government owned company, once the negotiations with trade unions are concluded.

However, these developments are conditional on the Ministry of Defence's demand that a law will be put in place to safeguard the nation's interests by establishing procedures regarding the ownership, control and influence over the privatised companies (Sadeh 2001).

Thus, we conclude that the future strategic direction of the Israeli electronics defence industry will be by and large in the business, market-orientated domain. TAMAM, Rafael and YellowTech would very likely see a growing pressure by stakeholders to present profits, increase revenues and secure a large backlog of orders in the near future.

However, because of the ongoing conflict in the Middle-East, past and present Israeli governments have sought to maintain the Israeli defence industrial base as the source of advanced technological solutions in the battlefield, reinforcing the perception held by engineers that their identity is highly associated with research and invention.

So, yet another stage of development emerges that introduces further tension between current identity and future strategic direction in the Israeli electronics defence industry.

7.8 Conclusion

This chapter addresses two questions: is there any strategic pattern for cross-project learning in the data presented above? If so, under what conditions are these cross-project learning strategies subject to change?

It was argued that the most relevant literature (Cusumano and Nobeoka 1998) does not provide a suitable framework to understand the strategies carried out by the studied companies. Following this, a 2x2 model was developed suggesting two contingent factors, revealed in the context of the present study, for the development of cross-project learning: the *present identity* and *future strategic direction*. We then incorporated the main findings of this study into a framework that suggests that the path of development of cross-project learning is subject to the dynamics of change in present identity and future strategic direction.

Lastly, a projection into the future has been provided, suggesting that the studied companies are yet to experience further tension between the past research-orientation and the future market-orientation. However, these companies are moving into the market-orientation domain.

8 CHAPTER EIGHT: CONCLUSIONS

8.1 Introduction

In our journey around the concept of cross-project learning we have progressively moved from the classical, rational approach to the evolutionary view in relation to cross-project learning. Furthermore, the analysis of cross-project learning has revealed that tension and disturbance between organisational processes, i.e. expertise development and knowledge management, has been associated with the introduction of cross-project learning in the studied companies. In this journey we have been comforted by some organisational literature that has attempted to explore the nature of cross-project learning in organisations and the impact that this process innovation would have on other organisational systems.

Thus, in this last chapter I shall assess the main contributions of the study in relation to the existing literature. These contributions can be organised around three themes: empirical, theoretical, and research methods. Going back to the main research interests, this chapter will assess what the study has achieved and what are its main limitations.

Section 8.2 will discuss the empirical contributions of this study. Three areas of theoretical contribution will then be outlined in section 8.3. The unique research method approach to cross-project learning applied in this study will be presented in section 8.4. Section 8.5 will offer an analytical framework to R & D managers that attempts to capture in one shot the tension between investing in the company's knowledge base and boosting competitive positioning. The main limitation of the present study will be outlined in section 8.6, followed by some suggestions for future research.

8.2 Empirical Contributions

At the most basic level, the three case studies represent a contribution to the emerging field in their own right. By putting together the empirical material collected on the field sites, my main purpose was to convey an image of structures and activities related to cross-project learning. This is justified because thus far research on cross-project learning has offered evidence mainly from the automobile industry (Cusumano and Nobeoka 1998; Mayer and Utterback 1993; Clark and Fujimoto 1991: Sobek et al. 1998). Furthermore, by and large, studies in this area focused on the Japanese case, with little attention to the organisation of product development for cross-project learning activities in other geographical areas and contexts. The context-specific characteristics of the Japanese and some American automobile companies raises a concern that the reported data, although significant, may represent only those practices which are embedded in the Japanese/American management style and culture. With this argument, I align the present study with the approach that argues that the context within which the case study company operates is imperative to understanding the organisation and its strategic approach towards cross-project learning (Pettigrew 1987; Collinson 2001). In support of the above argument, this study offers additional evidence on the practice of reusability. Indeed, the Israeli electronics defence industry offers a rather different approach to cross-project learning from the Japanese or the American case. In particular, some of the more central mechanisms reported in Chapter 5, such as the role of the system engineer at TAMAM and the entrepreneurship spirit at Rafael, have not been previously reported by studies addressing cross-project learning (Cusumano and Nobeoka 1998; Mayer and Utterback 1993; Baldwin and Clark 1997). The high degree of autonomy associated with the Israeli electronics defence industry, which was reported as one of the chief factors for the participation of engineers in cross-project learning, has not been observed or reported in the context of the Japanese automobile industry. Also, the strategy to integrate the Sales teams and clients into R & D activities has been unique to the studied industry. These new findings demonstrate the importance of research outside the domain of the automobile industry, despite its image as 'the industry of the industries' (Womack, Jones and Roos 1990).

In addition, the case studies offer a distinct perspective on a variety of themes that, although sharing an interest with the present study, could well be studied as phenomena in their own right: the evolution of the innovation system in defence companies (perhaps in comparison to commercial-civilian innovation systems); the interplay between product innovation and process innovation in defence companies; the strategic change in Marketing and Sales in the defence business; and the different project management practices and styles for managing R & D projects. A lesson to be learned from the case studies is that some classical organisational topics, such as those listed above, can possibly be revised through the application of different analytical lenses, such as activity theory, or by researching the same phenomenon in different cultural contexts.

8.3 Theoretical Contributions

Cross-project learning is examined in this research from three different angles. It is analysed in Chapter 5 as a knowledge management practice that enhances product development activities. In Chapter 6, cross-project learning is studied as a source of tension in product development. Lastly, cross-project learning is presented in Chapter 7 as a strategy. One can look at these three areas of contribution as associated respectively with the operational, dysfunctional and strategic levels. The contribution of the present study to the development of theory in these areas is provided in the following sections.

8.3.1 Cross-Project Learning as a Knowledge Management Practice

There are many advantages in studying innovation processes from a knowledge management practice perspective (Coombs and Hull 1996). The ability to detail the activities involved in the learning process, through the observation of 'knowing in practice' in communities, and to understand the effect on the management and organisation of innovation systems are only some of the values that this approach may offer. However, there are additional benefits in applying the knowledge management practice approach.

First, the knowledge management practice encourages the researcher to perceive the array of knowledge activities as the knowing infrastructure of the innovation system under investigation. Similarly, activity theory offers a lens that avoids the fragmentation of different disciplines and knowledge activities by treating the space under investigation as an activity system. In particular, the study of cross-project learning has suffered from fragmentation and segregation, failing to integrate the various mechanisms, structures, and practices involved in the transfer of designs into one framework of capabilities. For example, research related to cross-project learning has separately highlighted the management of product family (Sundren 1999; Mayer and Utterback 1993), the support for modularity in designs (Baldwin and Clark 1997), the role of the organisational structure (Cusumano and Nobeoka 1998; Sanderson and Uzumeri 1994), the contribution of knowledge centres and development centres (Cusumano and Nobeoka 1998), and the integration and coordination mechanisms involved in R & D activity (Hauptman and Hirji 1999). Instead of segregating these knowledge activities, the present study, through the lens of knowledge management practice, integrates these knowledge activities into the framework of the knowing infrastructure of cross-project learning.

Secondly, the approach of studying innovation systems from a knowledge management practice perspective opens an opportunity to apply various analytical lenses that study one single phenomenon from various angles. For example, the meaning and perception of the knowledge involved in technology transfer can be manipulated through different analytical lenses. Thus far, the majority of the studies on cross-project learning emphasise the instrumental, functional character of the knowledge involved in the transfer process, as it is an object that can be moved from one place to another (e.g. Cusumano and Nobeoka 1998; Nobeoka 1995; Meyer and Utterback 1993). In contrast to the above studies and in order to extend the theory of cross-project learning in relation to the nature of knowledge involved in the transfer process, the present study applied a socially constructed lens that observed knowledge, or perhaps knowing, in action in communities of practice. This socially constructed lens on knowledge activities allowed this study to present a rather different perception and grant different meaning to the knowledge under investigation. It can be further claimed that by applying a socially constructed lens this study moves away from the static categorisation of knowledge to the dynamic terrain of modes of organisation for innovations. Another example is the literature related to technology transfer that takes a rational, classical approach to the management of product family (Mayer and Utterback 1993), cross-project learning (Nobeoka 1995; Cusumano and Nobeoka 1998) and the management of product development as a single project effort (Clark and Fujimoto 1991). Looking at the same phenomenon but from an evolutionary approach, a rather different picture of cross-project learning has emerged, that emphasises the *adaptive* nature of the organisation of knowledge activities.

