NORWEGIAN NATURAL GAS TRANSPORTATION SYSTEMS

Operations in a Liberalized European Gas Market

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A dissertation submitted to

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Faculty of Mechanical Engineering
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in partial fulfillment of the requirements for the degree of
"Doktor Ingeniør"

April 2001

Preface

In January 1992 the author took on the position as operations manager heading the Bygnes Control Center at Karmøy, Norway. This center is currently responsible for approximately 90% of the Norwegian natural gas transport operations. Following this position, which lasted for about five years the author started working with business development of the transportation systems.

At that point in time – in early 1997 – when the author moved into the latter position, the development of the European Union's Gas Directive was rapidly approaching its hectic finalization stage. The author, who became a member of a Statoil internal working group on the issue got quite involved in commenting – on behalf of Statoil – the different drafts that were released from Brussels.

The Gas Directive initiated many questions – but few answers were found. A growing recognition thus developed in the company and in the author's mind as well, that a thorough study was needed in order to find solutions on how to respond to the forces of change introduced by the Gas Directive. From January 1998 and up till now, this has been the author's full time job.

The story presented here documents this study. It aims to fill a gap in knowledge by answering some questions of how liberalization in the European gas market may affect Norwegian natural gas transport operations. The ultimate goal of the story is to find out how the Norwegians shall govern and conduct the natural gas transport operations in the North Sea in the near future.

As the author will show the story draws upon accumulated knowledge from several disciplines such as those applied by engineers, economists and lawyers. A core task of the thesis is thus to combine and utilize the knowledge of the different disciplines. This is done in such a way that the suggested solutions are adjusted and aligned to satisfactorily represent possible future "real world" applications – and in such a way that all major stakeholders' needs are met as far as possible and feasible.

This is a challenging task, indeed and the only way found feasible by the author to comprehend it was to have the work conducted and governed by a recognizable systems approach – an approach designed for engineering complex systems. This approach thus represents a new and modern way of solving tasks as specified here. The fruit that such an approach is bearing, are

results that go beyond – to some extent – those results that are obtained by traditional and less multidisciplinary approaches.

Authors occupying themselves with handling complex issues may find writing about it difficult. So it apparently was for one of the authors of the old Apocrypha, the author of The Second book of the Maccabees, way back in year 161 B.C. [1] That author was writing about complex issues in the old Hebrew society at the time and he was describing how to handle them. Finding the writing difficult the author reveals for the reader his own thoughts and evaluation of his work by the following words:

"If it is well told and to the point, that is what I myself desired; if it is poorly done and mediocre, that was the best I could do."

Having revealed such an honest statement the author from the distant past eventually expressed his hope that the reader would appreciate his work of describing complex issues and finding appropriate solutions by the following metaphor:

"For just as it is harmful to drink wine alone (i.e. the wine at that time was quite strong), or, again, to drink water alone (i.e. the water was often of poor quality), while wine mixed with water is sweet and delicious and enhances one's enjoyment, so also the style of the story delights the ears of those who read the work. "

These wishes and words of the old writer communicate this author's intentions as well. And finally then – for the sake of completeness – the analyses, opinions, and conclusions expressed in this work are entirely those of the author and should not be interpreted as reflecting the views or positions of the supporting organizations and institutions.

Trondheim, April 2001

Hans Jørgen Dahl

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[1] Chapter 15.38-39

Acknowledgement

There are many persons that deserve my deep thanks for their support, encouragement and valuable contributions in the form of comments, suggestions and answers to my many questions and draft documents. As it is impossible to mention them all by name my general gratitude is meant for them all.

There are however some few persons and organizations that should be mentioned specifically here:

- My employer, Statoil for its kind and generous support and financing of the work. The author is also thankful for all the assistance given to me by many colleagues.
- Professor Odd Andreas Asbjørnsen at NTNU who so sadly passed away in the spring of 1999. His stimulating and encouraging discussions in the early stages of the work were quite important to me.
- Adjunct Professor and Chief Engineer in Statoil, Karl Sjøen who challenged me in the first place to take a "Dr. ing." study at NTNU.
- Academic advisor Professor Otto K. Sønju at NTNU for his genuine interest in the work and for his professional advising. The many fruitful and encouraging status meetings, carried out during the last four years, have contributed much to the work.
- Main thesis supervisor Adjunct Professor Ole Jørgen Hanssen at NTNU for his professional support on systems theory, methodologies and research approaches. It has been a very stimulating and fruitful experience to draw upon his many years of research experience and scientific knowledge.
- Thesis supervisors Professor Kåre Petter Hagen at Norwegian School of Economics and Business Administration (NHH) and Dr. juris. Ulf Hammer at the Scandinavian Institute of Maritime Law. I am very grateful for the excellent support that has been given me over the last three years and the many interesting and instructive discussions we have had on complicated issues related to economics, regulation and law.
- My gratitude also goes to Executive Director Dr. Denny Ellerman and staff of the Center for Energy and Environmental Policy Research at Massachusetts Institute of Technology for all the assistance, support and informative discussions that were offered to me during my one year stay as a visiting researcher. The excellent research working conditions and

facilities, the many meetings and courses attended proved to be very valuable and fruitful for the work.

- My thanks also go to the many representatives of various companies and institutions visited in North America who so kindly shared their valuable experiences with me.
- My thanks also go to Siv. ing. Lars Bjarne Rørvang in Statoil who assisted me in the gas flow optimization simulations and to Dr. ing. Thor Bjørkvoll at The foundation for Science and Industrial Research (SINTEF) for interesting discussions.
- Finally, the author is also thankful to the anonymous reviewers of International Council on Systems Engineering (INCOSE) for comments offered on the first two papers and to the company Ascent Logic for letting me using a free copy of the RDD-100 computer program.

This book is dedicated to my wife Hellen and my four children, who made it all possible with their patience and co-operation.

Abstract

The main hypothesis tested in this work is:

"It is possible to operate future Norwegian natural gas transportation systems at a level that is approximately optimal, technically and economically, with major stakeholders duly attending to requirements specified in the Norwegian statutory framework and in the implemented "Gas Directive."

In order to test this hypothesis a multidisciplinary systems approach has been applied that includes analyses based on fluidmechanics and thermodynamics, economic theory and constrained by the prevailing and future legislative requirements. Operational experiences and empirical data also support the analyses.

It is assumed in this work that the introduction of the European Union's Gas Directive will result in some new or altered legal requirements for how to conduct future Norwegian natural gas transport operations. The work has identified these new requirements and the work has suggested realistic solutions for how to conduct future operations. The author therefore concludes that the main hypothesis above is true provided five recommendations are observed.

The first recommendation is to implement into the Norwegian legislation provisions that make possible two core requirements of the Gas Directive. The first provision is to allow domestic gas sellers to compete in the downstream market by marketing and selling their gas individually. The second provision is to allow access to the transportation systems for those stakeholders who according to the Gas Directive are defined as "eligible customers" and "natural gas undertakings", i.e. the future shippers.

The second recommendation follows as consequence of the latter provision and it recommends the future Norwegian regulatory regime to incorporate three main features. First, the transportation system is to be operated by an organization unit that has a transparent account on its transportation services or alternatively by an organization (i.e. the operator) that is functionally separated from and does not participate in any gas marketing and sales activities.

Secondly, and due to the fact that the Norwegian natural gas

transportation systems are highly physically integrated it is recommended to have one and only one transportation system operator. Only one operator will be in the best position to enhance cost efficiency in daily operations, energy efficiency, resource management in daily operations, optimized utilization and optimized gas blending.

Thirdly, new and altered transportation services must be designed to meet the future needs and requirements of the shippers and these services must be offered to all shippers. The latter feature is elaborated in the third recommendation.

The third recommendation is to redefine and develop new transportation services that support shippers' elastic demands for transportation services, both during periods of sufficient capacity as well as during peak load periods.

The above recommendation will imply that the future transportation services must comprise firm services i.e. booked and guaranteed transportation, and interruptible services i.e. transportation being interrupted either during off-peak periods or during peak periods as well as peak load services i.e. transportation services offered during peak load periods. The services must be offered to all shippers in an equal and impartial manner and be supported by a transparent and feasible tariff and toll regime. The toll regime must feature several properties that ensure recovery of fixed costs, cost efficiency in operations and maintenance, and rationing efficiency and this work recommends that the future toll regime shall be reasonable and fair and cost-based.

This work has identified that the existing toll regime does not feature all of the above properties and this work therefore suggests that the existing toll regime is re-designed and extended to include new elements. The first recommendation is to re-design the existing toll formula so that it acts as a two-part toll for firm capacity.

The fixed part of the toll shall act as a booking charge or capacity charge and it shall cover the financial costs based on the historic investment costs for the pipeline systems. It shall also include the fixed (annual) operations and maintenance costs, and any new costs for incremental new investments. The variable part of the toll may be set equal to average marginal costs per unit of gas, or be paid "in kind" as done in the current regime.

Further, a unitization of the fixed part of the firm toll is suggested here. The unitization shall include all pipelines that comprise the dry gas system. This means that the fixed part of the firm toll shall be calculated as an average fixed toll based on the historic investment costs for all the pipelines included. The unitization schema shall include the existing ship-or-pay contracts and

any new firm contracts in the dry gas system.

The unitization will accomplish a possibility for eliminating specific shipper's preferences for where to physically route gas in the dry gas system. This will subsequently improve rationing efficiency at high levels of utilization of the system when there is a concurrent need for auctioning of spare capacity. This is due to the physical behavior of the integrated system as any "internal" pre-booked routing in the system effectively may reduce the total throughput and thus a rationing efficient utilization of the system.

The above recommendations mean that the firm toll shall be charged as a "postage-stamp" toll for all pipeline systems comprising the dry gas systems. This means in practical terms that the dry gas system is to be considered as one zone only and pre-defined entry points and exit points must be established.

As a consequence of unitizing the toll for firm capacity either a unitization of the ownership structure must be done or a payment mechanism must be in force that secures the pipeline owners no extra profit or loss due to the introduction of unitization.

A new two-part toll formula that in its form is equal to the firm capacity toll is recommended for covering interruptible off-peak services. It is recommended to set the fixed part of the toll lower than the fixed part of the firm toll.

A new toll must be developed and be based on auctioning principles for allocation of spare capacity in the system during peak load periods. In order to facilitate the auction a tool is required for predicting the level of spare capacity that is available from time to time. This tool is also needed for optimizing the total throughput based on the different auction bids. In a similar manner as for the firm toll, the auction bids shall refer to a unitized dry gas system and the bids shall refer to transportation requests between any of the pre-defined entry and exits points. No shipper shall thus have a right to specify "internal" routing in the dry gas system.

The total revenues for the pipeline system owners shall not yield higher profits than the allowable regulated return and the balance shall be levied – at least in theory – the firm transportation shippers only. It is recommended to conduct such reallocations of revenues periodically.

The fourth recommendation is related to the necessity of changing documents and requirements, altering organizational forms and working processes, and how current incentive structures will be affected. All these issues will be influenced by an implementation of the Gas Directive. The work has briefly discussed these issues, but due to the many uncertainties no

detailed assessments are conducted or recommendations given. The work has however indicated that a majority of the documents assessed in this work must be revised and updated to reflect the new requirements caused by liberalization. It is recommended here that the governing documents more clearly specify which new responsibilities the independent transportation system operator shall be assigned. A vital area of concern is how the transportation system operator and the shippers' and sellers' dispatching representatives shall communicate and perform their duties in the future. To day these functions are highly integrated, but liberalization will make them counterparts.

Further, a detailed specification of the future working processes for the independent transportation system operator must be clarified. This applies especially for the how to optimize the operations in a liberalized context. New and carefully designed incentives are needed for enhancing optimal usage of the network during capacity constraints.

The last recommendation regards allocative and dynamic efficiency in a liberalized context. In the prevailing regime the individual company acts normally both as shipper and pipeline system owner. This regime ensures proper incentives for cost efficient development of new capacity and cost efficient operations and this regime may continue to exist in a liberalized context. This regime will continue to create proper incentives for allocative and dynamic efficiently in a liberalized context as well.

Further, in order to enhance allocative and dynamic efficiency on the Norwegian Continental Shelf a centralized planning and development system must be in force in order to secure resource management and utilization of the significant conditions for economy of scale. The transportation system operator must have a close liaison with these functions in order to share information about operational experiences, capacity constraints and shadow prices on capacity of constraints.

Finally, the work has provided several observations that show how a systems approach is quite attractive for finding solutions to complex and multidisciplinary problems as considered in this work. The systems approach applied here consists of two engineering processes comprising well-defined activities. These activities comprise assessment of information, definition of effectiveness measures and creation of information models. Trade-offs are identified between contradicting requirements and the outcome of the processes is accurate descriptions of the systems operations in the prevailing context and to some extent also in a future context. The systems engineering

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processes have included several methodologies to solve specific tasks. Several analyses based on economic and technical theories are included, as imperative activities required for solving the problems.

The ultimate results of a systems approach are solutions that go beyond traditional and non-disciplinary approaches. This is particularly true if the objective is to find concrete and sound solutions applicable in a "real-world" context where specific stakeholders' needs and legal requirements are present and well defined. Several observations are provided in the work showing how economic analyses are improved by combining them with technical theory, empirical data, operational experiences and last but not least: legal requirements.

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1   Introduction

1.1   Background

The European Union (EU) approved the Gas Directive on the 11th of May, 1998, for member states to introduce and implement through their national legislation by summer of the year 2000.[2] The directive suggests a new regulatory regime, which could influence the natural gas industry in any of a number of different ways.[3] It is not immediately clear to the industry stakeholders how to interpret and implement the directive[4], as its elements are open to a wide variety of interpretations and subsequent compliance measures. For some time now stakeholders have focused on research and strategic considerations in order to prepare for uncertain changes to come.

Norway is a major supplier of natural gas to Europe, and Norwegian gas sellers have signed a number of gas sales contracts with foreign customers. In light of these contracts, the Norwegian market share is expected to increase in all Norwegian natural gas markets in the years to come (for example, in Germany and France, Norwegian gas market shares are forecast to grow from 17% and 29% in 1996 to 28% and 37%, respectively, by year 2005).[5] The agreements specify how the parties involved share the significant financial business risks inherent in natural gas production, transportation and sales. One main provision is the "take or pay" (TOP) clause, specifying the sellers' long-term delivery commitments and the buyers' paying obligations. Such arrangements make the sellers and buyers largely and mutually dependent upon one another.[6]

The only feasible way to transport natural gas from the Norwegian Continental Shelf (NCS) to customers in Europe is through subsea pipeline systems. For the last 24 years, transportation system owners have been developing and constructing a transportation network that will soon comprise approximately 5500 km of pipelines. Pipeline diameters range typically from 28 to 42 inches in diameter[7] and maximum internal working pressure is limited to approximately 190 bar. By October 2000 the last of the current

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[2] Norwegian White Paper 46 (1997-98)
[3] Reference to Gundersen (1999), Statoil at GTS in Haugesund, Norway
[4] Such views are expressed by some authors; see, for example, J. P. Stern (1998)
[5] Source: Statoil; see also Appendix 11.1 and the Fact Sheet (1999)
[6] See Brautaset et al. (1998)
[7] Fact Sheet (1999) and St.prp. nr. 36 (2000-2001).

major transportation system was on stream.[8] Statoil operates approximately 90% of the Norwegian natural gas transportation system. The transportation system operator has predicted that in the years to come, the technical operations of this network will become increasingly complex.[9]

One cardinal question is how the Gas Directive influences Norwegian natural [10] gas transport operations. Little available research focuses on this issue, and limited documentation exists clarifying the potential impact or suggesting new business possibilities.[11] A recently issued Norwegian White Paper [12] emphasizes the importance of having operators on the NCS engaged in activities to better utilize the total natural gas transportation and production systems. One such activity is the present research program.[13]

The main objective of this research is to explore the new regulatory regime, suggest, and then test some approaches to align future operations with new requirements. This task requires first an assessment of the current regime in order to obtain an accurate description and understanding of current operations. The next step is to scrutinize new regimes, derive some plausible requirements for change, and identify those adjustments in current operations that would be called for. The adjustments must comply with sound economic and technical requirements.

