1

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

National Library
of Canada

Acquisitions and
Bibliographic Services Branch

395 Wellington Street
Ottawa, Ontario
K1A 0N4

Bibliothèque nationale
du Canada

Direction des acquisitions et
des services bibliographiques

395, rue Wellington
Ottawa (Ontario)
K1A 0N4

Your file / Votre référence

Our file / Notre référence

NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Reproduction in full or in part of this microform is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30, and subsequent amendments.

AVIS

La qualité de cette microforme dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

La reproduction, même partielle, de cette microforme est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30, et ses amendements subséquents.

Canada

**THE COORDINATION STRUCTURE OF ORGANIZATIONS
PRODUCING DESIGNS OF COMPLEX SYSTEMS**

by

Sean McCluskey, B.Comm. (Honor's)

**A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of**

Masters of Management Studies

School of Business

Carleton University

Ottawa, Ontario

August 1993

© Copyright

1993, Sean McCluskey

National Library
of Canada

Acquisitions and
Bibliographic Services Branch

395 Wellington Street
Ottawa, Ontario
K1A 0N4

Bibliothèque nationale
du Canada

Direction des acquisitions et
des services bibliographiques

395, rue Wellington
Ottawa (Ontario)
K1A 0N4

Your file Votre référence

Your file Votre référence

The author has granted an irrevocable non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of his/her thesis by any means and in any form or format, making this thesis available to interested persons.

L'auteur a accordé une licence irrévocable et non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de sa thèse de quelque manière et sous quelque forme que ce soit pour mettre des exemplaires de cette thèse à la disposition des personnes intéressées.

The author retains ownership of the copyright in his/her thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without his/her permission.

L'auteur conserve la propriété du droit d'auteur qui protège sa thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

ISBN 0-315-89880-1

Canada

Name Sean McCluskey

Dissertation Abstracts International is arranged by broad, general subject categories. Please select the one subject which most nearly describes the content of your dissertation. Enter the corresponding four-digit code in the spaces provided

0710

0710

U·M·I

SUBJECT TERM

SUBJECT CODE

Subject Categories

THE HUMANITIES AND SOCIAL SCIENCES

COMMUNICATIONS AND THE ARTS

Architecture 0729
Art History 0377
Cinema 0900
Dance 0378
Fine Arts 0357
Information Science 0723
Journalism 0391
Library Science 0399
Mass Communications 0708
Music 0413
Speech Communication 0459
Theater 0465

EDUCATION

General 0515
Administration 0514
Adult and Continuing 0516
Agricultural 0517
Art 0273
Bilingual and Multicultural 0282
Business 0688
Community College 0275
Curriculum and Instruction 0727
Early Childhood 0518
Elementary 0524
Finance 0277
Guidance and Counseling 0519
Health 0680
Higher 0745
History of 0520
Home Economics 0278
Industrial 0521
Language and Literature 0279
Mathematics 0280
Music 0522
Philosophy of 0998
Physical 0523

Psychology 0525
Reading 0535
Religious 0527
Sciences 0714
Secondary 0533
Social Sciences 0534
Sociology of 0340
Special 0529
Teacher Training 0530
Technology 0710
Tests and Measurements 0288
Vocational 0747

LANGUAGE, LITERATURE AND LINGUISTICS

Language 0679
General 0289
Ancient 0290
Linguistics 0291
Modern
Literature 0401
General 0294
Classical 0295
Comparative 0297
Medieval 0298
Modern 0316
African 0591
American 0305
Asian 0352
Canadian (English) 0355
Canadian (French) 0593
English 0311
Germanic 0312
Latin American 0315
Middle Eastern 0313
Romance 0314
Slavic and East European

PHILOSOPHY, RELIGION AND THEOLOGY

Philosophy 0422
Religion
General 0318
Biblical Studies 0321
Clergy 0319
History of 0320
Philosophy of 0322
Theology 0469

SOCIAL SCIENCES

American Studies 0323
Anthropology
Archaeology 0324
Cultural 0326
Physical 0327
Business Administration
General 0310
Accounting 0272
Banking 0770
Management 0454
Marketing 0338
Canadian Studies 0385
Economics
General 0501
Agricultural 0503
Commerce Business 0505
Finance 0508
History 0509
Labor 0510
Theory 0511
Folklore 0358
Geography 0366
Gerontology 0351
History
General 0578

Ancient 0579
Medieval 0581
Modern 0582
Black 0328
African 0331
Asia, Australia and Oceania 0332
Canadian 0334
European 0335
Latin American 0336
Middle Eastern 0333
United States 0337
History of Science 0585
Law 0398
Political Science
General 0615
International Law and Relations 0616
Public Administration 0617
Recreation 0814
Social Work 0452
Sociology
General 0626
Criminology and Penology 0627
Demography 0938
Ethnic and Racial Studies 0631
Individual and Family Studies 0628
Industrial and Labor Relations 0629
Public and Social Welfare 0630
Social Structure and Development 0700
Theory and Methods 0344
Transportation 0709
Urban and Regional Planning 0999
Women's Studies 0453

THE SCIENCES AND ENGINEERING

BIOLOGICAL SCIENCES

Agriculture
General 0473
Agronomy 0285
Animal Culture and Nutrition 0475
Animal Pathology 0476
Food Science and Technology 0359
Forestry and Wildlife 0478
Plant Culture 0479
Plant Pathology 0480
Plant Physiology 0817
Range Management 0777
Wood Technology 0746
Biology
General 0306
Anatomy 0287
Biostatistics 0308
Botany 0309
Cell 0379
Ecology 0329
Entomology 0353
Genetics 0369
Limnology 0793
Microbiology 0410
Molecular 0307
Neuroscience 0317
Oceanography 0416
Physiology 0433
Radiation 0821
Veterinary Science 0778
Zoology 0472
Biophysics
General 0786
Medical 0760

EARTH SCIENCES

Biogeochemistry 0425
Geochemistry 0996

Geodesy 0370
Geology 0372
Geophysics 0373
Hydrology 0388
Mineralogy 0411
Paleobotany 0345
Paleoecology 0426
Paleontology 0418
Paleozoology 0985
Palynology 0427
Physical Geography 0368
Physical Oceanography 0415

HEALTH AND ENVIRONMENTAL SCIENCES

Environmental Sciences 0768
Health Sciences
General 0566
Audiology 0300
Chemotherapy 0992
Dentistry 0567
Education 0350
Hospital Management 0769
Human Development 0758
Immunology 0982
Medicine and Surgery 0564
Mental Health 0347
Nursing 0569
Nutrition 0570
Obstetrics and Gynecology 0380
Occupational Health and Therapy 0354
Ophthalmology 0381
Pathology 0571
Pharmacology 0419
Pharmacy 0572
Physical Therapy 0382
Public Health 0573
Radiology 0574
Recreation 0575

Speech Pathology 0460
Toxicology 0383
Home Economics 0386

PHYSICAL SCIENCES

Pure Sciences

Chemistry
General 0485
Agricultural 0749
Analytical 0486
Biochemistry 0487
Inorganic 0488
Nuclear 0738
Organic 0490
Pharmaceutical 0491
Physical 0494
Polymer 0495
Radiation 0754
Mathematics 0405
Physics
General 0605
Acoustics 0986
Astronomy and Astrophysics 0606
Atmospheric Science 0608
Atomic 0748
Electronics and Electricity 0607
Elementary Particles and High Energy 0798
Fluid and Plasma 0759
Molecular 0609
Nuclear 0610
Optics 0752
Radiation 0756
Solid State 0611
Statistics 0463

Applied Sciences

Applied Mechanics 0346
Computer Science 0984

Engineering
General 0537
Aerospace 0538
Agricultural 0539
Automotive 0540
Biomedical 0541
Chemical 0542
Civil 0543
Electronics and Electrical 0544
Heat and Thermodynamics 0348
Hydraulic 0545
Industrial 0546
Marine 0547
Materials Science 0794
Mechanical 0548
Metallurgy 0743
Mining 0551
Nuclear 0552
Packaging 0549
Petroleum 0765
Sanitary and Municipal System Science 0554
Geotechnology 0790
Operations Research 0428
Plastics Technology 0796
Textile Technology 0795

PSYCHOLOGY

General 0621
Behavioral 0384
Clinical 0622
Developmental 0620
Experimental 0623
Industrial 0624
Personality 0625
Physiological 0989
Psychobiology 0349
Psychometrics 0632
Social 0451

**The undersigned recommend to the Faculty of Graduate Studies
and Research acceptance of the thesis**

**THE COORDINATION STRUCTURE OF ORGANIZATIONS
PRODUCING DESIGNS OF COMPLEX SYSTEMS**

**submitted by Sean McCluskey, B.Comm. (Honours)
in partial fulfilment of the requirements for
the degree of Master of Management Studies**

Thesis Supervisor

Director, School of Business

Carleton University

August 30, 1993

ABSTRACT

THE COORDINATION STRUCTURE OF ORGANIZATIONS PRODUCING DESIGNS OF COMPLEX SYSTEMS

Sean McCluskey

The objective of this thesis is to examine the coordination of complex, design-intensive projects at various phases of the new product development cycle. An object based diagrammatic representation approach that focuses on the interdependencies of the actors and objects in the problem domain has been used to examine coordination rather than the prevalent approach of examining the interdependencies between pairs of activities.

Representations of the structure of coordination at four keypoints in the product development cycle are generated from the literature. The structure of coordination in two projects developing designs of complex systems for each keypoint from two large R&D organizations are generated and contrasted with the representations from the literature.

Results of the analysis identify differences in coordination structure across phases in terms of four dimensions: 1. relevant actors; 2. shared objects; 3. underlying configuration of shared objects; and 4. nature of integration.

ACKNOWLEDGEMENTS

I would like to thank the School of Business and the Department of Systems and Computer Engineering for providing the opportunity to do this research. I would also like to express my appreciation to Bell Northern Research and The Charles Stark Draper Laboratory, Inc. for their financial support.

I would also like to express my appreciation to my thesis supervisor, Tony Bailetti, and one of my thesis committee members, John Callahan for their assistance and support throughout this entire effort. I would also like to thank Oscar Hauptman for his input into the thesis.

I am also grateful to Moshe Cohen and Bob Regan for assisting in the logistics of data collection and for providing valuable feedback.

TABLE OF CONTENTS

ACCEPTANCE SHEET	ii
ABSTRACT	iii
ACKNOWLEDGEMENTS	iv
TABLE OF CONTENTS	v
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF APPENDICES	xiii
CHAPTER 1 INTRODUCTION	1
1.1 RESEARCH QUESTIONS	1
1.2 CONTRIBUTION OF THE THESIS TO KNOWLEDGE	5
1.3 THESIS OVERVIEW	5
CHAPTER 2 LITERATURE REVIEW	8
2.1 CONCEPTUALIZATION OF COORDINATION	8
2.1.1 The Organizational Behaviour Perspective	9
2.1.2 An Interdisciplinary Theory of Coordination	14
2.2 CONCEPTUALIZATION OF COORDINATION USED IN THE THESIS	15
2.3 PRODUCT DEVELOPMENT MANAGEMENT LITERATURE	17
2.3.1 Project SAPPHO	17
2.3.2 Project NEWPROD	18
2.3.3 Stanford Innovation Project	21
2.3.4 McTavish (1985)	22
2.3.5 Clark and Fujimoto (1991) and Fujimoto (1989)	23
2.3.6 Nobeoka and Cusumano (1992)	26
2.3.7 Wheelwright and Clark (1992)	28

2.4	DESIGN MANAGEMENT LITERATURE	30
2.4.1	Frischmuth and Allen (1969)	30
2.4.2	Akin (1984)	31
2.4.3	Luckman (1984)	32
2.4.4	Guindon (1990)	34
2.4.5	Philipson (1990)	35
2.4.6	Franke and Purvis (1991)	36
2.4.7	Jain (1991)	37
2.5	COORDINATION IN THE PRODUCT DEVELOPMENT DOMAIN	39
2.5.1	Elements of the Coordination Structure Identified in the Literature	39
2.5.2	Coordination Mechanisms Identified in the Review of the Organizational Behaviour Literature	40
2.5.3	Coordination Mechanisms Identified in the Review of the Product Development Literature	41
CHAPTER 3	KEY ELEMENTS OF THE RESEARCH	44
3.1	REPRESENTATION OF COORDINATION STRUCTURE	44
3.1.1	Visual Formalism	44
3.1.2	Benefits of Diagrammatic Representations	45
3.1.3	Example of an Object Based Representation	47
3.2	PHASES OF NEW PRODUCT DEVELOPMENT	48
3.2.1	Approaches Found in the Literature	49
3.2.2	Approach Used in the Thesis	50
3.2.3	Rationale for Selecting Resource Commitments to Define Phases	52
3.3	PROPOSITIONS	53
3.3.1	Proposition 1	54
3.3.2	Proposition 2	56
3.3.3	Proposition 3	57
3.3.4	Proposition 4	59
CHAPTER 4	RESEARCH DESIGN	62
4.1	RESEARCH METHOD	62

4.2	THE SAMPLE	62
4.2.1	Research Domain	62
4.2.2	Project Selection	63
4.2.3	Time of Data Collection	63
4.2.4	Sampling Unit for the Interviews	63
4.3	DATA COLLECTION AND ANALYSIS PLAN	64
4.3.1	Three Object Based Representations Generated Using Semi-structured Interviews with the Design Manager and Two Other Actors	65
4.3.2	Design Manager Develops the Final Representation of the Project	66
4.3.3	Representations of the Coordination Structures Compared at Each Keypoint with the Propositions	67
4.3.4	Eliciting Managerial Implications of Representing the Coordination Structure of the Project Organization	67
CHAPTER 5	DISCUSSION OF RESULTS	68
5.1	OBJECTIVES AND REPRESENTATIONS OF PROJECTS DEVELOPED BY DESIGN MANAGERS	68
5.1.1	Project 1.1: Hardware Platform	69
5.1.2	Project 1.2: Composites Automated Manufacturing Initiative	70
5.1.3	Project 2.1: German Intelligent Network	72
5.1.4	Project 2.2: Energy Storage Wheel	76
5.1.5	Project 3.1: Advanced Intelligent Networks	78
5.1.6	Project 3.2: Micro-Mechanical Inertial Measurement Unit	80
5.1.7	Project 4.1: Falcon	82
5.1.8	Project 4.2: Interferometric Fiber Optic Gyro	84
5.2	COMPARISON BETWEEN REPRESENTATIONS COMMON TO PROJECTS AT EACH KEYPOINT AND REPRESENTATIONS OF PROPOSITIONS	86
5.2.1	Comparison between the Representation Common to Both Keypoint 1 Projects and the Representation of Proposition 1	86

5.2.2	Comparison between the Representation Common to Both Keypoint 2 Projects and the Representation of Proposition 2	88
5.2.3	Comparison Between the Representation Common to Both Keypoint 3 Projects and the Representation of Proposition 3	90
5.2.4	Comparison Between the Representation Common to Both Keypoint 4 Projects and the Representation of Proposition 4	93
5.3	REASONS FOR DIFFERENCES IN REPRESENTATIONS	94
5.4	DIFFERENCES BETWEEN THE TWO ORGANIZATIONS PARTICIPATING IN THE STUDY	97
CHAPTER 6	ANSWER TO RESEARCH QUESTION AND CONCLUSIONS	99
6.1	DIFFERENCES ACROSS PHASES OF NEW PRODUCT DEVELOPMENT	100
6.2	NEW KNOWLEDGE PROVIDED BY USING OBJECT BASED MODELLING	102
6.3	CONCLUSIONS	104
6.4	LIMITATIONS OF RESEARCH APPROACH	106
6.5	SUGGESTIONS FOR FUTURE RESEARCH	107
REFERENCES		109

LIST OF TABLES

Table	Description	Page
1	Coordination Process Decomposition	15a
2	Actors and Objects in the Propositions	53a
3	Characterization of the Coordination Structure at Four Keypoints	60b
4	Sample Projects at Each Keypoint	63a
5	Objectives of the Projects in the Sample	68a
6	Relation Between the Responsibilities of Actors and Objects in Figure 16 to those in Figures 8, 9A, 9B, and 9C	86b
7	Relation Between the Responsibilities of Actors and Objects in Figure 17 to those in Figures 10A, 10B, and 11	88b
8	Relation Between the Responsibilities of Actors and Objects in Figure 18 to those in Figures 12A, 12B, 12C, and 13	90b
9	Relation Between the Responsibilities of Actors and Objects in Figure 20 to those in Figures 14A, 14B, and 15	93b
10	Characterization of the Coordination Structure of Project Organizations Producing Designs of Complex Systems at Each Keypoint	100a
11	Characterization of the Coordination Structure of Project Organizations Producing Designs of Complex Systems at Each Keypoint	100b

LIST OF FIGURES

Figure	Description	Page
1	Example of an Object Based Representation	47a
2	Phases of New Product Development	50a
3	Proposition 1	55a
4	Proposition 2	56a
5	Proposition 3	58a
6	Proposition 4	60a
7	Outline of Data Collection and Analysis Plan	64a
8	Design Manager's Representation of Project 1.1 Hardware Platform	69a
9A	Design Manager's Representation of Project 1.2 Composites Automated Manufacturing Initiative <u>Internal Module</u>	70a
9B	Design Manager's Representation of Project 1.2 Composites Automated Manufacturing Initiative <u>External Module</u>	70b
9C	Design Manager's Representation of Project 1.1 Composites Automated Manufacturing Initiative <u>Management Module</u>	70c
10A	Design Manager's Representation of Project 2.1 German Intelligent Network <u>Design Module</u>	73a
10B	Design Manager's Representation of Project 2.1 German Intelligent Network <u>Customer Interface Module</u>	74a
11	Design Manager's Representation of Project 2.2 Energy Storage Wheel	76a

LIST OF FIGURES

Figure	Description	Page
12A	Design Manager's Representation of Project 3.1 Advanced Intelligent Network <u>Design Interfaces Module</u>	78a
12B	Design Manager's Representation of Project 3.1 Advanced Intelligent Network <u>Services/Specification Module</u>	78b
12C	Design Manager's Representation of Project 3.1 Advanced Intelligent Network <u>Development Actor Module</u>	78c
13	Design Manager's Representation of Project 3.2 Micro-Mechanical Inertial Measurement Unit	81a
14A	Design Manager's Representation of Project 4.1 Falcon <u>Marketing Module</u>	83a
14B	Design Manager's Representation of Project 4.1 Falcon <u>Development Module</u>	83b
15	Design Manager's Representation of Project 4.2 Interferometric Fiber Optic Gyro	84a
16	Representation Common to Both Keypoint 1 Projects	86a
17	Representation Common to Both Keypoint 2 Projects	88a
18	Representation Common to Both Keypoint 3 Projects	90a
19	Component Validation Structure for the Advanced Intelligent Network Project	91a
20	Representation Common to Both Keypoint 4 Projects	93a

LIST OF FIGURES

Figure	Description	Page
21	Strategic Management Module of International Collaborative Arrangements	103a
22	German Intelligent Network: Strategic Management Module	103b
23	Configuration of Actors Around the Architecture in the German Intelligent Network Project	104a

LIST OF APPENDICES

Appendix	Description	Page
APPENDIX A.1	ACTORS AND OBJECTS IDENTIFIED IN THE LITERATURE	114
A.1.1	Actors Identified in the Product Development Management Literature	114
A.1.2	Objects Identified in the Product Development Management Literature	117
A.1.3	Actors Identified in the Design Management Literature	121
A.1.4	Objects Identified in the Design Management Literature	122
APPENDIX A.2	ACTOR AND OBJECT CLASSES	124
A.2.1	Actors Identified in the Literature	124
A.2.2	Objects Identified in the Literature	128
APPENDIX A.3	CLASS RESPONSIBILITY DICTIONARY	136
APPENDIX A.4	DESCRIPTION OF SAMPLE PROJECTS	140
APPENDIX A.5	DATA COLLECTION AND ANALYSIS PROTOCOLS	144
A.5.1	Protocol for Initial Interviews	144
A.5.2	Iterate Three Representations With Design Manager Protocol	145
A.5.3	Elicitation of Managerial Implications of Object Based Modelling Protocol	146
APPENDIX A.6	OBJECTIVES OF THE PROJECTS IN THE SAMPLE	148
APPENDIX A.7	CLASS RESPONSIBILITY DICTIONARY FOR THE SYNTHESIZED REPRESENTATIONS	152
A.7.1	Hardware Platform Project	152
A.7.2	Composites Automated Manufacturing Initiative Project	153
A.7.3	German Intelligent Network Project	155
A.7.4	Energy Storage Wheel Project	157
A.7.5	Advanced Intelligent Network Project	159
A.7.6	Micro-Mechanical Inertial Measurement Unit Project	161
A.7.7	Falcon Project	163
A.7.8	Interferometric Fiber Optic Gyro Project	165

LIST OF APPENDICES

Appendix	Description	Page
APPENDIX A.8	RESPONSIBILITIES OF OBJECTS AND ACTORS COMMON TO PROJECTS AT VARIOUS KEYPOINTS	167
APPENDIX A.9	DERIVATION OF THE REPRESENTATION OF KEYPOINT 1 PROJECTS FROM FIGURE 16	169

CHAPTER 1

INTRODUCTION

1.1 RESEARCH QUESTIONS

Coordination is an important factor for new product success (Calantone and di Benedetto 1988; Clark and Fujimoto 1991; Cooper 1979; Cooper and Kleinschmidt 1986; Franke and Purvis 1991; Gupta and Wilemon 1990; Gupta, Raj, and Wilemon 1985, 1986; Jain 1991; Lucas and Bush 1988; Maidique and Zirger 1984, 1985; Rothwell et al 1974; Souder 1988; Von Hippel 1988; Wheelwright and Clark 1992; and Zirger and Maidique 1990).

Coordination has been conceptualized as a means of achieving concerted action in situations where interdependencies among different tasks exist (Thompson 1967, 55) or as the act of managing interdependencies between activities (Malone and Crowston 1991, 12). The prevalent approach to the study of coordination is to focus on textual descriptions of the interdependencies between activities or tasks taken two at a time. These activities are assumed to be discrete.

In this thesis, I study coordination in complex development projects by focussing on diagrammatic representations of the interdependencies between the actors and objects that exist in the problem domain rather than on sentential representations of the interdependencies between activities. This approach has been used to examine

coordination in product development and standard setting (Bailetti and Callahan 1992), international technology based collaborative arrangements (Bailetti and Callahan 1993), and custom silicon design projects (Bailetti, Callahan, and DiPietro 1993).

Activity breakdown structures used to manage complex development projects are highly unstable over time. It is difficult to clearly specify ex ante the nature, duration, and interdependencies of activities. In complex projects the sequence of interdependencies between activities cannot be specified before hand because these interdependencies are contingent upon previous activities, many of which cannot be anticipated (Chase and Aquilano 1992, 560; Krajewski and Ritzman 1990, 703). Therefore, focusing solely on interdependencies between activities leads to the development of unstable frameworks to study coordination in the product development domain. It is well known that the formalization of activity based work structures using PERT or CPM models tends to constrain the integration of efforts in the product development domain. I argue that activity based representations of coordination seriously limit the study of coordination in complex development projects.

I argue that explicitly focussing on the interdependencies between actors and objects that exist in the problem domain leads to the development of frameworks for studying coordination that are more stable than those

developed from examining the interdependencies between activities. Objects are more stable than the activities that create, evolve, and discard them. It is easier to identify and manipulate actors and objects as discrete entities than activities.

Object based structures incorporate the effects of past activities. Activity based structures focus solely on the interdependencies that exist at a given time and ignore past interdependencies.

Finally, object based representations enable the development of a system level view of the binding that holds together the network of cooperating actors in terms of the array of objects around which individual and group efforts are coordinated. Activity based representations only allow the development of a series of local views of the relationship between two activities.

The use of object based diagrams grounds coordination in a particular representation of what is being produced and the process and the organization that produces it.

Diagrams preserve explicitly the information about the topological and geometric relations among the components of the problem (Larkin and Simon 1987, 66). This contrasts with the use of sentential representations prevalent in the literature. In sentential representations the data structure or functional units "are indexed by position in a list, with each element 'adjacent' only to the next element in the list"

(ibid, 98). Diagrammatical representations preserve the complexity of the relationships and provide a means to define complex coordination problems and generate their solutions in ways that could not be achieved using sentential representations of coordination.

The specific research questions addressed in this thesis are:

1. What are the differences across phases of product development in coordination structures of project organizations that produce designs of complex systems?
2. What new knowledge is provided by using object based modelling in the above context?

For the purposes of this thesis, coordination structure is defined as the configuration of associations between a meaningful collection of actors that collaborate by creating, modifying, and using an array of shared objects to plan and implement a complex system design (Bailetti & Callahan 1992, 5; 1993).

A project organization that produces complex system designs is a network of individuals that produce and use a design of a system and the design objects around which they coordinate their efforts.

A design object is an object recognizable in the product development domain that contains a portion or all of the information required to realize a complex design.

An object refers to an entity, concept, abstraction, or thing with crisp boundaries recognizable in a given problem domain that channels actors with different viewpoints to cooperate in distributed problem solving situations (Booch 1991, Rumbaugh et al 1991).

A complex system design refers to the objects which embody the design of a system comprised of components from various implementation domains.

1.2 CONTRIBUTION OF THE THESIS TO KNOWLEDGE

This thesis contributes to the literature and to management practice in three ways. First, the thesis characterizes the differences in coordination structure across four distinct keypoints in the product development cycle. Second, the thesis develops an approach for the capture, specification, validation, and synthesis of object based representations. Third, this thesis provides an approach to design alternate mechanisms to coordinate.

1.3 THESIS OVERVIEW

Chapter 2 provides a review of the literature. In section 2.1 the conceptualization of coordination in the literature is discussed. Section 2.2 describes the elements of coordination theory around which the analysis of the literature is anchored. Sections 2.3 and 2.4 provide a review of the product development management and the design management literature respectively. Section 2.5 summarizes the key findings from the literature review.

Chapter 3 provides the rationale for three key elements of the research undertaken in the thesis. Section 3.1 is an overview of the object based diagrammatical approach used to represent the coordination structure of a design system. Section 3.2 identifies the phases in new product development selected for this research and justifies the approach used to identify the end of one phase and the beginning of the next. In section 3.3, I build on the literature to generate propositions of the coordination structures that I expect exist at four keypoints of the product development cycle.

Chapter 4 provides the details of the research design used in this thesis. This chapter describes the research method (section 4.1), the sample (section 4.2), and the data collection and analysis plan (section 4.3).