Lastly, cross-project learning as a knowledge management practice allows the comparison between contexts and environments within which the studied companies operate. Within the knowledge management framework, three different approaches to cross-project learning have emerged, suggesting that the interactions between action and structure cannot be detached from the context within which these interactions occur. Thus, structures and actions cannot be treated as independent variables but rather they need to be studied in the context of the surrounding environments. Structuration theory (Giddens 1984) suggests that agency and structure are not independent from each other but rather mutually interact and shape each other. Activity theory provides the tools to understand these interactions by perceiving the universe of structures as a multi-activity system environment in which activity systems interact and thus shape each other. The knowledge management practice framework provides the space within which such an analysis can be carried out, as demonstrated in the present study.

8.3.2 Cross-Project Learning as a Source of Tension

The literature on cross-project learning offers little in terms of the discussion of disturbances and tensions involved in introducing and implementing such a practice. Furthermore, the literature on process innovation avoids discussing the dysfunctionality that innovation systems encounter when they evolve and change. Rather, the obsession of Cartesian approaches to pursue and present superior performances and extraordinary skills hindered research from thoroughly studying the disturbances and tension embedded in innovation systems. The present study takes a step in correcting this injustice. Through the lens of activity theory, disturbance and tension become evident as the product development activity system is accelerated. The past harmony between expertise development and knowledge management activity systems is replaced by contradictory tools, social spaces and images of knowledge. More importantly, disturbance and tension is evidently an avenue to learning through the introduction of proximal innovations that bridge the inherent tension between intra- and inter-community interests and between the notion of exploitation and exploitation in an R & D environment.

Yet tension has spread into other areas, including my own arguments. There is tension between the competing interpretations presented in Chapter 5 with regard to the different organisation of cross-project learning systems in the studied companies. Tension is also apparent between my own arguments for the potential future strategic steps to be carried out by the studied companies outlined in Chapter 7. This tension drives research to question and challenge our own assumptions and about what we perceive as reality. In the words of Albert Einstein, 'the important thing is not to stop questioning'.

8.3.3 Cross-Project Learning as a Strategy

Before this study was carried out research on technology transfer between projects offered four cross-project learning strategies; new design, concurrent, sequential and modification (Cusumano and Nobeoka 1998). The latter also argued that concurrent technology transfer is the practice that managers should follow.

The present research challenged the above proposition. This study extends the strategic approach to cross-project learning by offering two fundamental strategies to cross-project learning: *exploit product success* and/or *design to reuse*. Within each strategy, managers can plan either a sequential or a concurrent technology transfer, subject to the contractual and market conditions.

Furthermore, against the classical strategic approach demonstrated in the technology transfer literature, the present study suggests that the organisation of cross-project learning capabilities is contingent upon the trajectory of identity and future strategic direction. There is an evolutionary process in which companies adapt their innovation systems to various elements that play a role in their environments.

8.4 Contributions to Research Methods

The contributions of the applied research methods in the present study to understanding the introduction and implementation of any process innovation such as cross-project learning are particularly relevant given the interest in understanding the operational, dysfunctional and strategic levels associated with the cross-project learning. Research thus far has focused on either the operational level of cross-project learning or the strategic approach to managing product families. As far as the researcher knows, this is the first attempt to capture three levels of analysis in the context of cross-project learning. Thus, the research methods applied in this study provide a lens (or maybe a multi-lens) that assists in addressing the following question: how is it possible to gain access to, and explain knowledge activities associated with the operational, dysfunctional and strategic levels of cross-project learning?

The technique undertaken in the present study can be described in terms of photography jargon as the 'zoom in - zoom out' technique. By this I mean that there are at least two positions that the lens can be in. One, the 'zoom in' position, in which the photographer attempts to achieve a detailed image of the object in the frame. A detailed image will show the beauty of, and some distortion in the object; however, it will lack the wide-angle view of the surrounding and the environment within which the object is located. Second, the 'zoom-out' position, in which the photographer seeks to capture the wide-angle image of the objects in the frame. In this case the 'big picture' is more important than the detailed image of each object. A clear overview of the landscape and surroundings is captured in the frame in this mode, allowing the viewer to realise the elements and the dynamics involved in the picture.

In Chapter 7, a 'zoom out' technique has been applied to capture the evolution of cross-project learning strategies during time. The emphasis in Chapter 7 is on the 'big picture' view of cross-project learning, in which the various capabilities have been categorised into two main cross-project learning strategies: *exploit product success* and *design to reuse*.

In Chapter 6, a close look at the processes associated with product development, expertise development and knowledge management has advocated the use of the 'zoom in' technique. This research method technique revealed the tension and disturbance in activity systems which erupt as they interact and change.

Lastly, a 'half-way zoom' research technique has been applied in Chapter 5 to capture the operations involved in cross-project learning in the studied companies. This mode allows the study to identify organisational mechanisms, managerial practices, concepts, tools and other practices that constitute cross-project learning capabilities in the studied companies.

When taken as a whole, the three lenses provide a coherent framework for studying the operational, dysfunctional and strategic level of process innovation in a systematic way.

8.5 Managerial Implications

In line with the study argument that the context-specific attributes of the knowledge management practice under investigation would probably inhibit the successful transfer of best practices across the industry, and following the argument that cross-project learning strategies are actually evolutionary in nature, it has not been the researcher's intention to advise management how to organise innovation systems for a successful cross-project learning.

Rather, in my own perspective and based on the experience gained from participating in three research projects, perhaps the main theme that management should be considering as a result of this study is how to creatively manage tension in the numerous areas presented above.

I argue that there is no one single ideal way to creatively manage tension between such knowledge activities and concepts. Each case has its own unique circumstances and hence needs to be carefully studied by either management, consultants or academic researchers. Only then can a solution be provided. Yet a solution that works for one company is not necessarily appropriate for another. Furthermore, 'magic' solutions or industry recipes, such as IT systems, have not always been proven to solve problems in an R & D environment. In some cases, IT systems, for example, created even more disturbances to the R & D process.

However, understanding the vectors involved in managing an R & D environment would assist in providing a solution per situation. I argue that Figure 63 represents the dilemma that R & D managers face and hence the tension that they need to ease on a daily basis.

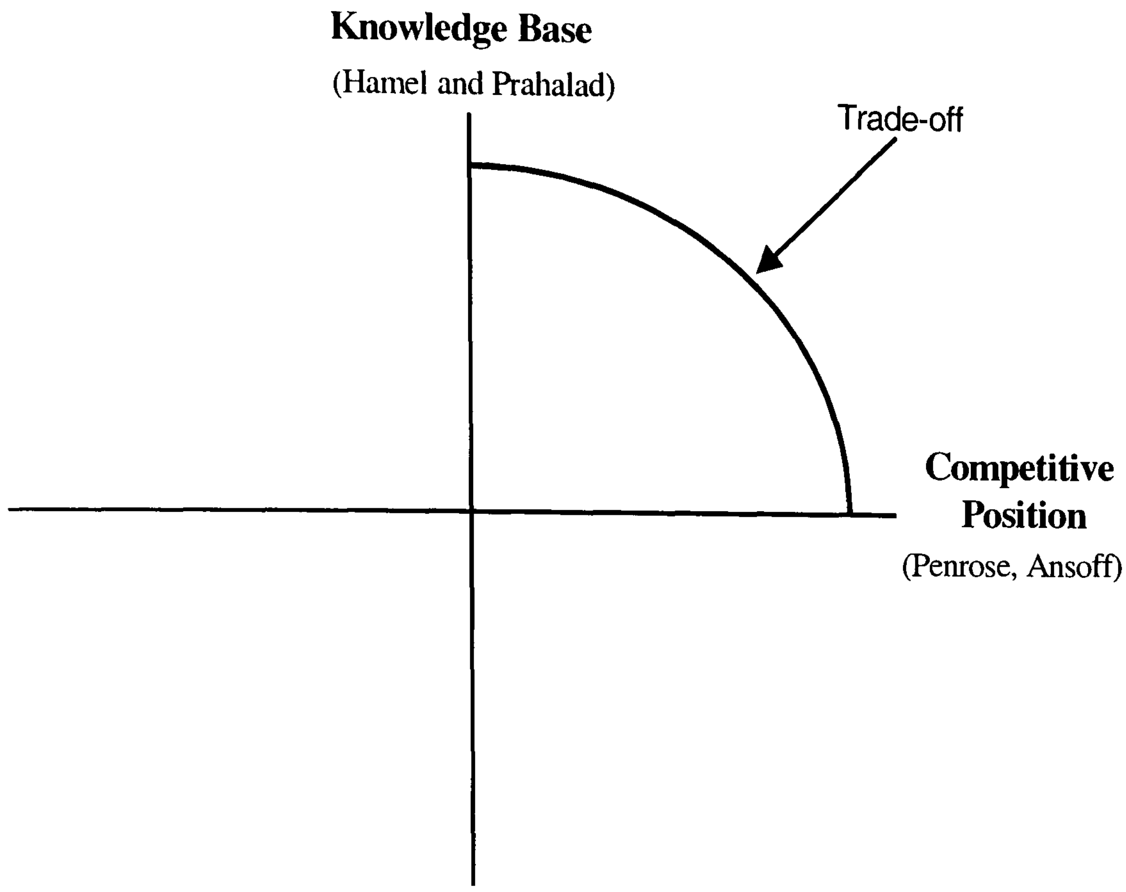

Figure 63: Knowledge Base – Competitive Position (based on Hickson et al. forthcoming)