This work addresses Norwegian national interests overall and does not pertain directly to any individual stakeholders' preferences. It therefore suggests actions to optimize Norwegian natural gas operations as a whole without seeking near-optimal solutions for any individual stakeholder of this industry. The work, however does employ Statoil operations as its object for the analyses conducted. The dissertation investigates ways to cope with changes forced by new legislation. It provides a systematic approach to analyze, consider and discuss these topics based on systems theory, economic and technical theories.

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[8] Source: Statoil, see Appendix 11.2 for a schematic of the systems

[9] Fact sheet (1998) and information from Statoil

[10] Throughout this work the entire natural gas transportation system is subject for analyses. However, in order to simplify the discussions and the modelling work, several parts of the work has limited the analyses to the dry gas system only.

[11] See Dahl (1999-B)

[12] White Paper 46 (1997-98), page 34

[13] The author's doctoral program was initiated by Statoil in 1997.

1.2   Main hypothesis

The main hypothesis tested in this dissertation is:

"It is possible to operate future Norwegian natural gas transportation systems at a level that is approximately optimal, technically and economically, with major stakeholders duly attending to requirements specified in the Norwegian statutory framework and in the implemented "Gas Directive."

The main hypothesis emphasizes the importance of multidisciplinary understanding and skills. It proposes that all major conditions for future transport operations must be analyzed and all systems requirements derived from technical, economic, and legislative needs must be identified, understood, and adhered to by all stakeholders. Included here is the assumption that the Gas Directive will affect future operations, necessitating actions to maintain optimal profits and a technically sound, adequate operation.

The academic definition of *"a level that is approximately optimal, technically and economically",* as applied in this dissertation, is an operation that satisfies three conditions:

- Optimization of the of the pipeline network's physical utilization, based on the theory of fluidmechanics and thermodynamics.
- Optimization of economic considerations, based on microeconomic theory and economic theory for regulating natural monopolies.
- Identification of and response to all stakeholders' major needs and systems requirements, based on systems engineering theory.

In Norwegian natural gas transportation agreements and gas sales agreements, the term *"reasonable and prudent"* describes an optimal operation. [14] The term, defined below, must be understood to describe the industry's *best practice*. However, the current definition does not offer an adequate (a priori) measure for defining an optimal level of operations since the definition is ambiguous and difficult to test in an academic sense.

"Reasonable and prudent" when used to describe the standard of care to be exercised by a Party in performing its obligations hereunder shall mean that degree of diligence, prudence and foresight reasonably and ordinarily exercised by experienced operators engaged in the same line of business

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[14] Source: Statoil

under the same or similar circumstances and conditions having due consideration to the interests of the other Party.

A "Party" in this context refers to any of the following major stakeholders: gas buyers, gas sellers, shippers, transportation system owners, or transportation system operators. *"Reasonable and prudent"* transport operations shall optimize utilization of the transportation system in a cost-effective manner with high regularity, giving priority to safety in order to protect life, health, environment, and property. [14]

The present dissertation faces the challenge of balancing the different objectives of the work to develop models and methods that are approved at a high academic level. At the same time, the industry being subject to this research must understand and recognize the models and methods and acknowledge their validity in practice.

In the main hypothesis, the word *approximate* underpins the assumption that no *single* optimal operating condition is believed to exist, but rather a set of alternative operating solutions, each improving or worsening the probability of attaining a given stakeholder preference. An approximate or *near-optimal* solution must therefore be based on trade-offs between alternatives. [15] The near-optimal solution may also be a rule of conduct found satisfactory by a given stakeholder, without necessarily considering all possible alternatives and choosing the best, a task simply impossible. [16]

The research and test cases are complicated by the fact that implementation of the Gas Directive is still pending in Norway. [17] The outcome of the implementation process as well as possible industry response remain open questions. [18] A vast diversity of outcomes are possible in European industry, so the present research has had to choose among the most probable options. Research issues have been selected, therefore, and test cases designed to minimize uncertainties. The dissertation aims thus to provide some answers to essential questions concerning the liberalization process currently under way in the European natural gas industry.

1.3 Disposition

The dissertation comprises nine main sections. The first presents the background of the work and the main hypothesis. The second gives a short

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[15] See Bahill & Dean, (1996) and Oliver et al. (1997)
[16] This rule of conduct is called *satisficing* according to Black (1997)
[17] As per February 2001.
[18] Stern (1998)

review of relevant literature and identifies the need for the present research. The third section identifies and elaborates on the scientific theories applied. The forth applies the systems approach principles and develops two systems engineering processes and the sub-hypotheses of this work. The fifth assesses the prevailing regulatory regime. The sixth assesses regulatory regimes in transition elsewhere in the world. The seventh section derives on regulatory and operational consequences for Norwegian operations. The section develops test case scenarios and new methods for handling new operational modes and modifies information models and effectiveness measures. The eighth section discusses results and the ninth section offers some overall conclusions.

1.4   Definitions

In order to ease the reading of the thesis an illustration is provided in Figure 1 below. The figure defines and displays several of the institutional issues discussed in the work and it indicates how these issues are related. This figure will be referred to at several occasions throughout the work.
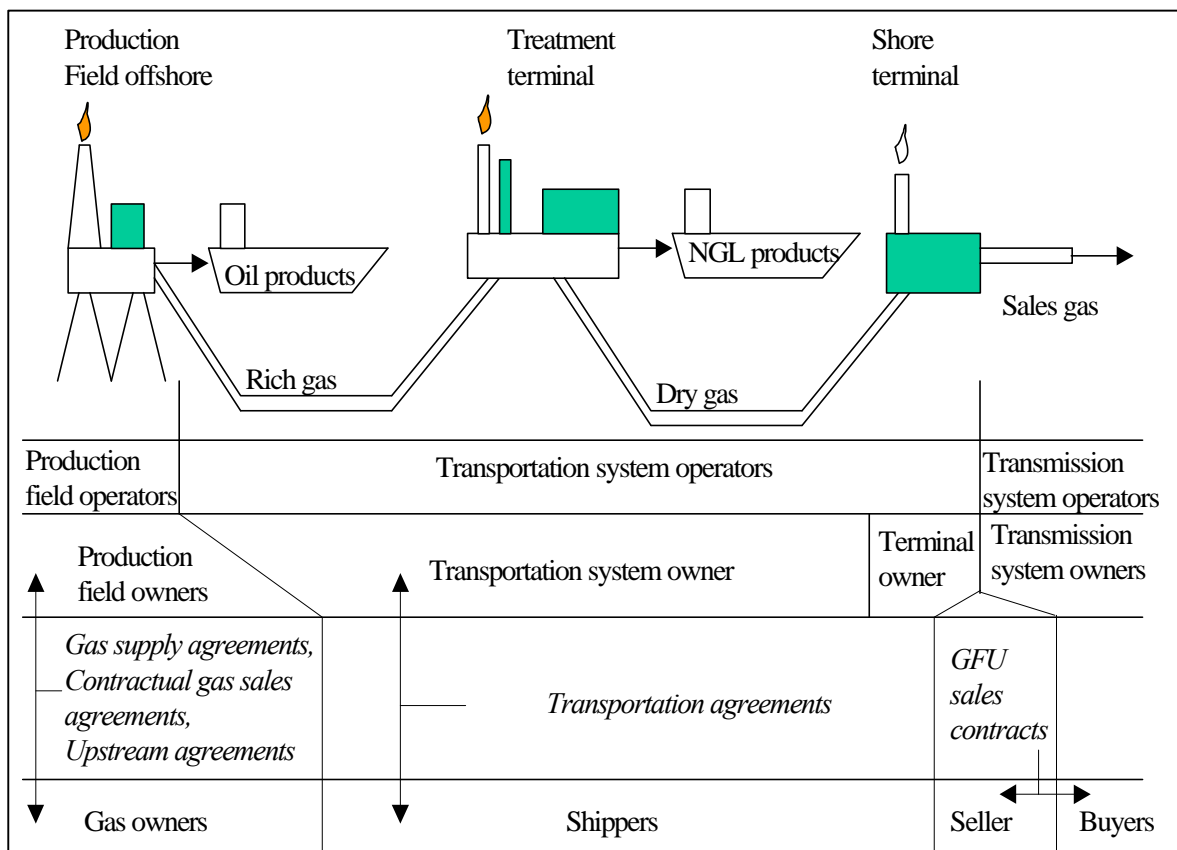
Figure 1. Definition of the institutional structure of the Norwegian natural gas industry

2   Status of recent research and work objectives

2.1   The problem statement

This Section aims to answer the following four questions [19] pertinent the future Norwegian natural gas transport operations:

- What is the problem?
- Why is this problem important?
- What have others done?
- What must be done?

In Section 1 the answer to the first question above was briefly identified. The problem can be summarized as follows: If we assume that the Gas Directive will be implemented into the Norwegian legislation, some new requirements will be enforced on how to conduct the Norwegian natural gas transport operations. The core problem identified in this work is thus first to identify these new requirements of change and secondly to find solutions on how to implement the new requirements so that the future operations comply with the Gas Directive.

A specific condition yielding for the latter problem is that the solutions suggested shall be feasible and appropriate in such a way that they may be implemented realistically in a "real world" context. This requirement means that the solutions identified must be compatible with the specific technical characteristics of the Norwegian pipeline systems. The solutions will also be constrained by the prevailing legal regime to a large extent as many of the existing legal and institutional requirements and political objectives as well as stakeholders' agreements, likely remain unchanged – or stakeholders will at least seek to keep them unchanged.

This constraint to the solutions domain is based on the assumption that the stakeholders will adjust to the forces of change "one step at the time" and not jump into dramatic and paradigmatic changes unnecessarily or unmotivated. Another way of putting it is that the solutions suggested here should be minimum solutions for fulfilling the Gas Directive and these solutions should cause the least distortions possible into the existing regime. A core concern is that the prevailing regime has been carefully designed and it

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[19] Professor Jon Steinar Gudmundsson at NTNU specified this definition of a problem statement.

functions satisfactorily and it yields good results. These facts make the stakeholders reluctant to change the system unless it is deemed necessary.

Of course, it can be of interest to open up the research domain in such a way that all possible and thinkable solutions for how to comply with the Gas Directive are studied given that the existing legal framework can be altered unconstrained and quite substantially. In this work such research scenarios may be identified to some extent. It will not be a prime priority however to conduct in-depth analyses of any specific issue *if it can be verified* that the outcome of the analysis or any condition for its solution will alter the legislative requirements paradigmatically and unrealistically. Nor will such analyses be conducted if the outcome evidently contradicts a specific technical and legal requirement that has to be obeyed.

The author recognizes that it may be difficult to make such distinctions as described above especially because there are many uncertainties related to how the Norwegian authorities will actually implement the Gas Directive into the Norwegian law.

Why is it important to identify how to implement the Gas Directive into Norwegian natural gas transport operations? Again, in Section 1 this question was partly addressed and it was stated that it is important to optimize the Norwegian production of oil and gas. The transportation system plays a crucial part as a means to enhance the resource management on the NCS and any changes in how to conduct the operations of the transportation systems may inevitably affect the resource management.

Further, new requirements will probably affect the organization structures, incentive structures and the working processes in different ways. The current organization is complex and comprises many stakeholders. The working processes are based on many formal documents and requirements and changes to be introduced must be carefully designed to prevent adverse effects from occurring.

Having now identified the problem and having argued that the problem is important, the next question is to study what others have done to solve it. This is the topic of the next two sub-sections.

2.2   Status of recent research

It is a broad and comprehensive scientific knowledge base available regarding the regulation and organization of natural monopolies and public utility industries in particular. For some decades now these industries have been de-regulated or liberalized in many regions of world. This fact has triggered research activities and policy studies at many universities and research institutions. As the research has advanced relevant courses and

textbooks have been developed, and journals, papers and conference proceedings are many.

The literature identified here is particularly relevant in a Norwegian context. The more general type of relevant literature and the literature comprising the basic theories are referred to in the proceeding text where appropriate. The references below are organized into three major fields being legal, economic and technical issues respectively.

Legal aspects
- *Brautaset et al. (1998)* offer a comprehensive and descriptive assessment of the Norwegian gas sales arrangement. This work includes descriptions and assessments of such topics as the gas sales contracts, the Gas Negotiation Committee (GFU) and the Gas Supply Committee (FU) and related issues. This work offers useful information and background knowledge and it is often referred to in this work.
- *Nielsen (1999)* offers a descriptive assessment of the Norwegian Transportation Agreements and this work provides useful insights into important aspects such as the tariff and toll formulas.
- *Dyrland et al. (2000)* offer a descriptive and useful assessment of the Gas Directive.

Economic aspects
- *Bjørkvoll (1994)* offers a doctoral thesis dealing with costs, the setting of tariffs and the determining of investments in the offshore natural gas pipeline industry. One important goal of his work is to find an optimal level of investment in pipeline capacity under different situations. The focus of Bjørkvoll's work is different from the present research, as the former work to a large extent is occupying itself with investment decisions, while this work primarily is focusing on the operational aspects of existing systems. Bjørkvoll's work identifies some useful and essential technical equations related to gas transportation. Bjørkvoll's work does not focus on empirical data and legal aspects or on the special implications caused by integrated systems and operations.
- *Bjørkvoll (1996)* offers a review and analysis of different tariff and toll regimes again with an optimal investment decision in mind. This work provides a useful overview of these formulas and the different tariff notions and it offers some interesting discussions on the topic.
- *Brottemsmo et al. (1993)* offer a study of how pipeline and processing tariffs are influencing on issues such as exploration, timing of

development, transportation alternatives and so on. They discuss the basic notions applicable in this field such as monopolistic tariffs and sub-optimal adaptation by stakeholders. The work applies some very few empirical data from the transportation systems, but does not address operational and technical aspects.

- *Brottemsmo (1994-A and 1994-B)* discuss whether the joint venture in field licensees is beneficial to the infrastructure provisions and related topics. Brottemsmo has developed an analytical approach that has been adapted to some extent in the present work in order to discuss some similar, but different problems.
- *Nese (1998)* offers a study regarding pricing of natural gas transportation in a Norwegian context. One ultimate goal of Nese's work is to suggest some auctioning principles for allocation of scarce capacity. This author has carefully assessed these principles and evaluated their usefulness in light of technical considerations and physical constraints. Nese's work presents a brief overview of some European and Norwegian institutional aspects but offers no in-depth analyses of legal, operational and technical issues relevant for the discussion.

Some few other publications of particular interest must also be mentioned.

- *Mansell et al. (1995)* offer a particularly relevant book and it is based on the Canadian experience. This book applies experiences, empirical data and industry knowledge for assessing many issues that are relevant for the present research. Such issues are cost evaluations, the applicability and usefulness of different tariff and toll regimes under given situations, allocation of costs and much more. This book focuses less on analytical theory but is mostly descriptive by nature.
- *Armstrong et al. (1994)* offer a fairly theoretical approach assessing different tariff and toll formulas and notions. The authors apply the British experiences in the utilities as reference cases.
- *IEA study report (1994)* offers a useful overview of the different regulatory regimes around the world as well as a detailed overview and assessment of different tariff and toll notions.
- *Hope (2000)* offers a comprehensive collection of research reports basically from a related industry, namely the power industry in Norway. *Hammer (1999)* offers a legal research of the same Norwegian industry

and market. There are many similarities when it comes to the theoretical and conceptual notions.

The last issue discussed here – for the sake of completeness – are two particularly relevant documents dealing with systems thinking, systems engineering processes and information modelling in particular.

- *Oliver et al. (1997)* offer a textbook on the issue of engineering complex systems and information modelling. This book comprises a foundation for the systems approach of this work. The systems engineering processes conducted here follow largely the conceptual thinking of Oliver et al.
- *Purves et al. (1998)* summarize the conceptual approach of information modelling in particular. The information modelling conducted in this research follows largely the principles discussed in Purves et al's work.

2.3   Discussion of recent research

Even though there is a rich literature related to regulation of utility industries in general and for specific regions as well, limited research exists on the regulation of the Norwegian natural gas industries in particular. This lack of research is especially observable in four dimensions.

- First, quite limited research is conducted analyzing how the industry must respond in order to comply with the EU's Gas Directive. This statement is specifically true regarding Norwegian natural gas transport operations and very little research is available clarifying how to change the operations in order to meet future requirements.
- Secondly, the research conducted on regulatory issues is often based on economic considerations alone and there is little research available combining economic analyses with operational and technical knowledge from the Norwegian natural gas transportation systems.
- Thirdly, a complex legal setting governs Norwegian natural gas transport operations and many stakeholders are involved. Very little research is available combining legal aspects and economic and technical analyses in order to derive comprehensive, relevant and adequate solutions to the problems identified.
- Lastly, little research is available combining analytical discussions with relevant empirical data.