Chapter 5 discusses the results of the research. In section 5.1, I discuss the objectives and the representations of the projects developed by the design managers. In section 5.2, I compare the representations common to the projects at each keypoint and the representations of the propositions. In section 5.3 and 5.4 I identify six reasons for the differences in the representations provided by the respondents and I discuss the differences between the responses of the two organizations participating in this research.

Chapter 6 provides the answers to the research questions and the conclusions. In section 6.1 and 6.2 I answer the first and second research questions. In section 6.3, 6.4, and

6.5 I discuss the conclusions of the thesis, the limitations of the research, and the suggestions for further research.

CHAPTER 2

LITERATURE REVIEW

This chapter first examines what is meant by coordination in the organizational behaviour literature and in recent studies on coordination theory. In section 2.2 I specify the perspective on "what are the elements of coordination" that is used in this thesis. The next two sections are a review of the relevant literature. Section 2.5 provides an inventory of the actors and shared objects identified in studies on product development management and design management and an inventory of the different coordination mechanisms identified in the literature on organizational behaviour and on product development.

2.1 CONCEPTUALIZATION OF COORDINATION

Coordination is critical to product development success (Calantone and di Benedetto 1988; Clark and Fujimoto 1991; Cooper 1979; Cooper and Kleinschmidt 1986; Franke and Purvis 1991; Gupta and Wilemon 1990; Gupta Raj and Wilemon 1985, 1986; Jain 1991; Lucas and Bush 1988; Maidique and Zirger 1984, 1985; Rothwell et al 1974; Souder 1988; Von Hippel 1988; Wheelwright and Clark 1992; and Zirger and Maidique 1990). This section examines what is meant by coordination and the basic mechanisms used to coordinate.

Coordination can be examined in two ways. The first conceptualizes coordination as a single interdependent relationship between two activities or tasks. This view is

the one that is prevalent in the organizational behaviour literature. Efforts to create an interdisciplinary theory of coordination led to the second view of coordination. It conceptualizes coordination as being comprised of four distinct layers of generic sub-processes.

2.1.1 The Organizational Behaviour Perspective

Thompson (1967) conceptualized coordination as a means of achieving concerted action in situations where interdependencies among differing tasks exist. Thompson identified three different types of interdependencies: i. pooled ("each renders a discrete part to the whole and each is supported by the whole"), ii. sequential (outputs for one part become inputs for the other), and iii. reciprocal ("outputs for each become inputs for the other") (Thompson 1967, 54).

Thompson identified three base mechanisms of coordination: i. rules or routines which constrain the actions of units, ii. schedules and plans for interdependent units to govern their actions, and iii. mutual adjustments during the process of action (ibid, 56). Each successive mechanism represents heavier burdens on communication and decisions. Thompson noted that each of these coordination mechanisms parallels each of the respective interdependencies listed above.

Galbraith (1973) provided an analytical framework for the design of organizations. The author viewed organizations as an information processing system. The need for coordination

results from the presence of interdependent tasks and task uncertainty. Interdependent tasks result from the partitioning of organizational activities into subtasks. Task uncertainty is defined as "the difference between the amount of information required to perform the task and the amount of information already possessed by the organization." (Galbraith 1973, 5).

Galbraith identified three mechanisms that can be used to coordinate interdependent tasks: i. specify the necessary behaviours in rules or have them programmed into tasks, ii. develop an organizational hierarchy "to handle information collection and decision making tasks necessitated by uncertainty." (ibid, 11), and iii. establish targets for the interdependent groups to achieve and let them determine behaviours appropriate to the target (ibid, 10-12).

The organizational hierarchy is a resolution mechanism used in organizations to handle exceptions of task problems. As the frequency of exceptions of task problems increases the size of the hierarchy increases until it becomes overloaded (ibid, 14-15). To solve this problem requires different organizational designs to either reduce the need for information processing or increase information processing capacity. Two solutions for each of these have been suggested. The need for information processing can be reduced by: i. investing greater resources to reduce the number of task exceptions and ii. creating self contained task groups

with all the necessary resources to produce a particular output. Information processing capacity can be increased by:

- i. creating mechanisms which allow the organization "to process information acquired during task performance without overloading hierarchical communications channels" (ibid, 17)
- and ii. creating lateral relations in interdependent decision processes.

Van de Ven, Delbecq, and Koenig (1976) examine variations and interactions between different coordination mechanisms. These are explained by task uncertainty, interdependence, and unit size. The authors define coordination as "integrating or linking together different parts of an organization to accomplish a collective set of tasks." (Van de Ven, Delbecq, and Koenig 1976, 322).

They identify three modes for classifying coordination mechanisms: i. impersonal coordination mode which uses mechanisms such as rules, plans, schedules, ii. personal mode in which plans and mutual task adjustments are made at the personal level "through either horizontal or vertical channels of communication" , and iii. group mode, in which the plans and mutual adjustment "mechanisms (are) vested in a group of role occupants through scheduled or unscheduled meetings." (ibid, 323).

The authors identified the following relationships between task uncertainty, interdependence, unit size, and each of the coordination modes. As task uncertainty increases, the

use of impersonal modes of coordination decreases and the use of personal and group modes increases. As task interdependence among unit members increases, from pooled to reciprocal interdependence identified in Thompson (1967), the use of personal and impersonal modes of coordination remains invariant and the use of group modes increases. An increase in work unit size results in a significant increase in the use of impersonal modes, an increase in personal modes, and a decrease in group modes of coordination.

Mintzberg (1989, 100) noted that an organized activity is complex as a result of two fundamental and opposing requirements, the division of labour into tasks and the coordination of these tasks to accomplish the activity. In complex system design, participants direct their activities towards the production of objects. These objects embody the design of the product. As a result of the necessity to divide up activities for the sake of efficiency, tasks are interdependent. For example, to generate a circuit design requires that tasks be partitioned between designers and test developers in order to leverage the skills that each group acquires from specialization. However, this type of specialization creates interdependencies because the design of the circuit determines the test strategy and the test strategy can alter the design.

Mintzberg (1989) identified six fundamental mechanisms to coordinate tasks: i. informal communication or mutual

adjustment, ii. direct supervision, iii. standardization of work processes, iv. standardization of outputs, v. standardization of skills and knowledge through training, and vi. standardization of norms or beliefs. These mechanisms could be "considered the most basic element of structure, the glue that holds organizations together." (Mintzberg 1989, 101). These mechanisms are used in various forms in the design of organizations.

Nadler and Tushman (1992) studied specific types of coordination mechanisms which provided adequate structures, procedures, and information flows to deal with information requirements resulting from task-related interdependencies. The authors outlined specific coordination mechanisms to link the efforts of organizational groups. These actors and roles which would make up the basis for the coordination structure, included: i. a management role created by developing hierarchical structural linkages which distribute power and authority to the manager through which subordinates can coordinate, ii. a liaison role in which individuals are responsible for coordinating between units, iii. a cross unit group which is made of task relevant representatives focusing on a particular market, client, problem, or issue, iv. an integrator role in which an individual is responsible for helping multiple-work groups accomplish a joint task from a management perspective, and v. a matrix structure in which power is balanced between dimensions of the organization, and

systems and roles for achieving multiple objectives are established (Nadler and Tushman 1992, 137-148).

Nadler and Tushman identified the impact of the use of particular coordination mechanisms on cost, dependence on the informal organization, and information processing capacity. The cost of coordination successively increased from hierarchy, liaison roles, cross-unit groups, integrator, to matrix organization mechanisms. This relationship was also true for the dependence on a healthy informal organization which could deal with the complexities and conflict introduced as coordination mechanism complexity increased. The information processing capacity of the coordination mechanisms also progressed from low to high in the same manner. As decisions were pushed down into the organization through integrator roles, matrix structures, and cross unit groups, the amount of information which could be processed increased.

2.1.2 An Interdisciplinary Theory of Coordination

Malone and Crowston (1990, 1991) characterize a new research domain referred to as an interdisciplinary theory of coordination. The authors defined coordination as "the act of managing interdependencies between activities." (Malone and Crowston 1991, 12). Their coordination theory builds on the literature from organizational behaviour, economics, operations research, computer science, and biology (Malone and Crowston 1990, 1991). From this synthesis, the authors generated the four layered representation of coordination,

shown in Table 1. For each layer, Table 1 identifies its components and provides examples of generic sub-processes.

The top layer of coordination characterizes processes in which goals are identified, activities are ordered and assigned to actors, resources are allocated, and activities are synchronized. The ability to achieve these ends is dependent upon group decision making. Group decision making refers to "the process by which a group of actors choose a consistent set of alternatives." (Malone and Crowston 1991, 17).

In order for group decision making to occur there must be communication. Communication includes the establishment of common languages, information routing, and information delivery (ibid, 17-18).

Ultimately, "the ability of actors to communicate or work together at all depends on their ability to perceive the same things" (ibid, 18). The base layer of Malone and Crowston's representation of coordination is denoted perception of common objects. The perception of common objects, both physical and conceptual, provides a common basis for communication between actors.

2.2 CONCEPTUALIZATION OF COORDINATION USED IN THE THESIS

The efforts of actors conceptualizing and developing complex designs for systems are channelled around the production of abstract objects (e.g., product concept, product specification, test strategy, integration strategy) and

Table 1
Layered Representation of the Processes Underlying Coordination

Process Layer	Components	Examples of Generic Processes
Coordination	goals, activities, actors, resources, interdependencies	identifying goals, ordering activities, assigning activities to actors, allocating resources, synchronising activities
Group Decision Making	goals, actors, alternatives, evaluations, choices	proposing alternatives, evaluating alternatives, making choices (e.g., by authority, consensus, or voting)
Communication	senders, receivers, messages, languages	establishing common languages, selecting receiver (routing), transporting message (delivering)
Perceptions of Common Objects	actors, objects	seeing same physical objects, access to shared databases

SOURCE: Malone, T.W. and K. Crowston. Toward an Interdisciplinary Theory of Coordination. Technical Report # 120. Center for Coordination Science, M.I.T., Massachusetts. p. 16, Table 2.

concrete objects (e.g., circuit boards, integrated circuits, mechanical components, and software). These efforts are linked by many activity-based and always-changing interdependencies.

The conceptualization of coordination as a mechanism to manage a single interdependent relationship between two activities is limited and cannot be used to examine the product development domain which is characterized by many complex interdependencies that change over time.

Malone and Crowston's (1990, 1991) layered representation of coordination enables the creation of a system level view of the configuration of all interdependent relationships among the two elements of the base layer: actors and objects. It is the foundation upon which the upper layers of coordination are built.

This thesis examines the system level view of the base layer conceptualized by Malone and Crowston. I refer to it as coordination structure. A system level view of the base layer, or the coordination structure, provides a common vocabulary with which to understand and communicate the interdependencies that exist in an organization that produces complex designs.

The objective of the literature presented in the next two sections is to build an inventory of the actors and shared objects that have been identified for the product development domain in the product development management literature and

the design management literature.

2.3 PRODUCT DEVELOPMENT MANAGEMENT LITERATURE

The studies to be reviewed include: i. project SAPPHO (Rothwell et al 1974), ii. project NEWPROD (Cooper 1979), iii. the Stanford Innovation Project (Maidique and Zirger 1984, 1985; Zirger and Maidique 1990), iv. McTavish (1985), v. Clark and Fujimoto (1991) and Fujimoto (1989), vi. Nobeoka and Cusumano (1992), and vii. Wheelwright and Clark (1992).

For each of the empirical studies, the review will: i. outline the objectives and the research method; ii. review the main findings of the research; and iii. identify the elements of the base layer of coordination. For conceptual works, the objective of the research and the major insights the author provides from the research will be identified. This will be followed by an identification of the elements of the base layer of coordination that were included in the research.

2.3.1 Project SAPPHO

The objective of project SAPPHO was to discover differences between successful and unsuccessful innovations (Rothwell et al 1974, 258). In project SAPPHO phase II, 43 pairs of technological innovations were investigated, 22 in chemical processes and 21 in scientific instruments. Successes and failures were compared on ten index variables generated from 122 measures. For each success/failure pair, the researchers identified whether the measure for the successful innovation was greater than, equal to, or less than

the measure for the failed innovation.

The results of SAPPHO phase II, identified a number of success factors pertaining to characteristics of the firm, the innovation, and the executive in charge. Relating specifically to coordination, 69.8% of the pairs had the communications factor rated greater in successes than in failures. The communication factors included: better coupling with the external scientific and technical community, benefit from dependence on outside technology, better external communication, and better internal communication. The communications variable was rated fourth overall as determining project outcome.

The SAPPHO results identified three actors which are outlined in Appendix A.1.1. The objects identified from the SAPPHO results are listed in Appendix A.1.2. The results from SAPPHO indicate the need for coordination with external actors, in particular the user and external sources of technology, and effective internal communication (ibid).

2.3.2 Project NEWPROD

The objective of project NEWPROD was to identify the factors that discriminate successful from unsuccessful products. Project NEWPROD was divided into three phases. Phase I (Cooper 1979) examined 195 projects (102 successes and 93 failures) from 103 active industrial product producers in Ontario and Quebec. The research was directed towards the identification of product characteristics, nature of the

information acquired, proficiency of activities performed, nature of the marketplace, resource base of the firm, and nature of the project for product development, that discriminates successful from unsuccessful projects. Respondents for Phase II consisted of 123 firms and 252 new product case histories. Cooper and Kleinschmidt (1986) directed the focus of phase II to the performance and proficiency of particular activities. In NEWPROD phase III, Cooper's (1990) research focussed on quality of execution and resources invested in particular activities. Respondents included 125 industrial product firms and a retrospective analysis of 203 new product projects.

Phase I of project NEWPROD identified three key factors for new product success: i. product uniqueness and superiority, ii. market knowledge and proficiency of marketing activities, and iii. technical and production synergy and proficiencies (Cooper 1979, 100-101). Three barriers to success were also identified: i. "having a high-priced product relative to competition, ii. being in a dynamic market (with many new product introductions), and iii. being in a competitive market, where customers are already well satisfied." (ibid, 101).

NEWPROD phase II identified activities which were critical for product development. These included: initial screening, preliminary market assessment, business financial analysis, product development, in-house product tests, and

market launch. Product development and market launch were identified as needing improvement in coordination. Initial screening, a group decision making process in 71.1% of the respondent firms, had the lowest proficiency rating. Suggested improvements were better market assessment and more formal and consistent procedures (Cooper and Kleinschmidt 1986, 77).

Seven critical lessons were generated from NEWPROD phase III. The first two lessons reiterated the conclusions from phase I, that unique superior products and a market orientation were critical for product development success. The third lesson identified pre-development activities as vital to product development success. "The quality of the execution of the pre-development steps was closely tied to the product's financial performance." (Cooper 1990, 30).

In the fourth lesson, Cooper (1990, 30) noted that "early product definition improves the odds of winning, . . . (because) the definition serves as a communication tool and guide. All party agreement means that each functional area involved in the project has a clear and consistent definition of what the product and project are."

The fifth lesson was that "new product success is controllable" by the people involved in the projects (ibid, 31). In the sixth lesson Cooper notes that there is no simplistic solution to new product success. Finally, in the seventh lesson, the author noted that implementing a formal

product development process can address problems within new product development, thereby leading to success.

In identifying particular success factors, Cooper (1979, 1990) and Cooper and Kleinschmidt (1986) identify actors and objects within the product development domain. Each of these have particular attributes which are discriminants of success and failure. Actors and Objects identified from the NEWPROD research are outlined in Appendix A.1.

Two insights relevant to the thesis were generated: i. there is a need for improvement in the coordination between product development and market launch and ii. a common perception of the product definition object early in the project is strongly related to success.

2.3.3 Stanford Innovation Project

The objective of the Stanford Innovation Project (Maidique and Zirger 1984, 194) was to fill in the gaps of the previous success/failure literature in identifying characteristics of successful product development projects. The project had three phases. Phase I involved a survey administered to 120 respondents from electronics firms (ibid, 194). Phase II was anchored around a detailed questionnaire which 59 respondents completed. Phase III was an in-depth case study of 40 of the companies that responded to Phases I and II (Maidique and Zirger 1985). In later research, Zirger and Maidique (1990) tested a model of product development that incorporated the findings from the earlier research. The

sample consisted of pairs of successes and failures, in total 172 electronics products.

Results from the Stanford Innovation Project identified particular characteristics relating positively to product success and negatively to product failure. These include: i. R&D competence and management, ii. marketing and manufacturing competence and coordination, iii. a product providing significant value to the customer, iv. a technically superior product, v. products that build upon the firm's existing market, technology, and product competencies, vi. weak competitive environments, and vii. markets that are large and growing.

In discussing the results, Zirger and Maidique (1990) noted that communication and coordination between marketing, production, and engineering/R&D is critical for success. The actors and objects identified by Zirger and Maidique are outlined in Appendix A.1. Zirger and Maidique's research results reinforce findings from NEWPROD and SAPPHO that interfunctional coordination is important for success.

2.3.4 McTavish (1985)

The objective of McTavish (1985, 30) was to illustrate "the practical problems faced by companies in organizing new product activity." Five case studies based on in-depth, repeated, direct interviews with executives involved in product development and senior management representatives were used. The results indicated the extent of the use of formal

coordinating groups and responsibilities for various tasks throughout the product development process within each of the organizations.

McTavish identified three implications from his research. First, organizations need a contingency approach to organizing product development: organization structure should be largely dependent upon the nature of new product opportunities. Second, management needs to have a willingness and an ability to change. Third, management's ability "to foster and manage change . . . emerges as centrally important to successful new product development." (McTavish 1985, 41).

McTavish characterized the product development organization structure of five organizations. The characterization identified actors and objects which are outlined in Appendix A.1.

McTavish's research results provide two insights relevant to this thesis. First, it highlights the notion that the success of a particular coordination structure within an organization is dependent upon the business opportunity being addressed. Second, management support for a project and for change is identified as centrally important for new product success.

2.3.5 Clark and Fujimoto (1991) and Fujimoto (1989)

The objective of Fujimoto's (1989) thesis and the book by Clark and Fujimoto (1991) was to identify the ". . . organization patterns of product development, both in process

and structure, (that) contribute to higher effectiveness of product development" in the automobile industry (Fujimoto 1989, 1). This study examined 29 product development projects within 22 automobile manufacturers from the U.S.A., Japan, and Western Europe using questionnaires and in-depth interviews. Data was collected at three levels: company, new product organization, and project.

Product development was characterized as an information processing system made up of a "bundle of information chains, each of which consists of information assets of different degrees of completeness at a given time" (ibid, 101).

Two critical elements for this information processing system are the maintenance of internal and external integrity. Internal integrity refers to the "consistency among the information assets (or objects) created within a producer", external integrity is the "matching between each information asset on the producer side and expectations on the consumer side." (ibid, 100).

Clark and Fujimoto's characterization of product development identified particular actors outlined in Appendix A.1.1, under the title: Clark and Fujimoto's information processing framework. Objects are identified in a similar fashion in Appendix A.1.2.

Clark and Fujimoto classified the product development process of automobiles into four phases. The first, concept generation is the process of moving a group of actors from

engaging in individual cognitive processes around their perspective of the concept to the translation of customer feedback, top management directive, and information on available technologies into a "producer's plan for satisfying the needs of the customer." (ibid, 602). The second phase, product planning, involves the translation of the product concept into "product targets, specifications, styling, layout, and major component choices." (ibid, 664). The third phase, product engineering, involves detailed product design, and fabrication and testing of the prototype. (ibid, 711). The final phase, process engineering, refers to the design and development of the manufacturing processes (ibid, 800). The actors and objects from each phase are outlined in Appendix A.1.

In identifying conclusions and insights from the research, Clark and Fujimoto noted that a heavyweight product manager was better at maintaining internal and external integration (see also Womack, Jones, and Roos 1990). This is a result of the integration of the information assets under one control, the heavy weight product manager.

A second insight Clark and Fujimoto provided was the recommendation of manufacturing for design. Manufacturing for design directs its focus at the point where product and process activities come together. Manufacturing for design involves product designers importing the manufacturing principles to improve operations, the nature of prototyping

changing from a test of the design to "a rehearsal of the production process", and creating an outstanding capability in the manufacture of tools and dies. Manufacturing for design provides "faster, more efficient product development." (Clark and Fujimoto 1991, 345).

The critical insights from Clark and Fujimoto relevant to this thesis are the identification of a strong project oriented structure as a means of coordinating functional units. Placing the authority in the hands of a strong project manager provides a means of ensuring that product development, production, and marketing jointly and cumulatively create consistent information assets that match existing and future customer expectations (Fujimoto 1989, 99). Second, this research identifies actors and objects within each phase and provides a greater level of detail than the previous research. Finally, differences exist between the expected actors and objects identified in the information processing framework and the actors and objects identified in the results.

2.3.6 Nobeoka and Cusumano (1992)

The objective of Nobeoka and Cusumano's study (1992, 4) was to "explore product development strategy and organization for multiple projects within the firm." Twenty-one automotive manufacturers: seven Japanese, three U.S., and eleven European producers provided responses on 223 new car products introduced between 1980 and 1990.

Nobeoka and Cusumano identified four different types of

inter-project strategies, which were characterised on two dimensions: the extent of changes of the design and sources of the base design of the product. The four different strategies included: i. developing a new base design, ii. concurrent transfer of the base design to another project prior to completion of design engineering, iii. sequential transfer of the base design to another project once development is completed, and iv. modification of a direct predecessor product. The authors noted from the responses that "high performers utilized concurrent transfer strategy more than the other firms" (ibid, 13). The actors and objects from a concurrent inter-project strategy are identified in Appendix A.1.

Nobeoka and Cusumano's (1992, 16) research also established the relationship between project and functional coordination and performance when inter-project interaction was and was not present. The results indicated that in projects where inter-project interaction was present, respondents perceptions of meeting schedules and costs, design quality, and matching of user needs were correlated with project and functional coordination. In projects where no inter-project interaction was present, schedule/cost performance was correlated with project coordination and design quality with functional coordination.

The actors and objects involved in inter-project interaction are outlined in Appendix A.1.1 and A.1.2

respectively.

The critical insight from Nobeoka and Cusumano was that coordination between functions and between projects occurs within a product development organization. Functional coordination is associated with the perception of higher design quality, project coordination is associated with the perception of meeting cost and time schedules.

2.3.7 Wheelwright and Clark (1992)

The objective of Wheelwright and Clark's book (1992, 25) was to "lay out concepts for the effective organization and management of product and process development." A number of issues in the area of product development were addressed both at the organizational and project level. Particular attention was paid to the concept of cross-functional integration. Within a product development organization effective action is required from each functional unit: engineering, marketing, and manufacturing, to develop a new product or process. Great products and processes are achieved when functional activities fit together and reinforce each other (Wheelwright and Clark 1992, 165).

The activities of the various functional units provide a development capability which is a tremendous source of competitive advantage. Wheelwright and Clark noted that this capability is not static. In their conclusions they identified four independent approaches to building this development capability: i. create a new product development

strategy, ii. change the development process, iii. create building block skills and tools in critical activities, and iv. perform a demonstration project to address competitive opportunities/threats and to demonstrate a new product development process within the organization.

Wheelwright and Clark developed cross functional integration between functional units using a five phase model of product development: concept development, product planning, detailed design and development, commercial preparation, and market introduction. Within this phase model particular actors and objects are identified. Actors and objects in each of the five phases are identified in Appendix A.1. Wheelwright and Clark provided the most complete characterization of the coordination structure of product development among those studied. However, their representation was not based upon empirical data.

The authors generated two insights relevant to this thesis. First, Wheelwright and Clark noted that cross-functional integration could be achieved through integrated problem solving. Actors coordinate around a problem, its representation, or an object which embodies the problem. The richness, frequency, direction, and timing of the communication around this problem will be critical for success. Second, upstream-downstream interaction of actors allows downstream actors to get a jump on their work and it allows upstream actors to take into account downstream

parameters and constraints in their upstream activities.

2.4 DESIGN MANAGEMENT LITERATURE

The design management literature examined in this research is comprised of studies that: i. model the design process and ii. examine hardware and software system design. The literature which will be reviewed includes: i. Frischmuth and Allen (1969), ii. Akin (1984), iii. Luckman (1984), iv. Guindon (1990), v. Philipson (1990), vi. Franke and Purvis (1991), and vii. Jain (1991).

2.4.1 Frischmuth and Allen (1969)

The objective of Frischmuth and Allen's research was to generate a model of technical problem solving as a means of assisting management in "improving the organizational support of the process, and in so doing, increase the effectiveness of total R&D" (Frischmuth and Allen 1969, 58). Tape recorded weekly protocols from three engineers working on the same problem in parallel R&D projects were used. Each of the projects were from three different firms who had been awarded the same contract to study the development of the same system. Contracts had six month durations.

The research methodology was directed at collecting detailed descriptions of the engineers decision making processes. This model involves the identification of critical dimensions, the generation of alternative solutions, prioritization of critical dimensions and comparison of alternative solutions, and final investigation. Actors and

objects identified in the process model are outlined in Appendix A.1.3 and A.1.4 respectively.

Frischmuth and Allen's technical problem solving conceptualization coordinates actors around the creation, analysis, or distribution of information. Central to this process is the problem solver who collects and analyzes information to generate and evaluate solutions.

2.4.2 Akin (1984)

The objective of Akin's study was to disaggregate the process of design and to better develop its 'intuitive' aspects (Akin 1984, 189). Protocol analysis of a designer in laboratory conditions designing a home was used to achieve the objectives.

Akin (1984, 191) views the process of design as consisting of a series of operations which transform "a given state of information about the problem into another state such that the second state is closer to containing the information that describes a solution to the problem than the first one." The operations and their respective input and output when generalized are termed schemata. Akin identified eight schemata which characterize the design process of the respondents: instantiation, generalization, enquiry, inference, representation, goal-definition, specification, and integration.

Akin splits the design process into two phases. First, pre-sketching involves mostly the schemata of enquiry,

instantiation, and inference. This phase involves acquiring and assimilating external information to generate a representation of the problem context.

The second phase is sketching. This phase involves mostly the schemata of specification, integration, and inquiry. This phase represents a search cycle to identify solutions. The actors and objects within each of these phases is outlined in Appendix A.1.

Akin's research provides insight about the process of design itself. Akin's concept of symbols represents a lower level conceptualization of design. The symbols represent particular pieces of information within objects such as the problem documents or problem representation. Encountering particular information results in a certain response or performance of a particular schemata. In interdependent activities, such as complex design, the creation and search for new symbol relations and solutions increases in complexity as a result of the shared understanding which must be created amongst the various participants.