On the one hand managers would like to maximise the knowledge base by investing in expertise development systems and practices. On the other hand, managers would like to achieve market success by accelerating product development processes, customising products and reusing designs. Nevertheless, there is trade-off between these two concepts. Managers may impede the build-up of expertise by enhancing product development processes and reusing designs. This tension is the core challenge that R & D managers face in the Israeli electronics defence industry and perhaps in other similar industries.

8.6 Main Limitations of the Study

Some of the limitations of this study have already been illustrated in Chapter 3. These limitations revolved around issues related to security clearance, difficulties in gaining access, and the studied companies' preconditions for participating in the research.

In addition, given time constraints, institutional specifications (e.g. maximum length of a doctoral thesis, and the practical concerns of a PhD endeavour), and above all the scope and complexity of the phenomena under investigation, the study inevitably presents some deficiencies.

First, the design of the research was somewhat artificial: of six projects, three were well-established product family ones and three were relatively young product families. In a time perspective, it would have been more beneficial to study projects belonging to well-established product families. Yet the data provided by participants from projects belonging to a relatively young product family contributed to the understanding of how cross-project learning capabilities are built up. This extended the researcher's understanding beyond the discussion of how technologies are reused to the point of how capabilities to reuse designs are born. However, given the research design and objectives, the findings of this study invite speculation about possible different reuse core capabilities across product families, subject to the product family maturity. These findings need further validation and may hopefully stimulate further research in this direction.

Secondly, the selection of the studied companies was a 'second best choice'. Indeed, all three studied companies operate in the electronics defence industry; however, they do not directly compete with each other, apart from some direct competition between Rafael and TAMAM in the Optronic field. A lack of striking similarities in products and production systems between the studied companies has limited the debate on the differences between the organisation of cross-project learning to themes associated with the evolutionary path of these companies. The different evolutionary paths have directed the discussion to factors that are associated with the growth of the organisation, i.e. identity and future strategic path. Perhaps rather similar evolutionary paths of the studied companies would have extended the discussion beyond these two factors.

Lastly, some potentially relevant themes (e.g. the debate about how knowledge is created, the debate about the tension between exploitation and exploration, the discussion about integration and coordination mechanisms in an R & D environment and so on) have been deliberately left in the background because of lack of time and the constraints of length on a doctoral thesis.

8.5 Suggestions for Future Research

The present study will hopefully offer a template for future research on cross-project learning. The above-mentioned limitations and the context-specific environment in which this study was carried out suggest a number of interesting themes and techniques to be pursued by future research on cross-project learning in organisations.

Firstly, the 'zoom-in, zoom-out' research method needs further testing in order to validate and possibly refine its contribution to understanding the operational, dysfunctional and strategic level in innovation systems. The 'zoom-in, zoom out' research method can be applied in the study of any process innovation or strategic change process.

Secondly, research in other industries on cross-project learning is needed. Thus far only the automobile and the electronics defence industry have produced substantial evidence on the systematic reusability of hardware and software designs. The context within which the company under investigation operates has proven to be significant to the unique organisation of the innovation system. Therefore, future research design should target additional but not only manufacturing companies.

Thirdly, the links between 'strategic development' (i.e. identity and future strategic direction) and 'modes of reusability' should be further investigated. The evolutionary path of cross-project learning within organisations also needs further validation. Future research should take into account the interplay between identity/future strategic direction, and modes of organisation for cross-project learning in the selection of the field settings. Some of the possible variations in the design of future research may be as follows: (i) comparative studies considering companies operating in the same sector and belonging to the same evolutionary path; (ii) comparative studies considering companies operating in different sectors but belonging to the same evolutionary path; (iii) comparative studies considering companies operating in different sectors and geographical regions but belonging to the same evolutionary path.

REFERENCES

Adler, P. S. and Shenhar A. 1990. "Adapting Your Technological Base: The Organizational Challenge." *Sloan Management Review* 25:25-37.

Allen T.J. 1986. "Organizational Structure, Information Technology, and R & D Productivity." *IEEE Transactions on Engineering Management* EM-33(4):212--217.

Anthony L.V. 1998. "Efficiency Gains Elude Biggest Merger Survivors." *Aviation Week & Space Technology* 149(6).

Argyris C. and Schon D.A. 1978. *Organizational Learning*. Reading: Addison-Wesley.

Bahrami H. and Evans S. 1995. "Flexible Re-Cycling and High-Technology Entrepreneurship." *California Management Review* 37(3):62-78.

Baldwin C.Y. and Clark K.B. 1997. "Managing in the Age of Modularity." *Harvard Business Review* 75(5):84-93.

Bandura A. 1977. *Social Learning Theory*. Englewood Cliffs, NJ: Prentice Hall.

Barber J.D. 1966. *Power in Committees*. Chicago: Rand McNally & Company.

Bart C. 1986. "Product Strategy and Formal Structure." *Strategic Management Journal* 7(4):293-313.

Barzilai A. 9 Aug 1999. "Israel Is Sixth-Largest Arms Producer in World (in Hebrew)." *Haaretz* (Israel).

———. 15 Nov 1999. "The Israeli Defence Industry Is Facing Crisis (in Hebrew)." *Haaretz* (Israel).

———. 3 Oct 1999. "Rafael Did Not Order This Crisis (in Hebrew)." *Haaretz* (Israel).

———. 26 Jul 1999. "A Sense of Loosing Control at Rafael (in Hebrew)." *Haaretz* (Israel).

Barzilai A. 26 Jul 1999. "US Navy Chose Raytheon (in Hebrew)." *Haaretz* (Israel).

Beers C., Long M., Thomas H., and Davenport D. 1998. "Successful Knowledge Management Projects." *Sloan Management Review* 39(2):43-57.

Bergen S.A. 1990. *R&D Management and New Products*. Oxford: Basil Blackwell.

Bernasco W., de Weerd-Nederhof P.C., Tillema H., and Boer H. 1999. "Balanced Matrix Structure and New Product Development Process at Texas Instruments Materials and Controls Division." *R & D Management* 29(2):121-31.

Bior H. 2 Nov 1999. "Rafael: Changing Ownership Is Like Declaring a War (in Hebrew)." *Haaretz* (Israel).

Blackler F. 1993. "Knowledge and the Theory of Organizations: Organizations As Activity Systems and the Reframing of Management." *Journal of Management Studies* 30(6):862-84.

———. 1995. "Knowledge, Knowledge Work and Organizations: An Overview and Interpretation." *Organisation Studies* 16(6):1201-041.

Blackler F., Crump N. a. M. S. 1999. "Managing Experts and Competing Through Innovation: An Activity Theoretical Analysis ." *Organization* 6(1):5-31.

———. 2000. *Organizing Processes in Complex Activity Networks.* Lancaster University.

Blackler F., Crump N., and McDonald S. 1998. "Organizational Learning and Organizational Forgetting: Lessons From a High Technology Company." in *Organizational Learning and Learning Organization*, M. Eaterby-Suidi. (Ed.) London: Sage.

Bodker S. and Gronbaek K. 1996. "Users and Designers in Mutual Activity: An Analysis of Cooperative Activities in System Design." Pp. 130-158 in *Cognition and Communication at Work*, Y. Engestrom and D. Middleton (Eds.). Cambridge//MA: Cambridge University Press.