The Norwegian natural gas transportation systems are installed sub-sea, they are highly pressurized and run over very long distances and they are physically highly integrated. This leads to the observation that many experiences from elsewhere may prove inadequate or less relevant for the Norwegian system operations.

Based on the observations listed above several objectives for the present research can be stated in order to fill the gap in knowledge. These objectives constitute the research objectives for this work and they are described in the next sub-section.

2.4 Objectives of present research

Based on the literature assessment above and the status and discussion of recent research in this field, some few but essential objectives and constraints are defined for this work as follows:

Legal foundation
- The dissertation shall be based on and be constrained by the Norwegian legislative framework, including the potentially implemented Gas Directive.
- The work shall analyze how to change natural gas transport operations from a Norwegian national point of view and not narrow the analysis to individual or specific company preferences.

Conduct of work
- The dissertation shall conduct the work in a recognizably systematic manner. A systematic approach shall be applied to assess the current and future regimes and to derive and test new methods, operational modes and solutions in order to secure consistency among solutions and trade-offs between contradicting requirements.

Main objectives
- The work shall identify and assess the main economic principles of regulatory regimes in transition – in theory and by assessing experiences from selected and relevant countries.
- The dissertation shall identify and analyze the potential impact of the Gas Directive on Norwegian natural gas transport operations and requirements of change caused by the Gas Directive shall be identified and inferred.
- Based on the economic principles, the results of the assessment of

regulatory regimes in transition, and identified requirements of the Gas Directive, the dissertation shall analyze and infer new operational modes for the future Norwegian natural gas transport operations.

- In order to comply with the new operational modes solutions shall be suggested for how to change the transport operations. Such suggested solutions will typically comprise legal and documental changes, new transportation services, revised and new tariff and toll regimes, organizational implications, amended working processes and incentive structures.
- The dissertation aims to distribute general knowledge and research results to the oil and gas industry, and to authorities and research institutes in Norway and abroad.

Empirical data
- The work shall apply operational experiences from the Statoil-operated pipeline network in the North Sea as its empirical background material.
- The work shall apply typical and representative empirical physical data from the Norwegian natural gas transportation systems, to the extent such data are available in the public domain. If proprietary data must be applied the data shall be made anonymous and they shall normally not be published.

Solutions shall be realistic and be adaptable to "real world" problems
- The suggested solutions shall be constrained in such a way that they are verified to be technically and economic feasible and sound and compatible with the legal framework assumed to exist in a Norwegian liberalized context.

The latter constraint follows from the discussion in Section 2.1 above. The next step is now to derive some main scientific assumptions that shall govern the work.

2.5 Scientific assumptions

In order to conduct the work some basic assumptions are made. The major scientific fields drawn upon by this work are defined as well and referred to collectively as the *master strategic approach* as shown in Table 1 below. The main principles on which the strategic assumptions and constraints are based upon are, to some degree, discussed in the "INCOSE'99" paper.

Table 1.   The master strategic approach

ID	Basic assumptions, strategies and constraints of the dissertation work	Related papers [20]
A.1	The academic fields of engineering, economics, and Norwegian law are most significant for analyzing the work, which is based on these fields.	INCOSE' 1999
A.2	The work of identifying future Norwegian natural gas transport operations can be organized into a systematic set of hypotheses and research activities.	Disser-tation
A.3	A systems approach can be developed encompassing two systems engineering processes. The first process assesses transport operations in the current regulatory regime while the second process assesses operations in a possible future regulatory regime. These processes provide a systematic framework and enable the suggested solutions to be validated as consistent with the "real world."	INCOSE' 1999 INCOSE' 2000
A.4	The commercially available systems engineering computer program "RDD 100" adequately facilitates the systems engineering processes and the information modelling in practical manners.	INCOSE' 2000

Based on the "scientific assumptions", the work applies different scientific theories to accomplish the goals, in an integrated and well-balanced manner. The work does not however aim to develop new incremental scientific theories within the academic fields applied. The scientific contribution of this dissertation consists of methods and ways the different scientific fields are mutually applied in order to find solutions to the specified problems.

2.6   Test cases for the work

During the initial stage of the work, some test-case scenarios were suggested. The proceeding work shall validate the test cases or adjusted them as deemed necessary. The test scenarios provide the work with relevant problem descriptions and act as test cases for the models and methods developed. Two test-case scenarios are identified below:

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[20] The present dissertation together with papers specified here, documents all relevant research and results of the work. Please note that some degree of overlap exists between the text in the dissertation and the papers.

- *Scenario 1*: The dissertation shall analyze and suggest possible means to include short-term sales agreements in addition to the existing take or pay agreements, taking into consideration the effect of possibly varying natural gas market prices.

- *Scenario 2*: The dissertation shall analyze and suggest possible means to incorporate access of "third party shippers" in the transportation system.

3 Theoretical foundation and research domain

3.1 Introduction

The work has a multidisciplinary nature and it applies theories from different scientific fields. The scientific field first reviewed in this section is *systems theory*. Systems theory provides a systematic framework for the activities and it outlines rules for how to specify complex systems unambiguously. The systems engineering processes and the information modelling are essential features and the generics of these features are reviewed.

The next part of the section recaptures the main elements of *the theory of fluidmechanics and thermodynamics* applicable for calculation of gas flow and compressor work. The work briefly reviews the Weymouth's flow equation and related theory.

Classic *microeconomic theory,* based on market economy, comprises the economic foundation for the legislative provisions of Norwegian regulation of natural gas transportation. The work reviews relevant elements of the microeconomic theory. The work also reviews the economic principles of new regulatory regimes, later utilized in the work, when new operational modes are suggested for the Norwegian transport operations.

3.2 Systems theory

3.2.1 Development of systems theory

According to Blanchard, [21] the evolution of *systemology (the science of systems)* can be traced back through an examination of *cybernetics.* Later a broader unifying concept of *general systems theory* was defined. Norbert Wiener first used the word "cybernetics", coming from Greek and meaning "steersman", in 1947. Cybernetics deals with self-regulation both in a narrow view such as servo theory in engineering or in a broader view encompassing much of natural science. The concept of feedback is central to cybernetics theory. Feedback is also central to all goal-seeking behavior, which is controlled by correcting information regarding deviation from a desired state. The science of cybernetics has contributed to the area of regulation and control by stressing the concept of information flow as a distinct system component, distinguishing between activating power and the information signal and given feedback mathematical expression.

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[21] See Blanchard et al. (1990)

The phrase "general systems theory" was first used around 1950. [22] The idea was to find and describe basic principles common to all systems that went beyond the concepts of cybernetics and self-regulation. General systems theory is concerned with the development a systematic framework for describing general relationships in natural and man-made systems. System theory aims to bridge the communication gap between various disciplines and different scientific methods. These communication difficulties can be experienced between various disciplines, for example between the physical sciences and the life sciences. [23] Efforts were made to develop a common ground for interdisciplinary relationships and unified scientific principles for analyzing complex systems. The concept of *hierarchy of levels* was developed and the concept led to a systematic approach of defining systems with broad applications.

Throughout the subsequent evolution of systemology other expressions were applied, such as *reductionism, mechanism* and *expansionism.* [24] Reductionism consists of the idea that everything can be decomposed or be disassembled into simple parts. The deterministic view of mechanism was that effects are completely determined by causes. Expansionism focuses on the whole of which everything is a part.

Later, the *systems approach* has been developed as a way of thinking to cover the observation that despite the fact that each part is performing as well as possible, the system as a whole is not performing as well as possible. A systems approach seeks to overcome the often-observed predisposition to perfect details and ignore system outcomes. The properties of the systems outcomes are often called the systems' *emergent properties* and emergent properties depend on interactions between components comprising the system.[25]

3.2.2 Development of systems engineering

The science of systems, World War II production experience, the US Air Force nuclear missiles programs and the efforts of the US Department of Defense in systems engineering education and standardization contributed to the development of the systems engineering discipline in the USA. [26] Systems

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[22] By Ludwig von Bertalanffy according to Blanchard et al. (1990)

[23] These type of challenges are also discussed in more recent work, as for example papers discussing innovation, science and technology policy such as by Rosenberg (1991) and Rosenberg (1994).

[24] Blanchard et a. (1990)

[25] Stevens et al. (1998)

[26] Malcolm (1993) and INCOSE (1998)

engineering as a discipline has experienced both a rise and decline throughout the last 35 years. The discipline has been shaped and influenced by different events such as governmental funding for military missile development, commercial company needs in a competitive climate and a general recognition that many complex systems often failed or become very expensive to develop.

In the late 1980s and in the 1990s systems engineering has had a revival. In 1990, an International Counsel on Systems Engineering (INCOSE) was founded [27] and an increasing number of universities are offering systems engineering courses and education. [28] During the 1990's, systems engineering activities have been supported by a number of computer programs tailored to systems engineering applications. Software developers are continuously improving these programs to incorporate systems engineering computer-aided programs with other engineering and management specialty tools. [29]

In recent years, several books and an increasing number of papers have been issued on systems engineering and the literature indicates or approaches in many cases a common understanding of systems engineering. In order to illustrate the observation some definitions or explanations of "systems engineering" are compared with each other, based on different books and publications. As an example of the comparison, INCOSE (1998) defines systems engineering as "an interdisciplinary approach and means to enable the realization of successful systems", while Stevens et al. (1998) wrote: "Systems engineering is about creating effective solutions to problems, and managing the complexity of the resulting developments. At the outset, it is a creative activity, defining the requirements and the product to be built". [30]

INCOSE has developed a systems engineering handbook, with the objective of providing a description of the key process activities performed by systems engineers. [31]From this handbook the definition of a "system" is quoted: "An integrated set of elements to accomplish a defined objective. These include hardware, software, firmware, people, information, techniques, facilities, services and other support elements". This definition is applied in this work. The same publication specifies system architecture as: "The arrangement of elements and subsystems and the allocation of functions to

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[27] Oliver et al. (1997) and INCOSE (1998)

[28] Asbjørnsen (1992)

[29] Malcolm (1993).

[30] Other examples are Bahil et al. (1996): *Systems Engineering is an interdisciplinary process that ensures that the customer's needs are satisfied through a system's entire life cycle*", or Hitchins et al. (1999): *"The structure and ordered creation of a System that achieves the required Emergent Properties"*.

[31] A guide is also provided by Hitchins et al. (1999).

them to meet system requirements".

One important activity, normally recognized in all systems engineering literature, is the "systems engineering process". Many of the activities dealt with in this work are parts of a systems engineering process and the next sub-section is thus devoted to explain this process in more detail.

3.2.3 Systems engineering processes

The systems engineering process plays a crucial part when bringing a complex system into being, [32] but the process is also useful for analyzing existing systems. In order to bring a complex system into being, many basic functions must be established such as project management, planning, cost control, acquisition strategies and so on. There are many different philosophies to choose among to set up these functions. Normally all large scale development projects are compiled by several distinctive and common project actives that can be conceptualized, see the Blanchard et al., Stevens et al. and Oliver et al. These activities typically consist of: [33]

- Identification of stakeholders and their needs (what actually is needed)
- Definition of system requirements
- Design of system architecture
- Component development (design and manufacturing)
- Integration and verification (system testing)
- Installation and validation (acceptance testing)
- Operation

Systems engineering and the "systems engineering processes" are most active during the three first activities from the list above while project management covers all actives. Feedback and change control activities are taking place between all activities. The actual performance of the systems engineering activities are often referred to as a systems engineering process, defined as follows: [34] "A logical, systematic process devised to accomplish system engineering tasks". The systems engineering process is thus often applied in connection with creating a *new* complex system from the very beginning. The systems engineering process is a main activity that secures a

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[32] Blanchard et al. (1990)

[33] Stevens et al. (1998), this list is a significant simplification of the many activities required, however it is useful to indicate where systems engineering efforts are most dominate during the development of a system.

[34] INCOSE (1998)

successful new project development.

If there is a need to assess an existing system or a part of it, the systems engineering process is an appropriate approach. [35] "Re-engineering" or "reverse" engineering are terms used to describe this type of activity. [36] In this work, two systems engineering processes are carried out. The first is a systems re-engineering process and the second a systems engineering process. These processes are defined by the B-activities and the C- activities accordingly, (see Section 4) and specified as the dissertation's hypotheses.

3.2.4 *Effectiveness measures* [37]

"Effectiveness measures" are defined in the systems engineering literature. Oliver et al. suggest that effectiveness measures are "the small subset of requirements that are so important that the system will fail if they are not met and will be a huge success if they are met". Sproles [38] defines measures of effectiveness (MOE) as "standards against which the capacity of a solution to meet the needs of a problem may be judged. The standards are specific properties which any potential solution must exhibit to some extent. MOEs are independent of any solution and specify neither performance nor criteria." The stakeholders are responsible for establishing the effectiveness measures.

Effectiveness measures are thus not supposed to be quantified directly. When a given problem shall be solved, different solutions may exhibit different levels of capabilities of fulfilling the effectiveness measures. The different solutions must be evaluated and quantified by means of different economic and technical efficiency criteria.

An example of an effectiveness measure already mentioned is the requirement that operations shall be "reasonable and prudent" (see Section 1). This measure is not directly quantifiable and different operational solutions will yield different quantitative properties if evaluated by technical or economic efficiency criteria. A given operational mode for example, will result in a given "mechanical efficiency" related to the ratio of physical flow output (work) versus energy consumption or a given "rationing efficiency" related to economic efficient allocation of transport capacity between shippers.

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[35] Dahl (2000-A).

[36] This is discussed by Oliver et al. (1997)

[37] In this work "effectiveness measures" and "measures of effectiveness" are synonyms and the term is a noun and it expresses a measure of success or is simply a success criteria.

[38] Sproles (2000)

3.2.5 Information models

3.2.5.1   Flow diagrams

Several recent papers and books discuss the concept of information models and they identify reasons for why to use them.[39] Models can enhance multidisciplinary communication of ideas and concepts. They can be applied to check the information for completeness and consistency and as a means to ease the engineering process by reducing time and efforts expended. All these reasons are prime objectives of this work.

The concept of Entity-Relationship-Attribute (ERA) information models has been recognized as one successful approach for several years.[40] In the Figure 2 below, an ERA model is illustrated showing the basic language applied.

Entity	Relationship (bi-directional)	Entity
•Attribute • •		•Attribute • •
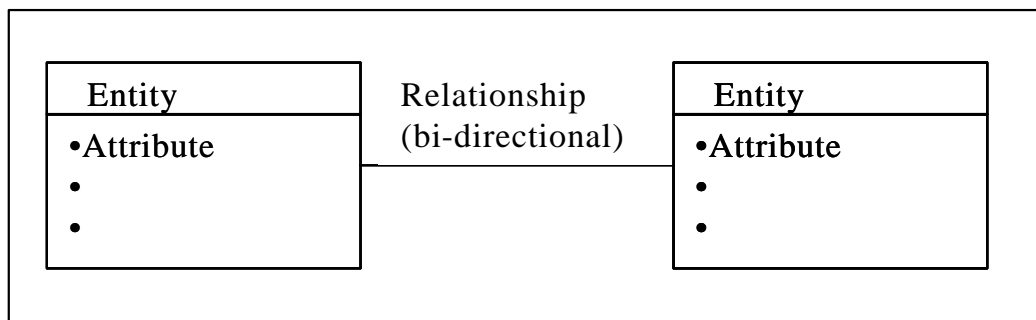
Figure 2.   Conventional ERA modelling language

The *Entity*, or the object, identifies the "thing" or "element" of importance. An entity can be a document such as the Norwegian Petroleum Act, a physical component like a pipeline or a gas terminal, or an organizational unit such as the gas dispatchers. According to Purves,[41] an entity corresponds to a "noun" in the English language. Entities have attributes and they have relationships to other entities. Relationships define associations between the entities and correspond to "verbs" in the English language. For example, a given document *specifies* a requirement, a dispatcher *issues* a request or the pipeline *receives* natural gas. The entities may also have attributes. Attribute corresponds to "adjective" in the English language. Attributes define properties and characteristics of entities. A document's *name and status* are attributes or *the intensive and extensive properties* of the natural gas at a given location in the pipeline may be defined as attributes.