2.4.3 Luckman (1984)

The objective in Luckman's research was to present simple representations of the design process (Luckman 1984, 84). Luckman used a case study as a means of comparing his concepts of design against 'regular' design activities. From this research, Luckman provides a representation of the process of design and a technique for representing the dependence of

components in architecture.

Luckman represents the generic structure of the process of design as three stages which take place at different levels of the decision process. Each level represents the analysis of information and the synthesis and evaluation of a potential solution. Within this model particular actors and objects are identified. These are outlined in Appendix A.1.

Luckman noted that the process of design involved a series of interdependent decisions. The decisions could be viewed as component selections. Complexity of these decisions results from the component alternatives and their interdependencies. Luckman proposed that a design group should coordinate these decisions together through decision graphs and options graphs. Decision graphs illustrate "the principle decisions and their probable dependence pattern" (ibid, 92). Option graphs illustrate the technical options and their probable dependence patterns. The major benefit of these techniques is that once a particular interdependence is represented it can be reused in future applications with similar subcomponent alternatives.

Luckman's research clearly identifies the interdependent decisions that exist in system design. Alternative solutions within one aspect of the design preclude other alternatives within another aspect of design. Luckman uses option and decision graphs as a means of representing these interdependencies. However, Luckman (1984, 96) notes that a

comprehensive map of the total set of decisions is a formidable task. The application of these concepts in complex system design involving hardware and software components would prove even more difficult.

2.4.4 Guindon (1990)

The objective of Guindon's research is to examine the applicability of top-down decomposition in the early stages of software design (Guindon 1990, 305). Protocol analysis of the process of designing a software system "of realistic complexity" (ibid, 305) was examined from three respondents.

Guindon (1990, 321) found that opportunistic solution development is prevalent in the early stages of software design. The main causes included: "the immediate recognition of a partial solution in another part of the problem, immediate handling of inferred or added requirements, drifting through partial solutions, and interleaving problem specification with solution development" (ibid, 327). The deviation from top-down decomposition is attributed to the "intrinsic features of design problems: incomplete specification of the problem, lack of a predetermined solution path, and integration of multiple sources of knowledge" (ibid, 342).

The insights derived from the Guindon article are twofold. First, it provides a description of the software design process identifying particular common objects. Actors and objects are outlined in Appendix A.1.

Second, it illustrates that the objects embodying the problem definition and the solution are interdependent (Roozenburg and Cross 1991) and developed opportunistically.

2.4.5 Philipson (1990)

The objective of Philipson's study was to identify a technique for the design of complex hardware/software systems to improve time to market and quality (Philipson 1990, 714). His technique was based on observations of system design projects at Lund University. The research followed no formal method.

Philipson's motivation for creating a new method of complex systems design is to improve the speed and correctness of the design process. The author notes that in complex system design there is an unlimited complexity of the design space. Optimal solutions are made by making trade-offs in "algorithms, system structure, hardware/software partitioning, and implementation technology" amongst others (ibid, 714).

To determine an optimal solution requires the exploration of alternative configurations. Philipson's technique focusses on the functional modelling of different hardware/software partitioning and implementation technology alternatives with increasing levels of detail. In modelling the system either functionalities or communications between subunits are selected to be modelled (ibid, 715). As these and other abstractions are modelled and elaborated a stepwise refinement of the system design occurs. The actor and objects identified

from Philipson are outlined in Appendix A.1.

2.4.6 Franke and Purvis (1991)

The objective of Franke and Purvis's study was to present a new hardware/software system design method (Franke and Purvis 1991, 344). The principle is to "combine the hardware and software perspectives from the earliest stages of the design process and exploit the design flexibility and efficient allocation of function that such an approach offers" (ibid, 344). This is called co-design.

With a change in the current state of hardware from general to special purpose technology, the functionality of certain systems can be allocated either in software or special purpose hardware. Allocation of functionality into either of these sub-systems is no longer straightforward. "Each application area requires a separate analysis concerning the optimal distribution of such functionality." (ibid, 345).

To resolve this issue, Franke and Purvis proposed co-design. The representation of co-design identifies specific actors and objects, which are outlined in Appendix A.1.

Franke and Purvis's research focusses on the necessity of coordination between component groups. Early decisions made by the system engineer about the system design significantly impact on the component design alternatives. Therefore, Franke and Purvis's recommendation is to coordinate the actors activities at the earliest moment possible.

Contrasting with Philipson, functional modelling begins

with system partitioning and implementation technology selection, whereas co-design attempts to delay the decisions to the furthest moment possible to avoid the costs from inappropriate partitioning and implementation technology decisions. Co-design attempts to determine the optimal configuration of components and implementation technologies by synthesizing and coordinating the expertise of the system and component designers. Functional modelling attempts to determine the optimal configuration by running through alternative component and implementation technology configurations.

2.4.7 Jain (1991)

The objective in Jain's study was to outline the top-down approach to system design using architectural modelling (Jain 1991, 57). The author noted that by 1995 electronic design engineering would be dominated by a top-down system design approach. This involves an engineering designer, hereafter referred to as the architect, developing an initial architecture of the system.

Current electronic systems design is "traditionally ad hoc and manual-that is, without system level design tools." (ibid, 59) As a result, the architectures are derived mostly from the architects experiences. The top-down approach suggested by Jain involves converting the specification of requirements into a data-flow graph, from which component types are selected to implement various functions.

Architectural models are developed to simulate systems. Subsequently, the model is compared against requirements and constraints, in which component re-partitioning may occur. The process iterates until an optimal solution is achieved.

The actor and objects identified from Jain are outlined in Appendix A.1. In contrast with Franke and Purvis (1991), Jain (1991) outlines a methodology with lesser actor involvement in the initial stages of design, however, it maintains the codesign methodology at the subsystem level.

Jain's modelling is anchored around architectural modelling functionality to determine feasible partitioning and implementation technologies, whereas Philipson (1990) selects alternative partitioning and technology implementations and evaluates each.

Franke and Purvis, Jain, and Philipson conceptualize the designer in a different manner than the more management oriented literature. They view the designer as an architect who constructs the initial architecture of the system either through participation with hardware and software engineers, functional modelling, or behavioural modelling. The architect partitions the system design such that each component group can design to specifications and parameters of the partitions. This actor has not been captured in the product development management literature. This literature conceptualizes design as a black box with particular inputs and outputs.

The other design management literature has not captured

this actor either because the research deals with architecture of buildings (Akin 1984, Luckman 1984), a component of the system design (Guindon 1990), or with the problem solving aspect of design (Frischmuth and Allen 1969).

2.5 COORDINATION IN THE PRODUCT DEVELOPMENT DOMAIN

Section 2.5.1 introduces the Appendices that provide an inventory of the actors and shared objects identified in the literature on new product development and design management. Section 2.5.2 and 2.5.3 identify the coordination mechanisms identified in the review of the literature.

2.5.1 Elements of the Coordination Structure Identified in the Literature

Appendix A.1 provides a list of the actors and objects identified in the literature review. Appendix A.1.1 and A.1.2 show the actors and objects identified in the new product management literature. Appendix A.1.3 and A.1.4 show the actors and objects identified in the design management literature.

Appendix A.2.1 shows actor classes which group actors identified in the literature in terms of role similarities. I have given each class a name. This name will hereafter denote the role of an actor in the new product development domain. Appendix A.2.2 lists object classes which group objects identified in the literature in terms of similar information content. Similar to actors, I have given each object class a name. This name will hereafter denote a shared

object in the new product development domain.

2.5.2 Coordination Mechanisms Identified in the Review of the Organizational Behaviour Literature

Four mechanisms organizations use to coordinate interdependent tasks were identified from the review of the literature on organizational behaviour.

The first mechanism is the creation of a particular object to coordinate multiple interdependent tasks performed by at least two actors. These objects include: i. rules (Thompson 1967, 56), programs, procedures (Galbraith 1973, 10) and work processes (Mintzberg 1989, 101), ii. schedules (Thompson 1967, 56), iii. targets, goals (Galbraith 1973, 12), and outputs (Mintzberg 1989, 101), and iv. skills training and norms (ibid, 101).

The second mechanism is to charge actors with coordination roles (Nadler and Tushman 1992, 137-148 and Van de Ven, Delbecq, and Koenig 1976, 323). These coordination roles include: liaison role, integrator role, and cross unit group.

The third mechanism used to coordinate actors is the creation of an organizational hierarchy (Galbraith 1973, 11) or direct supervision (Mintzberg 1989, 101). This mechanism involves the addition of a management actor or multiple actors in the case of a matrix structure (Nadler and Tushman 1992, 116-147), to generate new responses to problems previously

unencountered by the task performers (Galbraith 1973, 11) and to issue orders or instructions to interdependent task workers (Mintzberg 1989, 101).

The fourth mechanism for coordinating actors refers to actors coordinating through feedback (Thompson 1967, 56). This process is characterized as mutual adjustment between multiple actors involved in interdependent tasks. Mintzberg (1989, 101) identifies this mechanism as the "simple process of informal communication".

Coordination is viewed as the implementation of these four mechanisms to manage the task interdependencies and overcome the stumbling blocks resulting from the division of labour.

2.5.3 Coordination Mechanisms Identified in the Review of the Product Development Literature

The new product development literature conceptualizes coordination as the organization of functional units in order to minimize information loss between units and to maximize the synergies from cooperative efforts. From the product development literature, I have identified five mechanisms for coordinating functional units: i. management support, ii. project teams, iii. an individual integrator, iv. shared objects within a project, and v. shared objects across projects.

First, management support and impetus to assure organizational support for change and sufficient resource

allocation (Zirger and Maidique 1990, 872). This includes strong support for the product from general management and project management. Second, product development project team or multiple project teams each specializing in a particular product to attain integration of the functional units and its requisite management (McTavish 1985, 32).

Third, an individual integrator or "business innovator" coordinating functions and integrating them into a continuous innovation process (Rothwell et al 1974, 290). Fujimoto (1989) identifies a heavyweight product manager as a means of maintaining internal and external system integrity, resulting in more efficient product development. The product manager coordinates with the project team through particular objects: product concept, technical details of the product, major components, cost targets, specification, and high level design. The product manager should also be directly linked with the customer.

Fourth, Wheelwright and Clark (1992) characterize their perceptions of cross-functional unit integration within product development. Specific objects between the functional units are identified: components, detailed process design, detailed product design, pilot units, product & process architecture, product & process concept, program parameters, prototypes, and tooling & equipment. The functional units coordinate together and with other actors through the above objects.

Fifth, Nobeoka and Cusumano (1992) view coordination in a similar vein as the authors above. However, they add in the concept of coordination within a functional unit across projects. Actors within the functional unit coordinate around functions such as design or manufacturing or they coordinate around technical specialties such as components (Nobeoka and Cusumano 1992, 16). For example, functional coordination can take place around particular components being shared across projects. The design group for each project coordinates around the component design, state of the art technologies, and all design groups from a functional unit coordinate with the design manager through technology component issues (ibid, 16-17).

Selection of a particular integrating method is a function of the new product opportunities which present themselves to the organization (McTavish 1985, 40).

The design management literature is not focussed on coordination mechanisms. Rather, it analyses design as it pertains to an individual (Akin 1984, Frischmuth and Allen, Guidon 1990, and Luckman 1984), or it focusses on the process of abstracting design solutions (Franke and Purvis 1991, Jain 1991, and Philipson 1990).

CHAPTER 3

KEY ELEMENTS OF THE RESEARCH

3.1 REPRESENTATION OF COORDINATION STRUCTURE

3.1.1 Visual Formalism

Bailetti and Callahan (1992, 1993) outline a methodology of representing the interaction of actors through shared objects using object based modelling.

The methodology outlined in Bailetti and Callahan (1992, 1993) builds on Rumbaugh et al (1991) and Malone and Crowston (1991). This methodology is used to diagrammatically represent coordination structure as the configuration of the associations between actors and the shared objects around which they coordinate their activities. The diagrams consist of three critical elements. The first is shared objects which are defined as entities, concepts, abstractions, or things with crisp boundaries that channel actors with different viewpoints to cooperate in distributed problem solving situations (Bailetti and Callahan 1992, Rumbaugh et al 1991). Shared objects are represented as circles. The second is actors, which are the participants, individuals, groups, or roles that operate and use the objects in a variety of ways. Actors are represented as rectangles.

The third is the associations between actors and shared objects. These represent how the actors create, modify, or use the shared objects. Links between actors are also present but are only of the "part of" type. (Bailetti and Callahan

1992). Associations are represented by lines between actors and objects. Each line has an associated verb which describes the nature in which the actors create, operate, or use the object. Direct links between objects are not permitted. An object is only shared when there is a least two actors associated with it.

Shared objects, actors, and associations have attributes or properties that describe them (Rumbaugh et al 1991, 161).

This visual formalism representing coordination takes a system level view of the configuration of associations that must be managed in the product development process. "This draws attention to the importance of producing a view of the binding that holds together the network of cooperating actors in terms of the array of objects around which individual and group efforts are coordinated" (Bailetti and Callahan 1992, 5).

Coordination in this context is represented around objects rather than activities, procedures, or data. Typical activity or information driven representational approaches describe systems in terms of their parts and their operations respectively. Object based modelling, in contrast, describes a system in terms of the responsibilities of objects and actors (ibid).

3.1.2 Benefits of Diagrammatic Representations

The benefits of using diagrams are threefold: i. they can group all relevant information together avoiding large search

efforts; ii. they typically use location to group information about a single element, avoiding the need to match symbolic labels, and iii. they support a large number of perceptual inferences which are easy for humans (Larkin and Simon 1987, 98).

The diagrammatic representation of coordination in terms of objects simplifies the processing of information. Information processing consists of three processes: i. search: process of locating sets of elements within the representation that satisfy conditions of particular inference rules, an inference rule states a particular action given a certain condition.; ii. recognition: matching the conditions of an inference rule with the set of elements in the representation located through the search; iii. inference: execution of the actions of the inference rule to add new elements to the representation (ibid, 67-69).

Object based diagrams facilitate the process of search because they are more stable. Object based models represent more stable structures than activity or procedural based models. This is due to the difficulty in clearly specifying ex ante the nature, duration, and the interdependencies of activities (Chase and Aquilano 1992; Krajewski and Ritzman 1990).

Object based diagrams provide a system level view of all the relevant actors, the objects through which they coordinate their activities, and how they act upon the objects.

Without a system level view of the network of interdependencies, the process of recognition and inference in activity based models can not occur. What happens instead is that actions of inference rules are specified which have no visible link to the activity based models that were used to create them.

Object based diagrams have two strengths in the process of recognition and inference. First, Bailetti and Callahan (1992) noted that object based approaches close the gap between the complex real world design system and the model to represent it.

"The object based representation of coordination (structures) provides . . . (design participants) with a better appreciation of the complex system they work into, a common vocabulary of discourse to effectively communicate the nuances of the (design) system to others, and a tool to continuously improve the management of part-whole relationships embedded in the process of coordination for which they are accountable."

Bailetti and Callahan 1992, 6

Second, the object based representation of coordination facilitates the representation and the transition to specific action. Design participants can use the modelling to capture the essence of specific problem domains and design implementation strategies (ibid).

3.1.3 Example of an Object Based Representation

Using the methodology outlined in section 3.1, Figure 1 provides an example of an object based representation of one coordination mechanism identified in the organizational behaviour literature: the creation of a hierarchy or direct

Figure 1

Example of An Object Based Representation

Management Hierarchy or Direct Supervision Coordination Mechanism

supervision (see section 2.6).

In Figure 1, rectangles represent actors. Actors include: DESIGN, MANUFACTURING, and MANAGEMENT. Circles represent objects. Objects include: NEW RESPONSE, ORDERS, PROBLEM, and SPECIFICATION. Lines between actors and objects represent associations. Associations between the actors and objects have a verb which describes how the actor creates, modifies, or uses the object. The associations include: DESIGN **creates** SPECIFICATION, MANUFACTURING **contributes (to)** SPECIFICATION, DESIGN **identifies** PROBLEM, MANUFACTURING **identifies** PROBLEM, MANAGEMENT **recognizes** PROBLEM, MANAGEMENT **generates** NEW RESPONSE, DESIGN **uses** NEW RESPONSE, MANUFACTURING **uses** NEW RESPONSE, MANAGEMENT **issues** ORDERS, DESIGN **follows** ORDERS, and MANUFACTURING **follows** ORDERS.

Figure 1 provides an example of the coordination mechanism of creating a hierarchy. DESIGN and MANUFACTURING coordinate around the production of SPECIFICATION and they encounter and identify PROBLEMS for which no pre-planned response exists. MANAGEMENT generates NEW RESPONSES to previously unencountered PROBLEMS. MANAGEMENT also issues ORDERS to DESIGN and MANUFACTURING, which they follow.

3.2 PHASES OF NEW PRODUCT DEVELOPMENT

To examine coordination structures that exist across different phases of the product development cycle, it is necessary to identify the number of relevant phases and an unambiguous approach to defining the end of one phase and the

beginning of the next.

3.2.1 Approaches Found in the Literature

The literature partitions the product development process into a series of phases by examining: i. dominant activities, ii. criteria used to make go/kill decisions, and iii. organizational commitments to the project. The first approach identifies a logical sequence of dominant activities in the product development process and defines phases in terms of these dominant activities. Many models that identify phases on the basis of dominant activities exist. (Baker and McTavish 1976, Kotler 1976, Rothwell and Robertson 1973, Saren 1984). The most commonly referenced model is that of Booz, Allen, and Hamilton (1968, 1982). This consulting firm has developed a model of new product development comprised of six phases: idea generation, screening and evaluation, business analysis, development, testing, and commercialization. Each of these phases is anchored around a set of dominant sub-activities.

The second approach identifies phases in terms of go/kill decision points and then groups the activities between these points to identify phases. Cooper (1983, 1986) developed a phase model using go/kill evaluation decisions to mark the end of each stage in the process. These go/kill decisions are "bail-out points" (Cooper 1986, 49) for the project prior to committing to the next stage of activities.

The third approach identifies the boundaries between each phase by the events that signal an investment in the project

by the organization. Gladstein-Ancona and Caldwell (1987, 204) conceptualized the product development cycle as being partitioned into three phases: 1. creation, 2. development, and 3. diffusion. Organizational commitments of support (financial and human) for the product idea is used to mark the beginning of the development phase. The transfer of the product to other groups within the organization to test the product with the consumer is the mark of the beginning of the diffusion phase.

3.2.2 Approach Used in the Thesis

The organizational commitment events specified by Gladstein-Ancona and Caldwell, provide the most explicit means of partitioning the product development process and is used in this research to define the phases of product development. The three phases identified by Gladstein-Ancona and Caldwell are used in this research. The separation of the phases is defined in terms of three events shown in Figure 2:

EVENT 1:

The product manager allocates resources to help define a new product concept.

EVENT 2:

The project receives funding approval to begin design and development.

EVENT 3:

A final prototype has been approved for field testing.

These three events are the boundaries which mark the

Figure 2
Phases of New Product Development and Keypoints Used to Anchor Propositions

beginning of each phase.

For the purpose of this research, the three phases are:

1. Creation: a relatively low cost effort to develop a new product concept, to specify the functionalities and parameters of the concept, and to develop an initial system design in order to obtain organizational support for a project;
2. Development: a major capital investment requiring top management support where the project team has received adequate resources to take an architecture and develop a prototype;
3. Implementation: transfer of the ownership of the new product, process, or service from the team to the organization for field testing and pilot production.

This research focuses on the four keypoints identified in the bottom layer of Figure 2. The first keypoint is the time around which a manager allocates resources to help define a new product concept. This keypoint identifies the beginning of the creation phase.

The second keypoint is the period of time over which the case for development funding is made. This keypoint occurs near the end of the first phase. These two keypoints have been selected because of their prevalence in the literature. Van de Ven (1986) and Fujimoto (1989) both identify the initial conceptualization of a product and the refinement of the conceptualization in discussing the creation phase.

The third keypoint is the midpoint of development. In order to attempt to capture the configuration of actors around the design and the prototype objects the midpoint of the development phase is being used as the keypoint.

The fourth keypoint is the midpoint of field testing. In order to both capture the configuration of actors around the pilot products and field tests the midpoint of the implementation phase was selected as the keypoint.

3.2.3 Rationale for Selecting Resource Commitments to Define Phases

The organizational resource commitment points used in this thesis are clear and consistent across organizations, and create mutually exclusive categories. Going back one phase is possible only if the project team has to give all the committed resources back, an unlikely scenario.

The dominant activities model provides phases which are not necessarily sequential as noted in Cooper (1986). Gladstein-Ancona and Caldwell (1987) noted that teams may actually "cycle back through earlier phases or forward into later phases. . . (Product development) is less straight forward than the sequential model suggests." (Gladstein-Ancona and Caldwell 1987, 202). In addressing the issue of adherence to the stages Cooper noted that "no product project will necessarily follow the model religiously; certainly unforeseen events and special circumstances will dictate additional steps, recycling through previous steps, or

deletion of certain activities." (Cooper 1983, 10). This view is also supported by others (Axel-Johne and Snelson 1988, Quinn 1985, King 1973). As a result of this characteristic of the product development process, using dominant activities to partition the product development process would not create mutually exclusive phases.

The go/kill criteria models lack clarity. The exact nature of a go/kill decision point is not clearly specified and is not necessarily consistent across organizations. Product development as a non-sequential, "messy, undirected process" (Gladstein-Ancona and Caldwell 1987, 203) complicates the use of go/kill decision points as phase determinants because the decision points could have multiple occurrences. On the other hand, with the organizational resource commitments, by definition either the resources are committed for particular activities or they are not.

3.3 PROPOSITIONS

The actor and object classes summarized in Appendix A.2 were used to generate propositions regarding the configuration of actors and objects found at each of the four keypoints identified in section 3.2. Table 2 identifies the actors and objects from Appendix A.2 that are in each of the four propositions. Appendix A.3 defines the actors and the objects. Fujimoto (1989), Clark and Fujimoto (1991), and Wheelwright and Clark (1992) were central to the generation of these propositions.

Table 2

ACTORS AND OBJECTS IN THE PROPOSITIONS

Actors and Objects	Propositions			
	1	2	3	4
ACTORS:				
Architect	X	X	X	X
Component Design Core Engineers		X		
Component Design Group			X	X
Concept Creator	X	X		
Customer				X
Manufacturing				X
Marketing	X			
Pilot Plant				X
Product Manager	X	X		
Prototype Group			X	
Specification Group		X		
Test Group			X	X
OBJECTS:				
Architecture		X		
Component Issues			X	
Component Specification			X	
Customer Feedback				X
Manufacturing Feedback				X
Product Concept	X	X		
Product Design				X
Prototype			X	X
Prototype Test Results			X	X
Specification		X		

The evolution of shared objects into a producible design is determined by actors who make decisions regarding the direction of the evolution of the design (Koomen 1991). The propositions are anchored around the individuals determining the direction of the evolution of the design of the system. The propositions describe system level diagrammatic representations of coordination structure that exist at four different keypoints of the product development cycle. The configuration of actors and objects is emphasized in this research and not particular actor-object relationships.

3.3.1 Proposition 1

The literature characterized the first phase of product development as consisting of actors coordinating around their own perspectives of what the new product opportunity is. These perspectives are inferred by the actors own knowledge domains (Dougherty 1992, Van de Ven 1986). The associations between actors are few and are very weak. As a result no truly shared objects exist. One object is the initial product concept which is owned by the concept creator (Clark and Fujimoto 1991, Fujimoto 1989). However, few actors share that conceptualization of the new product idea. Their efforts are being channelled by their own perspectives of what the product concept is.

Proposition 1:

At keypoint 1, decisions regarding the direction the PRODUCT CONCEPT should evolve are made by a configuration of actors, including the CONCEPT CREATOR, the ARCHITECT, and the PRODUCT MANAGER, whose efforts are being channelled by their own perspectives of what the PRODUCT CONCEPT is.

Figure 3 is the object based representation of proposition 1. This representation illustrates that the various actors coordinate their efforts around different versions of what the PRODUCT CONCEPT is. Some of these versions may be shared. However, a shared view of what the product is does not exist in the coordination structure.

Various PRODUCT CONCEPTS exist, although only one is linked to the CONCEPT CREATOR. Other actors coordinate around other objects which result from their differing frames of reference. An initial solution path is derived from actions of actors coordinating around different views of the PRODUCT CONCEPT.

Key actors participating at the first keypoint include: PRODUCT MANAGER, CONCEPT CREATOR, and ARCHITECT. The other actors in figure 4 will not necessarily be present at the keypoint. They are drawn in to illustrate the possible variety of actors participating at keypoint 1. The CONCEPT CREATOR with the support of the PRODUCT MANAGER will drive and evolve the initial PRODUCT CONCEPT through to keypoint 2.

Figure 3

Proposition 1

At keypoint 1, decisions regarding the direction the PRODUCT CONCEPT should evolve are made by a configuration of actors, including the CONCEPT CREATOR, the ARCHITECT, and the PRODUCT MANAGER, whose efforts are being channelled by their own perspectives of what the PRODUCT CONCEPT is.

3.3.2 Proposition 2

From Fujimoto (1989), I identified the objects that exist at the second keypoint: product concept, specification, and architecture. These objects are developed concurrently and represent refinements of knowledge in the same problem solving cycle (Fujimoto 1989). These objects specify the functionality of the product, initial architecture, and component selection (Cooper 1983, Fujimoto 1989, Clark and Fujimoto 1991). Development of these three objects determine the future direction of the project.

Relevant actors coordinate around these three objects. The dominant actors involved at this keypoint include the architect responsible for developing an initial architecture of the product, the specification group responsible for creating a specification, the concept creator who originated the idea, the product manager responsible for the success of the project, and component design core engineers who will be designing and developing components for the product.

Proposition 2:

At keypoint 2, decisions regarding the direction the product should evolve are made by a configuration of individuals comprised of the ARCHITECT, SPECIFICATION GROUP, CONCEPT CREATOR, PRODUCT MANAGER, and COMPONENT DESIGN CORE ENGINEERS who integrate their efforts to define the SPECIFICATION, PRODUCT CONCEPT, and ARCHITECTURE.