Boland R.J. and Tenkasi R.V. 1995. "Perspective Making and Perspective Taking in Communities of Knowing ." *Organisation Science* 6(4):350-372.

Bonn International Center for Conversion (BICC). 2000. "Conversion of Military Resources for Civilian Purposes" [Web Page]. Available at www.bicc.de.

Bradshaw G. 1992. "The Airplane and the Logic of Invention." Pp. 239-50 in *Cognitive Models of Science: Minnesota Studies in the Philosophy of Science*, vol. XV, R. Giere (Ed.). Minneapolis: Minneapolis University Press.

Brenner M. 1985. "Intensive Interviewing." in *The Research Interview: Uses and Approaches*, M. Brenner, J. Brown, and D. Canter (Eds.). London: Academic Press.

Browing M.A. 2000. "De-Construction Theory: A Look at the Institutional Theory That Positivism Built." *Journal of Management Inquiry* 9(3):258-70.

Brown R. 1981. *Social Psychology*. New York: The Free Press.

Brown S.L. and Eisenhardt K.M. 1995. "Product Development: Past Research, Present Findings, and Future Directions." *Academy of Management Review* 20:343-78.

Chandler A.D. 1962. *Strategy and Structure: Chapters in the History of the American Industrial Enterprise*. Cambridge, MA: MIT Press.

Child J. and Smith C. 1987. "The Context and Process of Organizational Transformation - Cadbury Limited in Its Sector." *Journal of Management Studies* 24(6):565-93.

Clark K.B. and Wheelwright S.C. 1993. *Managing New Product and Process Development*. New York: The Free Press.

Clark K.B. and Fujimoto T. 1991. *Product Development Performance*. Boston, MA: Harvard Business School Press.

Clark W.W. 1995. "Defence Conversion: The Economic Conversion of the American Economy." *Industrial Marketing Management* 24(5):391-409.

Cohen L., Duberley J., and McAuley J. 1999. "The Purpose and Process of Science: Contrasting Understandings in UK Research Establishments." *R & D Management* 29(3):233-45.

Collinson S. 1999. "Knowledge Management Capabilities for Steel Makers: A British-Japanese Corporate Alliance Organizational Learning." *Technology Analysis & Strategic Management* 11(3):337-58.

———. 2001. "Knowledge Management Capabilities in R & D: A UK - Japan Company Comparison." *R & D Management* 31(3):335-48.

Coombs R. 1996. "Core Competencies and the Strategic Management of R & D." *R & D Management* 26(4):345-55.

———. 1998. "A Reflection on the Major Themes of the 1997 R & D Management Conference." *R & D Management* 28(3):213-14.

Coombs R. and Hull R. 1998. "'Knowledge Management Practices' and Path-Dependency in Innovation." *Research Policy* 27:237-53.

Crocombe G.T., Enright M.J., and Porter M.E. 1991. *Upgrading New Zealand's Competitive Advantage*. Auckland: Oxford University Press.

Cusumano M.A. and Nobeoka K. 1998. *Thinking Beyond Lean: How Multi-Project Environment Is Transforming Product Development at Toyota and Other Companies*. N.Y: The Free Press.

Cyert R.M. and March J.G. 1963. *A Behavioral Theory of the Firm*. Englewood Cliffs, NJ: Prentice Hall.

Dean Jr .J.W. 1987. "Building the Future: The Justification Process for New Technology." Pp. 35-58 in *New Technology As Organizational Innovation*, J.M. Pennings and A. Buitendam (Eds.). Cambridge, MA: Ballinger.

Dyer B. and Gupta A.K. 1999. "What First-to-Market Companies Do Differently." *Research Technology Management* 42(2):15-21.

Eisenhardt K.M. 1989. "Making Fast Strategic Decisions in High-Velocity Environments." *Academy of Management Journal* 32:543-76.

Eldred E. and McGrath M.E. 1997. "Commercializing New Technology." *Research Technology Management* 49(2):29-33.

Engestrom Y. 1996. "Developmental Studies of Work As a Testbench of Activity Theory: The Case of Primary Care Medical Practice." in *Understanding Practice: Perspectives on Activity and Context*, Chaiklin S. and Lave J. N.Y.: Cambridge University Press.

———. 1992. "Interactive Expertise: Studies in Distributed Working Intelligence." *Research Bulletin, University of Helsinki* 83.

———. 1987. *Learning by Expanding* . Helsinki: Orienta-Konsultit.

Engestrom Y., Miettinen R., and Punamaki R.L. 1999. "Perspectives on Activity Theory." Pp. 377-407 in *Innovative Learning in Work Team: Analyzing Cycles of Knowledge Creation in Practice*, Engestrom Y. Cambridge: Cambridge University Press.

Ericsson K.A. and Smith J. (Eds). 1991. *Toward a General Theory of Expertise: Prospects and Limits*. Cambridge, MA: Cambridge University Press.

Ettlie J.E. and Bridges W.P. 1987. "Technology Policy and Innovation in Organizations." Pp. 117-37 in *New Technology As Organizational Innovation,* J.M. Pennings and A. Buitendam. Cambridge, MA: Ballinger.

Floyd S.W. and Wooldridge B. 1999. "Knowledge Creation and Social Networks in Corpo-Rate Entrepreneurship: The Renewal of Organizational Capability." *Entrepreneurship, Theory and Practice* 23(3):123-43.

Fudge S.R. and Schlatler J.S. 1999. "Motivating Employees to Act Ethically: An Expectancy Theory Approach ." *Journal of Business Ethics* 18(3):295-304.

Gehani R. R. 1998. *Management of Technology and Operations* . New York: John Wiley and Sons.

Gherardi S. and Nicolini D. 1999. "The Organizational Learning of Safety in Communities of Practice." *EGOS* (Warwick Business School, Aug). UK.

Giddens A. 1984. *The Constitution of Society* . Cambridge: Polity Press.

Ginsborg A. 7 Jan 1998. "Elbit Wins $57 Mln Contract in the Far East (in Hebrew)." *Globes* (Israel).

Gold A.H., Malhotra A., and Segars A.H. 2001. "Knowledge Management: An Organizational Capabilities Perspective." *Journal of Management Information Systems* 18(1):185-214.

Grant R.M. 1995. *Contemporary Strategic Analysis*. Oxford: Blackwell.

Gummesson E. 1991. *Qualitative Methods in Management Research*. Newbury Park: Sage Publications.

Gupta A.K. and Wilemon D.L. 1990. "Accelerating the Development of Technology-Based New Products." *California Management Review* :24-44.

Habermas J. 1972. *Knowledge and Human Interests*. London: Heinemann.

Hamel G. 1994. "The Concept of Core Competence ." Pp. 11-35 in *Competence-Based Competition*, Hamel G. and Heene A. West Sussex: John Wiley & Sons Ltd.

———. 1996. "Strategy As Revolution." *Harvard Business Review* 74(4):69-.

Hammersley M. and Atkinson S. 1995. *Ethnography: Principles in Practice*. London: Routledge.

Haque B. and Pawar K.S. 1931. "Improving the Management of Concurrent New Product Development Using Process Modelling and Analysis." *R & D Management* 127-39.

Harrison J.A. 1995. "Giant Merger If Two Survivors." *Mergers and Acquisitions* 29(4):44-.

Hauptman O. and Hirji K.K. 1999. "Managing Integration and Coordination in Cross-Functional Teams: An International Study of Concurrent Engineering Product Development." *R & D Management* 29(2):179-91.

Henderson B.D. 1989. "The Origin of Strategy." *Harvard Business Review* November-December:139-43.

Herzberg F.A., Mausner B., and Snderman B. 1959. *The Motivation to Work*. New York: John Wiley.

Hickson D., Miller S., and Wilson D. Forthcoming. "Planned or Driven: Implementing Strategic Decision." *Journal of Management Studies* .

Hosking D. and Morley I. 1991. *A Social Psychology of Organizing*. Hemel Hempstead: Harvester Wheatsheaf.

Hougui S. and Shenhar A. 1996. "Defence Conversion in Small Companies: Risk, Activities and Success Assessment." University of Minnesota, Minnesota, US. Yes.

Hull R., Coombs R., and Peltu M. 2000. "Knowledge Management Practices for Innovation: An Audit Tool for Improvement." *Journal of Technology Management* 20(5/6/7/8):633-56.

Inbar E. and Zilberfarb B. 1998. *The Politics and Economics of Defence Industry* . London: Frank Cass Publishers.