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[39] See Oliver et al. (1997), Oliver (1999) and Purves et al. (1998).
[40] Blanchard et al. (1990)
[41] Purves et al. (1998)

Based on the concept of ERA, different modelling notations are developed, such as Object Modelling Technique (OMT) or Functional Flow Block Diagrams (FFBD). Oliver et al. [42] apply both of these notations and these notations are constituting the base for the modelling applications of this work.

Further, in complex systems, it is often an advantage to apply several types of information models, each focusing on different aspects of the system. Modern systems engineering theory suggests that one possible approach is to describe the system in four different ways – the four information models. One may think with this approach as if one should describe the shape of a three-dimensional object. A single two-dimensional drawing would not suffice; at least two drawings are required. Similarly, several models are required to specify a complex system, each model focusing on different aspects of the system. In this work *four different types* of information models are created and the following sub-sections outline the basic principles of these four models.

3.2.5.2   *Requirement traceability information model*

The first information model is *the requirement traceability information model.* The main purpose of the model is to show the flow down from the initial source documents to the appropriate entities. All requirements must start somewhere and they must have a purpose. The main purpose of the model is to create an unambiguous identification, clarification and traceability between documents, requirements, facilities, personnel, functions and processes.

The model applies a specific convention or language so that different entities, relationships and attributes are accurately defined. The main words used in this work for describing and defining *entities* are: [43]

- *Source*.   The source documents are of the highest level. These documents initiate or "trigger" lower levels of documents and requirements. All source documents belong to the identified stakeholders.
- *Requirement*.   The requirements are specified and identified requirements derived from the source documents and lower tiers of documents.
- *Component (and stakeholder)*. The components are all the physical parts of the transportation system. Due to the convention of the systems

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[42] Oliver et al. (1997)

[43] The list presented here is not all inclusive, see the results for a complete list.

engineering software program applied in this work, stakeholders are also referred to as "components". [44]

- *Interface.* The term "interface" identifies different natural gas pipelines. This word is used due to the convention of the systems engineering software program applied.
- *Itemlink.* The term "itemlink" identifies the different flows of natural gas streams in the pipelines. This word is used due to the convention of the systems engineering software program applied.
- *Function.* The word "function" identifies all functions performed by the stakeholders. Much of the main focus of this work relates to the functions and processes performed by stakeholders in the current and the future legislative regimes. An accurate and comprehensive identification and modelling of functions are thus emphasized throughout the work.

The words used for *relationships* are:

- *Documents.* This word is applied for describing the fact that a source document documents requirements. Typically source documents require that the stakeholders concerned must create lower tiers of documents.
- *Incorporates.* A requirement will typically incorporate lower tiers of requirements. Such break down of requirements will be conducted throughout the modelling work as far as is deemed necessary (see next bullet point). The lowest tier of requirements is referred to as the "leaf-level" requirements. [45]
- *Specifies.* The leaf-level requirements specify functions. Throughout this work all leaf-level requirements specify one, and only one, function. The requirements are broken down into such a detailing level that the lowest requirement may be characterized as a leaf-level requirement. In other words, there is no need to break down a given requirement any further if the given requirement unambiguously specifies one and only one function.
- *Allocated to.* The expression "allocated to" allocates an identified function to an identified stakeholder. All functions identified are allocated to stakeholders, and visa versa.

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[44] It may be somewhat confusing to allocate the term "component" to "stakeholders", but throughout the actual modelling, pre-fixes are used to prevent misunderstandings. For further details, see the results.
[45] RDD-100 User manual (1996), page 228

Based on this convention and use of words a (relatively) large model is developed. A systems engineering software program is applied to conduct the modelling. In Section 5, the results of the work are presented together with further details pertinent the software program and the modelling work.

3.2.5.3   *System architecture information model*

According to INCOSE (1998), a system may be broken down into lower levels of systems and components. The top level is defined as *the system* and it consists of "an integrated set of elements to accomplish the defined objective". In this work, the top level is "the total Norwegian natural gas system". The next level is *the subsystem* "applied to apparatus, which performs a cleanly separated function, such as communication, structures or control". This level comprises the main facilities, such as terminals and riser platforms.

The next level is *the assembly*, defined as "an integrated set of components and/or subassemblies that comprise a defined part of a subsystem". These assemblies are the *input valves* and *output valves* installed on each sub-system. *The component* is defined as "comprised of multiple parts, a cleanly identified item". In this work, this level equals the pipeline segments connecting an input valve and output valve. The lowest level is *the part*, defined as "the lowest level of separately identifiable items". In this work this level is equal to the physical gas streams flowing in the pipelines.

The architecture information model introduces some additional types of *relationships* between entities. These relationships give the architecture information model its specific features and qualities. The new relationships are:

- *Built from*. The term is used to identify that a higher level component is built from lower level components.
- *Connected to*. The term "connected to" is applied to show that the lowest level component is connected to an interface. In the models applied here it simply means that the pipelines are connected to either an input valve or an output valve.
- *Contains*. The term is applied here to show that the pipeline contains a stream of natural gas flowing through the pipelines.

3.2.5.4   *Behavior information model*

Behavior can be abstracted as functions, inputs and outputs to the functions, ordering of the functions and how inputs trigger functions. The main purpose of the behavior information model is to order the functions into

processes. The processes specify the sequence of functions and identify the individual functions by assigning a unique identity number to the functions. The model identifies the input and output from the functions. In the case of this work, only those functions performed by the stakeholders are considered. Stakeholders conduct their functions in different manners for example as sequential or concurrent (in parallel) work tasks. The model captures these properties and it identifies iteration loops, decision trees and trade-off among different potential options and solutions.

3.2.5.5 *Context information model*

The last conceptual model is the context information model, also referred to as the interface model and it identifies interfaces crossing the system's boundary. It is considered imperative to clearly define a systems boundary in the modelling work. As all systems normally interfere with its surrounding environment, it is important to clarify such interactions. The basic principle of the context model is to clarify such interactions.

Finally and generally, one should remember that an entity or a relationship defined, always remains the same. All information is thus specified only once. The difference between the four information models consists of which entities and relationships that are viewed. One may think of the models as different types of "mirrors" or cross-section pictures, viewing the system from different perspectives or facing angels.

Another feature of the models is the fact that there is coherence between the models, provided the modelling work is properly done. The models are "mapped" to one another throughout the modelling process. If an amendment is introduced into one of the models, a "warning" or a call for amending the other models will immediately be flagged, ensuring that all changes are dealt with in a consistent manner and that no "loose ends" are left unsolved.

3.3   Theory of fluidmechanics and thermodynamics
3.3.1 *Gas flow equations*
In the following sub-sections some relevant parts of the theory of fluidmechanics and thermodynamics are reproduced in order to specify the theoretical foundation required to perform technical, commercial and operational analyses of the transportation network. This theory is required in order to understand, assess and analyze a number of critical questions. These questions are related to cost functions, optimizing operations, evaluating potential measures for profit and revenues; designing potential auctioning principles, confining regulatory regimes and so on. This theory represents the

"law of nature" and it constitutes inevitably the foundation governing the physical operations of the network.

The theory presented here is derived from relevant textbooks and teaching literature and the compilation of the theory and formulas presented here is to a large extent derived and collected from the author's earlier work, see Dahl (1998-A and -B). [46] The basic sources applied are those listed in the footnote below. [47]

The first topic reviewed is how to calculate flow and input or output pressures in a given pipeline for a given gas composition. Throughout this dissertation the typical task is to calculate the value of the one of these three parameters, given the other two and assuming that all other conditions are known. In order to do so a simplified flow equation has been derived, known as the Weymouth's equation. In the author's previous work it has been shown that provided the gas composition is known, as well as the different pipeline dependant specific parameters, the equation produces results within acceptable limits for the analyses of this work.

Two particularly difficult tasks are how to calculate the given gas' deviation from an ideal gas (specified as the Z-factor), and how to calculate the friction occurring between the gas molecules and the pipeline wall (specified by the friction factor). The values applied for these parameters are largely based on empirical data derived from the Statoil operated pipeline systems in the North Sea. By applying such empirical data and the Weymouth's equation it has been shown that results have a tolerance typically within a range of a few percent from actual true values. In relation to hypothesis C.5 (see Table 2 on page 61) a further discussion of the accuracy in calculations is presented.

The Weymouth's equation is specified as follows:

$$Q_{SC} = \left(\frac{T_{SC}}{P_{SC}} \frac{\boldsymbol{p}}{8} 1{,}44 * 10^{-3} \right) \left[\frac{\left(P_1^2 - P_2^2 \right) d^5 R}{M_{gas} T Z L f} \right]^{0,5} \qquad \text{(Eq. 3.3.1)}$$

The terms have the following meaning:

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[46] Dahl (1998-A, -B)
[47] Sjøen (1998), Albrechtsen (1998), Katz et al.(1990), Kotas (1995) and Bjørkvoll (1994).

Q_{SC} is the throughput (or flow rate), MSm³/day[48]
P_1 is the pipeline inlet pressure, bar
P_2 is the pipeline outlet pressure, bar
d is the pipeline diameter, m
L is the pipeline length, m
M_{gas} is the molecular weight = 21,38 kg/kmol [49]
T is the ambient temperature of gas = 280 K
T_{SC} is the temperature at standard conditions = 288,15 K
P_{SC} is the pressure at standard conditions = 1,01325 bar
      $= 1,01325 *10^5 \, Pa$
R is the gas constant = 8314,34 J/(kmol*K)

The average compressibility factor is calculated by means of the theory given by Katz et al. The value calculated has been compared, adjusted and verified by empirical data. The typical value applied throughout the calculations of this work is:

Z is the average compressibility factor = 0,7

The friction factor f is calculated based on the "AGA method" [50] (see Katz et al.), [51] by applying the following equations:

$$\frac{1}{\sqrt{f}} = 4\log\frac{3,74}{e}$$
(Eq. 3.3.2)

$$e = \frac{e}{d}$$
(Eq. 3.3.3)

Here,

e is the relative pipeline roughness
e is the absolute pipeline roughness $= 10*10^{-6} \, m$

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[48] The correct expression is $\dot{Q}$, but for simplicity the flow is simplified as Q several places throughout this work. The term Q is usually applied as a term for flow in many agreements.
[49] The molecular weight listed here represents a typical "rich" gas. The "dry" gas has normally a lower molecular weight.
[50] American Gas Association.
[51] Katz et al. (1990)

3.3.2 Pipeline inventory calculations

In order to calculate pipeline inventory at standard conditions, the gas volume at standard conditions must be calculated. At a given ambient temperature, the gas volume at standard conditions can be calculated according to the equations below:

$$V_{SC} = \frac{P_{PIPE}}{P_{SC}} * \frac{T_{SC}}{T} * \frac{V_{PIPE}}{Z} \qquad \text{(Eq. 3.3.4)}$$

Here the terms have the following meaning:

V_{SC} = is the gas volume at standard conditions, MSm^3
V_{PIPE} = is the metric volume of the pipeline, Mm^3
P_{PIPE} = is the average pressure in the pipeline, bar

The average pipeline pressure is calculated according to the following equation, which is a minor simplification of reality, still providing acceptable results in relation to the questions discussed here:

$$P_{PIPE} = \frac{P_1 + P_2}{2} \qquad \text{(Eq. 3.3.5)}$$

3.3.3 Calculation of compressor work and power

Another important field of interest is to clarify compressor power requirements needed for transporting the natural gas in the transportation system. The variable costs are directly linked to the fuel consumption in the compressor drive motors. Such motors are either gas turbines or electric motors. These relationships will also clarify marginal costs of transportation as being the marginal cost function, defined as the derivative of the variable cost function.

The compressor work can be found based on an isentropic analysis: [52]

$$W = \frac{c}{c-1} * \frac{RTZ}{M_{gas}} \left[\left(\frac{P_1}{P_s} \right)^{\frac{c-1}{c}} - 1 \right] \qquad \text{(Eq. 3.3.6)}$$

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[52] Katz et al. (1990), p. 260, eq. 6.27b. See also Dahl (1998-B) and Bjørkvoll (1994) page 34.

As the isentropic analysis disregard irreversibility, the above equation must be corrected for these losses in order to reflect reality. The compressor power requirements can thus be found by the following equation:

$$\dot{W} = \frac{W * \dot{m}_{SC}}{h} \qquad \text{(Eq. 3.3.7)}$$

$$\dot{m}_{SC} = \frac{Q_{SC} * r_{SC}}{24 * 60 * 60} \qquad \text{(Eq. 3.3.8)}$$

$$r_{SC} = \frac{P_{SC} M_{gas}}{ZRT_{SC}} \qquad \text{(Eq. 3.3.9)}$$

In the two equations above the terms have the following meaning:

W is the compressor work, J/kg

$\dot{W}$ is the compressor power, W

r_{SC} is the density of the gas at standard conditions, kg/Sm^3

$c = \dfrac{c_p}{c_v}$ is a ratio between specific heat capacities = 1,4, where:

c_p, c_v are the specific heat capacities at constant pressure and constant volume

P_s is the suction pressure at the compressor inlet, bar

$\dot{m}_{SC}$ is the mass flow at standard conditions, kg/s

h is the isentropic compressor efficiency = 0.75 (the efficiency also includes corrections for irreversibilities caused by mechanical friction etc.)[53]

The above equations will provide theoretical values of compressor power requirements. The efficiency specified is assumed to be an average efficiency over the entire operation range of the compressor. Further, it is assumed in all calculations that the compressor is working only as a one-stage compressor. This assumption may not necessarily reflect reality under all conditions, especially when the relative difference between the suction pressure and delivery pressure is high. However, and once more, the results of

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[53] Based on Katz et al. (1990), see page 265, figure 6-20.

the calculations are compared with empirical data, basically applying the Kollsnes compressor unit as a reference case. By applying the efficiency rate as indicated, the accuracy of the calculations are shown to be well within what is needed in relation to this thesis. Further, some of the calculations done are verified by using an expert software system provided by MIT Energy Laboratory with satisfactory results as well as by means of a similar program developed by Statoil.

The final power requirement is obtained by correcting for irreversibilities caused by the drives:

$$\dot{W}_{gt} = \frac{\dot{W}}{h_{gt}}$$
(Eq. 3.3.10)

$$\dot{W}_{el} = \frac{\dot{W}}{h_{el}}$$
(Eq. 3.3.11)

Here the terms have the following meaning:

h_{gt} is the gas turbine efficiency = 0.33 [54]

h_{el} is the electric motor efficiency = 0.98 [55]

3.3.4 Technical efficiency criteria

The last issue to be discussed here is whether it is possible to suggest a suitable technically based criteria of performance. The objective sought here is to derive a possible means to measure the performance of the transport operations in technical terms. From the thermodynamics literature we know that a simple and much applied criterion is the mechanical efficiency. This measure is normally formulated in such a manner that the performance of a given plant (for example a power plant) is specified as the ratio between mechanical work produced by the plant divided by the energy consumed by the plant.

In the thermodynamics literature many different efficiency criteria are defined taken into account the Second Law of thermodynamics in sophisticated ways. However, as the main task in this work is to suggest how to optimize transport operations, one feasible approach may be to measure the

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[54] See Bjørklund (1994), page 35
[55] Kotas (1995), page 205

ratio of gas volume being transported through a given pipeline at a given operating mode versus the compressor energy consumed. This "quasi" efficiency criterion has some similarities with the mechanical efficiency criteria mentioned above. As the variable costs are directly related to the energy consumption, this approach will constitute one possible criterion for energy cost-effective operation.

In mathematical terms such a "quasi" technical efficiency criterion may be expressed as follows:

$$h_{tech} = \frac{Q_{SC}}{\overset{\bullet}{W}}$$
(Eq. 3.3.12)

3.4   Economic theory
3.4.1 *Microeconomic theory of transportation systems*
3.4.1.1   *The natural monopoly argument*

Economists have for a long time considered the utility industries and related networks as *natural monopolies*. Joskow and Schmalensee [56] point to this fact when discussing transmission in connection with electricity utilities. The IEA (International Energy Agency) natural gas transportation study [57] concludes the same in relation to natural gas transportation. In microeconomic theory, a monopoly market is by definition a *monopoly* if there is only one supplier and this supplier chooses to produce at a price level that is substantially above that under competitive conditions. Other firms find it unprofitable or impossible to enter the market and *barriers to entry* is thus the source of monopoly power. As pointed out by Nicholson [58], there are two general types of barriers to entry, *technical barriers* and *legal barriers.* Technical barriers may occur due to the technical nature of an industry and legal barriers may occur because of regulation or legal requirements. Economic barriers may exist as well if the industry has large sunk costs.