Figure 4 illustrates the object based representation of

Figure 4

Proposition 2

At Keypoint 2, decisions regarding the direction the product should evolve are made by a configuration of individuals comprised of the ARCHITECT, SPECIFICATION GROUP, CONCEPT CREATOR, PRODUCT MANAGER, and COMPONENT DESIGN CORE ENGINEERS who integrate their efforts to define the SPECIFICATION, PRODUCT CONCEPT, and ARCHITECTURE.

proposition 2. It shows that at keypoint 2 actors coordinate around PRODUCT CONCEPT, SPECIFICATION, and ARCHITECTURE. Further details of the PRODUCT CONCEPT are created by the CONCEPT CREATOR with the assistance of PRODUCT MANAGER. As the PRODUCT CONCEPT is being evolved it is used as the basis to generate a SPECIFICATION. The SPECIFICATION GROUP is responsible for the creation of this object, the ARCHITECT, and the COMPONENT DESIGN CORE ENGINEERS contribute to the SPECIFICATION. The SPECIFICATION in turn, guides the creation of ARCHITECTURE by the ARCHITECT with the assistance of the COMPONENT DESIGN CORE ENGINEERS. These three objects are highly interdependent, which is reflected in the strong linkages within the coordination structure.

The overall configuration of actors and objects represents a system in which PRODUCT MANAGER, CONCEPT CREATOR, and SPECIFICATION GROUP define the PRODUCT CONCEPT and its features and functionality within the SPECIFICATION. In parallel ARCHITECT and COMPONENT DESIGN CORE ENGINEERS use this information to create ARCHITECTURE which partitions the system design into components and defines the implementation technologies to be used.

3.3.3 Proposition 3

In phase three of product development, a partitioning decision is made by the architect (Franke and Purvis 1991, Jain 1991, Philipson 1990). Activities performed by various component design groups are focussed around converting the

component specification generated from the partitioning, into a detailed design which is then prototyped. Interaction between groups lead to clearer, more consistent specifications about the component interfaces and the overall system design (Franke and Purvis 1991, Guindon 1990, and Jain 1991). Components are then prototyped and the results feedback to the component groups (Fujimoto 1989).

Proposition 3:

At keypoint 3, decisions regarding the direction the COMPONENT DESIGNS should evolve are made by a configuration of groups comprised of various COMPONENT DESIGN GROUPS, a PROTOTYPE GROUP, and a TEST GROUP, working to integrate COMPONENT SPECIFICATIONS as partitioned by the project ARCHITECT into a PROTOTYPE.

Figure 5 illustrates the object based representation of proposition 3. The information from the PRODUCT CONCEPT, SPECIFICATION, and ARCHITECTURE are partitioned into COMPONENT SPECIFICATIONS by the ARCHITECT. These COMPONENT SPECIFICATIONS define the functionality, operational parameters, and the interfaces of each component (ibid). COMPONENT SPECIFICATIONS represent the constraints in which the COMPONENT DESIGN GROUPS must design. The efforts of the COMPONENT DESIGN GROUPS are directed at producing a COMPONENT DESIGN which can be prototyped. The PROTOTYPE GROUP uses the COMPONENT DESIGN to generate COMPONENT PROTOTYPES, and then SYSTEM PROTOTYPES. The design-prototype process is iterative.

Figure 5
Proposition 3

At keypoint 3, decisions regarding the direction the COMPONENT DESIGNS should evolve are made by a configuration of groups comprised of various COMPONENT DESIGN GROUPS, a PROTOTYPE GROUP, and a TEST GROUP working to integrate COMPONENT SPECIFICATIONS as partitioned by the ARCHITECT into a PROTOTYPE.

Each PROTOTYPE is tested by TEST GROUP who provide the PROTOTYPE TEST RESULTS to the COMPONENT DESIGN GROUPS. This information is used to amend the COMPONENT DESIGNS to meet specified requirements. Interaction between COMPONENT GROUPS is intended to clarify any unclear elements of the COMPONENT SPECIFICATIONS and is anchored around the COMPONENT ISSUES particularly pertaining to the interfaces between each of the components.

The system at this keypoint represents the point where the information defining functionality and specifying system attributes has been developed enough to require partitioning into smaller problem domains to create a design. Components are developed and prototyped iteratively until a system meeting functional requirements has been created.

3.3.4 Proposition 4

In the final phase of product development, actors coordinate around developing and testing prototypes from the product design. Feedback from the tests is directed to the component design groups and the architect, who use the information to amend the product design. Coordinated efforts are now directed at fixing problems and learning about what changes to make to the product design through learning about the prototype. Information feedback from customers, manufacturing's pilot plant, and the test group is used to make modifications to the design. Major modifications are only made in exceptional cases (ibid).

Proposition 4:

At keypoint 4, decisions regarding the direction the PRODUCT DESIGN should evolve are made by a configuration of actors, comprised of the ARCHITECT, various COMPONENT DESIGN GROUPS, PILOT PLANT, and TEST GROUP, working to integrate the learning from the use of the PROTOTYPE into the PRODUCT DESIGN.

Figure 6 illustrates the object based representation of proposition 4. Manufacturing use DESIGN INFORMATION to generate PROTOTYPES in a PILOT PLANT (ibid). These PROTOTYPES are used by CUSTOMER and TEST GROUP to test the performance of the product. CUSTOMER and PROTOTYPE TEST RESULTS are directed towards PILOT PLANT and COMPONENT DESIGN GROUPS. Feedback from the TEST GROUP on system performance is also sent to the ARCHITECT. PILOT PLANT sends MANUFACTURING FEEDBACK about the producibility of the design to the COMPONENT DESIGN GROUPS. Finally, COMPONENT DESIGN GROUPS and ARCHITECT use the feedback to amend PRODUCT DESIGN.

The coordination structure at keypoint 4 supports design validation and process qualification. PILOT PLANT and TEST GROUP provide information to ARCHITECT and to COMPONENT DESIGN GROUPS which they use to amend documentation and the PRODUCT DESIGN.

Table 3 characterizes the four propositions on four characteristics. First, the actors define the conceptual level of actor involvement, either group representatives or groups and the critical actors at each keypoint. Second,

Figure 6

Proposition 4

At keypoint 4, decisions regarding the direction the **PRODUCT DESIGN** should evolve are made by a configuration of actors comprised of the **ARCHITECT**, various **COMPONENT DESIGN GROUPS**, **PILOT PLANT**, and **TEST GROUP** working to integrate the learning from the use of the **PROTOTYPE** into the **PRODUCT DESIGN**.

Table 3
Characterisation of the Coordination Structure at the Four Keypoints

	KEYPOINT 1	KEYPOINT 2	KEYPOINT 3	KEYPOINT 4
Description	Manager allocates resources to help define a new product concept	Case for development funding is made	Midpoint in development	Midpoint in field testing
Actors	Individuals working independently: Architect; Concept Creator; and Product Manager	Individuals representing groups: Component Design Core Engineers; Architect; Concept Creator; and Specification Group; and Product Manager	Groups: Component Design Groups; Prototype Group; Test Group; and Architect	Groups: Component Design Groups; Pilot Plant; Test Group; Customer; and Architect
Critical Objects that are Acted Upon	Product Concept	Product Concept Specification Architecture	Component Specification Component Designs Prototype Test Results	Product Design Prototype Test Results Customer Feedback Manufacturing Feedback
Associations in the Coordination Structure	Few Weak	Few Strong	Many Strong	Moderate Strong
State of Knowledge Required to Implement the Product	Not determined	Definition of functionality and high level component partitioning	Detailed component specification	Prototype and product design

critical objects that are acted upon define the objects which actors create, modify, or use to advance the state of knowledge in order to implement the product. Third, the associations in the coordination structure characterize the number of associations and their strength. Fourth, the state of knowledge required to implement the product, identifies the current state of knowledge of the product design at each keypoint.

Design tools and methods in the responding organizations may influence the nature of the coordination structures. These propositions have built upon literature from various sources which have discussed a number of different design methods and tools. The proposition have been generated in such a manner that they are consistent with the reviewed literature. In achieving this, specific shared objects unique to any particular design methodology were excluded from the propositions. However, the propositions still represent the base coordination structure of project organizations in a manner congruent with the perspectives in the new product development and design management literature regardless of design tools and methods.

CHAPTER 4

RESEARCH DESIGN

This chapter describes the research method, the sample, and the data collection and analysis plan.

4.1 RESEARCH METHOD

Semi-structured interviews with the design manager and two individuals in each project provided the raw data. The design manager in this context is the individual who is responsible for the creation, management, and delivery of a producible design.

4.2 THE SAMPLE

4.2.1 Research Domain

The research domain is comprised of design and development projects within two organizations that produce designs of complex systems: a telecommunications equipment manufacturer and a weapon systems R&D organization. This domain was selected for the following reasons. First, the selection of system design intensive organizations ensured that a relatively large amount of coordination activity around tasks with high uncertainty was taking place. Second, complex system designs are more interesting and have more difficult coordination problems than simple design projects. Third, the two organizations embody different organizational structures: the telecommunications equipment manufacturer is project oriented, the other functionally oriented. Finally, these firms have expressed an interest in coordination problems in

designing complex systems and were accessible to the researcher.

The extent and time of the data collection was constrained by the time and resources associated with the development of an M.M.S. thesis.

4.2.2 Project Selection

The eight projects identified in Table 4 were selected as the sample. Table 4 identifies the four keypoints around which the data collection was directed: i. the time around which a manager allocates resources to help define a new product concept, ii. the period of time over which the case for development funding is made, iii. the midpoint of development, and iv. the midpoint of field testing. For each keypoint, two projects were selected, one from each firm. Each of the projects is briefly described in Appendix A.4.

4.2.3 Time of Data Collection

Data was collected from March to the end of May 1993.

4.2.4 Sampling Unit for the Interviews

Three respondents from each project were selected for the semi-structured interviews in order to provide a more comprehensive view of the project and to provide varied perspectives of the object based representation of the coordination structure of the projects.

Design managers were chosen for the interviews because they had the most knowledge of the way relevant actors coordinate their efforts around design objects. For each

Table 4
Sample Projects at Each Keypoint

	KEYPOINT 1 Manager allocates resources to help define a new product concept	KEYPOINT 2 Case for development funding is made	KEYPOINT 3 Midpoint in development	KEYPOINT 4 Midpoint in field testing
Telecommunications Equipment Manufacturer	Project 1.1: Hardware Platform	Project 2.1: German Intelligent Network	Project 3.1: Advanced Intelligent Network	Project 4.1: Falcon
Weapon System R&D Organization	Project 1.2: Composite Automated Manufacturing Initiative	Project 2.2: Energy Storage Wheel	Project 3.2: Micro-Mechanical Inertial Measurement Unit	Project 4.2: Interferometric Fiber Optic Gyro

project, two other actors participated in similar interviews. These actors were selected by the design managers. These two individuals have major responsibilities in coordinating the project or in managing a particular group in the design project or function in the organization, for example, the test and verification manager, the project coordinator, or a manager of a functional group.

4.3 DATA COLLECTION AND ANALYSIS PLAN

Data collection and analysis followed four steps (see Figure 7). For each project:

- i. three object based representations of the coordination structure of the project organization producing a particular design of a complex system were generated using semi-structured interviews with the design manager and two other actors;
- ii. the design manager developed one representation of the coordination structure of the project as the synthesis of the three representations developed in step i;
- iii. the representations of the coordination structure of the project organization were compared at each keypoint with the propositions; and
- iv. managerial implications of representing the coordination structure of the project organization were elicited from the design manager.

Each of these steps is outlined below and the data collection protocols for steps i., ii., and iv. are provided

Figure 7
Outline of Data Collection and Analysis Plan

in Appendix A.5.

4.3.1 Three Object Based Representations Generated Using Semi-structured Interviews with the Design Manager and Two Other Actors

For each project, the design manager and two other actors participated in separate semi-structured interviews. The interview followed the format outlined in Appendix A.5.1.

Responses to question one were used to verify that the projects were taking place around the respective keypoints for which they were selected. Responses to question two provided a description of the project. The responses to this question were used to define the responsibilities of the project organizations in the sample. Responses for question three provided a description of the specific tools and methods that were used in creating the design. Although the basic coordination structure as identified in the propositions may remain the same, collecting information about the different design tools and methods might provide a means of associating differences between coordination structures with their respective design tools and methods, should differences arise.

Responses to question four defined the objects which were used in the project. Question five asked the respondents to identify and describe the responsibility of the actors acting upon the objects. These actors are the participants within the coordination structure. They coordinate around the objects from question four which are shared by two or more

actors.

Question six inquired about the associations between each of the actors and the objects. Responses to question six were drawn onto bipartite object based graphs. These graphs are the respondents perceptions of the coordination structure of the project organization producing the complex design. The responses from the three interviews were contrasted in the next data collection step.

4.3.2 Design Manager Develops the Final Representation of the Project

For each project, three object-based representations of the coordination structure of the design system were generated separately from the initial interviews. In a subsequent interview with the design manager, the models were compared for similarity, see Appendix A.5.2. The design manager matched the similar actors, objects, and associations. Unmatched actors, objects, or associations between the design manager's and the two other respondents responses were identified by the design manager. The reasons for the dissimilarities were identified by the design manager. Differences between the various models were discussed by the researcher and the design manager as a means of gaining some insight into the different perceptions of the coordination structure by the respondents.

The design manager created a final representation which included: a purpose of the project, class responsibility

dictionary of actors and objects, and an object model.

4.3.3 Representations of the Coordination Structures Compared at Each Keypoint with the Propositions

The object based representations generated with the design managers from each project, outlined in the previous step, were contrasted against the propositions. The common elements were identified for the two projects at each keypoint.

The common elements at each keypoint was compared against the respective proposition. Insights from this qualitative comparison were used to provide some support or opposition for the propositions.

4.3.4 Eliciting Managerial Implications of Representing the Coordination Structure of the Project Organization

The final object based representation of the coordination structure of the design system was used as the basis for a discussion with the respective design manager. The design manager was asked to answer the questions outlined in Appendix A.5 3.

CHAPTER 5

DISCUSSION OF RESULTS

This chapter contains the results of the research. Section 5.1 provides the object based representations developed by the design managers from the first three interviews as outlined in step two of the data collection process. These representations are compared against the propositions in section 5.2. Section 5.3 contains the reasons for the differences in the representations provided by the respondents for each project. Section 5.4 contains the differences between the two organizations that participated in the study.

5.1 OBJECTIVES AND REPRESENTATIONS OF PROJECTS DEVELOPED BY DESIGN MANAGERS

This section identifies the objectives of the development projects and provides the representations developed by the design manager in step two of the data collection process. For each keypoint, Table 5 provides each design manager's view of the objective that best described the project for which he was responsible.

The actors and objects included in the design managers' representations developed in step two of the data collection process are defined in Appendix A.7. The columns labelled: R1, R2, and R3 identify the three respondents. R1 denotes the design manager. A check mark indicates the actors and objects in the final representation of the project that the

Table 5
Objectives of the Projects in the Sample

Keypoint 1: Manager allocates resources to help define a new product concept	
Project 1.1: Hardware Platform	Purpose of the project can not be disclosed
Project 1.2: Composites Automated Manufacturing Initiative	To develop cost effective automated equipment and machinery for manufacturing composite structures to reduce the acquisition costs of composites
Keypoint 2: Case for development funding is made	
Project 2.1: German Intelligent Network	To deliver an intelligent network system into the German telecommunications network, and to become the third telephone equipment supplier to the Bundespost
Project 2.2: Energy Storage Wheel	Internal R&D effort to develop an energy storage wheel with dual applications of energy storage and attitude control, configured into a system for satellite applications
Keypoint 3: Midpoint in development	
Project 3.1: Advanced Intelligent Network	To deliver a software package in the 1993-1994 time frame to meet the demands of the customer base as outlined in a specification provided by the customer. Other non-revenue specific goals are to use AIN as a justification for software modernisation on the existing system and to provide a new platform for designing services.
Project 3.2: Micro-Mechanical Inertial Measurement Unit	Advanced Research Project Agency funded project to develop a micro-mechanical sensor and the associated electronics for military and commercial markets
Keypoint 4: Midpoint in Field Testing	
Project 4.1: Falcon	To develop a next generation high performance data switching product to broaden the business in network communication for data, voice, and video
Project 4.2: Interferometric Fiber Optic Gyro	To produce a high performance navigation grade fiber optic gyro for deep space navigation and pointing and tracking problems

2

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
1963-A-1010 TEST CHART No. 25

respondents identified in the first interview. Numbers refer to footnotes which describe how a respondent aggregated or partitioned actors or objects in a manner that varied from that identified in Appendix A.7.

5.1.1 Project 1.1: Hardware Platform

The object based representation of the hardware platform project is shown in Figure 8. Actors and objects shown in Figure 8 are defined in Appendix A.7-1.1. Actors integrate their efforts around the evolution of the COMMERCIAL SPEC, BUSINESS PLAN, PRODUCT REQUIREMENTS, and various COMPONENT ARCHITECTURES. EXECUTIVE and PRODUCT LINE MANAGEMENT evolve the COMMERCIAL SPEC and the BUSINESS PLAN. SYSTEM ENGINEERING and CORPORATE DESIGN evolve PRODUCT REQUIREMENTS. ARCHITECTURE MANAGERS and COMPONENT ARCHITECTS evolve an architecture distributed across COMPONENT ARCHITECTURES.

Appendix A.7-1.1 shows the actors and objects in Figure 8 identified by the three respondents in the first step of the data collection process. The three columns in Appendix A.7-1.1 labelled R1, R2, and R3 provide an indication of the extent to which the objects in Figure 8 were identified by the three respondents in the first interview. R1 and R2 are both ARCHITECTURE MANAGERS and R3 is responsible for the definition of the hardware design process. While intimately familiar with the project R3 is not in Figure 8.

R2 identified EXECUTIVE, PRODUCT LINE MANAGEMENT, SYSTEM ENGINEERING, and CORPORATE DESIGN during the first interview.

Figure 8
Design Manager's Representation of Project 1.1: Hardware Platform

In the second interview, R1 immediately recognized that these actors should be part of the representation. R1, R2, and R3 had a shared view of the aggregation comprised of ARCHITECTURE MANAGERS and COMPONENT ARCHITECTS. However, they partitioned the ARCHITECTURE in different ways. The design manager's synthesis included three COMPONENT ARCHITECTURES: hardware, software, and physical design.

5.1.2 Project 1.2: Composites Automated Manufacturing Initiative

The design manager of the Composites Automated Manufacturing Initiative (CAMI) project was of the view that the responses to "what is the objective of the project?" shown in Appendix A.6 were similar. Response one reflects a description of the entire project of which the weapon systems R&D organization is a part. Responses two and three describe the tasks to be undertaken by the weapons systems R&D organization. The design manager selected response one as best describing the purpose of the project: to develop cost-effective automated equipment and machinery for manufacturing composite structures to reduce the acquisition costs of composites.

The representation of the CAMI project can be partitioned into three modules: the Internal Module, the External Module, and the Management Module. These are shown in Figures 9A, 9B, and 9C respectively. Actors and objects in these Figures are defined in Appendix A.7-1.2.

Figure 9A
Design Manager's Representation of Project 1.2: Composites Automated
Manufacturing Initiative
Internal Module

Figure 9B

**Design Manager's Representation of Project 1.2: Composites Automated
Manufacturing Initiative**
External Module

Figure 9C

**Design Manager's Representation of Project .12:
Composites Automated Manufacturing Initiative
Management Module**

The Internal Module shown in Figure 9A includes the actors within the organization who are responsible for the technical activities of the project. Two shared objects in Figure 9A were key to the integration of efforts within the Internal Module: MACHINE SPEC and BEST CONCEPTS. Because CUSTOMER did not know what the requirements were, it was necessary for the weapon systems R&D organization to generate them. In order to do this, DESIGN INFO, MFG PROCESSES, and CUSTOMER NEEDS were used to create HOUSE OF QUALITY which was translated into prose to create MACHINE SPEC. MACHINE SPEC guided the creation of IDEAS. Alternative IDEAS were analyzed and tested through MOCK UPS, TEST RESULTS, and RISK ASSESSMENT. These objects provided the basis for deducing BEST CONCEPTS.

The External Module includes two actors CONSORTIUM MANAGEMENT and TQM MANAGER. CONSORTIUM MANAGEMENT is responsible for the entire development effort. TQM MANAGER is an individual from another firm in the consortium responsible for ensuring the process meets specific quality standards. Figure 9B shows that the two actors in the External Module coordinate their efforts around the objects produced within the Internal Module: MOCK UPS, RISK ASSESSMENT, IDEAS, BEST CONCEPTS, MACHINE SPEC, and HOUSE OF QUALITY.

The Management Module shown in Figure 9C illustrates that the TASK LEADER, PROGRAM MANAGER, and CONSORTIUM MANAGEMENT integrate efforts through three objects which they all share:

SCHEDULE & BUDGET, PROJECT FEEDBACK, and TECHNICAL OBJECTIVES. In addition, TASK LEADER and PROGRAM MANAGER share RESOURCES; PROGRAM MANAGER and CONSORTIUM MANAGEMENT share CUSTOMER PERCEPTIONS; and CONSORTIUM MANAGEMENT and TASK LEADER share STATEMENT OF WORK.

Appendix A.7-1.2 shows the actors and objects in Figure 9A, 9B, and 9C identified by the respondents in the first step of data collection. R1 is the TASK LEADER, R2 is part of DESIGNERS, and R3 is the PROGRAM MANAGER. R1's responses in the first interview excluded the Management Module entirely. R1 noted that this was largely an error of omission. R2 provided a more detailed perspective of the Internal Module than R1 and R3. R3 provided details of the Management Module and a high level view of the Internal Module.

5.1.3 Project 2.1: German Intelligent Network

Appendix A.6 includes the three responses to the question: what was the objective of the project? The design manager perceived these responses as being very similar. The third response, "to deliver an intelligent network system into the German telecommunications network and to become the third telephone equipment supplier to the Bundespost", was selected as being the one that best described the objective of the project. It incorporated an ulterior motive the other two responses did not: that the organization was using the intelligent network efforts as a means of becoming a telecom equipment supplier to the German Bundespost.

The object based representation of the German Intelligent Network project can be partitioned into: the Design Module and the Customer Interface Module. The Design Module shown as Figure 10A is comprised of three clusters identified on the basis of location. The first cluster includes three actors located in Europe, DESIGN TEAM U.K., AUSTRIAN TELEKOM DESIGN, and PHASE 1 PROJECT MANAGER that were responsible for developing SS7, the code with the appropriate protocol to make the intelligent network product operate within the German telecom network.

The second cluster is comprised of six actors located in two Canadian cities: PLM, HLD TEAM, TECHNICAL EXPERT, DESIGN TEAM, NPI, and PHASE 2 PROJECT MANAGER. The HLD TEAM and the DESIGN TEAM are responsible for the design and development of the intelligent network product. The HLD TEAM and TECHNICAL EXPERT produced HLD, the high level design, specifically for the intelligent network for Germany. The DESIGN TEAM working jointly with DESIGN TEAM U.K. and AUSTRIAN TELEKOM DESIGN developed the details of the HLD and the required software components for the German intelligent network. The European and Canadian actors integrated their efforts through SW ENVIRONMENT and DESIGN DOCS.

The third cluster is comprised of three external actors distributed in three cities in the U.S.: EXTERNAL PLM, SMS DESIGN TEAM, and BTX DESIGN TEAM. These three external actors are responsible for developing the SMS component and its

Figure 10A

**Design Manager's Representation of Project 2.1: German Intelligent Network
Design Module**

interface to the operator, denoted BTX. The SMS DESIGN TEAM and BTX DESIGN TEAM coordinate their efforts around BTX-SMS I/F SPEC. The Canadian and American actors integrate their efforts through the CONTRACT and through the SCP-SMS I/F SPEC.

The shared object PROJECT PLAN is used to integrate efforts of the actors in Europe, Canada, and the U.S. PROJECT PLAN is created by PHASE 1 PROJECT MANAGER and PHASE 2 PROJECT MANAGER with input from DESIGN TEAM U.K., AUSTRIAN TELEKOM DESIGN, SMS DESIGN TEAM, BTX DESIGN TEAM, and DESIGN TEAM.

The Customer Interface Module shown in Figure 10B has two functions. The first is to create an understanding of what the customer wants and to disseminate it throughout the project team. CUSTOMER creates TEST BOOK, CUSTOMER SPEC, and CUSTOMER FEEDBACK. TEST BOOK and CUSTOMER SPEC define what the customer wants and the tests to which the end product will be subjected. CUSTOMER FEEDBACK is used to clarify details and redirect the development efforts.

The second function of the Customer Interface Module is to keep the customer updated on the direction and the status of the development effort. FUNCTIONAL SPEC and CUSTOMER PMM (Project Management Meeting) RESULTS are used to achieve this. FUNCTIONAL SPEC is created by the PLM to reflect the functional requirements as embodied in the CUSTOMER SPEC and to direct the evolution of DESIGN DOCS. The CUSTOMER reviews this FUNCTIONAL SPEC to keep abreast of the direction which the development effort is taking. This review activity and

Figure 10B

**Design Manager's Representation of Project 2.1: German Intelligent Network
Customer Interface Module**

direct dialogue between the CUSTOMER and the TECHNICAL EXPERT and PLM is the catalyst for the creation of CUSTOMER FEEDBACK.

Appendix A.7-2.1 indicates the extent to which the representation generated with the design manager in the second step of the data collection process resembles those obtained in the three interviews in the first step of this process. R1 is the PHASE 2 PROJECT MANAGER, R2 is a manager in DESIGN TEAM, and R3 is a liaison between DESIGN TEAM and SMS DESIGN TEAM, who is included in DESIGN TEAM. R1 incorporated more informal aspects, such as meetings and communication, into the representation. The design manager perceived that the responses of R2 were a formal view of the project. Actors were identified by geographic location and objects were the respective interfaces. The design manager perceived that many of the objects were not identified by R3 because they were not visible to him.

R2 identified two other objects that R1 did not feel were present at keypoint 2: i. TMS1.1 which was the software created by SMS DESIGN TEAM and BTX DESIGN TEAM and approved by EXTERNAL PLM, and ii. SSP-SCP INTERFACE SPECIFICATION which was used by AUSTRIAN TELEKOM DESIGN, DESIGN TEAM U.K., and DESIGN TEAM. R1 identified an object and an actor in the first interview, that were subsequently excluded from the representation of the project: CAPTIVE OFFICE was a test platform for the software and DELIVERY TEAM which was the group responsible for initial test planning and evaluation of

the TEST BOOK. These were excluded in the second interview because the design manager perceived that neither was critical at keypoint two.

5.1.4 Project 2.2: Energy Storage Wheel

The design manager perceived the three responses shown in Appendix A.6 as identifying essentially the same objective for the project. During the second interview with the design manager, the first and second responses were used to develop the statement that best described the objective of the project: an internal R&D effort to develop an energy storage wheel with dual applications of energy storage and attitude control, configured into a system for satellite applications.