Jarrar Y.F. and Zairi M. 2000. "Best Practice Transfer for Future Competitiveness: A Study of Best Practices." *Total Quality Management* 11(4-6):734-40.

Johnson G. and Scholes K. 1993. *Exploring Corporate Strategy*. London: Prentice Hall.

Kahn R. and Cannell C. 1957. *The Dynamics of Interviewing*. London: John Wiley.

Kanter R.M. 1985. *The Change Masters: Corporate Entrepreneurs at Work*. London: Unwin.

———. 1996. "When a Thousand Flowers Bloom: Structural, Collective, and Social Conditions for Innovation in Organizations ." *Knowledge Management and Organizational Design*, Myers P.S. Boston: Butterworth-Heinemann.

Kerzner H. 1995. *Project Management: A System Approach to Planning, Scheduling and Controling*. NY, USA: Van Nostrand Reinhold.

Kirkbride P. S. 1992. "Power." in *Employment Relations*, Hartley J.E. and Stephenson G.M. (Eds.) Oxford : Blackwell.

Klieman A. 1998. "Adapting to a Shrinking Market: The Israeli Case." Pp. 111-35 in *The Politics and Econics of Defence Industries*, Inbar E. and Zilberfarb B. (Eds.) London: Frank Cass Publishers.

Koren O. 8 Oct 1999. "Koor Examines Merger Between YellowTech, Tadiran and SpectraLink (In Hebrew)." *Haaretz* (Israel).

Kreiner K. and Schultz M. 1993. "Informal Collaboration in R & D: The Formation of Networks Across Organizations." *Organization Studies* 1(1):189-209.

Krishnan V. and Ulrich K.T. 2001. "Product Development Decisions: A Review of the Literature." *Management Science* 47(1):1-21.

Kuhn T. 1962-1970. *The Structure of Scientific Revolutions.* Chicago: University of Chicago Press.

Kuutti K. 1999. "Activity Theory, Transformation of Work, and Information Systems Design." in *Perspectives on Activity Theory*, Y. Engestrom, R. Miettinen, and R.L. Punamaki. (Eds.) Cambridge, MA: Cambridge University Press.

Lam A. 1997. "Embedded Firms, Embedded Knowledge: Problems of Collaboration and Knowledge Transfer in Global Cooperative Ventures." *Organisation Studies* 18(6):973-96.

Landau E. 6 Aug 1999. "YellowTech and Trek Join Forces (In Hebrew)." *Globes* (Israel).

Laurila, J. 1997. "The Thin Line Between Advanced and Conventional New Technology: A Case Study on Paper Industry Management." *Journal of Management Studies* 34(2):221-39.

Lave J. 1996. "The Practice of Learning." in *Understanding Practice: Perspective on Activity and Context*, Chaiklin S. and Lave J. (Eds.) N.Y: Cambridge University Press.

Lave J. and Wenger E. 1991. *Situated Learning, Legitimate Peripheral Participation.* Cambridge UK: Cambridge University Press.

Lavitt T. 1960. "Marketing Myopia ." *Harvard Business Review* July-August :45-56.

Lawrence P.R. and Lorsch J.W. 1967. *Organizations and Environment: Managing Differentiation and Integration.* Boston, MA: Harvard Business School, Division of Research.

Leont'ev A.N. 1978. *Activity, Consciousness, and Personality*. Englewood Cliffs, N.J.: Prentice Hall.

Lukes S. 1974. *Power: A Radical View*. London: Macmillan Publishers Ltd.

March J.G. 1999. *The Pursuit of Organizational Intelligence*. Malden, MA: Blackwell.

Markus M.J. 2001. "Toward a Theory of Knowledge Reuse: Types of Knowledge Reuse Situations and Factors in Reuse Success." *Journal of Management Information Systems* 18(1):57-93.

Marom D. 13 Jan 1998. "Concern at IAI, IMI: Both Export $500 Mln Annually to Far East (in Hebrew)." *Globes* (Israel).

———. 4 Jan 2000. "First Time: Rafael Orders Backlog Over $1 Bln; Expected to Show Operating Profit This Year (in Hebrew)." *Globes* (Israel).

———. 22 Jul 1999. "IAI Sales Soar 75% to 1.4 Bln in 1st Half 1999 (in Hebrew)." *Globes* (Israel).

———. 28 Feb 2001. "IAI Subsideries Show Improved Results in 2000 (In Hebrew)." *Globes* (Israel).

———. 27 Nov 1999. "IAI Workers to Strike Tomorrow: Government Plans to Close Company (in Hebrew)." *Globes* (Israel).

———. 20 Jan 1999. "Joint Venture Between YellowTech and Northrop Grumman (in Hebrew)." *Globes* (Israel).

———. 16 Jan 2001. "Koor Planning to Issue YellowTech at $350 Mln (in Hebrew)." *Globes* (Israel).

———. 28 Mar 2001. "Rafael Posts Its First Ever Profit." *Globes* (Israel).

———. 17 Jul 1997. "Work Stoppages at Airport, Broadcast Authority, Electric Co and IAI to Show Solidarity With Bezeq Employees (In Hebrew)." *Globes* (Israel).

McCollum J.K. and Sherman J.D. 1993. "The Matrix Structure: Bane or Benefit to High Tech Organizations?" *Project Management Journal* XXIV(2):23-25.

McDonough E.F. and Barczak G. 1991. "Speeding Up New Product Development: The Effects of Leadership Style and Source of Technology." *The Journal of Product Innovation Management* 8(3):203-12.

Meyer M.H. and Utterback J.M. 1993. "The Product Family and the Dynamic of Core Capability." *Sloan Management Review*:29-38.

Mintzberg H. 1987. "Crafting Strategy." *Harvard Business Review* .

———. 1979. "An Emerging Strategy of Direct Research." *Administrative Science Quarterly* 24:580-589.

———. 1983. *Structures in Fives: Designing Effective Organizations*. N.J.: Prentice Hall.

———. 1988. "The Structuring of Organizations." Pp. 276-314 in *The Strategy Process*, Quinn J.B., Mintzberg H., and James R.M. (Eds.) Englewood Cliffs, N.J.: Prentice-Hall Inc.

Mintzberg H. and Waters J.A. 1985. "Of Strategies, Deliberate and Emergent." *Strategic Management Journal* 6:257-72.

Morris P.W.G. 1997. *The Management of Projects*. London: Thomas Telford Services.

Myers I.B. and Briggs K.C. 1962. *Myers-Briggs Type Indicator.* Princeton N.J.: Education Testing Service.

Myers P.S. 1996. *Knowledge Management and Organizational Design.* Newton, MA: Butterworth-Heinemann.

Nelson R.R. and Winter S.G. 1982. *An Evolutionary Theory of Economic Change.* Cambridge, MA: Harvard University Press.

Nicoll A. 24 Jan 2002. "Europe's Aircraft Makers Fail to Unite." *Financial Times* (UK).

Nobeoka K. 1995. "Inter-Project Learning in New Product Development." *Academic of Management Journal* Special Issue 1995:432-40.

Nonaka I. 1994. "A Dynamic Theory of Organizational Knowledge Creation." *Organization Science* 5(1):14-37.

Nonaka I. and Takeuchi H. 1995. *The Knowledge-Creating Company* . New York: Oxford University Press.

Olson E.M., Walker O.C., and Ruekert R.W. 1995. "Organizing for Effective New Product Development." *Journal of Marketing* 59(1):48-76.

Orr J. 1990. "Sharing Knowledge, Celebrating Identity: Community Memory in a Service Culture." *Collective Remembering*, D. Middleton and D. Edwards (Eds.). London: SAGE.

Orr J. 1996. *Talking About Machines: An Ethnography of a Modern Job.* N.Y.: Cornell University Press.

Pavitt K. 1984. "Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory." *Research Policy* 13:343-73.

Pelz D. C. 1985. "Innovation Complexity and the Sequence of Innovation Stages." *Knowledge, Creation, Diffusion, Utilization* 6(3):261-91.

Penrose E.T. 1952. "Biological Analogies in the Theory of the Firm." *American Economic Review* 42(5):804-19.

Perlow L. 1999. "The Time Famine." *Administrative Science Quarterly* 44:57-81.

Peters T.J. 1979. "Beyond the Matrix Organization." *Business Horizons* 22(10):15-27.

Pettigrew A. 1987. "Context and Action in the Transformation of the Firm." *Journal of Management Studies* 24(6):649-70.