Natural gas transportation in subsea pipeline networks exhibits technical barriers since an expansion of capacity results in a reduction of costs per unit transported. The technology of the transportation system (and in the case of natural gas; also the distribution systems) [59] exhibits decreasing short-term

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[56] Joskow and Schmalensee (1983), page 65.
[57] A general description on natural monopoly in natural gas transportation is given by IEA (1994).
[58] Nicolsen (1995)
[59] IEA natural gas distribution study (1998)

average costs and increasing short-term *marginal costs* over the whole range of the output levels. The marginal costs are below the average costs within the entire output level. These economic conditions presuppose that transportation demand in the short-term is within maximum capacity restrictions of the transportation system.

The *natural monopoly argument* is that a transportation system, in theory, will exercise *market power* and collect *monopoly profit* if left unregulated. The transportation system will seek to maximize its profit at a throughput level where marginal cost equals marginal revenue. At this given level of output, the demand curve will specify the transportation toll, which may be set at a price above average costs. As there are shippers in the transportation market with a willingness to utilize the system if tolls were set below the monopoly level but above the marginal cost, welfare loss is occurring. Monopoly profit (or monopoly rent) is a "super profit" above ordinary profits based on normal rate of return requirements on investments undertaken by the transportation system owners.

These economic facts create in theory the technical barrier for potential competitors. If a competitor attempts to enter the existing market by constructing a new pipeline, the incumbent transporter will enjoy the possibility of expanding the output and reduce the toll until it eliminates potential willingness to construct a new competing pipeline. Another important contribution to limit competition is the fact that investments in utility industries are significant *sunk cost.* If the investor withdraws from the market, there is no alternative usage of the investments. There is today no alternative usage of the subsea natural gas transportation system, other than for the purpose of transporting natural gas.

A last notion here is that the sunk costs are irrelevant for the incumbent for the question of whether it is profitable to continue operations. For the newcomer however, they are highly relevant if the newcomer must establish his own pipeline.

3.4.1.2 *Economy of scale and scope*

Natural monopolies exercise some specific economic conditions known as *economy of scale* and sometimes *economy of scope*, as pointed out by IEA (1994). Economies of scale are normally defined as changes in long-run average cost with an equal proportional change in all input factors. In terms of natural gas transportation, economy of scale refers to the fact that the average unit cost for transporting one unit of physical gas is declining as the pipeline diameter is increasing.

The definition of a natural monopoly is that the cost function is *subadditive*. [60] This means that the cost of production will be minimized if there is only one firm in the industry. A decreasing average cost function [61] may thus be a sufficient condition for a (single product) natural monopoly.

A condition for *economy of scope* [62] exists, in general terms, if the same producer produces more than one output unit from the same production plant and the cost of producing several units jointly is less than the cost of producing them separately. In relation to natural gas transportation, economy of scope exists for example, if a given organization performs several different transportation related tasks cheaper than having several organization units performing the tasks individually.

3.4.2 *Regulation by public authorities*

Public authorities normally regulate public network utilities. The basic philosophy is that private firms will exercise market power, if left unregulated, due to the natural monopoly characteristics of the industry. This will cause consumer welfare loss. In many countries, such as for example Norway, the traditional regulatory regime has thus specified state ownership, control and operations in many of the utility sectors such as railways, mail, electricity, highways and telecommunication. Statutory regulations and state ownership are quite significant, pertinent to the Norwegian petroleum industry as well, [63] a topic that will be looked into in a later sub-section.

The EEA[64] agreement and the Norwegian legislation are basically based on market economy, and microeconomic theory, [65] normally constitutes an analytic basis for the regulation. But as discussed above, several parts of the economy are influenced by strong public regulation and planning. This applies particularly to those utility industries discussed here, where competition or contestable markets are believed not to function adequately. The regulatory principles recognize that the natural gas transportation activity operates under economy of scale and the regulation seeks to utilize this fact to increase welfare. The regulation specifies the extent to which pipeline owners can collect profit based on a given rate of return on the investment. In Sections 5

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[60] Nese (1998) and Mansell et al. (1995)

[61] This conclusion assumes the following: When throughput increases the *capital costs toll element* will be adjusted down as reduced toll, to the benefit of the shipper. Similar reductions are assumed for the fixed O&M costs.

[62] See also Grøn (1996) page 62 and IEA (1994) page 69

[63] See Fact Sheet (1999)

[64] EEA: The European Economic Area.

[65] Sejersted et al. (1995) page 283

and 7, the current Norwegian regime is scrutinized and discussed in light of the theory and empirical data.

A strong regulation of the natural gas industry is also prominent in many countries around the world. The IEA natural gas transportation studies, as well as several other authors, provide a comprehensive review of the vast diversity of regulatory regimes in the OECD countries. This literature shows how the regulatory regimes have evolved in later years as deregulation and liberalization advance in many countries. Generally, new and modern regulatory regimes focus on some key issues that are derived from the basic theory described above. In the following sub-sections, these key notions are highlighted, together with a graphical and mathematical expression of the theory.

3.4.3 Economic theory of regimes in transition
3.4.3.1 The liberalization notion [66]

The main purpose of the following sub-sections is to identify the major economic principles and notions that capture the theory behind the liberalization process currently going on in the European gas market. The literature on the topic is rich and a number of books, papers and reports are published in recent years. The synthesis of the economic theory outlined below is derived from a number of these references as specified in the footnote.[67]

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[66] In the present work, the term *liberalization* is used to describe the process that is currently underway in the European gas market. As noted by Armstrong et al. (1994, p. 99), deregulation may remove restrictions on competition, but it may also remove regulation (which does not necessarily enhance competition). Liberalization, to the contrary, is used here to describe measures aimed only at "opening up for competition," or for "removal of restrictions on competition."

[67] A few examples are Kahn (1988), who discusses the theory of economy of regulation in great detail. Joskow and Schmalensee (1983) contribute to the same discussion, using the U.S. electricity industry as the subject of their analysis. Another book by Hunt and Shuttleworth (1996), discusses the same topics, based on the development of recent years in the electricity industry. Several books and a collection of articles have been published relating to the Norwegian petroleum and gas industry and its regulation; see, for example, Bjerkholt et al. (1990) and Golombek and Hoel (1987). A more recent book is Hannesson (1998); see especially Chapter 3, in which natural gas economics is discussed. Another particularly interesting book is Mansell and Church (1995), which discusses the Canadian experience in natural gas pipeline regulations, and their analyses of incentive regulation within this industry. The U.S. experience is discussed by a number of authors; see, for example, De Vany and Walls (1994 and 1995), and Jensen (1992). Armstrong et al. (1994) offer a detailed review of economic theories, supported with a number of examples from

As was discussed in the previous sub-sections the transportation (and production) of natural gas possesses natural monopoly characteristics, a situation that may lead, in theory, to a situation where stakeholders exercise market power. Such exercise of market power will lead to market failures, as the market will suffer from ineffective competition. According to economic theory, such inefficiencies are caused by pricing the gas deliveries at a price above the sum of marginal cost of production and transportation (including transmission and distribution).

These relationships are commonly expressed in mathematical and graphical terms. If we assume that the gas deliveries are bundled and merchant, i.e. the same company is vertically integrated and undertakes the sole production, shipping, selling and transportation (which in essence is the reality today for Norwegian gas sellers), a number of relationships can be specified. In order to do so several terms and relationships must be defined.

The gas volume sold in the downstream market is termed Q. The total cost of production and transportation is termed $TC(Q)$ and the average cost is termed $AC(Q) = TC(Q)/Q$. The marginal cost of production and transportation is termed $MC(Q) = dTC(Q)/dQ$. [68] The average cost is decreasing over the output range and the marginal cost is increasing, but its numerical value is significantly lower than average cost, over the whole range of output. The company's total revenue is termed $TR(Q)= P(Q)*Q$. Here $P(Q)$ is the inverse demand curve. We assume that the demand is elastic and downward sloping.

The company's profit function can be expressed as shown below.

$$\prod(Q) = TR(Q) - TC(Q) \qquad \text{(Eq. 3.4.1)}$$

The monopolist will exploit the market power and the classic solution is to maximize the profit at a volume Q^* and price P^* that satisfy the first-degree solution; $MR(Q)$ marginal revenue equals marginal costs:

$$MR(Q) = P(Q) + \frac{dP(Q)}{dQ} Q = MC(Q) \qquad \text{(Eq. 3.4.2)}$$

The elasticity of the market demand, $e_{Q,P}$ can be introduced into the

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British experience. See also Hope (2000) and Nese (1998).

[68] This expression is a simplification of reality. A precise marginal cost function for transportation of natural gas in a pipeline system will be developed in Section 7.

analysis. The elasticity is defined as follows:

$$e_{Q,P} = \frac{dQ}{dP} * \frac{P}{Q}$$

The solution in (Eq. 3.4.2) can now be written on the well-known form as follows:

$$\frac{P^* - MC}{P^*} = -\frac{1}{e_{Q,P}}$$

(Eq. 3.4.3)

This result is known at the inverse-elasticity rule for optimal price/marginal cost markups. The result can be illustrated as shown in Figure 3 below.
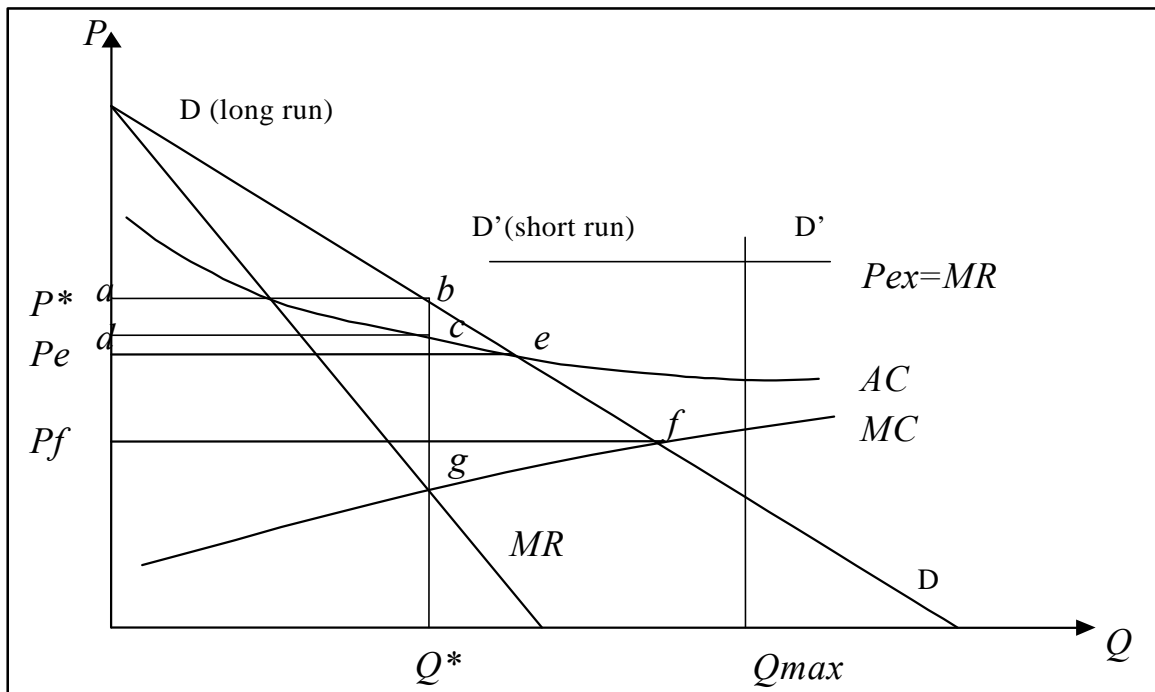
Figure 3. Economic relationships

A number of core problems can easily be identified by reference to the figure above. The long run demand is noted by the line marked D. The monopoly profit is equal to the rectangle marked a-b-c-d and the welfare loss is equal to the area b-g-f.

As noted by Hope, [69] if the monopolist can exercise full price discrimination, he can reap all consumer surpluses over the *MC* line and the optimal output level would be Q at the point f.

Further, by the same monopoly maximization arguments as stated above, the figure clearly illustrates the incentives for restricting the producer's market power in order to improve social welfare. How this can be obtained, from a theoretical perspective is discussed below. We see that a price equal to average cost *(Pe)* will cover the producer's cost, but the corresponding output level will still cause welfare loss. A price equal to marginal cost *(Pf)* will, according to this theoretical approach, cause no social welfare loss. [70] This price however, is not sufficient to cover the producer's fixed costs, i.e. the investment and fixed operational and maintenance costs, as will be shown later.

3.4.3.2 Drive for competition

The problem identified above may be characterized as a specific class of market failure. [71] The market suffers from insufficient competition, due to the natural monopoly characteristics of the industry. Broadly speaking, there are two alternative ways of correcting such distortions:

- introduction of regulation (by some means) in order to prevent the producer from exercising market power
- inducing of more competition - if and where possible.

In a fully competitive market – assuming now that the market was functioning, and assuming a long-term perspective – the market would be characterized by *dP(Q)/dQ = 0*, causing *P(Q) = P = MR = MC = AC*. In that case the demand curve would have been a horizontal strait line. The producers would be price takers and they would have no market power. The elasticity of market demand would be infinitely elastic ($e_{Q,P} = - \infty$) in that case.

Before proceeding any further, one interesting observation regarding market failure is illustrated in the figure above. In the figure it is shown how the current European gas market distinguishes itself from a fully competitive

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[69] See Hope (2000) page 179

[70] If we consider the market as being the continental European gas market, this solution will cause no welfare loss for continental Europeans. As there is practically speaking no consumption of natural gas in Norway this solution will however not optimize the profit for Norwegian producers and it will not cover the producer's fixed costs.

[71] See Armstrong et al (1995)

market in a *short-run* perspective. In this market the short-run demand curve may be illustrated as shown in the figure by the *horizontal line marked D'-D'*. Based on the gas sales agreement the customers can nominate different volumes of gas, but the price is set constant regardless of the volume taken.

The price is also normally set above the average costs and the gas price is specified as a function of alternative energy prices and not as a result of a "gas to gas" competition in an elastic gas market. The price remains the same (from a principle point of view) regardless of the volume delivered to the customer under the given contract. This pricing principle stays the same throughout the entire contract period. [72] The price may thus be thought of as an exogenously given price during the contract period. This situation, illustrated in the Figure 3 is indicated by setting *Pex = MR = demand curve D'-D'*.

We immediately see that the optimal solution for the producer in the short-run is to set production at *Qmax* (note: we do not consider the demand curve marked D-D in this case, as this line refers to the long-run illustration), which is equal to the systems' maximum capacity. [73] Or in other words, the optimal solution for the producer (the seller) is that the customer nominates full requests according to his rights in the given contract.

The perhaps most interesting question after all, from a consumer point of view, is whether the pricing mechanism currently applied (prior to the introduction of the Gas Directive) for negotiating gas prices in the European market, is appropriate and secures efficient outcomes. The political view in the EU and answer to this question is an expressed willingness to seek other options than the prevailing alternative-fuel net-back pricing mechanism.

If we therefore return to the two basic principles for correcting inefficient markets, the Gas Directive essentially applies both of the (bullet-point) measures identified above. In theory, and as will be discussed later, the Gas Directive opens up for competition and it simultaneously regulates the industry. The key issue to be noted here is that the political position of the Gas Directive is a view that competition is achievable in the down stream market, i.e. the "burner tip" market. The natural monopoly activities, to the contrary, are not believed to be neither competitive nor contestable and therefore subject to regulation. This principle therefore inevitably calls for regulation of access to the natural monopolies, being the natural gas transportation activities as

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[72] See Brautaset et al. (1998)

[73] This conclusion can be show analytically as presented for example by Brottemsmo (1994-A) see page 17 and figure 3.2.

well as some few others as defined in the Gas Directive. [74]

3.4.3.3 *Organizational structures – integration versus separation*

The next logical notion of the analytic framework follows as a requisite or a corollary of the "opening up of the market" provisions and the "regulation of access" to the transportation system provisions of the Gas Directive. The notion is that a vertically integrated company may be in a better position in the downstream competitive market than the rival firms who are not vertically integrated, but dependent on the vertically company's transportation services. There are several reasons for this argument.