The design manager's representation of the energy storage wheel project is provided in Figure 11. The actors and objects are defined in Appendix A.7-2.2. This representation has two clusters defined in terms of the joint responsibility of the actors. The first cluster incorporates the component design actors. BEARING ENGINEER, MOTOR ENGINEER, and STRUKTURAL DESIGNER are responsible for creating alternative designs for their components to meet the requirements of the ARCHITECTURE.

The second cluster involves the integration of the components. INTEGRATOR, ROTOR DYNAMICS ANALYST, and DESIGNER/DRAFTER integrate the component designs into SYSTEM INTEGRATION. This SYSTEM INTEGRATION is analyzed and component designs modified, based on the ROTOR DYNAMICS

Figure 11

Design Manager's Representation of Project 2.2: Energy Storage Wheel

ANALYSIS. MECHANICAL DETAILS of the best implementation to date are developed and are subsequently used to create a final proposed design.

The last three columns in Appendix A.7-2.2 provide the actors and objects in Figure 11 that were identified by the three respondents in the first step of the data collection process. The data suggests that many of the actors and objects in Figure 11 were identified by the three respondents during the first interview.

R2 and R3 identified actors and objects that the design manager excluded from Figure 11. R2 provided a management module where STRUCTURAL DESIGNER, TASK LEADER, GROUP LEADER, and PROGRAM OFFICE integrate their efforts through four objects: FINAL REPORT, PROPOSAL, PROJECT PLAN, and REQUIREMENTS. R3 identified how PROGRAM DIVISION, PROGRAM MANAGER, and ARCHITECT evolved IDEA, SPECIFICATION, and SYSTEM ARCHITECTURE. The design manager did not perceive that these two clusters were present at keypoint 2.

In addition, both R2 and R3 identified an ELECTRONICS ENGINEER who used the ARCHITECTURE to create ELECTRONICS DESIGN which is used by the INTEGRATOR in the same manner as the other component designs. The design manager did not include these elements claiming that although at one point in time there was an ELECTRONICS ENGINEER and an ELECTRONICS DESIGN, they were dropped because of a lack of funds.

5.1.5 Project 3.1: Advanced Intelligent Networks

The third response shown in Appendix A.6 was selected by the design manager as the best description of the objective of the project. Although the other two responses were technically correct, the third response emphasizes the customer driven nature of this project and the ulterior motive of software modernization.

The object based representation of the advanced intelligent network (AIN) project is partitioned into Design Interfaces Module (Figure 12A) and Services/Specification Module (Figure 12B). Figure 12C details the DEVELOPMENT actor that appears in both Figure 12A and 12B. Actors and objects are defined in Appendix A.7-3.1.

In Figure 12A, PRODUCT LINE MANAGEMENT, MARKETING, and REGION are jointly responsible for making the business case for the AIN product and for supporting the interface between CUSTOMER and DEVELOPMENT.

In Figure 12B, DEVELOPMENT, PLANNING, and TEST GROUP are responsible for all design activities, from system specification to validation and delivery. SERVICES DEVELOPMENT GROUP, OTHER SERVICES DEVELOPMENT GROUP, BELLCORE, and CUSTOMER are responsible for the definition of the STANDARDS for the AIN product, the definition of the SERVICES which should be provided in the current product release, and OTHER SERVICES which will be provided in future product releases. BELLCORE and CUSTOMER represent telephone companies

Figure 12A
Design Manager's Representation of Project 3.1: Advanced
Intelligent Network
Design Interfaces Module

Figure 12B
Design Manager's Representation of Project 3.1: Advanced
Intelligent Network
Services/Specification Module

Figure 12C
Design Manager's Representation of Project 3.1: Advanced
Intelligent Network
Development Actor

and end-users and provide input into the process.

How DEVELOPMENT functions is shown in Figure 12C. This Figure shows that DEVELOPMENT is partitioned into TPE DEVELOPMENT, CALL PROCESSING DEVELOPMENT, and SYSTEM INTEGRATION.

The last three columns in Appendix A.7-3.1 show the actors and objects in Figure 12A, 12B, and 12C that each of the three respondents identified in the first step of data collection process. R1 was responsible for the development of TPE and CALL PROCESSING. R2 was responsible for managing the development of the entire AIN system. R3 defined the requirements for PRODUCT SPEC.

R1 provided a very detailed view of the design and delivery associated with keypoint 3. R2 provided a higher level view of the project reflecting his higher position in the organizational hierarchy. R3 was responsible for the front-end activities. As a result he was not aware of the details of most of the technical activities. It is interesting to note that the activities for which R3 is responsible, developing the requirements for the product, were more closely associated with keypoint 1. However, they were still taking place at keypoint 3.

R2 identified an ARCHITECT which still played a role at keypoint 3. The design manager did not perceive this actor as being significant. Similarly, R3 identified SCP REQUIREMENTS and SCP DEVELOPMENT GROUP which were the requirements and the

development group for another component, but the design manager did not perceive these objects as relevant to the efforts at keypoint 3.

5.1.6 Project 3.2: Micro-Mechanical Inertial Measurement Unit

The design manager perceived the responses shown in Appendix A.6 to differ significantly. The first response was a description of current efforts to develop a high g accelerometer for the advanced research project agency. This accelerometer would be one component of the micro-mechanical Inertial Measurement Unit (IMU) which was the focus of the other two responses.

The second response focuses on efforts to develop an accelerometer for an external customer and to develop a gyro for an internal customer. The technologies used to develop these two products are quite similar. Both would be components of the micro-mechanical IMU. However, development of the IMU will not be pursued until development of the gyro and the accelerometer met specific technical objectives.

The third response reflects the objectives of a customer who is no longer interested in the product. However, the design manager deemed this response to best describe the long term objective of the project. The statement for the purpose of the project provided by the design manager was: an advanced research project agency funded project to develop a micro-mechanical sensor and the associated electronics for military

and commercial markets.

The object based representation of the micro-mechanical IMU project is provided in Figure 13. The actors and objects are defined in Appendix A.7-3.2. The representation is anchored around the development and evolution of the GYRO SPEC on the one hand and the creation of the three components of the system: PRODUCTION GYRO, IMU PACKAGE, and INSTRUMENT OPER HW on the other hand.

Five actors, ENGINEERING MANAGER, PROGRAM MANAGER, MARKETING, CUSTOMER, and INSTRUMENT DESIGN define GYRO SPEC. INSTRUMENT FABRICATION, PACKAGING, CUSTOMER, INSTRUMENT TEST, and ELECTRONIC DESIGN develop three components: PRODUCTION GYRO, IMU PACKAGE, and INSTRUMENT OPER HW. These efforts are anchored around PRODUCTION GYRO. The INSTRUMENT DESIGN, the creator of PRODUCTION GYRO, is perceived as being more important than the other two component groups. TEST GROUP integrates PRODUCTION GYRO, IMU PACKAGE, and INSTRUMENT OPER HW and validates the integration using TEST PLAN.

The actors and objects in Figure 13 identified by the three respondents in the first step of the data collection process are shown in the last three columns of Appendix A.7-3.2. R1 is in INSTRUMENT DESIGN, R2 is the PROGRAM MANAGER, and R3 is a manager in SYSTEM ENGINEERING, an actor excluded from the representation by the design manager. The responses of R1 and R3 are virtually the same. The responses of R2 differed significantly from those of the other actors. The

Figure 13
Design Manager's Representation of Project 3.2: Micro-Mechanical Inertial Measurement Unit

design manager stated that R2 is responsible for a strategic alliance with an external organization. The design manager perceived R2's view of the project as being defined in terms of the management aspects of resource flow and allocation, whereas the other two respondents had a technical orientation.

R2 and R3 described management type objects such as task definition, resources, and high level requirements. They were excluded by the design manager because he did not view them as being relevant.

The design manager did not agree that the following elements identified by R2 were relevant: i. CAD TOOL which PACKAGING and ELECTRONICS DESIGN used, ii. MATERIALS which were provided by VENDORS to INSTRUMENT DESIGN GROUP and PACKAGING, and iii. OTHER SERVICES which were provide by VENDORS to PACKAGING.

R3 identified the existence of SYSTEM ENGINEER, an actor responsible for the creation and evolution of the GYRO SPEC. However, the design manager did not agree that this actor existed. The design manager stated that a project needed a specific mission for a SYSTEM ENGINEER to be involved. This project did not have a clear mission. If it did, the SYSTEM ENGINEER role would have replaced that of the ENGINEERING MANAGER.

5.1.7 Project 4.1: Falcon

The second response in Appendix A.6 was favoured by the design manager as being the best description of the purpose of

the project. However, he created what he deemed to be a better description of the project: to develop a next generation high performance data switching product to broaden the business in network communication for data, voice, and video.

The object based representation of the Falcon project is partitioned into the Marketing Module (Figure 14A) and the DEVELOPMENT actor (Figure 14B). The actors and objects in the Figures are defined in Appendix A.7-4.1.

Figure 14A can be deemed to be comprised of two clusters of actors. The first includes: MARKETING REGIONS, PRODUCT MANAGER, and DEVELOPMENT who are jointly responsible for providing or approving the objects necessary for market release. They coordinate around: SUPPORT SERVICES, MARKET REQ/S, and MARKET INFO. The second cluster includes: MANUFACTURING, GLOBAL PRODUCT SUPPORT, BUSINESS CHAMPION, and GLOBAL NPI. These actors are jointly responsible for the introduction of the product and the daily business operations.

Figure 14B, shows how DEVELOPMENT includes TEST GROUP, SW DEVELOPMENT MANAGER, SW DEVELOPERS, DOCUMENTATION GROUP, HW DEVELOPMENT MANAGER, HW DEVELOPERS, and PRODUCT INTEGRITY. DEVELOPMENT is responsible for creating PRODUCT to meet the requirements as specified in the PRODUCT SPEC.

The actors and objects in Figure 14A and 14B identified in the first step of the data collection process are shown in Appendix A.7-4.1. R1 is involved in DEVELOPMENT, R2 is a part

Figure 14A
Design Manager's Representation of Project 4.1: Falcon
Market Module

Figure 14B
Design Manager's Representation of Project 4.1: Falcon
Development Module

of PRODUCT MANAGER, and R3 is part of GLOBAL NPI.

The differences between the responses provided by R2 and R3 were due to their different levels within the organizational hierarchy. The design manager perceived that the response from R2 was at a higher level and described the coordination structure used to sell ideas and products internally as well as the delivery of the product. R3 described solely the delivery of the product.

R2 identified ARCHITECTURE DOCUMENT which captured the intent and the capabilities of the product and its architecture and HLD TOOLS which allow the translation and partitioning of the architecture into high level designs. The design manager did not perceive ARCHITECTURE DOCUMENT and HLD TOOLS as relevant at keypoint 4, thus they were not included in Figures 14A and 14B.

5.1.8 Project 4.2: Interferometric Fiber Optic Gyro

The design manager selected the third response in Appendix A.6 as the one that best described the purpose of the Interferometric Fiber Optic Gyro (IFOG) project.

The object based representation of the IFOG project is illustrated in Figure 15. The actors and objects are defined in Appendix A.7-4.2. Figure 15 can be partitioned into two: i. component development and integration and ii. product test and analysis. The component development and integration cluster is responsible for the production of a manufacturable PRODUCT to SPECIFICATION. The PHOTONICS DESIGNER, MECHANICAL

DESIGNERS, and ELECTRONICS DESIGNERS develop the three components of the interferometric fiber optic gyro: PHOTONICS MODULE, ENV & PKG MODULE, and DET & CONTROL MODULE. INTEGRATION integrates the COMPONENTS into PRODUCT.

The product test and analysis cluster includes TEST GROUP, QA (quality assurance), and ANALYSIS. These actors are responsible for validating the product against the SPECIFICATION to ensure it meets functional requirements and to determine the cause of any deviations. The involvement of QA is due to the premature failure of the components.

The last three columns in Appendix A.7-4.2 show the actors and objects in Figure 15 that each of the respondents identified during the first step of the data collection process. R1 is in PHOTONICS DESIGNERS, R2 is in TEST GROUP, and R3 is PROGRAM MANAGER. The design manager perceived the responses as being similar. Most of the differences were a result of the way in which the respondents partitioned actors and objects. For example, R3 did not have an ENV & PKG MODULE because the MECHANICAL DESIGNERS in R3's representation contributed directly to the PRODUCT. Likewise TEST BED/DATA was not present in R2 and R3's representation because they did not partition the test and the detailed analysis functions. R2 did not recognize the role of the INTEGRATOR in integrating the components into a PRODUCT but still performed tests on each of the components.

R2 identified VENDORS who used OPTICAL DESIGNS to produce

PHOTONICS COMPONENTS. The design manager excluded this actor because it did not play a significant role. FEEDBACK to the customer was not identified by R1 and R2. The design manager perceived that he and R2 excluded this object because they did not communicate with CUSTOMER.

5.2 COMPARISON BETWEEN REPRESENTATIONS COMMON TO PROJECTS AT EACH KEYPOINT AND REPRESENTATIONS OF PROPOSITIONS

In this section, for each keypoint representations common to the two projects are compared against the representation of the relevant proposition. Appendix A.8 defines the responsibilities of each of the actors and the objects in the representations common to the projects.

I use the following formalism to make inferences about whether or not a representation common to two projects at each keypoint supports a proposition. The common representation supports the proposition, if it contains the same actors, objects, and associations as in the proposition. The common representation provides some support for the proposition if a majority of the actors and objects are the same and if the patterns of associations are similar. Otherwise, the proposition is not supported.

5.2.1 Comparison between the Representation Common to Both Keypoint 1 Projects and the Representation of Proposition 1

Figure 16 shows the diagrammatic representation that is common to the projects at keypoint 1: Project 1.1 Hardware

Figure 16
Representation Common to Both Keypoint 1
Projects

Table 6

**Relation Between the Responsibilities of Actors and Objects in
in Figure 16 to those in Figures 8, 9A, 9B, and 9C**

Representation Common to Both Keypoint 1 Projects (Figure 16)	Hardware Design (Figure 8)	Composites Automated Manufacturing Initiative (Figure 9A, 9B, and 9C)
Architect	<ul style="list-style-type: none">• Architecture Managers	<ul style="list-style-type: none">• Task Leaders• Designers
Component Design Core Engineers	<ul style="list-style-type: none">• Component Architects	<ul style="list-style-type: none">• Designers
Concept Creator	<ul style="list-style-type: none">• Product Line Management	<ul style="list-style-type: none">• Task Leader• Consortium Management
Specification Group	<ul style="list-style-type: none">• System Engineering• Corporate Design	<ul style="list-style-type: none">• Task Leader• Designers
Resource Provider	<ul style="list-style-type: none">• Executive	<ul style="list-style-type: none">• Program Manager
Architecture	<ul style="list-style-type: none">• Component Architectures	<ul style="list-style-type: none">• Best Concepts
Product Concept	<ul style="list-style-type: none">• Commercial Specification	<ul style="list-style-type: none">• Technical Description
Specification	<ul style="list-style-type: none">• Product Requirements	<ul style="list-style-type: none">• Machine Specification
Resources	<ul style="list-style-type: none">• Business Plan	<ul style="list-style-type: none">• Schedule & Budget• Resources

Platform (Figure 8) and Project 1.2 Composites Automated Manufacturing Initiative (Figures 9A, 9B, and 9C). Table 6 relates the actors and objects in Figure 16 to those in Figures 8, 9A, 9B, and 9C. Appendix A.9 shows how Figure 16 was derived from Figure 8, 9A, 9B, and 9C.

The critical issue highlighted in proposition 1 was that at keypoint 1 the CONCEPT CREATOR, ARCHITECT, and PRODUCT MANAGER coordinated their efforts around different versions of PRODUCT CONCEPT. This clearly was not supported by the representation shown in Figure 16.

Figure 16 suggests that at keypoint 1, RESOURCE PROVIDER, CONCEPT CREATOR, SPECIFICATION GROUP, ARCHITECT, and various COMPONENT DESIGN CORE ENGINEERS secure and apply RESOURCES to add detail to PRODUCT CONCEPT, SPECIFICATION, and ARCHITECTURE. The data suggest that the product management function can be undertaken either by the RESOURCE PROVIDER or the CONCEPT CREATOR.

At keypoint 1, decisions regarding the direction the PRODUCT CONCEPT, SPECIFICATION, and the ARCHITECTURE should evolve result from: i. RESOURCE PROVIDER and CONCEPT CREATOR aligning RESOURCES with PRODUCT CONCEPT, ii. CONCEPT CREATOR and the SPECIFICATION GROUP aligning the PRODUCT CONCEPT with SPECIFICATION, and iii. ARCHITECT and the various COMPONENT DESIGN CORE ENGINEERS aligning the SPECIFICATION with ARCHITECTURE.

There are two major differences between the two keypoint

1 projects. First, in the CAMI project, CUSTOMER (CONSORTIUM MANAGEMENT in Figure 9C) creates the PRODUCT CONCEPT with the CONCEPT CREATOR and selects the ARCHITECTURE that best fits the PRODUCT CONCEPT. CUSTOMER is not involved in the hardware platform project. For this reason, CUSTOMER does not appear in Figure 16, it is not common to both projects. Inclusion of CUSTOMER at keypoint 1 modifies the processes used to align RESOURCES with PRODUCT CONCEPT and ARCHITECTURE with PRODUCT CONCEPT. Inclusion of CUSTOMER reduces the relative power of RESOURCE PROVIDER and CONCEPT CREATOR to determine PRODUCT CONCEPT. When CUSTOMER fixes PRODUCT CONCEPT, the alignment process is mainly one of changing the amount and breakdown of RESOURCES required to deliver PRODUCT CONCEPT.

Second, in the CAMI project the roles of CONCEPT CREATOR, SPECIFICATION GROUP, and ARCHITECT are exercised by the same individuals. In the hardware platform project these roles are undertaken by different individuals. For this reason, the process by which PRODUCT CONCEPT, SPECIFICATION, and ARCHITECTURE are aligned, is much easier in the CAMI project than in the hardware platform project.

5.2.2 Comparison between the Representation Common to Both Keypoint 2 Projects and the Representation of Proposition 2

Figure 17 provides the diagrammatic representation that is common to the projects at keypoint 2: Project 2.1 German Intelligent Network (Figure 10A and 10B) and Project 2.2

Figure 17
Representation Common to Both Keypoint 2
Projects

Table 7

**Relation Between the Responsibilities of Actors and Objects in
in Figure 17 to those in Figures 10A, 10B, and 11**

Representation Common to Keypoint 2 Projects (Figure 17)	German Intelligent Network (Figures 10A and 10B)	Energy Storage Wheel (Figure 11)
Architect	<ul style="list-style-type: none">• HLD Team• Technical Expert	<ul style="list-style-type: none">• Integrator
Component Design Group	<ul style="list-style-type: none">• Design Team• Design Team U.K.• Austrian Telekom Design• SMS Design Team• BTX Design Team	<ul style="list-style-type: none">• Motor Design• Bearing Engineer• Structural Engineer
Architecture	<ul style="list-style-type: none">• HLD	<ul style="list-style-type: none">• Architecture
Component Designs	<ul style="list-style-type: none">• Design Docs	<ul style="list-style-type: none">• Structural Design• Bearing Design• Motor Design
Specification	<ul style="list-style-type: none">• Functional Specification	<ul style="list-style-type: none">• Architecture

Energy Storage Wheel (Figure 11). Table 7 relates the responsibilities of the actors and objects in Figure 17 to the responsibilities of the actors and objects in Figure 10A, 10B, and 11.

The critical issue in proposition 2 was that ARCHITECT, SPECIFICATION GROUP, CONCEPT CREATOR, PRODUCT MANAGER, and COMPONENT DESIGN CORE ENGINEERS simultaneously evolved PRODUCT CONCEPT, SPECIFICATION, and ARCHITECTURE. This was not supported by the representation in Figure 17.

The representations of both projects indicate that at keypoint 2 the designs of the components of the product are already in the process of being developed. Thus, COMPONENT DESIGN GROUPS are very much involved at keypoint 2 while SPECIFICATION GROUP, and CONCEPT CREATOR are not. The critical actors: ARCHITECT and COMPONENT DESIGN GROUPS integrate their efforts to detail the SPECIFICATION, ARCHITECTURE, and COMPONENT DESIGNS.

There are two major differences between the keypoint 2 projects. First, the design manager of the German Intelligent Network Project, readily recognized SPECIFICATION and ARCHITECTURE as being two distinct objects. However, the design manager from the Energy Storage Wheel Project viewed SPECIFICATION as being an attribute of ARCHITECTURE. This view was not shared by the other two respondents in the project. They viewed SPECIFICATION and ARCHITECTURE as being two separate objects.

Second, the means of aligning SPECIFICATION and COMPONENT DESIGNS differed for the two projects. In the German Intelligent Network Project, the clarity of SPECIFICATION allowed the development of a stable ARCHITECTURE. This ARCHITECTURE was then partitioned into various COMPONENT DESIGNS. The COMPONENT DESIGN GROUPS detailed their designs and aligned them with each other through the use of interface specifications and design documents. In the energy storage wheel project, the SPECIFICATION and the ARCHITECTURE were not stable. The COMPONENT DESIGNS evolved at the same time that SPECIFICATION and ARCHITECTURE were changing.

5.2.3 Comparison Between the Representation Common to Both Keypoint 3 Projects and the Representation of Proposition 3

Figure 18 provides the diagrammatic representation that is common to the projects at keypoint 3: Project 3.1 Advanced Intelligent Network (Figures 12A, 12B, and 12C) and Project 3.2 Micro-Mechanical Inertial Measurement Unit (Figure 13). Table 8 relates the actors and objects in Figure 18 to those in Figures 12A, 12B, 12C, and 13.

Proposition 3 states that at keypoint 3, decisions regarding the direction the COMPONENT DESIGNS should evolve are made by a configuration of various COMPONENT DESIGN GROUPS that use the COMPONENT SPECIFICATIONS created by the ARCHITECT to develop COMPONENT DESIGNS to be integrated into a PROTOTYPE by a PROTOTYPE GROUP and tested by a TEST GROUP. Figure 18

Figure 18
Representation Common to Both Keypoint 3
Projects

Table 8

**Relation Between the Responsibilities of Actors and Objects in
Figure 18 to those in Figures 12A, 12B, 12C, and 13**

Representation Common to Both Keypoint 3 Projects (Figure 18)	Advanced Intelligent Network (Figures 12A, 12B, and 12C)	Micro-Mechanical Inertial Measurement Unit (Figure 13)
Component Design Group	<ul style="list-style-type: none">• TPE Development• Call Processing Development	<ul style="list-style-type: none">• Instrument Design• Packaging• Electronics Design
Integration	<ul style="list-style-type: none">• System Integration	<ul style="list-style-type: none">• Test Group
Product Manager	<ul style="list-style-type: none">• Product Line Management	<ul style="list-style-type: none">• Program Manager• Engineering Manager
Test Group	<ul style="list-style-type: none">• Test Group	<ul style="list-style-type: none">• Test Group
Components	<ul style="list-style-type: none">• TPE• Call Processing	<ul style="list-style-type: none">• Production Gyro• IMU pkg• Instr Oper. H/W
Specification	<ul style="list-style-type: none">• System Description	<ul style="list-style-type: none">• Gyro Spec
System Test Feedback	<ul style="list-style-type: none">• System Test Feedback	<ul style="list-style-type: none">• Test Results
System Test Plan	<ul style="list-style-type: none">• System Test Plan	<ul style="list-style-type: none">• Test Plan

provided some support for proposition 3.

The representation common to the two projects differs from that for proposition 3 in two respects. First, the data suggest that there is no PROTOTYPE GROUP responsible for generating component and system prototypes from the COMPONENT DESIGNS. The data suggest that COMPONENT DESIGN GROUPS develop their own COMPONENT prototypes.

Second, COMPONENT DESIGN GROUPS coordinate around the SPECIFICATION, not the ARCHITECTURE. The SPECIFICATION is used as the basis for integrating development efforts around functional requirements.

The representation in Figure 18 suggest that, at keypoint 3, decisions regarding the direction the COMPONENT DESIGNS should evolve are made by a configuration of groups comprised of the COMPONENT DESIGN GROUPS, INTEGRATION GROUP and TEST GROUP working to develop and integrate COMPONENTS to meet the functional requirements as outlined in the SPECIFICATION.

There are four differences between the representation for the Advanced Intelligent Network Project as shown in Figure 12A, 12B, and 12C and the representation of the Micro-Mechanical Inertial Measurement Unit Project shown in Figure 13. First, actors in the Advanced Intelligent Network Project validate each COMPONENT using the structure shown in Figure 19. Actors in the Micro-Mechanical Inertial Measurement Unit Project do not validate COMPONENTS individually. The reason

Figure 19

**Component Validation Structure for Project 3.1:
Advanced Intelligent Network**

for this was that there was one critical COMPONENT which embodied the bulk of the functionality of the SPECIFICATION. This COMPONENT was used to define the other COMPONENTS.

Second, in the Micro-Mechanical Inertial Measurement Unit Project one of the COMPONENT DESIGN GROUPS contributes to SPECIFICATION as well as uses it. This COMPONENT DESIGN GROUP defines the work efforts of the other COMPONENT DESIGN GROUPS. In the Advanced Intelligent Network Project the COMPONENT DESIGN GROUPS did not contribute to the SPECIFICATION.

Third, in the Advanced Intelligent Network Project INTEGRATION GROUP created SYSTEM INTEGRATION which was validated using the SYSTEM TEST PLAN to produce SYSTEM TEST FEEDBACK. In the Micro-Mechanical Inertial Measurement Unit Project, the role of INTEGRATION GROUP was performed by TEST GROUP. As a result, SYSTEM INTEGRATION was not visible in this project and was excluded from Figure 18.

Fourth, in the Advanced Intelligent Network Project all COMPONENT DESIGN GROUPS influence SYSTEM TEST PLAN and use SYSTEM TEST FEEDBACK. In the Micro-Mechanical Inertial Measurement Unit Project only the COMPONENT DESIGN GROUP responsible for the critical COMPONENT contributes to the SYSTEM TEST PLAN and uses SYSTEM TEST FEEDBACK.

5.2.4 Comparison Between the Representation Common to Both Keypoint 4 Projects and the Representation of Proposition 4

Figure 20 provides the diagrammatic representation that is common to the projects at keypoint 4: Project 4.1 Falcon (Figures 14A and 14B) and Project 4.2 Interferometric Fiber Optic Gyro (Figure 15). Table 9 relates the actors and objects in Figure 21 to those in Figures 14A, 14B, and 15.