Pettigrew A.M. 1973. *The Politics of Organizational Decision-Making*. London: Tavistock Publications.

Pettigrew A. and Whipp R. 1991. *Managing Change for Competitive Success*. Oxford: Blackwell.

Pfeffer J. 1992. *Managing With Power: Politics and Influence in Organizations*. London: Routledge.

Pfeffer J. and Salancik G.R. 1978. *The External Control of Organizations*. N.Y.: Harper and Row.

Polanyi M. 1966. *The Tacit Dimension*. New York: Doubleday.

Prahalad C.K. and Hamel G. 1990. "The Core Competence of the Corporation." *Harvard Business Review* 68(3):79-91.

Quinn J.B., Mintzberg H., and James R.M. 1988. *The Strategy Process: Concepts, Contexts, and Cases*. N.J.: Prentice-Hall.

Rafael. 1998. *Rafael Bulletin*. Israel: Rafael Publishing Department.

Raval D. and Subramanian B. 2000. "Effective Transfer of Best Practices Across Cultures." *Competitiveness Review* 10(2):183-91.

Repenning N.P. 2001. "Understanding Fire Fighting in New Product Development." *The Journal of Product Innovation Management* 18(5):285-300.

Robbins S.P. 1987. *Organization Theory: Structure, Design, and Applications*. New Jersey: Prentice-Hall.

Rogers E.M. 1983. *Diffusion of Innovations* . New York: Free Press.

Sadeh A., Dvir D., and Shenhar A. 2000. "The Role of Contract Type in the Success of R & D Projects Under Increasing Uncertainties ." *Project Management Journal* 31(3):14-22.

Sadeh S. 2001. "Israel's Beleaguered Defence Industry." *Middle East Review of International Affairs* 5(1):64-76.

Sanchez R. and Mahoney J.T. 1996. "Modularity, Flexibility and Knowledge Management in Product and Organization Design." *Strategic Management Journal* 17:63-76.

Sanderson S. and Uzumeri M. 1994. "Managing Product Families: The Case of the Sony Walkman." *Research Policy* 24:761-82.

Saren M. 1987. "The Role of Strategy in Technological Innovation: A Re-Assessment." *Organization Analysis and Development*, I.L Mangham (Ed.). Chichester: Wiley.

Scarbrough H. 1996. "Knowledge As Work: Conflicts in the Management of Knowledge Workers ." *Technology Analysis & Strategic Management* 11(1):5-16.

Schilling M.A. 1998. "Technological Lockout: An Integrative Model of the Economic and Strategic Factors Driving Technology Success and Failure." *The Academy of Management Review* 23(2):267-84.

Schroeder R. R., ven de Ven A.H., Scudder G.D., and Polley D. 1989. "The Development of Innovation Ideas." Pp. 107-34 in *Research on the Management of Innovation: The Minnesota Studies*, A.H ven de Ven, H.L. Angle, and M.S. Poole (Eds.) . New York: Harper and Row.

Scott J. 1990. *A Matter of Record.* Oxford: Polity Press.

Senge P.M. 1996. "The Leader's New Work: Building Learning Organizations." *How Organizations Learn*, Starkey K. London: International Thompson Business Press.

Slappendel C. 1996. "Perspective on Innovation in Organizations." *Organisation Studies* 17(1):107-27.

Smith J. 2000. "From R & D to Strategic Knowledge Management: Transitions and Challenges for National Laboratories." *R & D Management* 30(4):305-11.

Smith K. 1995. "The Systems Approach to Innovations: Some Policy Implications." in *The Emerging Knowledge Society*. Jahres, Sweden.

Sparrius A. 1994. "You Can't Manage What You Don't Understand." *Project Management Journal* XXV(1):25-37.

Starkey K. 1996. "Executive Tourism: The Dynamics of Strategic Leadership in the MNC." *How Organizations Learn*, Starkey K. London: International Thompson.

Stone R. (Ed.). 1988. *Management of Engineering Projects.* London: MacMillan Education Ltd.

Tal-Or A. 1999. "Joint Assets." *Electronics* 2(1):40-46.

TAMAM Publisher. 1998. *TAMAM's Company Profile*. Israel: TAMAM Publishing Department.

Tayeb M. 1987. "Contingency Theory and Culture: A Study of Matched English and the Indian Manufacturing Firms." *Organization Studies* 8(3):241-61.

Teubal M. 1993. "The Innovation System of Israel: Description Performance and Outstanding Issues." *National Innovation System: A Comparative Analysis*, Nelson R.R. (Ed). Oxford: Oxford University Press.

Thompson J.D. 1967. *Organizations in Action*. New York: McGraw-Hill.

Tidd J., Bessant J., and Pavitt K. 1997. *Managing Innovation: Integrating Technological Market and Organizational Change*. West Sussex: John Wiley & Sons Ltd.

Todd D. 1988. "Defence Industries: A Global Perspective." London: Routledge.

Tsoukas H. 1993. "Analogical Reasoning and Knowledge Generation in Organization Theory." *Organization Studies* 14(3):323-46.

———. 1996. "The Firm As a Distributed Knowledge System: A Constructionist Approach." *Strategic Management Journal* 17(Winter Special Issue):11-25.

Tushman M. and Nadler D. 1996. "Organizing for Innovation." *How Organization Learn*, Starkey K. London: International Thomson Business Press.

Van Aken J.E. and Weggeman M.P. 2000. "Managing Learning in Informal Innovation Networks: Overcoming the Daphne-Dilemma." *R & D Management* 30(2):139-49.

van de Ven A.H. and Poole M.S. 1988. "Paradoxical Requirements for a Theory of Organizational Change." Pp. 19-63 in *Paradox and Transformation: Toward a Theory of Change in Organization and Management*, R.E. Quinn and K.S. (Eds.) Cameron. Cambridge, MA: Ballinger.

Van den Bulte C. and Moenaert R.K. 1998. "The Effects of R & D Team Co-Location on Communication Patterns Among R & D, Marketing, and Manufacturing." *Management Science* 44(11 (2)):S1-S23.

Victor B. and Boyton A.C. 1998. *Invented Here*. Boston, MA: Harvard Business School Press.

Von Hippel E. 1988. *The Sources of Innovation*. N.Y.: Oxford University Press.

Vroom, V. 1964. *Work and Motivation*. New York: John Wiley & Sons, Inc.

Walker W. 1991. "Defence." in *Technology and Future of Europe Global Competition and the Environment in the 90's*, Freeman C., Sharp M., and Walker W. (Eds.) London: Pinter Publishers .

Walton R.E. 1987. *Innovating to Compete*. San Francisco: Jossey-Bass Publisher .

Waterman R.H., Peters T.J., and Philips J.R. 1980. "Structure Is Not Organization." *Business Horizon* 23(6):14-26.

Weick K. and Roberts K. 1993. "Collective Mind in Organizations: Heedful Interrelating on Flight Decks." *Administrative Science Quarterly* 38:357-81.

Wenger E. 1998. *Communities of Practice; Learning, Meaning and Identity*. Cambridge: Cambridge University Press.

Whetten D.A. and Godfrey P.C. 1998. *Identity in Organizations; Building Theory Through Conversations*. London: Sage.

Whittington R. 1993. *What Is Strategy and Does It Matter?* London: International Thonson Business Press.

Williamson O.E. 1991. "Strategizing, Economizing and Economic Organization." *Strategic Management Journal* 12:75-94.

Wolfe R.A. 1994. "Organizational Innovation: Review, Critique and Suggested Research Directions." *Journal of Management Studies* 31(3):405-31.

Womack J., Jones D., and Roos D. 1990. *The Machine That Changed the World.* New York: Rawson Associates.

Wulf H. 1993. "Arms Industry Limited." London: Oxford University Press.

Yin R.K. 1993. *Applications of Case Study Research.* CA, USA: SAGE Publications.

APPENDIX 1

The Context of Cross-Project Learning: Product Development

Themes in Product Development Relating to Cross-Project Learning

Because cross-project learning was introduced in product development and hence affected the way products were produced in the Israeli electronics defence industry, an understanding of the philosophies, theories and methodologies related to product development is needed.