The first argument is that the vertically integrated company may conduct cross-subsidization between internal activities. The adverse effect is obvious as the company, if allowed, can pass on to competing shippers costs that have its origin in activities other than those needed to serve the competing shipper. To overcome this problem, regulatory regimes specify in some way transparency of accounting or separation of activities.

The second argument is that the vertically integrated company can benefit from information asymmetry. The vertically integrated company may have access to information on market and cost, as well as technical and operational information that is not available to the rival company (or the regulator – for that matter). The core notion here is that the Gas Directive requires transparent accounting of the transportation services presumably due to arguments as stated above. This requirement needs thus to be observed throughout the course of this work.

3.4.3.4 *Symmetry and asymmetry in information*

Access to information is a crucial topic for all stakeholders of this industry. [75] In many cases the choice of a regulatory regime and pricing principles are founded on a presumption regarding what information is readily available and what is not. As will be elaborated below, the different options for tariff and toll rules are all based on different presumptions about information availability and their individual attractiveness for practical implementation depends largely (as a viewpoint of the author) on the extent to which the required information is available.

The information concerned in the context of this work can be organized

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[74] Note that Norway and continental Europe may have asymmetric incentives in this case – at least conceptually as Norwegian interests are basically those of the producers.
[75] The very fact that this dissertation starts out with a comprehensive assessment of information is credited to this recognition.

into some distinct categories. The first category relates to the cost functions (i.e. total and marginal costs). Such information is important both in the short-term perspective as in the long-term perspective. Generally speaking, the short-term costs are fairly easily obtainable for production and transportation, based on empirical data. [76] The long-term costs are less available, due to significant uncertainties of future development on the NCS. These facts may have bearing on the choice of tariff and toll regimes; to be suggested later.

The next category of information is related to market demand functions for natural gas throughout the different regions in Europe and the demand for "stand-alone" transportation services. Accurate information on market demand functions is imperative in order to apply and utilize several of the economic optimizing rules listed below. If an unbundling of the merchant function should develop, new uncertainties will be introduced regarding demand functions for "stand-alone" transportation services. The market demand information is uncertain in the long-term perspective as well as in a short-term perspective. Such uncertainty is caused by the assumption that the market will develop differently in the future compared to what is has been doing in the past, due to the introduction and implementation of the Gas Directive. Again, any "real world" approaches for suggesting new principles for tariff and toll rules in a Norwegian context must consider such uncertainties when designed.

A third class of information relates to all the technicalities conducted by the transportation system operator and shippers' dispatching representatives for securing pipeline integrity, optimizing operations, performing imbalance control, utilizing operational flexibility and "line-pack" gas and so on. These are all features required in order to deliver gas under existing contracts as a bundled, merchant product with high security, regularity and quality of supply. In the current regime existing gas sales contracts and transportation agreements are silent about such features as regards to their details and separate costs of conduct. The extent to which such features shall be made transparent and included as separate costs and toll elements must be considered in the proceeding work.

3.4.4 *Economic efficiency criteria*
3.4.4.1 *Pareto optimal efficiency*

In order to quantify different possible solutions by means of economic analytic measures, a number of economic efficiency criteria are developed and

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[76] In Section 5 it has been shown that no significant or major resistance is observed in the stakeholder group assessed in this work, for releasing such information or making this information public.

listed in the literature. [77] This sub-section assesses some often-applied measures.

One ultimate economic measure is often referred to as Pareto efficient allocation of resources, defined as: "an allocation of available resources in which no mutually beneficial trading opportunities are unexploited. That is, an allocation in which no one person can be made better off without someone else being made worse off". [78] Another way of defining according to Mansell et al. is that "an effective outcome maximizes the sum of producer and consumer benefits from production and consumption".

In the literature several authors [79] have pointed out the fact that the Norwegian natural gas export interests represent almost solely the producer interests, due to the fact that only a minor portion of the gas is sold domestically. The corollary is that the gas buying nations to a large extent represent the consumer interests only. [80] This observation is presumably clearly understood by the major stakeholders of the industry, a fact that may have implications when it comes to national and enterprises' strategy development of their business. [81] For the cause of this work, the prevailing national and international legislation is taken as a matter of fact and any tariff or toll regimes suggested here comply with the Gas Directive and the EU's competition law.

The Pareto measure has a quite general nature and other measures may prove more useful in this context. The economic efficiency criteria ought to be useful for evaluating the attractiveness of different rules and options for allocation of costs, allocation of shippers' access to capacity and so on. Several such criteria are therefore listed below.

3.4.4.2 Dynamic efficiency

Dynamic efficiency [82] is a measure of a firm's ability to respond to changing market demands by producing more and better products and finding ways of producing at lower cost, see IEA (1994). Another way of putting it is that innovation and investments in cost reductions are socially efficient.

Due to the nature of this industry, dynamic efficiency is basically a

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[77] See, for example, the IEA study reports, Teece (1990), or Mansell and Church (1995).

[78] Nicolson (1972)

[79] See for example Nese (1998)

[80] The key questions typically are the sellers' concern related to gas price development and the buyers' concern related to security of supply. As both parties have undertaken large "sunk cost" investments they are mutually dependent to a large extent.

[81] See Radetzki (1999) for a related discussion.

[82] Armstrong et al. (1995) apply the word "productive" efficiency.

long-term related question due to several reasons of which a few can be mentioned here. The industry is characterized by large sunk costs. This causes limited scope for introducing new technology into old systems. If new technology should be introduced the old must be phased out. It may thus be more cost effective to operate and utilized the old technology. Further, new investments are throughput driven. No new investments are done if no more gas is sold in the market. Finally, new capacity is developed in large incremental steps. As a consequence of these facts, diffusion of innovation and technological change will largely take place in connection with development of new capacity, at least when it comes to the "hardware" components of the systems. [83]

Therefore, and as will be discussed in Sections 5 and 7, a major concern probably is to design proper incentives for dynamic efficiency into the nation's licensing systems and the industry's planning systems for development of new capacity on the NCS. This probably is more feasible than seeking to include strong incentives for dynamic efficiency in the toll regime.

In a liberalized regime, however an important consideration may be how to finance innovation and technological change. If an independent transportation system company shall be assigned the sole responsibility for development of new capacity including research, funding of such activities must be clarified. Given this situation, one may argue that the toll must cover the cost of research.

3.4.4.3 Static efficiency

According to Nese, [84] static efficiency may be defined as "an efficient use of resources at a given market structure and technology". Based on this understanding of static efficiency, Nese suggests that two "motivations" are present for optimal regulation of the Norwegian natural gas transportation system. The first motivation is to optimize the depletion of Norwegian natural gas resources. The second motivation is to maximize the profit from the natural gas export.

In this work, the above expressed motivations are identified as effectiveness measures and not as economic efficiency criteria as suggested motivations are very difficult to quantify and measure directly. Actually, and as will be verified in Section 5, such overall success criteria are fulfilled by means of conducting a large number of functions and carefully designed processes. As pointed out by Nese, the toll regime must not have an adverse

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[83] See Dahl (1999-A)
[84] Nese (1998)

effect, making it more difficult to succeed and fulfill the effectiveness measures.

As will be thoroughly discussed in Section 5, a number of effectiveness measures are stated by the stakeholders and in Section 7, revised effectiveness measures will be derived based on the liberalization process.

3.4.4.4 Allocative efficiency

According to Mansell et al. [85] allocative efficiency may be defined as "the quantity of product and services supplied is efficient". In a broad perspective this means that all customers who are willing to pay a price equal to or above marginal cost of production and transportation shall be supplied with gas. When it comes to transportation services only, the aim is to have sufficient capacity to serve all shippers with a willingness to pay a toll equal to or above marginal costs of transportation. Allocative inefficiency exists if this aim is not met or if there is excess capacity due to lack of willingness to pay the given toll.

The challenge of obtaining allocative efficiency is largely and basically a long perspective task. In a Norwegian context, the development of new transportation capacity has so far been done as an integral part of a production field development where considerations are given to oil, NGL, natural gas production and injection. The final need for new capacity is derived by a comprehensive assessment and planning process. [86]

Therefore and similarly as was argued in relation to dynamic efficiency, the main means for obtaining allocative efficiency in a Norwegian context has been the planning process rather than any incentive structure provided by the toll regimes. The basic argument – expressed somewhat simplified – is that the planing process generally has ensured that there is an overall balance between production capacity, transportation capacity and sales commitments. Of course, one question is whether a centralized planning function will persist in a liberalized setting and if liberalization will speed up the demand for new capacity faster than actual development of new capacity. Further, terms of transportation may become increasingly more important for securing allocative efficient transportation for tail production and for development of "small" fields.

One theoretical approach for enhancing allocative efficiency is a toll regime based on long-run marginal costs (LRMC) where the marginal costs

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[85] Armstrong et al. (1995), page 13 use the word allocative efficiency to express a combined view of Pareto allocation and "allocative efficiency".
[86] See the "legal framework," sub-section 5.3.

accurately reflects the development of new capacity in a region over a given time frame. If such information is available this may be a feasible approach, as the LRMC will inform the shippers of future incremental costs of transportation. [87]

One question is the following: is a toll based on LRMC for transportation a feasible approach for enhancing allocative efficiency in the Norwegian context? Again, to answer this question information is required regarding future developments on the NCS and the procedures to handle future decision making. Such information is uncertain in both respects, even though a contradicting argument is that LRMC can be predicted based on historic data.

To sum up one may argue – at least to some extent – that any calculation of LRMC may be uncertain in a Norwegian context. Allocative efficiency (as dynamic efficiency) may therefore in a foreseeable future be a prime objective for the licensing system and any future planning function of NCS development, rather than the toll regime. The toll regimes however, must not have any adverse effects on allocative efficiency.

3.4.4.5 Rationing efficiency [88]

According to Mansell et al. rationing efficiency measures whether "the distribution of the services among customers is efficient". This means that transportation services are given to those shippers who earn the most by using the service. The criterion is relevant in a short-run perspective and the criterion may be quite useful for measuring the efficiency of potential auction principles as well as capacity allocation and booking rules in general.

3.4.4.6 Cost efficiency

According to IEA and Mansell et al. cost efficiency includes the concept of providing the services at the lowest possible cost. [89] The efficiency criterion may also include managerial efficiency. This criterion is relevant in a short-term perspective when it comes to the variable operational costs as well as for fixed operational and maintenance costs. The measure also is applicable in a long-run perspective related to minimizing cost of new capacity.

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[87] These principles are applied in the UK's "network" code according to Madden (1997) at Financial Times, see page 56. The toll is based on a LRMC evaluation over future 10 years demands in a given region.

[88] Please note for the sake of completeness that the IEA report uses the word "allocative efficiency" where Mansell et al. use "rationing efficiency".

[89] According to IEA (1994) this is sometimes referred to as technical efficiency.

3.4.4.7 Efficient product selection [90]

The type of services offered is efficient; i.e., the "menu" of services is differentiated to match the services demanded by shippers. This measure is relevant in a short-term perspective, even though this type of services likely will develop over time.

3.4.4.8 Other criteria

Teece [91] lists a number of other quite specific additional criteria. These are according to Teece, efficiencies that are often improved by vertical integration of the industry. *Information efficiency* is related to the information flow between stakeholders. *Operating efficiency* relates to operational information and handling of operational tasks. This topic will be assessed in Section 7. *Transaction efficiency* relates to pooling of nominations and utilizing contractual flexibility, as will be discussed in detail in Section 7. *Efficiency due to credible commitment and supply* relates to the political and economic costs associated with failure to perform.

Several of the efficiencies characterized by Teece are observed in the prevailing vertically integrated Norwegian system. The introduction of the Gas Directive may have some adverse effect on some of these issues. Such adverse effects must be minimized if possible.

3.4.5 Tariff and toll principles
3.4.5.1 Definition of tariff and toll

In this work the term *tariff* is used to define the conditions of transportation services. A transportation system owner offers such services to shippers i.e. the users of the system. The tariff specifies such issues as access rules, services, terms of service, policies, procedures, and the *toll (or rate)*.

The latter term, *toll* defines the monetary compensation to be paid by shippers. In the Canadian literature the term *toll* is usually applied, while US industry often uses the term *rate*.

3.4.5.2 Main objectives of tariff and toll

Some main purposes of the tariff regime – in conceptualized terms – are to specify the services provided to shippers and to specify the toll applicable for that specific service. A number of authors, such as Von der Fehr (1996), Cave and Doyle (1994), Armstrong et al. (1994), Mansell and Church (1995),

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[90] See Mansell et al.
[91] Teece (1990)

the IEA Study (1994) reports, and Hope (2000) discuss these issues theoretically and practically.[92] According to the test cases specified in Section 2.4, and as discussed in Sections 6 and 7, three basic types of new transportation services are assessed in this work, namely firm services, interruptible services and peak load services. Each of these services will call for different toll rules and such toll rules may be founded on different well-known toll principles. In the following sub-sections these principles are reviewed and their advantages and disadvantages are identified from a theoretical point of view.

Based on the list of efficiency measures above, the main *ideal objectives* of the toll regime may be conceptualized into the following requirements:

- The toll shall provide appropriate signals to the shippers regarding the cost of providing additional capacity. This requirement is derived from the dynamic- and allocative efficiency criteria.
- The toll shall provide efficient rationing so that existing capacity is used optimally. The toll structure (supported by the tariff structure and an efficient product selection) shall be flexible enough to allocate capacity optimally between shippers, both when there is sufficient capacity and when there is insufficient capacity. This requirement is derived from the rationing efficiency (and static efficiency) criteria.
- The toll shall normally provide recovery of costs. [93]
- The toll shall provide incentives for cost minimization. This requirement is derived from the cost efficiency criteria. Cost minimization shall be conducted during development of new capacity, i.e. minimizing new investments. Costs minimization shall also be conducted in day-to-day operations, i.e. minimizing fixed and variable operations and maintenance costs.

The notion described in the analytic framework below is that the transportation company shall offer access to any shipper as defined in the Gas Directive. The shippers' demand is thus a demand for transportation services. The services offered are basically "access to the system" in order to transport a

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[92] Von der Fehr (1996), Cave and Doyle (1994), Armstrong et al. (1994), and Mansell and Church (1995). See also the study reports from IEA. Hope (2000) see page 177.

[93] This requirement is not necessarily so under all circumstances. For example given some regulatory regimes and applicable for some national utilities it may be more efficient for example to cover costs by general taxation.

specified volume of gas as firm, interruptible or peak load transportation. The gas transported in the pipelines always belongs to the shippers and it never belongs to the transportation system company. The transportation system company receives and re-delivers the gas at specified entry and exit points.

The transportation company can be organized either as an incumbent vertically integrated company (with transparent accounts) or as an independent transportation system company that offers these services as its sole business entity (sometimes referred to as a "common carrier"). [94]

Finally, a number of other considerations and requirements may be included into the analyses dependent on the type and extent to which information is available. Some toll regimes may prove to be more feasible and effective than others. In Section 7 it will be indicated how some of such additional requirements will rule out some toll regimes, simply because they may prove to be too complicated to implement in a practical manner or they may be judged "unfair" or unstable.

3.4.5.3 *Marginal cost pricing*

Given that the cost and demand functions are known and assuming some specific ideal conditions, several authors [95] have shown that the optimal toll based on a pareto allocation criteria is to set the toll equal to marginal cost of transportation. This solution is referred to as the marginal cost based pricing rule and it constitutes a "base case" solution. The solution is persistent regardless of the two organization structures identified above given "ideal" assumptions of demand and costs functions. [96] The solution is illustrated in the Figure 3 above and the toll would thus be equal to the price *Pf.* The toll formula will simply yield *T(Q) = MC(Q).* This toll formula is a linear toll function.

To summarize, [97] marginal cost pricing may secure an efficient rationing as long as there is sufficient capacity. Short-run marginal cost (SRMC) gives no rationing efficiency during periods of capacity constraints. If LRMC is applied it may improve allocative efficiency as it gives signals of capacity constraints and where to invest. The main caveat to the rule is that it does not contribute to cover the fixed costs. The rule requires knowledge of marginal costs of transportation and it will improve on cost efficiency.

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[94] See Hope (2000) and Carpenter, Jacoby and Wright (1986)

[95] See Von der Fehr (1996) or Bjørkvoll (1996)

[96] This topic will be further elaborated in section 7 of the dissertation.