The critical issue in proposition 4 is, that at keypoint 4, decisions regarding the direction the product design should evolve are made by a configuration of actors, comprised of the ARCHITECT, various COMPONENT DESIGN GROUPS, PILOT PLANT, and TEST GROUP, working to integrate the learning from the use of the prototype into the product design. Proposition 4 was not supported by Figure 21.

Figure 20 differs from the representation of proposition 4 in two ways. First, the data suggests that ARCHITECT and CUSTOMER do not participate in the evolution of the PRODUCT at keypoint 4. Proposition 4 assumed that they would. Second, COMPONENT DESIGN GROUPS produce their own COMPONENTS which are integrated into PRODUCT. There is no PILOT PLANT creating PROTOTYPES at keypoint 4.

The representation in Figure 20 suggests that, at keypoint 4, decisions regarding the direction the PRODUCT should evolve are made by a configuration of groups comprised of the PRODUCT MANAGER, COMPONENT DESIGN GROUPS, and

Figure 20
Representation Common to Both Keypoint 4
Projects

Table 9

**Relation Between the Responsibilities of Actors and Objects in
in Figure 20 to those in Figures 14A, 14B, and 15**

Representation Common to Both Keypoint 4 Projects (Figure 20)	Falcon (Figures 14A and 14B)	Interferometric Fiber Optic Gyro (Figure 15)
Component Design Group	<ul style="list-style-type: none">• SW Development Managers• SW Developers• HW Development Managers• HW Developers	<ul style="list-style-type: none">• Photonics Designers• Mechanical Designers• Electronics Designers
Integration	<ul style="list-style-type: none">• SW Developers	<ul style="list-style-type: none">• Integrator
Product Manager	<ul style="list-style-type: none">• Product Line Management	<ul style="list-style-type: none">• Program Manager
Components	<ul style="list-style-type: none">• Code• Unit Code• Hardware	<ul style="list-style-type: none">• Photonics Module• Env. & Pkg Module• Det & Control Module
Product	<ul style="list-style-type: none">• Product	<ul style="list-style-type: none">• Product
Specification	<ul style="list-style-type: none">• Product Spec	<ul style="list-style-type: none">• Specification

INTEGRATION GROUP working to align PRODUCT to SPECIFICATION.

There are four differences between the representation of the Falcon Project shown in Figure 14A and 14B and the representation of the IFOG Project shown in Figure 15. First, in the Falcon Project the COMPONENT DESIGN GROUPS test COMPONENTS. In the IFOG Project the COMPONENT DESIGN GROUPS do not test COMPONENTS. Second, in the Falcon Project the role of INTEGRATION GROUP is performed by one of the COMPONENT DESIGN GROUPS. In the IFOG Project the role of INTEGRATION GROUP is performed by individuals not in COMPONENT DESIGN GROUPS. Third, in the Falcon Project DESIGN FILES are being transferred from one of the COMPONENT DESIGN GROUPS to MANUFACTURING. In the IFOG Project MANUFACTURING is not involved. Fourth, in the Falcon Project a separate group verified COMPONENTS and there was no validation of PRODUCT. In the IFOG Project a TEST GROUP validated PRODUCT and there was no validation of COMPONENTS.

5.3 REASONS FOR DIFFERENCES IN REPRESENTATIONS

Six reasons seem to account for the differences in representations across respondents. First, in some of the interviews design managers forgot about particular actors and objects within the project. For example in the CAMI project the design manager forgot about the Management Module.

Second, in a few instances R2 and R3 associated actors and objects with a keypoint, however, the design manager disagreed with this view. For example, in Project 2.2: Energy

Storage Wheel, R2 identified PROGRAM DIVISION, PROGRAM MANAGER, and ARCHITECT simultaneously evolving IDEA, SPECIFICATION, and SYSTEM ARCHITECTURE. The design manager recognized that this cluster of actors was present at keypoint 1 but insisted that it was no longer critical at keypoint 2.

A third reason for the difference in representations was that respondents aggregated and partitioned actors and objects differently. For example, in the Advanced Intelligent Network project the design manager identified: MARKETING and REGION. R2 aggregated these two actors into MARKETING, while R3 aggregated the same two actors into REGIONAL MARKETING.

Fourth, the data suggests that actors in the same level of the organizational hierarchy but in different functions viewed the project structure differently. For example in the Falcon project, the design manager provided much of the detail of the Development Module, whereas R3 provided the details of the Market Module. This difference was prevalent in very large projects.

In addition, the data suggests that actors within the same function at different levels of the hierarchy also provided different views of the project. Typically, the lower the level in the hierarchy, the greater the specificity of actors associated with particular task responsibilities. Whereas, respondents at higher levels in the hierarchy provided more of a system level view. For example in the Falcon project, R2 a higher level manager, provided actors

which were the individuals who reported to him, such as MARKETING MANAGERS. Whereas, R3 provided the details of the group. R3 identified the groups working for MARKETING MANAGERS: GLOBAL NPI and MARKETING REGIONS.

It is apparent that certain design managers did not see the relevance of particular parts of the coordination structure to their efforts, although they did not necessarily say that it did not exist. This is the fifth reason for the differences in representations. Design managers excluded components not viewed as being relevant from their synthesized representations. In particular, in the Micro-Mechanical Inertial Measurement Unit project and the Energy Storage Wheel project, an entire Management Module was excluded from the design managers final representation.

Sixth, the lack of a shared view of particular actors and objects. In certain projects, differences existed between the responses about particular actors, actor responsibilities, objects, or the content of the objects. In addressing these actors or objects the design manager explicitly disagreed with their existence. In these types of differences, the other respondents response could not be explained. For example in the Micro-Mechanical Inertial Measurement Unit project, the design manager did not perceive SYSTEM ENGINEERING. The role of SYSTEM ENGINEERING was performed by R3. As a result, R3 was excluded from the design manager's final representation.

5.4 DIFFERENCES BETWEEN THE TWO ORGANIZATIONS PARTICIPATING IN THE STUDY

The two organizations in this research, a telecommunications equipment manufacturer and a weapon systems R&D organization, exhibited three major differences: i. extent to which the architect and the architecture were visible, ii. perspective of the management system, and iii. variance in the perspectives of what was the coordination structure of the project.

The weapon systems R&D organization made no efforts to make the architecture of the product visible. The telecommunications manufacturer invests in making the architecture visible and using it as the basis to anchor the product development efforts. Based on the data there appears to be two reasons for the differences. First, in the weapon systems R&D organization a large portion of their products are developed around a critical component. The design of this critical component determines the design of the supporting components. The specification typically reflects the functionality of the critical component. Therefore the specification can be used to define the activities of the critical component and the resulting configuration defines the structure of the supporting components avoiding the need for coordinating around the architecture.

Second, it is not apparent that individuals in the projects within the weapon systems R&D organization had the

appropriate skill set to perform the architecture role. Most activities were directed around particular functions. There did not appear to be any actor who had the ability to take a system level view and capture the various components' functional and performance requirements and interfaces and abstract the implementation technology to optimize a solution.

The respondents from the projects within the two organizations took very different perspectives of their management systems. Respondents in the telecommunications equipment manufacturer were very design oriented and perceived management as providing a supporting role of their design efforts.

Respondents in the weapon systems R&D organization provided a more elaborate view of their coordination structures. Their system level representations could be easily partitioned into a design and a management module. The management module included actors and objects that were not involved in the design module and were perceived as adding unnecessary complexity to the design module.

The extent of the shared view of the projects by the respondents within a project varied more in the telecommunications equipment manufacturer than in the weapon systems R&D organization. This appears to be largely a result of the difference in project size. The smallest project in the telecom equipment manufacturer had 130 people, whereas the other organization had a project as small as 10 people.

CHAPTER 6

ANSWER TO RESEARCH QUESTION AND CONCLUSIONS

The objective of this thesis was to examine the coordination structure of complex development projects at various keypoints in the product development cycle. The object based approach used focused on diagrammatic representations of the interdependencies between the actors and the objects that exist in the problem domain rather than on the prevalent approach comprised of examining sentential representations of interdependencies between pairs of activities.

The specific research questions addressed in this thesis are:

1. What are the differences across phases of new product development in coordination structures of project organizations that produce designs of complex systems?
2. What new knowledge is provided by using object based modelling in the above context?

The first two sections in this chapter provide answers to the two research questions. Section 6.3 provides the conclusions for the thesis. Limitations of the research and suggestions for future research are provided in Section 6.4 and 6.5 respectively.

6.1 DIFFERENCES ACROSS PHASES OF NEW PRODUCT DEVELOPMENT

Figures 16, 17, 18, and 20 provide the representations common to both projects at keypoint 1, 2, 3, and 4 respectively. I use four attributes to describe the state of each keypoint: i. relevant actors in the representations, ii. shared objects in the representation, iii. underlying configuration of the shared objects in the representation, iv. nature of integration. Tables 10 and 11 describe the four keypoints in terms of these four attributes.

Keypoints 1 and 2 represent the beginning and the end of the creation phase, keypoint 3 represents the midpoint of the development phase, and keypoint 4 represents the midpoint of the implementation phase.

Differences in Actors

The number of actors involved at each keypoint ranged from two to six. PRODUCT MANAGER was the only actor that was identified in the three phases of product development. Table 10 shows that at keypoint 1 there are more different roles involved in product development than at any other keypoint. However, the actual number of people involved in a project at keypoint 1 is probably less than the number of people involved in that project at any other keypoint.

Differences in Shared Objects

Table 10 shows that the number of shared objects identified at each keypoint ranged between three and four. SPECIFICATION was the only shared object that was identified

Table 10
Characterization of the Coordination Structure of Project Organizations
Producing Designs of Complex System at Each Keypoint

Phases	CREATION		DEVELOPMENT	IMPLEMENTATION
Keypoint Description	KEYPOINT 1 Manager allocates resources to help define a new product concept	KEYPOINT 2 Case for development funding is made	KEYPOINT 3 Midpoint in development	KEYPOINT 4 Midpoint in field testing
Actors	Individuals representing groups: Architect Component Design Core Engineers Concept Creator Resource Provider Specification Group	Groups: Architect Component Design Groups	Groups: Component Design Groups Integration Group Product Manager Test Group	Groups: Component Design Groups Integration Group Product Manager
Critical Objects that are Aided Upon	Product Concept Specification Architecture Resources	Component Designs Specification Architecture	Component Specification System Test Feedback System Test Plan	Components Specification Product

Table 11
Characterization of the Coordination Structure of Project Organizations
Producing Designs of Complex System at Each Keypoint

Phases	CREATION		DEVELOPMENT	IMPLEMENTATION
Keypoint Description	<p>KEYPOINT 1 Manager allocates resources to help define a new product concept</p>	<p>KEYPOINT 2 Case for development funding is made</p>	<p>KEYPOINT 3 Midpoint in development</p>	<p>KEYPOINT 4 Midpoint in field testing</p>
Underlying Configuration	<p>SEQUENTIAL</p>	<p>PARALLEL</p>	<p>CONCURRENT</p>	<p>INTEGRATING</p>
Nature of Integration	Resources evolve into product concept, specification, and architecture	Specification and architecture are used to maintain consistency in the evolution of component designs	Specification, system test plan, and system test feedback are used to maintain consistency in the evolution of components	Specification is used to maintain consistency in the integration of components into product

in all four keypoints. PRODUCT CONCEPT and RESOURCES were unique to keypoint 1, COMPONENT DESIGNS were unique to keypoint 2, SYSTEM TEST FEEDBACK and SYSTEM TEST PLAN were unique to keypoint 3, and PRODUCT was unique to keypoint 4.

Differences in Underlying Configuration of Shared Objects

The figures shown in Table 11 are transformations of Figures 16, 17, 18, and 20. The shared objects have a one to one correspondence between the representations in Table 11 and the representations in Figures 16, 17, 18 and 20. The linkages between shared objects shown in the figures in Table 11 have a one to one correspondence with the actors in the original representations shown in Figures 16, 17, 18, and 20.

Differences in Function of Internal Integration

The figures in Table 11 provide the underlying configurations of the coordination structures for the four keypoints. They have analogies to the configuration of computer networks denoted: Sequential, Parallel, Concurrent, and Integrating.

At keypoint 1, resources are integrated into a product concept, a specification, and an architecture in a sequential fashion. At keypoint 2, the specification and architecture of the product integrated into the designs of the various components in a parallel fashion.

The specification of the product, the system test plan and feedback for the system tests are used to maintain consistency in the development of components at keypoint 3 in

a concurrent fashion. The specification is used to integrate components into product at keypoint 4.

6.2 NEW KNOWLEDGE PROVIDED BY USING OBJECT BASED MODELLING

System Level View of Coordination

Object based diagrammatic representations provide the ability to examine interdependencies of multiple actors in a way that was not possible before. The object based approach provides a symbolic formalism for constructing and analyzing system level views of coordination structure. Each representation can be characterized in terms of dimensions that describe the nature of integration at the system level. Cross-section or longitudinal comparisons are then possible.

In this thesis, I have used an object based approach to examine the literature on organizational behaviour, product development management, and design management in order to make visible various coordination structures at the system level. I have then used the same approach to make visible coordination structures using data from real projects. I have been able to make cross-sectional and longitudinal comparisons of representations of coordination.

Library of Templates

Object based diagrammatic representations provide a library of modules that can be used to examine alternative ways to manage integration in a specific problem domain or across problem domains. For example, Bailetti and Callahan (1993) identified five object-based modules in international

collaborative agreements. The representation of their Strategic Management Module is provided in Figure 21. It can be readily used as a template to identify similar modules in other representations.

The German Intelligent Network (GIN) project represented in Figure 10 was an international collaborative arrangement. The Strategic Management Module for the GIN project can be readily found in Figure 10. It is shown in Figure 22. Contrasting the modules in Figures 21 and 22 provides two insights: i. INTENT can be used to create a shared view of the purpose of an international development effort and ii. CUSTOMER can contribute to and manage INTENT as a means of ensuring its requirements are fulfilled.

Using object based modelling provides a means of contrasting different instances of a module that can be maintained in a library. The module can be evolved as new and more detailed information is gained.

Activity Specification and Allocation

A shared view of object based representations of a project can be used to provide the framework for task specification and allocation. Tasks can be specified and allocated after the context set by the object based representation of the coordination structure of a project is agreed upon. Defining tasks in this manner provides a means of incorporating coordination needs into all tasks.

Figure 21
Strategic Management Module of International
Collaborative Arrangements

Figure 22
German Intelligent Network: Strategic Management Module

The Mechanics of Integration

Object oriented modelling can provide low level details on the means of integrating actors efforts. Attributes of actors and shared objects as well as those of their associations can be identified and examined at any level of detail.

For example, Figure 23 represents the configuration of actors around the architecture in the German Intelligent Network Project. In this configuration the architecture is used as the basis for managing the internal consistency of component design efforts. Object modelling provides a systematic way to make visible the information that is hidden in Figure 23 to the lowest level of detail.

6.3 CONCLUSIONS

The importance of coordination in new product development is well documented in the literature. To date, research has examined coordination using activities as the relevant unit of abstraction. In this thesis an object based diagrammatic approach was used to examine coordination in new product development. It made visible the actors, the objects, and what the actors do to the objects when they coordinate their activities.

A detailed review of the literature and the use of the object based representational approach provided the means to generate propositions on the coordination structure of development projects at four keypoints in the new product

Figure 23
Configuration of Actors Around the Architecture in the
German Intelligent Network Project

development cycle. Data from two projects at each keypoint were collected.

The data was compared against the propositions by comparing four representations of the common elements of the two projects for each keypoint against four propositions. For each comparison, the differences between the proposition and the representation common to the two projects were identified. Salient differences between the representations of the two projects were also identified. The results indicate that there was a difference between the coordination structure of organizations producing designs of complex systems in practice and the representations of organizations producing designs of complex systems derived from the literature.

The research indicates that in the first phase of new product development actors coordinate their efforts through an architecture which is used to maintain internal consistency in component design evolution. In the second and third phases of new product development actors direct and coordinate their efforts around the system design and its validation. Product manager and the specification maintain the consistency of the development effort throughout the entire new product development cycle.

I perceive that the representations common to the keypoint projects can be generalized to the population of project organizations producing designs of complex systems embodying multiple components which are not dominated by

physical design but rather focus towards hardware and software design. The partitioning of the responsibilities may differ but all coordination structures within this domain will exhibit similar actors and objects.

These common representations are based on the perspectives of designers. It is expected and has been made visible in the data that designers and managers perspectives differ. As a result, the common representations can not be generalized to managers.

6.4 LIMITATIONS OF RESEARCH APPROACH

Three limitations of the research approach are noted. First, results from a longitudinal research approach would have provided additional information relevant to the thesis that was not provided by this approach. However, time and cost constraints did not permit the researcher to follow projects throughout their entire life.

Second, the object based approach that led to the design system representations requires interaction between the researcher and the individuals providing the information. This may be questioned by those who support passive non invasive approaches to the collection of information by the researcher. However, the steps in the research method described in section 4.3.1 is essentially a modelling exercise intended to make visible the actors, objects, and associations in a design system. Therefore, the trade-off is between the benefits achieved in terms of a more detailed description of

the coordination structure of the design system that results from researcher-respondent interactions and the potential cost of bias introduction.

Third, the use of one respondent in the synthesis of the three representations for each project introduced some bias. Design managers may tend to favour their responses over the responses provided by the other respondents. A synthesis of the three representations by the three respondents would yield greater insight and be less biased. Although very time consuming, the technique would facilitate: i. the capture of the reasons for the different representations and ii. the creation of a synthesis representation which is a more accurate depiction of reality.

6.5 SUGGESTIONS FOR FUTURE RESEARCH

Three areas for future research have been identified. First, research can focus on architecture and how it maintains internal consistency in the evolution of component designs. Research could be initially focused on providing a clear definition of architecture and characterizing alternate configurations of actors and objects around the architecture.

Second, Clark and Fujimoto (1991) noted that internal consistency of the information assets or objects was important for new product development success. The process of maintaining this internal consistency between objects could be the focus of future research. Initially, the critical objects which should be consistent can be identified. Then, the

nature of the inconsistencies between these objects can be characterized and the strategies used to close the gaps between the inconsistencies in the objects can be represented in an object based framework.

Third, further research could be directed at examining the configuration of actors around the validation of the system design. This research indicates a dominant configuration exists in the process of system design validation. Examining this dominant configuration and any of its variations could be the focus of future research.

REFERENCES

- Akin, O. 1984. An Exploration of the Design Process. In Developments in Design Methodology, ed. N. Cross, 189-205.
- Allen, T. J., M. L. Tushman, and D. M. S. Lee. 1979. Technology Transfer as a Function of Position in the Spectrum from Research Through Development to Technical Services. Academy of Management Journal. Vol. 22 No. 4: 694-708.
- Axel Johne, F. and P.A. Snelson. 1988. Success Factors in Product Innovation: A Selective Review of the Literature. Journal of Product Innovation Management. Vol. 5:114-128.
- Bailetti, A. J. and J. R. Callahan. 1992. Coordination Ensembles for Standards Management. Working Paper, Research Center in Telecommunications Technology Management. Department of Systems and Computer Engineering, Carleton University.
- Bailetti, A. J. and J. R. Callahan. 1993. The Coordination Structure of International Collaborative Technology Arrangements. R & D Management. Vol 23 No. 2: 129-146.
- Bailetti, A. J., J. R. Callahan, and P. DiPietro. 1993. A Coordination Structure Approach to the Management of Design Projects: The Case of Custom Silicon. Working Paper, Research Center in Telecommunications Technology Management. Department of Systems and Computer Engineering, Carleton University.
- Baker, M. J. and R. McTavish. 1976. Product Policy and Management. McMillan.
- Booch, G. 1991. Object Oriented Design. Redwood City, California: The Benjamin/Cummings Publishing Company.
- Booz, Allen and Hamilton, Inc. 1968. Management of New Products. New York: Booz, Allen and Hamilton.
- Booz, Allen and Hamilton, Inc. 1982. New Products Management for the 1980s. New York: Booz, Allen and Hamilton.
- Calantone, R. J. and C. A. di Benedetto. 1988. An Integrative Model of the New Product Development Process: An Empirical Validation. Journal of Product Innovation Management. Vol. 5:201-215.

- Chase, R. B. and N. J. Aquilano. 1992. Production and Operations Management: A Life Cycle Approach, Sixth Edition. Homewood, IL. Irwin.
- Clark, K. B. and T. Fujimoto. 1991. Product Development Performance: Strategy, Organization, and Management in the World Auto Industry. Boston, MA: Harvard Business School Press.
- Cooper, R. G. 1979. The Dimensions of Industrial New Product Success and Failure. Journal of Marketing. Vol. 43 (Summer):93-103.
- _____. 1983. A Process Model For Industrial New Product Development. IEEE Transactions on Engineering Management. Vol. 30 (February):2-11.
- _____. 1986. Winning at New Products. Toronto: Holt, Rinehart, and Winston of Canada, Limited.
- _____. 1990. New Products What Distinguishes the Winners?. Research Technology Management. Nov-Dec:27-31.
- Cooper, R. G. and A. J. Kleinschmidt. 1986. An Investigation Into the New Product Process: Steps, Deficiencies, and Impact. Journal of Product Innovation Management. Vol. 3:71-85.
- Dougherty, D. 1992. Interpretive Barriers to Successful Product Innovation in Large Firms. Management Science. May 2:179-202.
- Franke, D. W. and M. K. Purvis. 1991. Hardware/Software CoDesign: A Perspective. IEEE 13th International Conference on Software Engineering. Austin, Texas. May 13-16:344-352.
- Frischmuth, D. S. and T. J. Allen. 1969. A Model for the Description and Evaluation of Technical Problem Solving. IEEE Transactions on Engineering Management. Vol. 16:58-64.
- Fujimoto, T. 1989. Organizations for Effective Product development: The Case of the Global Automotive Industry. Ph.d. diss. Harvard University.
- Galbraith, J. 1973. Designing Complex Organizations. Reading, MA: Addison-Wesley Publishing Company.

- Gladstein-Ancona, D. and D. F. Caldwell. 1987. Management Issues Facing New-Product Teams in High-Technology Companies. Advances in Industrial and Labour Relations. Vol. 4:199-221.
- Guindon R. 1990. Designing the Design Process: Exploiting Opportunistic Thoughts. Human-Computer Interaction. Vol. 5: 305-344.
- Gupta, A.K., S.P. Raj, and D. Wilemon. 1985. The Marketing-R&D Interface in High Technology Firms. Journal of Product Innovation Management. Vol. 2: 12-24.
- Gupta, A.K., S.P. Raj, and D. Wilemon. 1986. A Model for Studying R&D-Marketing Interface in the Product Innovation Process. Journal of Marketing. Vol. 50 (Apr): 7-17.
- Gupta, A.K., and D. Wilemon. 1990. Improving R&D/Marketing Relations: R&D's Perspective. R&D Management. Vol. 20 No. 4: 277-290.
- Jacobson, I., M. Christerson, P. Jonsson, and G. Overgaard, 1992. Object Oriented Software Engineering. Menlo Park, CA: Addison Wesley.
- Jain, P. P. 1991. Architectural Models are Key to System-Level Design. Electronic Design. Mar 28: 57-70.
- King, S. 1973. Developing New Brands. Pitman.
- Kotler, P. 1976. Marketing Management: Analysis, Planning, and Control. Prentice Hall. 3rd ed.
- Krajewski, L. J. and L. P. Ritzman. 1990. Operations Management Strategy and Analysis, Second Edition. Don Mills, ON: Addison-Wesley Publishing Company.
- Larkin, J. and H. A. Simon. 1987. Why a Diagram is (Sometimes) Worth Ten Thousand Words. Cognitive Science. Vol. 11: 65-99.
- Lucas, G.H. and Alan J. Bush. 1988. The Marketing-R&D Interface: Do Personality Factors Have an Impact?. Journal of Product Innovation Management. Vol. 5:257-268.
- Luckman, J. 1984. An Approach to the Management of Design. In Developments in Design Methodology, ed. N. Cross, 83-97.

- Maidique, M. A. and B. J. Zirger. 1984. A Study of Success and Failure in Product Innovation: The Case of the U.S. Electronics Industry. IEEE Transactions on Engineering Management. Vol. 4 (November): 192-203.
- Maidique, M. A. and B. J. Zirger. 1985. The New Product Learning Cycle. in IEEE Transactions on Engineering Management.
- Malone, T. M. and K. G. Crowston. 1990. What is Coordination Theory and How Can it Help Design Cooperative Work Systems. CSCW 90 Proceedings. Oct: 357-370.
- Malone, T. M. and K. G. Crowston. 1991. Toward an Interdisciplinary Theory of Coordination. Technical Report #120. Center for Coordination Science, Massachusetts Institute of Technology. Cambridge, MA.
- McTavish, C. 1985. Approaching the New Product Organization Problem: Favour Flexibility and Variety of Attack. European Journal of Marketing. Vol 18 No. 6/7: 30-42.
- Mintzberg, H. 1989. Mintzberg on Management. New York: Collier Macmillan Publishers.
- Nadler, D. A. and M. L. Tushman. 1992. Formal Organization Arrangements: Structure and Systems. In The Management of Organizations, ed. M. L. Tushman, C. O'Reilly, and D.A. Nadler.
- Nobeoka, K. and M. A. Cusumano. 1992. Multi-Project Strategy and Organizational Coordination in Automobile Product Development. Working Paper # 3487-92/BPS. MIT Sloan School of Management.
- Philipson, L. 1990. Multilevel Design and Verification of Hardware/Software Systems. IEEE Journal of Solid-State Circuits. Vol. 25 No. 3: 714-719.
- Quinn, J. B. 1985. Managing Innovation: Controlled Chaos. Harvard Business Review. Vol. 53 (May-June): 73-84.
- Roozenburg, N. F. M. and N. G. Cross. 1991. Models of the Design Process: Integrating Across the Disciplines. Design Studies. Vol. 12 No. 4.
- Rothwell, R., Freeman, Horsley, Tervis, Robertson, and Townsend. 1974. SAPHO Updated-Project SAPHO Phase II. Research Policy. Vol. 3: 258-291.