The successful management of product development has become a key challenge for companies competing in today's markets (Clark and Fujimoto 1991; Clark and Wheelwright 1992; 1994; 1995; Tidd, Bessant and Pavitt 1997; Van de Van, Angle and Poole 1989; Rothwell and Zegveld 1982; Utterback 1994). There is an impressive body of literature on the managerial and organisational aspects of new product development. Some studies point to the conclusion that the timely development and introduction of new products requires the maintenance of a flexible organisational structure (Bart 1986), frequent communication (Clark and Fujimoto 1991), the use of multifunctional teams (Cordero 1991), the style of leadership in new product teams (McDonough and Barczak 1991), an interface with customers (Gehani 1998), and the use of control practices (Bart 1993). Nevertheless, these studies and many others provide a rather fragmented picture of processes in, and factors related to, product development.

There are a number of excellent review articles on product development that assist in understanding the debates and opportunities for future research in this specific area (see for example Shocker and Sirinivasan 1979; Whitney 1993; Brown and Eisenhardt 1995; Griffin and Hauser 1996). Here, these articles and others will be reviewed in order to critically assess the literature and identify opportunities for future research.

Product Development as a Rational Plan: An Atheoretical, Disintegrated Approach

Like much of the literature on product development and project management, the rational plan perspective, as the name implies, believes in a careful planning of a product for an attractive market and the execution of that plan by a competent and well-coordinated team that operates with the support of senior management. According to this perspective, the successful product development process depends on three elements: planning, implementation and support. Studies in this stream (for example, the Stanford Innovation Project, which examined 86 success/failure product pairs) reveal the correlation between cross-functional teams and high product development project performance (i.e. revenue and market share). Cross-functional communication, customer involvement and team organisation of work have also been found to have a strong correlation with product development project performance (ibid.:350). In one study by Rothwell and colleagues (1974) 41 factors were found to be correlated with successful product development. Subsequent studies have added more factors related to product development, which make it difficult for both academics and practitioners to identify precise managerial and theoretical implications. Nevertheless, the work in this stream has revealed some important factors that contribute to the understanding of product development in this thesis. For example, Cooper and Kleinschmidt (1987) found a strong correlation between market conditions and product success. They revealed that products that entered growing and large markets were more likely to be successful. Also, products that entered markets with a low intensity of competition were more likely to be successful. And lastly, internal organisation factors such as a clear product concept and pre-development planning were found to be more important than market characteristics.

Recently there has been a growing interest in the aspect of speed in product development as part of the rational plan stream (for example, Cordero 1991; Gupta and Wilemon 1990). Since the beginning of the 1990s, the emphasis on accelerating new product innovation has gained more attention as the costs associated with slow product development have increased (Gupta and Wilemon

1990). For example, McKinsey & Co show that high-tech products that come to market six months late but on budget earn 33% less profit over five years (ibid.:25). Gupta and Wilemon (1990) found that increased competition and market demand were the main drivers in accelerating new product introduction. In terms of the factors leading to delayed product development projects, Gupta and Wilemon found that poor definition of product requirements was the main reason for this situation.

Technological uncertainty during product development is another reason for delays in R & D projects. Such uncertainty has been associated with a number of scenarios. One scenario is when new technology becomes available, leading to last-minute changes in the product because of engineers' desire to incorporate the latest technological improvement (ibid.: 30). Gupta and Wilemon describe this desire as the 'creeping elegance' phenomenon. Another scenario concerns the incompatibility of new technology with in-use product components. A third example is related to the complexity of learning new technologies in a short time. All these scenarios affect the organisation's ability to accelerate product development projects.

To conclude, the literature associated with the rational plan stream is quite impressive in identifying the breadth of factors involved in product development, with its emphasis on features of the product, internal organisation, and the market. The vast majority of the studies associated with this stream emphasise the relations between a few dozen variables in product development. Yet in some cases these clearly do not contribute to the understanding of product development (Brown and Eisenhardt 1995). This is because the results tend to present multivariate relations, which can be confusing and which suggest some vagueness with regard to the practical implications.

Furthermore, the rational stream of study suffers from some methodological weaknesses. In particular, it bases its conclusions on individual informants' quantified subjective judgements on their tasks and associates these with success and failure factors. According to Brown and Eisenhardt (Ibid.: 353), the research results 'are likely to suffer from a host of attributional and other biases, memory lapses, and myopia, which are associated with subjective, retrospective sense-making tasks'.

Lastly, the rational plan stream seems to be atheoretical and fails to take the next logical theory-building step. In particular, many of the studies are not integrated theoretically with existing research, nor do they report nonsignificant findings.

Despite these limitations, the rational plan stream contributes to the understanding of the role of markets in product development and reveals the factors that play a role in successful product development projects.

Results from studies on cross-functional communication confirm that individuals from different departments often understand certain aspects in the process of developing a product in a different manner (Dougherty 1990). In other words, individuals often interpret one specific piece of information, in this case related to product development, in their own way because they have their own perspective on what product development is and what are the main goals and ways to measure success (Krishnan and Ulrich 2001). Cross-functional team communication faces many barriers, and yet research reveals that overcoming these barriers through a 'combined perspective' (Boland et al. 1995; Blackler et al. 1999) improves product development projects. Also, Brown and Eisenhardt (1995: 358) argue that 'cross-functional teams that structure their internal communication around concrete tasks, novel routines, and fluid job descriptions also have been associated with improved internal communication and successful products'.

To conclude, external and internal communications are critical to product development. As we have seen, themes such as politics in product development and the existence of gatekeepers are amongst the major contributions of this stream to the understanding of the process of product development. The importance of combining perspectives when it comes to cross-functional project teams is another area of study that this stream has revealed, and this focus has been further developed by scholars from other schools of thought.

One major limitation of this stream is the extreme focus on communication that scholars employ when studying product development, even though this field involves many other factors, activities and interactions.

Product Development as Disciplined Problem-Solving: The Vagueness Around the Balancing-Act Process

This stream associates success in product development with factors such as the autonomy of the project team, leadership and vision (of the project manager) and (top) management style. Heavily based on case study methodology and originally evolved from studies of Japanese organisations, this stream reveals the importance of suppliers and R & D networks, the diversity of the backgrounds and skill sets of members of the project team, and overlapping development phases (Imai et al. 1985) in accelerating the product development process. In addition, the management style for successful products is expected to be based more on 'subtle control' than a 'supportive' orientation, as previously suggested. Imai and his colleagues (ibid.:357) explain that 'some checks are needed to prevent looseness, ambiguity, tension or conflict from getting out of control' during the course of product development. They argue that management can exercise control through various channels and still maintain 'self organised' teams. Some of the examples of 'subtle control' provided by Imai and his colleagues are: selecting the right people for the project team, monitoring the balance in team membership, adding or removing members, encouraging team members to extract information from customers and competitors, and an evaluation system for the team that encourages multi-learning and supports the formation of self organising teams. Imai and his colleagues also observed a management practice in successful product development projects that aimed to maintain the balance between allowing ambiguity with regard to the autonomy of project teams engaging in problem solving, and enforcing sufficient control over product and technology strategy across projects.

More recent studies (Clark and Fujimoto 1991; Wheelwright and Clark 1998) replicate these findings and confirm the links between communication, cross-functional groups and successful products. Their main contribution is to identify two concepts. First, they stress the role of the 'heavyweight' team leaders who act as a liaison between project teams and senior management, allowing management to exercise 'subtle control' over them. Secondly, 'product integrity' implies 'a clear vision of the product's intended image, performance, and fit with corporate competencies and customers' (Brown and Eisenhardt 1995: 363).

Accelerating product development is another branch in this stream of studies. Eisenhardt and Tabrizi (1995) examined 72 product development projects from 36 firms in Asia, the USA and Europe in order to explore the factors that determine a fast adaptive process. Their work confirms the link between fast product development, multifunctional teams, and the experiential strategy of iteration, testing, milestones, and powerful leaders. They argue that 'fast product development emerges as more uncertain than predictable, more experiential than planned, and more iterative than linear' (ibid.:104). This observation calls for further study of the accelerated product development process in order to provide more insight into the complexity of managing such innovation.

Brown and Eisenhardt (1995: 364) summarise the contribution of this stream as follows: 'successful product development involves relatively autonomous problem solving by cross-functional teams with high communication and the organization of work according to the demands of the development task'. This stream perceives product development as a *balancing act* between product vision developed at the top management level and problem-solving at the project level.

In contrast to the other two streams, this stream focuses on the development process and less on finance-related determinants of product success. Yet one weakness of this stream is its relatively vague definition of the central constructs such as subtle control, product vision and system focus, and of the conditions that maintain the balancing act described above. In addition, the over-reliance on a

Japanese perspective, either through the study of Japanese companies or by adopting Japanese management theories, highlights the need to study R & D-intensive companies from other regions in the world that apply different product development philosophies, in order to build a global body of knowledge on innovations (Collinson 2001).