[97] See also Nese (1998), page 50

3.4.5.4   Average cost pricing

Armstrong et al. for example have shown that given the constraint that the firm (i.e. presupposed here to be a single product form) breaks even the Pareto optimal allocation and maximizing welfare, is to set toll equal to average costs. In Figure 3 this is illustrated by setting toll equal to *Pe*. The toll formula will yield *T(Q) = AC(Q)*.

The average cost based toll covers cost by definition. It gives no rationing efficiency during periods of capacity constraints. Average cost pricing does not enhance allocative efficiency, as it gives no signal of capacity constraints. The rule requires knowledge of all costs functions related to transportation. The main caveat to the rule is that in theory it gives no incentives for cost efficiency and it causes welfare loss.

3.4.5.5   Two-part toll

A two-part toll is an example of a nonlinear toll. The main purpose is to improve on welfare beyond the possibilities of linear pricing (i.e. a fixed unit cost). A two-part toll is commonly applied in this industry. A two-part toll may consist of a fixed charge in order to obtain booking rights for a certain capacity and a variable part, charged per unit of gas actually transported, in order to cover variable costs.

Armstrong has shown that this toll regime improves upon a simple linear toll, constrained by the firm breaking even. The Pareto optimal allocation will yield a toll formula of the form:

$$T(Q)=F+t(Q)Q \tag{Eq. 3.4.4}$$

Generally, there are two objectives sought by applying this two-part toll formula. First, the fixed part, *F* shall be chosen to cover total costs and secondly, the variable part *t(Q)Q* shall be set equal to or close to the marginal cost pricing to ensure an efficient usage of capacity.

The two-part toll may improve rationing efficiency provided discrimination is possible between shippers. Those shippers who are only willing to pay marginal costs will not be granted access if a fixed charge is enforced. The regime will cover all transportation costs provided the fixed charge is chosen correctly. The regime will improve allocative efficiency as more price discrimination is provided. If the fixed charge is set differently for the individual parts of the system the actual costs of these parts are made more transparent. The regime requires information of the shippers demand functions and information on transportation costs. The disadvantage is the same as for

the average cost-pricing regime, it may in theory give poor incentives for cost efficiency as all fixed costs are covered by the toll.[98] It also causes some welfare loss, albeit less than average cost pricing.

The two-part tariff is a simplified case of non-linear pricing. If perfect price discrimination was obtainable, in theory, different segments of shippers could be split into groups according to their willingness to pay toll.

3.4.5.6 *Pricing with capacity constraints*

As will be discussed in the Section 5, new transportation capacity on the NCS is developed in large incremental steps based on a centralized planning procedure. So far, new incremental capacity has normally been introduced ahead of the enforcement of new sales commitments and the increased demand. In a liberalized context one may envisage that this situation may change due to several reasons. The result may be that the demand may exceed capacity during peak time periods. At such peak time periods demand may exceed either the total network capacity or local capacity in certain regions of the network. Such peak periods may consist of short daily peaks or yearly seasonal fluctuations. [99]

The first issue to be studied here is how to handle short daily peak demands. Somewhat simplified we may say that the aggregated shippers' demand for transportation services can normally never exceed the physical production capacity at any time. Obviously, no shipper can sell a given physical volume of gas if the gas is not produced in the first place. Due to the harmonization of production and transportation capacities, the aggregated transportation system capacity will normally always be sufficient to handle all the produced gas if the routing of gas is optimized purely on physical terms (and assuming there is a corresponding downstream off-take of the gas).

Another characteristic of the Norwegian natural gas transportation system is the fact that the transportation system operator is in full control of all the entry and exit points. All entry and exit points are physically controlled by a gas flow regulation valve, which means that unlike some other utilities or downstream networks, [100] no "drainage" of the system will be allowed in such

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[98] This may not necessarily be so as the fixed part can be set constant and at a level less than total cost.

[99] See the Canadian experiences discussed in Section 6.3.1 on page 102. In Canada, and following the liberalization, a significant growth in natural gas production and transportation has occurred. The pipeline systems have been utilized at a very high level.

[100] In the downstream market the consumers may typically take gas or electricity at any rate they wish, without any direct possibility for the system operator to limit their consumption, except of eventually completely shutting down a given region of consumers.

a manner that integrity is jeopardized. Therefore, the rationing task is important primarily for securing economic rationing efficiency, and has less importance for securing physical integrity of the systems and operations.

What is quite possible however, is that the given maximum gas production can be split and routed differently or distributed "unevenly" in the pipeline system network. This will cause constraints in some parts of the system and potentially spare capacity in other parts of the system. This fact leaves the shippers with a possibility to compete for transportation services, either in one given pipeline or between pipelines.

We now assume that the transportation system operator is acting as an independent system operator and he receives all the shippers' requests. The task is now to rationalize and prioritize the different shippers' requests so that an optimal rationing efficiency is obtained. One feasible means is to utilize the toll regime to do so. A feasible approach is an auction in which the individual shipper discloses information on his bid.

The rationing task is a quite complex achievement as added value due to increased transportation in one region of the system simultaneously may cause losses due to reduced transportation in other regions. Due to the technical nature of the gas network, several physical and technical threshold-values exist. If such values are trespassed, only minor incremental deliveries in on part can cause significant unintended reductions elsewhere. A rationing task must therefore involve a physical evaluation, optimization and trade-off between the additional and reduced volumes based on the individual shippers' information on where to receive and where to deliver the gas. Further, the rationing task must include and combine information on the individual shippers' bid of toll compensation, volume to be shipped and potentially the duration of the deliveries. The toll function must thus be a function of the following information received from each individual shipper:

$$T_{Auction} = maximize\ f(entry\ point,\ exit\ point,\ volume,\ bid\ price,\ duration)$$

In Section 7.5, a tolling regime for peak load toll based on the above principles is suggested.

A number of other issues must be solved in connection with peak load pricing. One interesting topic is the relative split between the revenues from auctions versus revenues from firm and other interruptible tolls. One question is to what extent the toll received from auctions shall contribute to cover fixed costs. Auctions are virgin ground in a Norwegian context and the size of revenues is uncertain. If the revenues are significant, some kind of for

example (annual) reimbursement principles may be introduced in order to limit the pipeline system owner's rate of return at a fixed level. Another question and uncertainty is to what extent shippers will shift their preferences from firm transportation to interruptible transportation and the extent to which there will be constraints.

A second issue to be discussed is whether a feasible toll regime is a means to deliberately encourage more usage of the system in seasonal off-peak periods. Traditionally, the Norwegian gas deliveries are higher during the winter period than the summer period. [101] The general principle is that the shippers shall be faced with a toll that reflects the shortage price for using the pipeline system in peak periods as well as in off-peak periods. The latter usage will typically be provided by means of implementation of interruptible services.

3.4.5.7 *Rate of Return and Cost of Service*

Rate of return regulation and costs of service regulations are refinements of average cost toll and these types of toll regimes are applied frequently in current regimes. The former regime is applied in the prevailing Norwegian regime, and the latter is quite common in North America.

These toll regimes will be discussed in detail in Sections 7.4.2.10 on page 160 and in Section 6.3.4 on page 105, respectively, and no further discussions are thus provided here.

3.4.5.8 *Ramsey pricing*

If price discrimination is possible between shippers and the aim is to optimize welfare, Ramsey pricing is a feasible means. If we presuppose that demand for transportation is a decreasing function of the toll, welfare is taken as the weighted sum of consumer surplus and firm profit. Assuming further that there are no cross-price effects, the rule for optimal price/marginal cost markups can be written as follows:

$$\frac{P_i^* - MC_i}{P_i^*} = -\frac{1}{e_{Q,P,i}}$$
(Eq. 3.4.5)

Here $e_{Q,P,i}$ is the elasticity of the market demand for transportation services in market i.

The implication of Ramsey pricing is that the toll shall be set closer to

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[101] Source: Statoil

marginal cost in the elastic market and farther from marginal cost in the inelastic market. The rule assumes perfect information on the individual shippers' demand for transportation services (the individual shippers' elasticity). Further, the rule assumes that price discrimination between shippers is acceptable. [102]

3.4.5.9 *Efficient component pricing rule*

The last toll rule of a generic nature – to be discussed here – is a rule known as the Baumol-Willig-rule or the "efficient component pricing rule", [103] and the rule is applicable in the context of scarce capacity. The rule is often presented in connection with solving the problem that typically occurs if a vertically integrated company is obliged to grant access to a third party shipper – a newcomer. The third party shipper, and his gas, competes in the same market as the incumbent. If the incumbent accepts to grant access to the newcomer he will potentially loose some gas sales and corresponding revenues. The rule thus constitutes an alternative approach to the auction type of toll regime, provided a fair amount of information is available.

According to Nese (1998), the rule says that an "optimal use of transportation capacity requires that each user is faced with a price reflecting the cost in money valued inconvenience that this use is causing for other agents." Another way of saying this is the newcomer shall pay a toll equal to the marginal cost of transportation plus a compensation for the loss incurred to the incumbent. The latter is referred to as the opportunity cost or the incumbent's profit margin. The formula can be expressed as follows: [104]

$$T = MC_t + (P - MC_p - MC_t)x \qquad\qquad \text{(Eq. 3.4.6)}$$

Here, the prefixes t and p represent transportation and production, respectively and x is the displacement ratio of the incumbent's sale of gas for the competitor's sale of gas. x has a value between 0 and 1.

We now assume that both the newcomer and the incumbent compete in the same market and they obtain the exact same price, P per unit of gas and x is thus equal to 1. The gas deliveries from the two companies' are perfect substitutes in the market. This is a perfectly sound assumption, as the natural gas in Norwegian pipelines is a commingled gas stream with a number of individual sources of supply. Further, the cost of transportation is the same

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[102] The Author provides further details of the rule in Dahl (1998-C) page 15.
[103] See Von der Fehr (1996) and Nese (1998)
[104] Nese (1998) page 35.

regardless of who owns the gas. (Neither the compressor nor the pipeline "distinguish" between who owns the gas). Therefore, both the incumbent and the newcomer face the same marginal cost of transportation.

The rule thus implies that the only way for the newcomer to make profit is to produce his gas at a *marginal cost* less than what the incumbent does. This conclusion inevitably leads to the caveat and the shortcoming of the rule, in the context of Norwegian natural gas transportation. To the extent marginal costs of production are available, the information is probably proprietary and not subject for release to the competitors. Further, in many cases, the production costs may be deemed almost negligible, as much of the gas produced on the NCS is associated gas derived from the oil production. If such latter assumptions are made, the rule will give no additional contribution at all.

If however, we assume that the gas price in the downstream market are differently priced the rule would give priority to the gas with the highest downstream price. Again, this information is probably not transparent for any potential regulator who should enforce the pricing rule.

4 Systems approach application and methodology

4.1 Development of systems engineering processes for the work

Based on systems theory the first major activity conducted in this research was to develop *two* systems engineering processes for the work. The subsequent steps were to develop sub-hypotheses and order these into the processes, and to develop and identify the different methodologies that the research has to apply.

The goal of the first process is to define the existing transport operations accurately and thoroughly. This process is called as *systems re-engineering process*. One should remember that the transportation system being scrutinized is already built and is operated for many years. The operations personnel are performing their tasks according to an established organization model and with operation functions and systems performance defined. This fact causes significant constrains on the results – or the outcome of the process – in the sense that the main objective of the re-engineering process is to describe the existing system as accurately as possible. One may thus summarize and say that the process is optimizing the description of an existing system.

The second process provides a systematic approach for analyzing future conditions and this process is referred to as *systems engineering process*. It incorporates and handles the new requirements and the process uses results obtained in the first process. The second process thus expands the first process and it seeks to find solutions to the problems identified.

The two systems engineering processes are shown in Figure 5 on page 60. The figure is a functional flow block diagram (FFBD), according to the conceptual thinking as described by Oliver et al. [105] Figure 5 specifies several work tasks and each task is formulated as a sub-hypothesis that accomplishes specific tasks as outlined in the next sub-section.

This figure is thus showing the *flow of information* as it is developed in the research work. This figure is thus illustrating how the systems approach is implemented in a practical manner into the research and how it contributes to derive and infer overall and consistent solutions to the problems identified.

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[105] Oliver et al. (1997). The FFBD concept will be described later in the report.

4.2   Development of work tasks and hypotheses

The main hypothesis has been decomposed [106] into a number of sub-hypotheses that are ordered into the systems engineering processes. The sub-hypotheses cover such work tasks as assessment activities (*assess*), modelling development (*model*), test-case scenario development, method development (*method*), test of models and methods (*test*) and conclusion and discussions (*doc*). The sub-hypotheses tested in this dissertation are tabulated in Table 2 on page 61. In the bullet points below some few comments are offered to each of the different tasks.

- The B.1 and C.1 activities assess available information regarding the systems requirements, design and operation. This step consists of documentation review and interviews. Different methodologies are applied for interviewing stakeholders and for assessing documents.
- The B.2 and C.2 activities consist of defining the effectiveness measures. These measures specify criteria for successful operations and system performance. They are derived and inferred from assessment activities.
- The B.3 and C.6 activities are creation and modification of information models. The models provide a communication mechanism that specifies the system and the system operations. A specialized systems engineering computer tool, called RDD-100 is applied to create these models.
- The B.4 and C.7 activities indicate the importance of iteration and feedback in the modelling work. The "trade-offs" performed in the first process (B.4) are trade-offs required in order to correctly create the models. In the C.7 activity similar trade-offs are carried out. The C.7 activity however also includes different trade-offs that optimize future operations based on the new requirements of change.
- The C.3 activity tests the validity of the two test cases defined in Section 2.6 and it infers essential requirements for future operational modes. The methodology applied here is simply to summarize the lessons learned throughout the assessment activities and synthesizing some main requirements of change.
- The C.4 activity comprises a major activity as it analyzes many different aspects of future operations based on technical and economic

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[106] Systems engineers often apply the term *decomposition* as an expression for breaking up (or disaggregating) any aggregated entity into hierarchic tiers of lower level entities.

theory. The activity is in essence a testing of the hypothesis C.4 and it suggests solutions for how to operate the Norwegian natural gas transportation system in the future. New transportation services and new tariff and toll regimes are developed.

- The C.5 activity verifies and tests that new economic methods for future operations are compatible with physical and operational considerations and constraints. A major feature applied is a specialized computer tool based on linear programming. The particular problem to be solved in this activity is how to allocate spare and scarce capacity in a rationing efficient manner and at the same time optimize the physical flow in the integrated system.
- The B.5 and C.8 activities cover the reporting and discussions and a simple methodology for aggregation of results are developed.

In order to test the different hypotheses defined in this work several different methodologies are applied. In the next sub-sections these methodologies are discussed.

4.3   Methodologies applied in the work
4.3.1 Methodology for literature review
During testing of the hypothesis B.1, simple scientific methods for qualitative research are applied. King [107] and Ilstad [108] describe such methodology and the core elements applied are described below.

The first task of the assessment B.1 was to establish an overview of the relevant literature. (Dahl 1998) [109] created a starting point for the activity. The documents reviewed comprised Norwegian legislative acts and Royal Decrees, [110] Norwegian White Papers, licensees' agreements and operating personnel's work instructions and procedures. Several other types of written information were also looked into such as Statoil presentations at various conferences, internal minutes of meetings, letters and the like. Finally, some few relevant textbooks, publications, and journals are available in the literature and such documents were read as well.

Having identified and assessed the written documents, a second task was to extract the prime information of concern. By doing so, a risk occurred of loosing important information. To minimize this risk all the interviewees

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[107] King et al. (1994)
[108] Ilstad (1998)
[109] Dahl (1998 -A,-B,-C)
[110] Royal Decree No 653 (1997)

were asked to identify the most essential information for their own needs. They were also asked to identify – as far as they could – the information being most important pertinent to other stakeholders. By applying this method, cross-references were achieved to the information believed to be most important.

4.3.2 Methodology for interviewing stakeholders

In connection with the B.1 activity a representative group of interviewees from the stakeholder population had to be select without bias. In order to do so an inital meeting was held with two of the stakeholders. [111] They were presented the up coming interview plan and asked to suggest interviewee candidates. A list of names was suggested and the list was subsequently presented to three persons mentioned on this list. They were also addressed with the same question, and a final list of candidates was settled.