- Rothwell, R. and A. B. Robertson. 1973. The Role of Communications In Technological Innovation. Research Policy. Vol. 2: 204-225.
- Rumbaugh, J., M. Blaha, W. Premerlani, F. Eddy, and W. Lorenson. 1991. Object-Oriented Modelling and Design. Englewood Cliffs: Prentice Hall.
- Saren, M. A. 1984. A Classification and Review of Models of the Intra-Firm Innovation Process. R&D Management. Vol. 14 No. 1: 11-24.
- Souder, W. W. 1988. Managing Relations Between Marketing and R&D in New Product Development Projects. Journal of Product Innovation Management. Vol. 5: 6-19.
- Thompson, J. D. 1967. Organizations In Action. New York, NY: McGraw-Hill Book Company.
- Turabian, K. L. 1987. A Manual for Writers of Term Papers, Theses, and Dissertations. Chicago: University of Chicago Press.
- Van de Ven, A. H. 1986. Central Problems in the Management of Innovation. Management Science. May: 103-122.
- Van de Ven, A. H, A. L. Delbecq, and R. Koenig. 1976. Determinants of Coordination Modes Within Organizations. American Sociological Review. Vol. 41: 322-338.
- Von Hippel, E. 1988. Task Partitioning: An Innovation Process Variable. Working Paper # 2030-88. MIT Sloan School of Management.
- Voss C. A. 1985. Determinants of Success in the Development of Application Software. Journal of Product Innovation Management. Vol. 3: 134-144.
- Wheelwright, S. C. and K. B. Clark. 1992. Revolutionizing Product Development: Quantum Leaps in Speed, Efficiency, and Quality. Toronto, ON: Maxwell MacMillan Canada.
- Womack J. P., D. T. Jones, and D. Roos. 1990. The Machine That Changed The World. New York: Rawson/MacMillan.
- Zirger, B. J. and M. A. Maidique. 1990. A Model of New Product Development: An Empirical Test. Management Science. Vol. 36 No. 4: 867-883.

APPENDIX A.1: ACTORS AND OBJECTS IDENTIFIED IN THE LITERATURE

A.1.1 Actors Identified in the Product Development Management Literature

Clark and Fujimoto 1991; Fujimoto 1989 Information Processing Framework	Customer Designers Planners Process Engineering Product Engineering Product Planning Engineers Production
Clark and Fujimoto 1991; Fujimoto 1989 Concept Generation	Concept Creator Core Engineers Customer Dealers Industrial Designers Planning Office Product Manager Top Management Users
Product Planning	Component Design Engineers Concept Creator Cost Planners Product Engineers Product Manager Product Planner Production Suppliers Styling Group Test Group
Product Engineering	Component Design Engineers Component Test Group Drafters Process Engineering Process Planning Engineers Prototype Department Vehicle Test Group
Process Engineering	Engineering Contractors Equipment Manufacturers Pilot Plant Process Engineering Production Tool Shops Vehicle Test Group Workers

NEWPROD I (Cooper 1979)	Market Marketing Technical and Production Group
NEWPROD II (Cooper & Kleinschmidt 1986)	Business Financial Analysis Group Competitor Customer Design and Development External Sources of Knowledge In-House Test Group Market Launch Group Precommercial Business Analysis Group Preliminary Market Assessment Group Preliminary Technical Assessment Group Salesperson
NEWPROD III (Cooper 1990)	Engineering Market Marketing Production R&D
Stanford Innovation Project (Maidique and Zirger 1984, 1985; Zirger and Maidique 1990)	Champion Customer General Management Introduction Team Manufacturing Market Marketing & Sales Product Development Team Project Manager R&D/Engineering
McTavish (1985)	Market Marketing New Product Planning Committee Product Engineering Group/R&D Sales Top Management

<p>Nobeoka and Cusumano (1992)</p>	<p>Design Engineers Other Engineering Functions Project Manager</p> <p>Design Engineer Functional Manager Manufacturing Engineer Other Engineering Functions Other Engineering Managers Project Manager</p>
<p>SAPPBO (Rothwell et al 1974)</p>	<p>External Sources of Technology Successful Firm User</p>
<p>Wheelwright and Clark (1992)</p> <p>Actors present in all Phases</p> <p>In phase II In phase IV</p>	<p>Customer Engineering Manufacturing Marketing Suppliers Field Service Personnel Sales Force</p>

**A.1.2 Objects Identified in the Product Development
Management Literature**

Clark and Fujimoto 1991; Fujimoto 1989 Information Processing Framework	CAD Databases Component Breakdown Component Prototype Drawings Early-stage Prototypes Engineering Prototype Future Market Needs Information on Other Conditions Interior Mockups Layout Physical Models Process Design Product Product Concept Product Design Product Plan Production Factors Production Inspection Results Production Performance Test Results Technical Possibilities Test Results
--	---

Clark and Fujimoto 1991; Fujimoto 1989	Dealer and User Feedback
Concept Generation	Early Information on Production Constraints
	Long Range Plan
	Market Surveys
	Product Concept
Product Planning	Basic Technical Assumptions
	CAD Simulation
	Clay Model
	Engineering Drawings
	Engineering Prototypes
	Mechanical Prototypes
	Pilot Vehicles
	Plastic Models
	Product Plan (made up of:)
	Component Choices
	Layout
	Parts Commonality Plan
	System Cost Targets
	Technical Targets
	Styling Sketch
Product Engineering	Component Parameters
	Detailed design
	Engineering Changes
	Functional Designs
	Interior Mockups
	Parts Engineering
	Prototypes
	Parts Plans
	Physical Models
	Piece Parts Drafts
	Prototype Test Results
	Sub-Assembly Drawings
	Targets
	Vehicle Engineering
	Prototypes
Process Engineering	Dies
	Early Production Feedback
	Equipment & Tools
	Individual Process Plans
	Pilot Runs
	Pilot Vehicles
	Process Plan
	Standard Operating Procedures
	Test Results
	Tool & Equipment Tryouts

NEWPROD I (Cooper 1979)	Market Knowledge Product Resources
NEWPROD II (Cooper & Kleinschmidt 1986)	Advertising Alternative Products Market Understanding Product Published Data Training
NEWPROD III (Cooper 1990)	Pre-development Activities Product Product Concept Product Definition Project Target Market Customer Needs, Wants, and Preferences
Stanford Innovation Project (Maidique and Zirger 1984, 1985; Zirger and Maidique 1990)	Development Process Product Product Concept
McTavish (1985)	Commercialization Approval Idea Product Resources Technical Developments
Nobeoka and Cusumano (1992)	Base Design Other Major Component Designs Component Designs "State of the Art" Technologies Technology Component Issues Technology Outputs Inputs and Intermediate Outputs
SAPPHO (Rothwell et al 1974)	Education External Technology & Scientific Advise Successful Innovation Understanding of User Needs

Wheelwright and Clark (1992)	
Phase I	Market Based Input Models New Technologies Process Concepts Product Concepts Product Ideas Product Simulations
Phase II	Components Cost Estimates Early System Prototypes Estimates of Sales and Margins Process Architecture Process Simulation Product Architecture Target Customer Parameters
Phase III	Detailed Process Design Detailed Product Design Full-Scale Prototypes Second-Phase Prototypes Tooling & Equipment
Phase IV	Pilot Units Training
Phase V	Commercial Objectives Field Experiences Volume Production

A.1.3 Actors Identified in the Design Management Literature

Akin (1984)	Designer
Franke and Purvis (1991)	Hardware Engineering Software Engineering Systems Engineer
Frischmuth and Allen (1969)	Consultants Customer Customer's Technical Personnel Environment Management Other Customer Agencies Problem Solver Project Group Representatives of Government Agencies Technical Staff Vendors
Guindon (1990)	Customer Design Colleagues Designer
Jain (1991)	Design Engineer
Luckman (1984)	Design Team Evaluation Team
Philipson (1990)	Designer

A.1.4 Objects Identified in the Design Management Literature

<p>Akin (1984)</p> <p>Pre-Sketching Phase</p> <p>Sketching Phase</p>	<p>Inconsistent Symbols</p> <p>Known Publications</p> <p>New Symbol Relations</p> <p>Problem Documents</p> <p>Problem Representation</p> <p>Sources of Information</p> <p>Inconsistent Symbols</p> <p>Known Publications</p> <p>New Information Sources</p> <p>New Partial Solution</p> <p>Problem Documents</p> <p>Specification of Current Solutions</p> <p>Transformations</p>
<p>Franke and Purvis (1991)</p>	<p>Abstract Component Notation</p> <p>Function</p> <p>Hardware Model</p> <p>Product Requirements</p> <p>Software Model</p> <p>Specification</p> <p>System Architecture</p> <p>System Model</p> <p>User Model</p>
<p>Frischmuth and Allen (1969)</p>	<p>Alternative Solutions</p> <p>Analysis Results</p> <p>Component Designs</p> <p>Critical Evaluation Dimensions</p> <p>Information</p> <p>Initial Conditions</p> <p>Literature</p> <p>Preliminary Analysis of Alternative Solutions</p> <p>Product Definition</p> <p>Test & Experiment Results</p>

Guindon (1990)	High Level Design Information Knowledge of Computer Science Partial Solutions Problem Domain Scenarios Software System Architecture Solution Specification
Jain (1991)	Architectural Models Data-Flow Diagram Design Specification Model Parameters Requirements
Luckman (1984)	The Brief Constraints Design Experiences Evaluation Criteria New Information Potential Solution Previous Level Decisions System Design Technology
Philipson (1990)	Algorithms Formalized System Specification Functional Models Hardware/Software Partitioning Implementation Technology Model Development Plan System Structure

APPENDIX A.2

ACTOR AND OBJECT CLASSES

A.2.1 Actors Identified in the Literature

ACTOR CLASS	NAME IN THE LITERATURE	REFERENCE
Architect	System Engineer Problem Solver Design Engineer Designer	Franke & Purvis Frischmuth & Allen Jain Philipson
Champion	Champion	Zirger & Maidique
Competitor	Competitor	Cooper & Kleinschmidt
Component Design Core Engineer	Core Engineers	Clark & Fujimoto
Component Design Groups	Component Design Engineers Styling Group Hardware Engineering Software Engineering	Clark & Fujimoto Franke and Purvis
Concept Creator	Concept Creators Introduction Team	Clark & Fujimoto Zirger and Maidique
Customer	Customer Dealers Users Customer Customer Customer's Technical Personnel Other Customer Agencies Representatives of Government Agencies Customer User Customer Customer	Clark & Fujimoto Cooper & Kleinschmidt Frischmuth and Allen Guindon Rothwell et al Wheelwright & Clark Zirger and Maidique

Design	Designer Designers Drafters Industrial Designers Product Engineers Engineering R&D Design and Development Designer Design Team Design Engineers Other Engineering Functions Engineering R&D/Engineering	Akin Clark & Fujimoto Cooper (1990) Cooper & Kleinschmidt Guindon Luckman Nobeoka & Cusumano Wheelwright & Clark Zirger and Maidique
Environment	Environment	Frischmuth & Allen
Equipment Manufacturers	Equipment Manufacturers Engineering Contractors	Clark & Fujimoto
External Sources of Knowledge & Technology	External Sources of Knowledge Consultants External Sources of Technology	Cooper & Kleinschmidt Frischmuth & Allen Rothwell et al
Field Service Personnel	Field Service Personnel	Wheelwright & Clark
Management	Top Management Management Top Management Functional Manager Other Engineering Managers General Management	Clark & Fujimoto Frischmuth and Allen McTavish Nobeoka and Cusumano Zirger and Maidique

Manufacturing	Production Workers Production Manufacturing Engineer Manufacturing Manufacturing	Clark & Fujimoto Cooper (1990) Nobeoka & Cusumano Wheelwright & Clark Zirger and Maidique
Market	Market Market Salesperson Market Market	Cooper (1979) Cooper (1990) Cooper & Kleinschmidt McTavish Zirger & Maidique
Market Launch Team	Market Launch Team	Cooper & Kleinschmidt
Marketing	Marketing Marketing Marketing Sales Marketing Sales Force Marketing & Sales	Cooper (1979) Cooper (1990) McTavish Wheelwright & Clark Zirger and Maidique
Non-Project Technical Staff	Design Colleagues Technical Staff	Guindon Frischmuth & Allen
Pilot Plant	Pilot Line Technical and Production Group Product Engineering Group/R&D	Clark & Fujimoto Cooper (1979) McTavish
Process Engineers	Process Planning Engineers Process Engineering Tool Shops	Clark & Fujimoto
Product Development Team	Project Group Product Development Team	Frischmuth & Allen Zirger & Maidique
Product Manager	Product Manager Project Manager Project Manager	Clark & Fujimoto Nobeoka & Cusumano Zirger and Maidique

Prototype Group	Prototype Department	Clark & Fujimoto
Specification Group	Cost Planners Product Planner Planners Planning Office Product Planning Engineers Business Financial Analysis Group Precommercial Business Analysis Group Preliminary Market Assessment Group Preliminary Technical Assessment Group New Product Planning Committee	Clark and Fujimoto Cooper & Kleinschmidt McTavish
Successful Firm	Successful Firm	Rothwell et al
Suppliers	Suppliers Vendors Suppliers	Clark & Fujimoto Frischmuth & Allen Wheelwright & Clark
Test Group	Test Group Component Test Group Vehicle Test Group In-House Test Group Evaluation Team	Clark & Fujimoto Cooper & Kleinschmidt Luckman

A.2.2 Objects Identified in the Literature

OBJECT CLASS	NAME IN THE LITERATURE	REFERENCES
Advertising	Advertising	Cooper & Kleinschmidt
Algorithms	Algorithms	Philipson
Alternative Products	Alternative Products	Cooper & Kleinschmidt
Alternative Solutions	New Partial Solutions Transformations Alternative Solutions Partial Solutions Potential Solutions	Akin Frischmuth & Allen Guindon Luckman
Architecture	Layout System Architecture High Level Design Architectural Models System Design Formalized System Specification System Structure Product Architecture	Clark & Fujimoto Franke and Purvis Guindon Jain Luckman Philipson Wheelwright & Clark
Basic Technical Assumptions	Basic Technical Assumptions	Clark & Fujimoto
Commercial Objectives	Commercial Objectives	Wheelwright & Clark
Commercial-ization Approval	Commercial-ization Approval	McTavish

Component Design	Component Parameters Detailed Designs Functional Designs Component Designs Component Designs Other Major Component Designs Components	Clark & Fujimoto Frischmuth and Allen Nobeoka & Cusumano Wheelwright & Clark
Component Issues	Technology Component Issues	Nobeoka & Cusumano
Component Specification	Component Breakdown Software System Architecture Previous Level Decisions Hardware-Software Partitioning	Clark & Fujimoto Guindon Luckman Philipson
Constraints	Constraints	Luckman
Customer Feedback	Field Experiences	Wheelwright & Clark
Development Process	Pre-development Activities Project Development Process	Cooper (1990) Zirger & Maidique
Drawings	CAD Databases Drawings Engineering Drawings Styling Sketch Piece Parts Drafts Sub-Assembly Drawings	Clark & Fujimoto

Early Information on Production Constraints	Early Information on Production Constraints	Clark & Fujimoto
Education	Training Education	Cooper & Kleinschmidt Rothwell et al
Engineering Changes	Engineering Changes	Clark & Fujimoto
Experiences	Design Experiences	Luckman
External Knowledge	Known Publications New Information Sources Sources of Information Published Data Information Literature Information New Information External Technology & Scientific Advice	Akin Cooper & Kleinschmidt Frischmuth & Allen Guindon Luckman Rothwell et al
Financial Estimates	Cost Estimates Estimates of Sales and Margins	Wheelwright & Clark
Idea	Idea Product Ideas	McTavish Wheelwright & Clark
Implementation Technology	Technology "State-of-The- Art" Technologies Technology Outputs Implementation Technology New Technologies	Luckman Nobeoka & Cusumano Philipson Wheelwright & Clark
Inputs and Intermediate Outputs	Inputs and Intermediate Outputs	Nobeoka and Cusumano

Knowledge of Computer Science	Knowledge of Computer Science	Guindon
Manufacturing Feedback	Production Inspection Results Production Performance Test Results Test Results Early Production Feedback	Clark & Fujimoto
Market Knowledge	Future Market Needs Information on Other Conditions Dealer & User Feedback Market Surveys Market Knowledge Target Market Customer Needs, Wants, and Preferences Market Understanding Understanding User Needs Market Based Input Target Customer Parameters	Clark & Fujimoto Cooper (1979) Cooper (1990) Cooper & Kleinschmidt Rothwell et al Wheelwright & Clark
Model Development Plan	Model Development Plan	Philipson

Models, Parameters, and Simulations	CAD Simulations Hardware Model Software Model System Model User Model Preliminary Analysis and Alternative Solutions Critical Evaluation Dimension Problem Domain Scenarios Data-Flow Diagram Model Parameters Evaluation Criteria Functional Models Models Product Simulations	Clark & Fujimoto Franke & Purvis Frischmuth & Allen Guindon Jain Luckman Philipson Wheelwright & Clark
Pilot Product	Pilot Vehicles Pilot Units	Clark & Fujimoto Wheelwright & Clark
Pilot Runs	Pilot Runs	Clark & Fujimoto
Process Architecture	Process Architecture	Wheelwright & Clark
Process Concept	Process Concept	Wheelwright & Clark
Process Design	Process Design Detailed Process Design	Clark & Fujimoto Wheelwright & Clark
Process Plan	Process Plan Individual Process Plans Standard Operating Procedures	Clark & Fujimoto
Process Simulation	Process Simulation	Wheelwright & Clark

Product	Product Product Product Product Product Successful Innovation Product	Clark & Fujimoto Cooper (1979) Cooper (1990) Cooper & Kleinschmidt McTavish Rothwell et al Zirger & Maidique
Product Concept	Problem Representation Product Concept Product Definition Product Concept Abstract Component Notation Function Specification Product Requirements Product Definition Specification Design Specification Requirements Product Concept Product Concept	Akin Clark & Fujimoto Cooper (1990) Franke and Purvis Frischmuth and Allen Guindon Jain Wheelwright & Clark Zirger and Maidique
Product Design	Product Design Solution Detailed Product Design	Clark & Fujimoto Guindon Wheelwright & Clark
Production Factors	Production Factors	Clark & Fujimoto

Technical Possibilities	Technical Possibilities Technical Developments	Clark & Fujimoto McTavish
Tools & Equipment	Dies Equipment & Tools Tool & Equipment Tryouts Tooling & Equipment	Clark & Fujimoto Wheelwright & Clark
Training	Training Training	Clark & Fujimoto Wheelwright & Clark
Volume Production	Volume Production	Wheelwright & Clark

APPENDIX A.3

CLASS RESPONSIBILITY DICTIONARY

ACTORS:	RESPONSIBILITY:	KEYPOINT:
Architect	Defines the system level design, component selection, and component interface	1,2,3,4
Component Design Core Engineers	Represents a particular component group participating in the project to ensure that the issues and concerns related to the component are addressed prior to full component group participation	1,2
Component Design Groups	Produces the designs of the components to specification	3,4
Concept Creator	Creates and champions the new product concept in the initial stages of product development	1,2
Customer	Commercial user of the new product	4
Manufacturing	Representative championing particular manufacturing issues in the project	1
Marketing	Representative championing particular marketing issues in the project	1
Pilot Plant	Initial manufacturing facility responsible for generating prototypes and testing manufacturability of the design	4
Product Manager	Coordinates across functional units for a particular product or product line	1,2

ACTORS:	RESPONSIBILITY:	KEYPOINT:
Prototype Group	Group responsible for generating a prototype of the components and the system from the detailed designs	3,4
Specification Group	Actor responsible for defining the functionality and performance requirements/constraints of the new product concept.	2
Test Group	Group responsible for performing tests on systems and components to verify conformance to defined functionality and performance requirements/constraints	3,4

NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
ANSI and ISO TEST CHART No. 21

OBJECTS:	DEFINITION:	KEYPOINT:
Architecture	Allocation of the functionality of the components along with major component selection and component interface characterization (Guindon 1990)	2
Component Issues	Information about the performance parameters of the components and their structure at the interfaces along with a system level configuration of components	3
Component Specification	Definition of functionality and performance requirements/constraints of the components along with a characterization of the component interfaces	3
Customer Feedback	Information about customer experiences with product	4
Manufacturing Feedback	Feedback about the performance of the design in initial production runs	4
Product Concept	"What the new product should do or should mean to the target customer" (Fujimoto 1989, p. 613). Includes a description of the target customer, high level technical targets/specifications, and holistic product structure. The initial idea around which the product development project is anchored.	2

OBJECTS:	DEFINITION:	KEYPOINT:
Product Concept (Initial)	The actors initial conceptualizations of the product ideas based on their perceptions of the product concept	1
Product Design	The synthesis of the product concept, product definition, architecture, component specification, detailed design, and prototype test results	4
Prototype	Full scale functional form of the component(s) or system	3,4
Prototype Test Results	Test results from system or component level verification of adherence to functionality and performance parameters	3,4
Specification	Definition of functionality and performance requirements of the new product concept (Guindon 1990)	2

APPENDIX A.4

DESCRIPTION OF SAMPLE PROJECTS

The prefix number identifies the keypoint of the project. The projects from the telecommunications equipment manufacturer have a suffix number one. The projects from the weapons system R&D organization have a suffix number two.

Project 1.1: Hardware Platform

This project involves the development of a hardware platform to support existing and future software functionality.

Project 1.2: Composites Automated Manufacturing Initiative

This project involves the development of a machine system and an in-process control system for the manufacture of advanced composites. The project is being sponsored by a consortium and the U.S. governments Advanced Research Projects Agency (ARPA). The weapon systems R&D organization has been hired to develop concepts for the project. At the initial keypoint, the project team, consisting of employees from the weapon systems R&D organization and external representatives from the consortium, will assess current features of advanced composites desired by designers and fabricators of space, air, land, and sea vehicles. Alternative technologies for processing systems will be analyzed and the three most promising concepts will be identified. From this, the most promising concept will be identified and funded. A

conceptual model of the machine will be developed and subjected to particular cost and performance requirements.

Project 2.1: German Intelligent Network

This project involved the development of an intelligent network for the German Bundespost. The intelligent network involves the attachment of a database function to switches within the telecom network. Two additional subsystems must be developed: i. for the switches to interface with the database and the German telecom network, and ii. for operations, administration, and maintenance of the database function. The development efforts are distributed across four companies in nine sites across North America and Europe.

Project 2.2: Energy Storage Wheel

This project involves the synthesis of two previously separate components of a space vehicle, the batteries for energy storage and the flywheels for attitude control. The intent of the project is to design a system of wheels that will store energy and provide attitude control for the vehicle. The requirements on the system are of sufficient complexity to require a new wheel design.

Project 3.1: Advanced Intelligent Network (AIN)

This project involves the development of a system that provides an interface in which number information is exported from a telecommunications switching system to an external computer which is used to develop specific features. The AIN system requires flexibility to meet the changing requirements

of the various customers. The system is largely a software project, building on existing hardware.

Project 3.2: Micro-Mechanical Inertial Measurement Unit

This project involves the development of a mass producible micro-mechanical device. The device is an inertial sensor with a number of expected applications, for example inertial guidance of projectiles and payloads or auto navigation and anti-skid systems for cars. The device consists of two different types of sensors, which are pieces of silicon etched in such a way to sense subtle changes in inertia, and the electronics used to interpret the data from the sensors. The objectives of the project is to achieve a particular sensing capability with the device under particular weight and price constraints.

Project 4.1: Falcon

This project involves the development of a new switching product, with both hardware and software components. This switching product, Falcon, is being developed as a means of broadening the telecommunications equipment manufacturers business in telecommunications. Current efforts in this project are being focussed at completing system and component tests and developing the business collaterals (for example support services, documentation, and training) in preparation for market introduction.

Project 4.2: Interferometric Fiber Optic Gyro

The purpose of this project is to produce a fiber optic gyro with a life of at least fifteen years without any moving parts for deep space navigation. The fiber optic gyro would also be developed to provide a stable platform for a camera when it is pointing at a planet. At this point in time the component designs are being implemented and updated, the components are undergoing failure analysis, and the product undergoing full tests.

APPENDIX A.5

DATA COLLECTION AND ANALYSIS PROTOCOLS

The data collection steps are outlined in the three protocols below. The protocols relate back to data collection steps i, ii, and iv outlined in section 4.3.

A.5.1 Protocol for Initial Interviews

The following questions were asked in the interview:

1. The project is closest to which of the following keypoints?
 1. new product concept is being defined
 2. development is about to be funded or has been recently approved for funding
 3. development is halfway complete
 4. field test is halfway complete
2. In general terms what is the objective of the development project?
3. What tools and methods are being used in the development of the design at this keypoint?
4. What objects (entities, concepts, abstractions or things both formal and informal with crisp boundaries which are recognizable to the actors within the domain of this project) are acted upon or used around the keypoint? Please describe each object.
5. What actors act upon or use the various objects? Please describe the responsibility of the actor within this project organization.

6. What are the linkages between the actors and the objects?

Questions 4 through 6 will be iterated until the respondent is satisfied with the responses. The questionnaire will be supplemented with a bipartite object based graph in which the respondents, with the help of the researcher, will illustrate the coordination structure of the project.

A.5.2 Iterate Three Representations With Design Manager Protocol

For each of the projects, a representation of the design manager's perspective incorporating the views of the other respondents representations of the coordination structure was generated. This followed two steps.

1. The three responses from question 2 regarding the purpose of the project were presented to the design manager. The design manager's response was identified and he/she was asked to note any differences which existed between his/her definition and the other two definitions in the following two question:
 - i. what are the differences between your response and the responses provided by the other two actors?
 - ii. why do you think these differences exist?
2. The design manager then made a final formal statement of what the purpose of the project was. The rationale for any modifications were elicited from the design manager.
3. The responses to questions 4, 5, and 6 were presented to the design manager. The design manager's responses were

identified and he/she was asked to identify the differences between his/her responses and the other responses in the following two question:

- i. what are the differences between your response and the responses provided by the other two actors?
 - ii. why do you think these differences exist?
4. The three models were synthesized to represent the design managers perceptions of reality. Reasons for the configuration of the final model were elicited from the design manager. Outputs of this synthesis included a class responsibility dictionary and an object model of the coordination structure of the project.

A.5.3 Elicitation of Managerial Implications of Object Based Modelling Protocol

This protocol involved the following three steps:

1. The design manager was asked the following questions
 1. what is(are) the critical object(s) in this system?
 2. who are the critical actors that influence the object?
 3. Who is the "customer" in this system? What objects are used to coordinate with the customer?
2. The responses from these questions were used to reconfigure the object based representation of the project organization. Associations between the critical actors, the project team, and the customer were discussed.

3. Based on the reconfigured representation, the design manager was asked to identify the means of embodying customer expectations into the critical objects, the method of validating the design against customer expectations, and how the project team interacts with a standard. The results and implications from the above responses were discussed.