Product Development: Concluding Remarks

As we have seen, the field of product development is atheoretical and suffers from a disintegrated approach towards theory and methodology. In addition to these shortcomings, research in this field is notable for the fact that some studies contradict others or imply such complex relations between factors that it is impossible to formulate clear and precise conclusions.

Future research is therefore needed. In particular, there is a need to study contemporary organisational structure and its impact on work and processes in product development. Future research also needs to extend the application of a theoretical lens when studying product development processes in order to establish the foundations for theory building in this field. Lastly, product development needs to be studied in new sectors, preferably in emerging countries, in order to extend the body of knowledge on the impact of the local political and social context on product development systems.

APPENDIX 2

List of Interviewees[23]

List of Interviewees: YellowTech (34)

Name	Position	Time (hours)
Avner Raz	President, YellowTech	1
Benny Raguan	Application Engineer	1.5
Danny Be'eri	Software Engineer	1.5
David Vinograd	Project Co-ordinator	1.5
Doron Vered	Manager, Customer Support	2
Dov Granot	Director, Sales and Contracts	1
Dov Valdman	Head of HR department	2
Dvir Lavi	Head of Application Group	1
Eli Bar	Senior Software Engineer	2
Gideon Chen	Head of Hardware Group and Co-researcher	6
Irvine Persky	Head of Software Group	2
Jacob Limor	Chief Scientist and Research Co-ordinator	5
Meir Levental	Head of MIS	2
Meir Michaili	Head of Q & A Group	2
Menachem Oren	Director, R & D Division	1
Naava Dabach	Software Engineer	1.5
Naftali Rubin	Q & A Engineer	1.5
Oded Shacham	System Engineer	2.5
Oved Dabach	Project Manager	1.5
Rafi Kodman	Senior Software Engineer	1.5
Ramy Hazarchi	Director, Future Developments	1
Ronen Dadush	Senior Hardware Technician	2.5
Shelomo Avni	Project Engineer	2
Shula Nicelush	Software Engineer	1.5
Tommy Zusman	Head of Planning and Control	2.5
Udi Baruch	Project Manager	1.5

[23] By alpha-bet order

Name	Position	Time (hours)
Vered Omer	Head of ASIC group	1.5
Yaron Tuvim	Head of Product Configuration Group	1.5
Yechzkel David	Software Engineer	1
Yeftach Gideony	Algorithm/Software Engineer	1.5
Yitzchak Yehushua	Senior Hardware Technician	1.5
Yonny Ives	Senior Hardware Technician	2
Zeev Feldman	System Engineer	1.5
Zeev Vishna	System Engineer	2

List of Interviewees: Rafael (26)

Name	Position	Time (hours)
Amiram Ash	Project Manager Popeye	1
Avi Gazit	Project Manager, Popeye	1.5
Barak Tur	System Engineer	1
Chanoch Gelman	Project Engineer	1
David Pereg	Project Engineer	1
David Sa'ar	Project Engineer	1.5
David Shatmer	Head of Popeye Administration	1.5
David Zeith	Head of Litening Programme	1.5
Eran Moore	Head of Programme	1
Gady Zilberman	Algorithm/Software Engineer	1
Haim Yacobovitz	Programme Manager, Litening	1.5
Israel Greenfeld	Project Manager; Litening	2
Itay Dinnerman	Sales, Manager	1.5
Loret Golan	Planning and Control, Manager	1
Michael Moscovitz	System Engineer	1.5
Mordechai Zimmerman	Project Engineer	1.5
Naama Toker	HR Specialist, Co-researcher	6
Nachum Nechemia	Project Engineer	1.5
Niv Kaplan	Sales Manager	1.5
Ramy Fabian	System Engineer	1
Ruth Berman	Software Engineer	1
Tuvya Ronen	General Manager of Operations and Research Co-ordinator	2.5
Yechzkel Saggy	Project Engineer	1
Yehuda Liabook	System Engineer	1

Name	Position	Time (hours)
Yossi Matalon	Head of HR department	2
Zeev Mitelman	Project Manager, Popeye	1
Ziva Peled	Operations manager	1

List of Interviewees: TAMAM (25)

Name	Position	Time (hours)
Arik Meister	System Engineer, sensors	1
Arik Meltzer	System Engineer	1
Arik Rabin	System Engineer	¾
Arlet Stern	Product Configuration Manager	1
Avi Bar	System Engineer	1.5
Boaaz Bibi	Project Engineer	1
David Livyatan	Senior Hardware Technician	1
Eli Molian	System Engineer	1
Gershon Leshem	Head of Q & A and Research Co-ordinator	6
Meir Mazor	Project Manager	1.5
Mordechai Harari	Logistics, Manager	1
Moshe Benisti	Hardware Technician	¾
Naftali Margalit	Project Manager	1
Dr Nechama Yellin	R & D Manager and Co-researcher	3
Neomi Admony	Product Configuration Manager	1
Shalom Vilk	Software Engineer	1.5
Shelomo Katshh	Operations, Manager	¾
Shelomo Stelreed	Senior Software Engineer	1
Sigalit Noyman	Senior Software Engineer	1.5
Yaron Green	Software Engineer	¾
Yitzchak Barazin	Project Engineer	¾
Yitzchak Moore	Technical Manager	1
Yossi Ritstien	Senior Hardware Technician	¾
Yehuda Katash	Project Engineer	1
Zeev Nachmoni	General Manager, Electronics Division	1

List of Interviewees: The Ministry of Defence (MoD) and Israeli Air Force (IAF) (4)

Name	Position	Time (hours)
Imry Tov	Financial Adviser, MoD	1
Max Sonego	Project Manager, IAF	2
Ronen Wolf	Project Manager, IAF	2
Yitzchak Ben Israel	Head of SIBAT, MoD	1

List of Informants (16)

Name	Affiliation
Anya Eldan	C.E.O., ITS, IAI
Professor Arnan Seginer	Director, Samuel Neaman Institute, Technion, Israel
Dr Edna Pasher	Consultant, Knowledge Management, Hertzelia, Israel
Efraim Valach	Manager, R & D, EL-OP, Israel
Ilan Kuziatin	Consultant, Defence Industries, Israel
Israel Baharav	Pilot, Israeli Air Force (Reserve)
Kobi Abrahami	Knowledge Management Manager, Tower Semiconductor, Migdal, Israel
Meir Bartov	Director, Marketing, YellowTech
Ofir Baharav	Pilot, Israeli Air Force (Reserve)
Rafi Bronstein	Director, Knowledge Management ,Scitex, Hertzelia, Israel
Ramy Bar-Joseph	Director, The Patent Group, Rafael
Ran Herstein	Knowledge Management Manager, Elbit, Israel
Shamay Keidar	Manager, Sales and Contracts, YellowTech
Tzvika Rosen	Former Sales Manager, YellowTech
Yaacov Nuss	Director, Finance, Electronics Group, IAI
Yaacov Zur	Consultant, Defence Industries, Israel

APPENDIX 3

Interview Schedules[24]

Pilot Study: General Description of the Interview Schedule[25]

- Describe the main changes in defence markets in the last 10 years.

- What are the main differences between the way your company competed in the past and the way it competes in the present?

- How did the company re-organise its product development process to cope with recent changes?

Case Study: General Description of the Interview Schedule with R & D personnel

- Describe your role in the company and how you learnt your job

- Describe how the company develops products

- Describe how the company reuses hardware and software components

- Describe the interactions with groups inside and outside the division during the reuse process

- Describe the organisational structure and its contribution to the reuse process

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[24] The interview schedule was translated from Hebrew. The interview schedules are just general guidelines that the researcher followed in order to explore the operations, disturbances and strategy associated with cross-project learning.

[25] The interview schedule slightly varied according to the role of the interviewee in the company.

- Describe the involvement of management in the reuse process
- Describe coordination mechanisms and their contribution to the reuse process
- Describe the culture in the company and its contribution to the reuse process
- Describe positive and negative implications that are directly associated with the reuse process

Case Study: General Description of the Interview Schedule with Non-R & D personnel

- Describe your role in the company and how you learnt your job
- Describe the main activities of your department
- Describe developments and changes in your field/department in the last 10 years
- Describe the impact that your department has had on product development activities