APPENDIX A.6

OBJECTIVES OF THE PROJECTS IN THE SAMPLE

The following are responses to the question: "what is the objective of the project?" provided by the three respondents during the first interview. The first response was provided by the design manager.

Project 1.1: Hardware Platform Project

Objective of the project can not be discussed.

Project 1.2: Composites Automated Manufacturing Initiative

1. To develop cost-effective automated equipment and machinery for manufacturing composite structures to reduce the acquisition costs of composites.
2. To review state-of-the-art composite manufacturing technology, and based on market assessments determine new composite needs for the aerospace market.
3. To develop new and innovative machine concepts for manufacturing composites based on technological and economic justification.

Project 2.1: German Intelligent Network

1. Contract with the German Bundespost to build and deliver intelligent network services for the German market.
2. To deliver a series of intelligent network products to the German Bundespost.
3. To deliver an intelligent network system into the German telecommunications network and to become the third

telephone equipment supplier to the Bundespost.

Project 2.2: Energy Storage Wheel

1. To develop an energy storage wheel with dual applications in energy storage and attitude control, reconfigure the existing system to provide the necessary functionality, and consider composites rather than metals to maximize the energy generated per pound.
2. Internal R&D effort to develop a concept for satellite applications which would take three of the existing systems on a satellite: actuator for attitude, batteries, and gyro, and configure them into one system.
3. To look at the potential of having a wheel which will provide energy storage and attitude control for space vehicles.

Project 3.1: Advanced Intelligent Networks

1. To take current telephone networks and break it into pieces, develop service switching points, try to allow external control of calls, and develop interfaces with the switch and with the end user.
2. To develop an interface on a switching system that allows the export of number information to an external computer which could be used to develop specific features.
3. To deliver a software package in 1993-1994 time frame to meet the demands of the customer base as outlined in a specification provided by the customer. Other non-revenue specific goals are to use AIN as a justification

for software modernisation on the existing switching system and to provide a new platform for designing services.

Project 3.2: Micro-Mechanical Inertial Measurement Unit

1. Advanced Research Project Agency funded project to develop a high g accelerometer.
2. To develop a micro-mechanical sensor and the associated electronics and controls focusing on two markets: military inertial guidance systems for projectiles or payloads, and commercial for example, anti-skid and air bag systems for automobiles.
3. To make the smallest inertial system in a weight goal of 50 grams below a cost of US\$ 500.

Project 4.1: Falcon

1. To develop a new high performance data switching product which can be used as a technology base for possible different products.
2. To develop a new product to add to the portfolio to broaden the business by addressing new and emerging network communication for data, voice, and video.
3. To produce a next generation product to stimulate growth of data communications and maintain the leadership the organization has in data switching.

Project 4.2: Interferometric Fiber Optic Gyro

1. To develop an instrument capable of keeping a camera on

- board a satellite stable when it is pointing at a planet.
2. To develop a fiber optic high performance gyroscope for satellite and deep space applications.
 3. To produce a high performance navigation grade fiber optic gyro for deep space navigation and pointing and tracking problems.

APPENDIX A.7

RESPONSIBILITIES OF OBJECTS AND ACTORS INCLUDED IN THE DESIGN MANAGERS REPRESENTATION OF PROJECTS IN THE SAMPLE

OBJECTS		Appendix A.7-1.1 Project 1.1: Hardware Platform		
		R1	R2	R3
Business Plan	statement of R&D expenditure, projected revenues, and marketing issues		✓	
Commercial Spec	formal list of product requirements, defines what the product has to do		✓	
Component Architecture	abstract definition of a components functionality, configuration, interfaces, and characteristics	✓	✓	✓
Product Requirements	definition of the specific requirements to be met by the product to fit the market		✓	

ACTORS		R1 R2 R3		
		R1	R2	R3
Architecture Managers	responsible for component definition, product strategy with respect to the existing portfolio of products, development estimates, and development team membership	✓	✓ ₁	✓
Component Architects	responsible for development of the architecture of a particular component	✓	✓ ₁	✓
Corporate Design	responsible for ensuring that product meets the companies standards of corporate image		✓	
Executive	senior managers responsible for running the business		✓	
Product Line Management	responsible for defining the product requirements in the Commercial Spec and creating the business plan		✓	✓
System Engineering	responsible for providing information on the network requirements of the product, so that the product will be compatible with other systems		✓	

1 : aggregated under architecture group

Appendix A.7-1.2
Project 1.2: Composites Automated Manufacturing Initiative

OBJECTS		R1	R2	R3
Best Concepts	top five ideas for the final system	✓	✓	✓
Customer Needs	what the customer feels is the manufacturing/development problem and what he feels the solution might be and what the team feels he needs	✓ ₃	✓	
Customer Perceptions	what the customer thinks he/she is getting	✓ ₄		✓
Design Information	information from previous research efforts, literature searches, and brainstorming sessions that outline component vendors and their processes and how concepts map together to meet customer requirements	✓ ₃	✓	
House of Quality	tool used to represent and identify customer desires and relate those to engineering characteristics	✓	✓ ₁	✓ ₁
Ideas	design concepts generated by designers where previous technologies are reconfigured	✓	✓	✓
Machine Spec	derivative of house of quality translates house of quality into prose	✓		
MFG Processes	information about the customers manufacturing processes including: cycle time, materials, tooling costs, production volume, and rate requirements	✓	✓	✓
Mock Ups	physical form of a major component of the system used to verify the assumptions of that particular technology/design	✓	✓	✓
Project Feedback	information to the customer on the progress of the project	✓ ₄		✓
Resources	facilities and people necessary to achieve milestones on budget	✓ ₄		✓
Risk Assessment	verification of tree of assumptions created in making the concepts and cost analysis	✓	✓ ₂	✓ ₂
Schedule & Budget	timing of milestones and their technical requirements and amount of money to spend at each milestone to achieve objectives	✓ ₄		✓

1 : represented as two objects; House of Quality & Pugh Chart

2 : identified cost analysis

3 : represented as two objects; Data & Component Analysis of Alternatives

4 : error of omission

Appendix A.7-1.2
Project 1.2: Composites Automated Manufacturing Initiative

OBJECTS

		R1	R2	R3
Statement of Work	outline of processes to follow and what to accomplish	✓		
Technical Objectives	high level technical description of each of the milestones	✓ ₄		✓
Test Results	results of how particular subsystems of design concepts have performed based on mockups		✓	

ACTORS

		R1	R2	R3
Consortium Management	responsible for overseeing the entire composite effort and coordinating external activities	✓	✓	
Cost Analysis	responsible for providing a cost analysis of the composite parts to be produced and cost of the concepts to produce the composite parts	✓	✓	✓
Customer	consists of composite parts and machine manufacturers responsible for identifying new technologies	✓		✓
Designers	responsible for generating ideas and sketches and helping out with the house of quality and the Pugh charts	✓	✓	✓
Program Manager	responsible for ensuring task leader handles external interfaces properly and assists in coordinating internal efforts	✓	✓	✓
Task Leader	responsible for coordinating internal efforts and keeping program management (internal) informed of the political situation	✓	✓	✓
Technician	responsible for building mockups and testing them and providing input to the design engineers		✓	
TQM Manager	responsible for coordinating TQM efforts	✓		✓
Upper Management	responsible for monitoring the project to ensure the representation of the organization and the presence of adequate resources			✓

Appendix A.7-2.1
Project 2.1: German Intelligent Network

OBJECTS

		R1	R2	R3
BTX-SMS I/F Spec	functional specification that defines the interfaces between the BTX and the SMS subsystems	✓ ₁	✓	✓ ₁
Contract	commercial obligation between telecom equipment manufacturer and the external design organization		✓	
Customer Feedback	Feedback from the customer about whether the right things are being done to fit the intelligent network services into the German telecom network	✓		
Customer PMM Results	minutes and slides associated with the review between telecom equipment supplier, the customer, and the external design organization		✓	✓
Customer Spec	document that describes the characteristics and service requirements of the product	✓		
Design Docs	functional specification and detailed design documents for the SSP, SCP, and A-link components	✓		✓
Functional Spec	non-technical description of the operation the customer expects from the equipment			✓
HLD	high level design of the product used to verify that customer requirements will be met	✓		✓
Project Plan	document that tracks how the projects components come together to meet the schedule	✓	✓	✓
SCP-SMS I/F Spec	document that describes the protocol between the SCP and the SMS subsystems	✓	✓	✓
SS7	software to meet the German trunk signaling protocol		✓	
SW Environment	development context in the software and documentation library	✓	✓	
Test Book	customer document that describes the criteria by which acceptance is granted	✓	✓	

1 : aggregation of SMS Design Team Actor and BTX Design Team Actor made this object invisible

Appendix A.7-2.1
Project 2.1: German Intelligent Network

ACTORS

		R1	R2	R3
Austrian Telekom Design	Austrian Telekom responsible for implementation of the SS7 program for the 1TR7 protocol	✓ ₂	✓	✓ ₄
BTX Design Team	responsible for the development of the BTX component:	✓ ₁	✓	✓ ₁
Customer	responsible for acceptance and purchase of the product	✓	✓	✓
Design Team	responsible for planning, design, and testing of the SSP, SCP, and A-link components with the appropriate interfaces between the components	✓	✓	✓ ₅
Design Team U.K.	responsible for SS7 design and Austrian Telekom Design	✓ ₂	✓	✓ ₄
External PLM	responsible for negotiation of the program content for the external design organization	✓ ₁	✓	
FAST	responsible for approval of the product and delivery to the field		✓	✓
German Operations	responsible for managing and communicating with the customer	✓ ₃	✓	✓ ₄
HLD Team	responsible for developing a high level design of how to meet customer requirements	✓		
NPI	responsible for project management of the project, tracking the project, and integration of the product specification		✓	
Phase 1 Project Manager	responsible for setting up the project plan and method for meeting customer deliverables and managing A. Telekom deliverables	✓		✓ ₄
Phase 2 Project Manager	responsible for the project and providing the deliverables to the customer	✓		✓
PLM	responsible for tracking the project and interpreting customer requirements	✓	✓ ₆	✓
SMS Design Team	responsible for the development of the SMS component and release of the SMS software	✓ ₁	✓	✓ ₁
Technical Expert	technical expert on the German telecom signal protocol responsible for interpreting customer requirements and reviewing the designs	✓		

1 : aggregated under External Design Team

2 : aggregated under Austrian Telekom Design Team

3 : aggregated under PLM

4 : European actors were not visible to the respondent

5 : represented as two actors; SSP Design Team and SCP Design Team

6 : represented as two actors; PLM and PLM U.K.

Appendix A.7-2.2
Project 2.2: Energy Storage
Wheel

OBJECTS

		R1	R2	R3
Architecture	system configuration, size and weight: constraints, performance specifications and requirements	✓	✓	✓
Bearing Design	bearing requirements of size, losses, types, sensitivities for different conditions and their tradeoffs	✓	✓	✓
Finite Element Models	analytical model of the structure of the system using finite elements, response evaluations of the elements, and overall model analysis for dynamics	✓	✓ ₃	✓ ₁
Mechanical Details	detailed mechanical drawings of all systems according to standard	✓		✓ ₁
Motor Design	multiple alternatives of motor designs varying in size, weights, characteristics, and materials and their tradeoffs	✓	✓	✓
Rotor Dynamics Analysis	rotor dynamics equations to evaluate the stability of the system under all loading conditions	✓	✓ ₂	✓ ₁
Structural Design	configuration, size, materials, stresses, deformation stability, and dynamics characteristics for different configurations of the structure and their tradeoffs	✓	✓ ₂	✓ ₁
System Integration	integration of the subsystems to optimise the system configuration and performance	✓	✓	✓ ₁

1 : represented as two objects; Rotor Design and Mechanical Assembly

2 : represented as two objects; All Composite Wheel Design and Hybrid Composite /Metal Wheel Design

3 : represented as two objects; Finite Element Model and Spreadsheet Results

Appendix A.7-2.2
Project 2.2: Energy Storage
Wheel

ACTORS		R1	R2	R3
Bearing Engineer	responsible for design and analysis of bearing options and trade-off studies	✓	✓	✓
Designer/Drafter	responsible for providing engineering drawings to standard specification and mechanical details		✓	✓
Integrator	responsible for carrying out all tasks and integrating the subsystems into a final product	✓	✓	✓
Motor Engineer	responsible for design and analysis of motor options and trade-off studies	✓	✓	✓
Rotor Dynamics Analyst	responsible for rotor dynamics and stability assessment of the system and shock mount design	✓ ₅	✓	✓ ₄
Structural Designer	responsible for mechanical and structural design, analysis, and the creation of finite element models of the outer structure of the system		✓	✓ ₄

4 : represented as composite wheel designer

5 : represented as two actors; Wheel Engineer 1 and Wheel Engineer 2

Appendix A.7-3.1
Project 3.1: Advanced Intelligent Network

OBJECTS

		R1	R2	R3
Business Need	definition of the business case for the product	✓		✓
Call Processing	software and the architecture for the call processing subsystem	✓		
Call Processing Feedback	results of the tests on the call processing component	✓		
Call Processing Test Plan	outline of the strategy to validate the call processing component	✓		
Commitment	what the customer expects and what the division funding the project expects	✓	✓	
Customer Dialog	information from and to the customer on different levels to establish the business case and the technical need for the product	✓		✓
Early Design Analysis	link between the specification and development stating how the product relates to the specification	✓	✓	
Other Services	definition of the service set for the end user which goes beyond the abilities of the current specification	✓		✓ ₁
Product Spec	a statement of the capabilities and characteristics of the product being defined	✓	✓	
Project Plan	vehicle that tells you the deliverables which need to be provided on specific dates	✓	✓	
Services	definition of the service set for the end user that is enabled by the current specification	✓	✓	✓ ₁
Standards	generic specification of the functionality of the product negotiated by multiple companies of which the product specification is a subset	✓	✓	
Subsystem Integration	synthesis of the services, and the components of the product	✓	✓	
System Description	an amalgamation of the component requirements, the impact of services assessment and the Service requirements	✓	✓	
System Feedback	results of the tests on the system	✓		
System Integration	integration of the A.I.N. product into the telecom system	✓		
System Test Plan	how the product will be tested	✓	✓	
TPE	software and the architecture for the trigger processing environment subsystem	✓		
TPE Feedback	results of the tests on the TPE component	✓		
TPE Test Plan	outline of the strategy to validate the TPE component	✓		

1 : represented in three objects; Service Requirements, SSP Impact of Services, and SSP Requirements

Appendix A.7-3.1
Project 3.1: Advanced Intelligent Network

ACTORS

		R1	R2	R3
Bellcore	central planning and requirements body for RBOCs	✓	✓	
Customer	responsible for providing initial product requirements	✓	✓	✓
Development	responsible for defining the architecture, creating the software, and testing the product; owns the product from cradle to grave	✓	✓	✓
Includes:				
Call Processing Development	responsible for developing the call processing sub-component	✓		
TPE Development	responsible for developing the TPE sub-component	✓		
System Integration Group	responsible for integrating the TPE and the call processing sub-components into an SSP component	✓		
Marketing	responsible for overall customer interface	✓	✓ ₁	✓ ₂
Other Services Development Group	responsible for the definition of new services which the product will provide beyond the current specification	✓		
Planning	responsible for the specification, coordination of the team, and interaction with appropriate external groups	✓	✓	
Product Line Management	responsible for the product and associated business	✓	✓	✓
Region	responsible for the interface with prime customers	✓	✓ ₁	✓ ₂
Services Development Group	responsible for the specification and development of services for the end customer (telephone users)	✓	✓	✓
Test Group	responsible for test and delivery of the product	✓	✓	

1 : aggregated together as Marketing

2 : aggregated together as Regional Marketing

Appendix A.7-3.2
Project 3.2: Micro-Mechanical Inertial
Measurement Unit

OBJECTS

		R1	R2	R3
Customer Objectives	what customer wants in terms of an instrument or the process supporting instrument production	✓		✓
Drawings	definition of the geometry and the design program which predicts performance and determines the specification and the fab process	✓	✓	✓ ₂
Experimental Gyro	represents the next generation gyro in terms of ease of fabrication or performance goals	✓		✓ ₄
Fab Results	results from the fab: instrument, test articles, or better photo resist	✓	✓	✓ ₃
Gyro Spec	near term subset of customer/manager requirements	✓	✓	✓ ₁
IMU Package	current final implementation of the technology	✓		✓
Instrument Oper. HW.	operational HW that puts in inertial and other stimuli and allows the measurement of how the instrument behaves	✓		✓
Production Gyro	current implementation closest to meeting customer objectives	✓		✓ ₄
Test Plan	procedures and equipment necessary to produce test data			✓
Test Results	data validating the production gyro against the specification and identifying any unforeseen problems	✓	✓	✓

1 : represented as three objects; Task Agreement, Requirements Document, and Contract with Customer

2 : represented as two objects; Design Program and Mask Set

3 : represented as two objects; Inspection Feedback and Micro-Mechanical Device

4 : represented as two objects; Micro-Mechanical Device and Product

Appendix A.7-3.2
Project 3.2: Micro-Mechanical Inertial
Measurement Unit

ACTORS

		R1	R2	R3
Customer	provides objectives and approves the specification	✓	✓	✓
Electronic Design	responsible for generating hardware to operate the instrument and equipment to test packaged IMU	✓	✓	✓
Engineering Manager	responsible for overseeing all design and test activities	✓	✓ ₅	✓
Instrument Design	responsible for generating new designs and creating and maintaining accurate design models to explain the test results and generate new designs	✓	✓ ₅	✓
Instrument Fabrication	responsible for producing the instrument, fab results, and experimental instruments	✓	✓ ₅	✓
Instrument Test	responsible for assembling the system and generating test results	✓	✓	✓
Marketing	responsible for helping the program manager to get customers and keep them happy	✓		
Packaging	responsible for form and fit of the IMU package to accommodate the system	✓	✓	✓
Program Manager	responsible for determining team membership, setting overall goals, funding, and satisfying the customer	✓	✓	✓

5 : represented as one actor; Sensor Design Group

Appendix A.7-4.1
Project 4.1: Falcon

OBJECTS		R1	R2	R3
Business Plan	definition of the major business goals for the project and description of how they will be achieved			✓
Code	blocks of code which performs a specific function	✓		✓ ₃
Doc	documentation describing how a customer can manage, configure, and use the product	✓		✓ ₃
Hardware	all of the hardware developed for the system	✓		✓ ₃
Hardware Design Files	description of all of the hardware components as designed	✓		✓ ₃
Market Info	sales presentations, product positioning in the marketplace, sales brochures, and pricing for the product		✓	✓
Market Req/s	specific product requirements for a particular customer or market, and definition of what needs to be done based on trends in the market place			✓
Product	the hardware and software for the product and the user documentation			✓
Product Req/s	what the product should be to meet market requirements			✓
Product Spec	description of the product's features and capabilities, and compliance with the product requirements		✓	✓
Project Plan	collection of project management schedules and processes, and list of major deliverables and their evaluation criteria	✓ ₂	✓ ₁	✓
Sales Forecast Plan	captures the potential revenues of products by geographic area and by application		✓	
Support Services	technical support for hardware and software, customer training services, and other special service offers		✓	✓
SW Interfaces	code and functional interfaces between blocks of code	✓		✓ ₃
Unit Code	entire body of software developed	✓		✓ ₃
Verification Plan	all testing activities performed by the various actors	✓		

1 : identified Project Integration Plan and Product Introduction Plan, a subset of the Project Plan

2 : identified Project Integration Plan, a subset of the Project Plan

3 : aggregated as Product

**Appendix A.7-4.1
Project 4.1: Falcon**

ACTORS

		R1	R2	R3
Business Champion	responsible for total ownership of the value and game plan of the business generated by the product		✓	
Customer	responsible for reviewing the product, includes support services and contributing to trial planning		✓	✓
Development	responsible for defining, architecting, developing, testing, and delivering the product; final tier support service provider	✓	✓	✓
Documentation Group	responsible for documentation of hardware and software; defines format, organisation, and implementation	✓		✓
Global NPI	responsible for successful introduction of the product	✓	✓ ₄	✓
Global Product Support	responsible for managing support policy and processes; second tier global support service provider		✓	✓
HW Developers	responsible for design, simulation, and test of the hardware components	✓		✓ ₅
HW Development Managers	responsible for coordinating hardware builds, HW debug, managing allocation of the hardware into the lab and transfer of design files	✓		✓ ₅
Manufacturing	responsible for introducing new products into manufacturing, and on-going manufacturing based on demand	✓	✓	✓
Marketing Regions	responsible for generating sales, lead marketing activities, bid responses, product announcements, and providing market input on the evolution of the product		✓ ₄	✓
Product Champion	responsible for working with business champion and the architect to ensure the right match between technology push and market pull		✓	
Product Integrity	responsible for ensuring hardware meets corporate standards and complies with regional requirements	✓		✓ ₅
Product Manager	responsible for managing the business, initiating product development in support of the business, and shaping the product based on market and business requirements		✓	✓
SW Developers	responsible for testing and integrating the software units, integrating the software and hardware, and functional testing and debugging	✓		✓ ₅
SW Development Manager	responsible for interfacing with other managers and overall project prime to ensure schedule is tracked	✓		✓ ₅
Verification Group	responsible for developing test verification plans and coordinating and delivering software sub-system and the overall system	✓	✓	

4 : aggregated as Marketing Managers

5 : aggregated as Development Group

Appendix A.7-4.2
Project 4.2: Interferometric Fiber Optic
Gyro

OBJECTS		R1	R2	R3
Det & Control Module	detection, control, and power conditioning modules used to process information from the photonics and the environment	✓	✓	✓
Env & Pkg Module	design of a suitable environment and a form fit package for the instrument to meet requirements	✓	✓	
Feedback	periodic feedback to the customer about the status of the project, results of tests			✓
Photonics Module	component which operates at optical wavelengths	✓	✓ ₁	✓
Product	the photonics module, detection and control module, and the environmental and package module.	✓		✓
QA Feedback	post-mortem of prematurely failed, damaged components	✓ ₂	✓	
Specification	specification from the customer of the desired characteristics of the instrument	✓	✓	✓
Test Bed/Data	rate tables, software and computers which produce test data and the data itself	✓		
Test Results	information about the characteristics of the device from the test data	✓	✓	✓

1 : represented as two objects; Optical Design and Optical Component

2 : error of omission

Appendix A.7-4.2
Project 4.2: Interferometric Fiber Optic Gyro

ACTORS		R1	R2	R3
Analysis	responsible for performing analysis on the data from the test bed and fitting the results into navigation equations	✓	✓ ₂	
Customer	provides funding and a goal	✓	✓	✓
Electronics Designers	responsible for detection signal processing and control loops for the gyro	✓	✓	✓
Integration	responsible for integrating all modules to produce a functioning product	✓		✓
Mechanical Designers	responsible for packaging design and thermal budget of the gyro	✓	✓	✓
Photonics Designers	responsible for specification, design, development and testing of the optical component for the navigation system	✓	✓ ₁	✓
Program Manager	responsible for ensuring the organization delivers the product on time within budget		✓	✓ ₃
QA	responsible for ensuring the delivery of a quality product	✓ ₄	✓	✓
Test Group	responsible for testing of the integrated product and design of the test bed to test requirements	✓	✓ ₂	✓

1 : represented as two actors; Photonics Designers and Vendors

2 : represented as Test & Analysis Group

3 : represented as two actors; Program Manager and System Engineer

4 : error of omission

APPENDIX A.8

RESPONSIBILITIES OF OBJECTS AND ACTORS COMMON TO PROJECTS AT VARIOUS KEYPOINTS

OBJECTS:	DEFINITION:	KEYPOINT:
Architecture	Allocation of the functionality of the components along with component selection and interface characterization	1,2
Component	Elements which make up the final product being developed	3,4
Component Designs	Designs of the components	2
Product	Integration of the components into a operational system	4
Product Concept	A description of the target customer, high level technical targets/ specifications, and holistic product structure. The initial idea around which the product development project is anchored.	1
Resources	Facilities, people, and funding necessary to achieve the milestones of the project	1
Specification	Definition of functionality and performance requirements of the new product concept	1,2,3,4
System Integration	Components integrated into a system	3
System Test Feedback	Test results from system level verification of adherence to functionality and performance parameters	3
System Test Plan	Strategy for testing the functional requirements and performance parameters of the system	3

ACTORS :	RESPONSIBILITY:	KEYPOINT:
Architect	Responsible for developing the architecture	1,2
Component Design Core Engineers	Represents a particular component group participating in the project to ensure that the issues and concerns related to the component are addressed	1
Component Design Groups	Responsible for producing the designs of the components to specification	2,3,4
Concept Creator	Creates and champions the new product concept	1
Integration Group	Responsible for integrating the components into a system	3,4
Product Manager	Responsible for the product development effort and coordination across functional groups	1 ¹ ,3,4
Resource Provider	Manager responsible for providing resources and tracking the project	1
Specification Group	Responsible for defining the functionality and performance requirements/constraints of the new product concept	1
Test Group	Responsible for performing tests on systems and components to verify conformance to defined functionality and performance requirements/constraints	3

¹

Present at keypoint 1 as either CONCEPT CREATOR or RESOURCE PROVIDER.

Appendix A.2

Derivation of the Representation of Keypoint 1 Projects from Figure 16

The derivation of the representation of the CAMI project from Figure 16 and the derivation of the representation of the hardware platform project from Figure 16 are shown on the following pages. These representations illustrate how Figure 16 was generated. The actors and objects from the individual representations mapped into the roles of the actors and objects from the common representation in three different ways. First, there may have been a one to one relationship between the actor or object in the individual representations and the actor or object in the common representation. For example in Figure B the role of RESOURCE PROVIDER was performed by the PROGRAM MANAGER in the CAMI project. Second, the role of the actor or object from the common representation may have been distributed across a number of actors or objects in the individual project representations. For example, in Figure A the role of SPECIFICATION GROUP in cluster 2 was distributed across SYSTEM ENGINEERING and CORPORATE DESIGN.

Third, the role of the actor from the common representation may have been distributed across a number of actors in the individual project representations and these actors integrated their efforts through particular objects not in the common representation. For example in Cluster two of Figure B, the role of CONCEPT CREATOR was distributed across CONSORTIUM MANAGEMENT and TASK LEADER who integrated their efforts through STATEMENT OF WORK.

Appendix A.2

Derivation of the Representation of the Hardware Platform Project from Figure 16

Figure A

Cluster One

Cluster Two

Cluster Three

Appendix A.2

Derivation of the Representation of the CAMI Project from Figure 16

Figure B

Cluster One

Cluster Two

Cluster Three

END

'20-07-94

FIN