Based on this list of names, an interview plan was worked out and seven persons were interviewed according to the plan. The interview schedule is enclosed in Appendix 11.3 and a copy of the questionnaire is enclosed in Appendix 11.4. In order to prevent bias and to obtain traceable and reproducible information pre-written questionnaires were developed and applied throughout the interview process. The interviewees got the questionnaires and background information prior to the interview.

In order to reduce bias in the results and to verify common understanding, several "cross-reference" types of questions were asked. Some questions were of a general nature, developed for all interviewees, while other questions were tailored for specific stakeholder functions. The questions were designed to gather descriptive data, facts and exploratory information.

Finally, and as an important ethical principle the information was processed and aggregated into the information models in such a manner that no traces exist to any individual stakeholders' answers or views. All answers are documented in an anonymous manner.

Regarding C.1, the interviews where not as formal as those conducted during the assessment activity B.1. The interviews conducted were more like a company presentation followed by a discussion and clarification session.

4.3.3 The systems engineering computer tool

The master strategic approach identifies the necessity of using a systems engineering computer program, see assumption A.4. One main reason for applying a computer tool is to run computerized consistency checks on the

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[111] Person A and B (names are available for Statoil employees).

data. A verification of the accuracy of the collected data requires neat and thorough work. Manual methods will easily create errors when handling such large amount of interrelated information.

Another significant feature of the systems engineering computer tool is its capability to support the modelling of information models. Each of the models specifies and "mirrors" different aspects of the system. It is therefore important to map the models against one another to verify consistency between the models. The tool provides easy means for such verification.

According to the "Tools Database" on the INCOSE web site [112] there are several systems engineering computer tools available in the market. The author did the first screening of this web site in the fall of 1998. Based on the information given on the INCOSE web-site several programs would probably meet the author's need.

In order to select an appropriate tool some evaluation criteria were established. The criteria and the results of the evaluation are given in Appendix 11.5. The most important criterion for the author was easy access to the supplier and its support function. This argument was based on the assumption that these programs are specialized tools and the author thought it was important to have the supplier easily available. The author assumed that a close relationship between the author and the supplier would ease and facilitate an effective support.

From the INCOSE list it appeared that it was only one supplier available in this region. The company in question was Ascent Logic Corporation located in Bergen, Norway and the product was "RDD-100". [113] It was decided to evaluate this program's feasibility against some additional author-defined needs and to verify its potential usefulness.

Based on an assessment of available systems engineering tools the RDD-100 program was chosen. The author recognizes however that there exist several other tools capable for solving the tasks of this work. RDD-100 was chosen primarily because it was easily available for the author. The listed evaluation in Appendix 11.5 is only intended to document the usefulness of the program for this work.

4.3.4 Economic and technical analyses

In several of the activities such as C.3, C.4 and C.5 different analyses are conducted based on the scientific theories identified as relevant for this

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[112] http://www.incose.org/

[113] Recently this technology was acquired by Holagent Corporations in California - USA, see http://www.holagent.com/new/index1.html

work. These analyses are of course core activities and they were performed in order to obtain insights, validations and inferences of the different problems and suggested solutions. The theoretical analyses are also supported by empirical data and operational experiences in order to make the analyses as relevant as possible.

4.3.5 *The optimization algorithm and the GassOptTKL program*

In relation to the conduct of activity C.5, linear programming (LP) is applied by means of the *GassOptTKL* program. The *GassOptTKL* program has been developed for Statoil by SINTEF in Trondheim, Norway. The main purpose of the program is to calculate and optimize flows through the entire natural gas transportation network in the case where an unexpected event has occurred. Such an unexpected event can for instance be a shutdown of a gas production field or unavailability of a pipeline or a riser platform due to technical problems. Given such abnormal conditions a tool is needed for optimizing the gas transportation until normal conditions are restored.

The *GassOptTKL* applies a software program XPRESS-MP to solve the LP optimization algorithm. The Wheymouth's equation (Eq. 3.3.1) is applied in the program in order to calculate pressures and flows. The techniques applied in the program are based on a linearization of the Wheymouth's equation by means of series expansion.

The *GassOptTKL* program optimizes the flows in the integrated systems by seeking the flows that cause the least pressure differentials in the systems. The delivery pressures are set equal to the lowest allowable contract delivery pressure at the exit points. For further details, see the user's manuals. [114]

4.3.6 *Methodology for aggregation of results*

In order to summarize and draw some main conclusions of this work and ultimately test the main hypothesis, a simple system for aggregation of the observations and conclusions made in the work is needed. Such a method is shown in Figure 4 below. The methodology applied is to summarize any lesson learned or any outcome of an analysis or a discussion into a numbered list of *Observations*. Upon completion of a given analysis or a discussion, these observations are aggregated in to *Conclusions*. Finally in Section 9 the main conclusions of this work are aggregated and inferred into some few main conclusions expressed as *Recommendations.*

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[114] See Sintef report STF38 A99613 (1999)

59
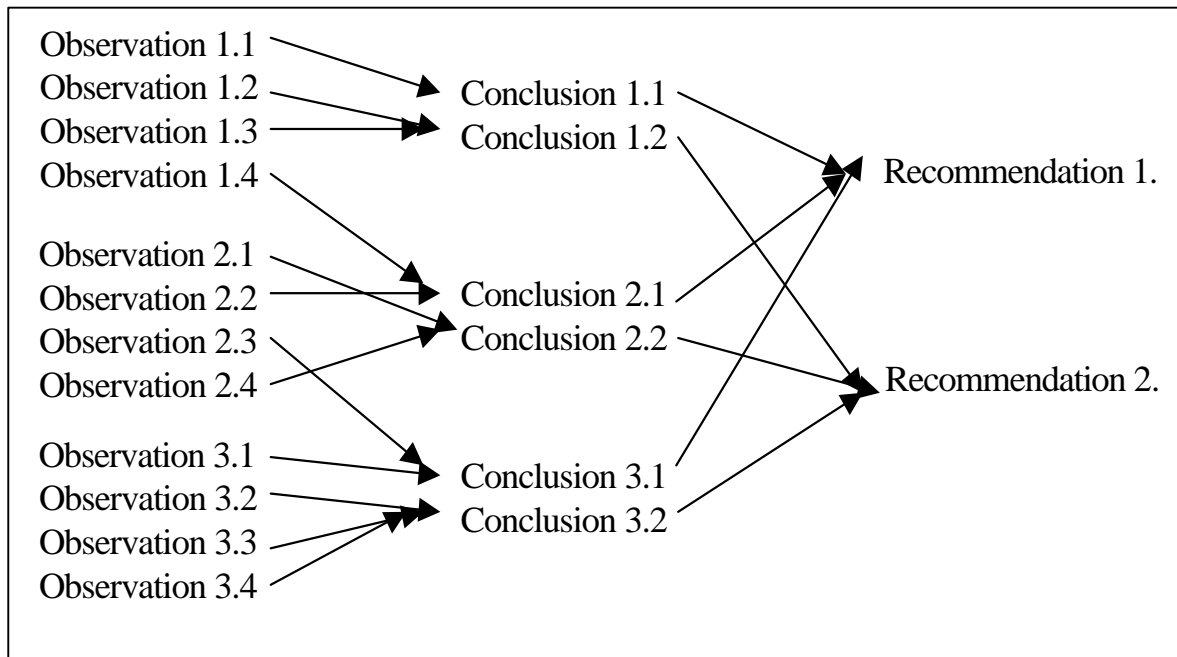
Figure 4. Structure for aggregation of results in this work

4.3.7 Work breakdown structure and scheduling of work

The Microsoft project planner computer program has been quite helpful in order to make the research work manageable and realistic given the limited timeframe of the work. The work was carefully broken down into a Gantt diagram and a planned workload was assigned to each activity. These plans have been updated some few times during the project execution, see Appendix 11.8 for details.
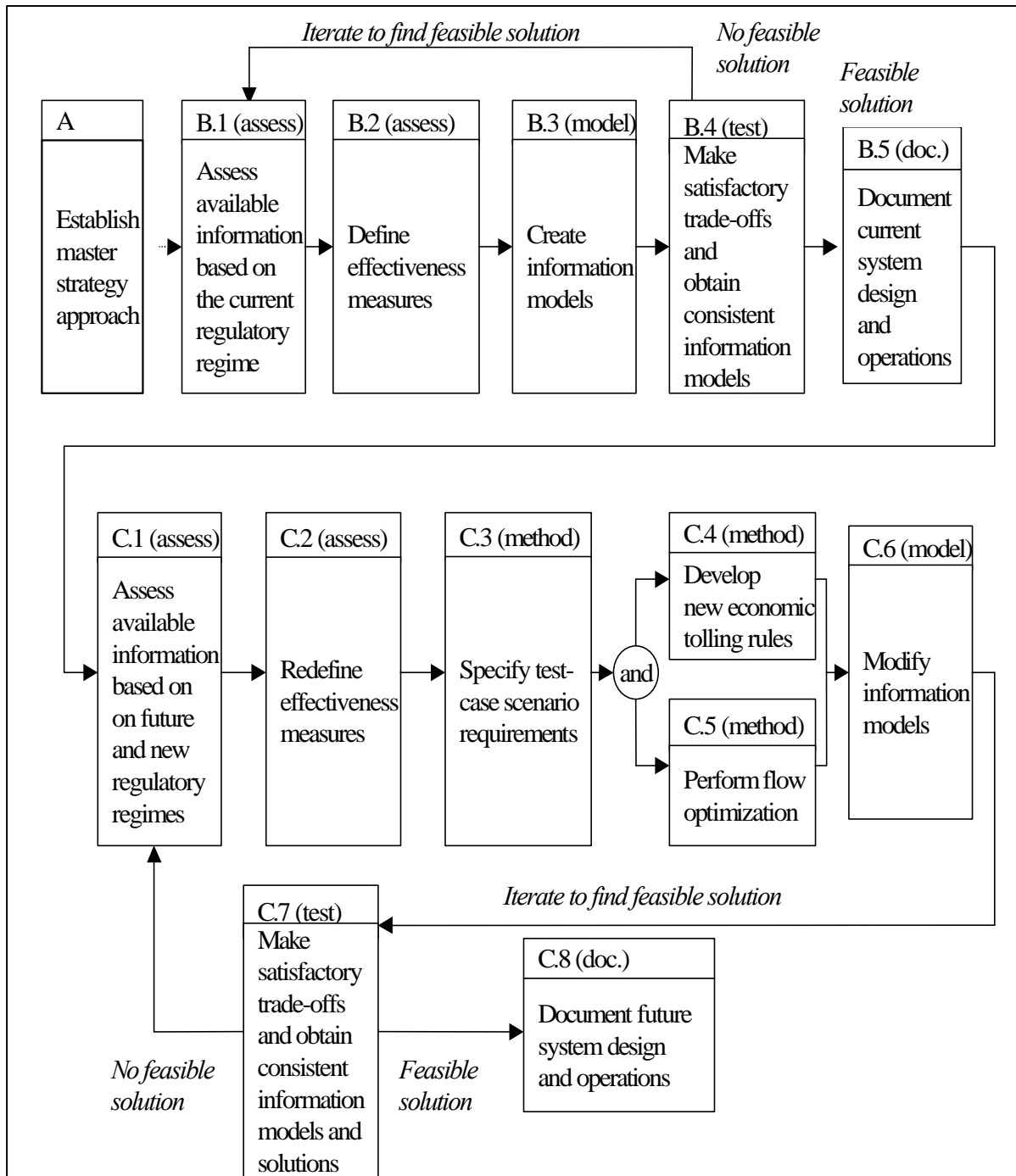
Figure 5. The systems engineering processes for the work showing the information flow and work tasks

Table 2.   The sub-hypotheses

ID	Sub-hypotheses tested in the dissertation work	Covered in paper [20]
B.0	It is possible to develop a systems re-engineering process for assessing, specifying, and documenting *current* operations.	INCOSE' 2000
B.1	Major stakeholders will provide empirical descriptive data regarding their needs and systems requirements.	INCOSE' 2000
B.2	It is possible to establish effectiveness measures for the prevailing operations.	INCOSE' 2000
B.3	It is possible to create information models that unambiguously specify the system.	INCOSE' 2000
B.4	The systems re-engineering process will provide means for making satisfactory trade-offs between identified requirements in order to obtain consistent information models and unambiguous descriptions.	INCOSE' 2000
B.5	The systems re-engineering process will document valuable information, identify complex interactions, and clarify the main features of the current transport operations.	Dissertation
C.0	It is possible to develop a systems engineering process for assessing, specifying and documenting *future* operations.	Dissertation
C.1	It is possible to assess relevant liberalized regulatory regimes and extrapolate some possible conditions that may prove applicable to future Norwegian transport operations.	IAEE 2000
C.2	It is possible to redefine the effectiveness measures applicable to future operations.	Dissertation
C.3	It is possible to unambiguously specify some future economic and technical requirements, and to express and treat these requirements as test-case scenarios in the succeeding work.	IAEE 2000
C.4	It is possible to develop new economic methods and rules in order to fulfill the future economic requirements.	IAEE 2000
C.5	It is possible to identify solutions that are feasible from a gas flow optimization point of view by applying the *GassOptTKL program*.	Dissertation

ID	Sub-hypotheses tested in the dissertation work	Covered in paper [20]
C.6	It is possible to *modify* the information models so they unambiguously specify future operations.	Dissertation
C.7	The systems engineering process will provide means for making satisfactory trade-offs between identified requirements and solutions in order to obtain consistent information models and unambiguous descriptions and solutions.	Dissertation
C.8	The systems engineering process will document valuable information, identify complex interactions and clarify the main features of future transport operations.	Dissertation

5   Assessment of the prevailing regime

5.1   Introduction

Section 5 covers the fist part of the master strategic approach; the systems re-engineering process. The main objective is to test the hypothesis B.0, stating that "*it is possible to develop a systems re-engineering process for assessing, specifying, and documenting current operations*". In order to test the hypothesis, system theory is applied and a systematic framework is developed.

The hypothesis B.0 consists of five sub-hypotheses as was briefly discussed in Section 4.2. The first one to be tested is hypothesis B.1. This activity is assessment of available information. The identified data are subsequently organized and classified into appropriate groups. In order to provide a systematic treatment of the data, the systems engineering expert computer tool is applied.

The next step is to establish the effectiveness measures as stated by hypothesis B.2. This activity extracts applicable data, identifies and writes out the measures. The subsequent step is testing of hypothesis B.3. The B.3 activity is the creation of the information models. The computer program is applied as the main tool for conducting this activity. The applicable data is fed into the computer and the information models are developed and printed. This is an iterative process as hypothesis B.4 suggests and the B.4 activity is an integral part of the information modelling activity. The last sub-section contains a discussion and summary (hypothesis B.5) of the results.

If we now turn to the two test-case scenarios specified in Section 2.6 of the work some few assumptions can be inferred regarding why it is important to conduct the B.0 activity.

> *Observation 5.1.* It may be assumed that liberalization will impact the existing organization and working procedures regarding Norwegian natural gas transport operations. The assessment activity B.0 therefore shall unambiguously identify the existing organizational set-up, the organization's working processes and the main documents governing the operations. This will create a starting point for later analyses related to changes in organizational issues, conduct of work and related topics.

> *Observation 5.2.* It may be assumed that liberalization will call for amended and new economic and operational requirements. The

assessment activity shall identify the most relevant economic conditions, requirements and rules governing existing transport operations. This must be done in order to analyze – at a later stage (Section 7) – how liberalization affects these requirements.

Observation 5.3. The assessed information shall be categorized in such a way that it can be applied in a commercially available systems engineering computer tool and thereby enhance the correctness of the results.

5.2 Assessment of available information

The hypothesis B.1 specifies that: *"major stakeholders will provide empirical descriptive data regarding their needs and system requirements"*. The hypothesis is true provided the following conditions are satisfied:

- information is obtained by literature review and interviews.
- the information is unambiguously defining the stakeholders needs.[115]
- the information contains sufficient information to completely specify the system and the system operations.
- upon completion the stakeholders shall review the information models and agree to the results.

However, if significant ambiguity exists, lack of information is revealed or disagreement between the stakeholders is apparent the hypothesis has failed. The work was conducted according to the methodology as described in Section 4.3.1 on page 55 and Section 4.3.2 on page 56. The results can be summarized in the following observations:

Observation 5.4. The literature review identified all main requirements related to operations of Norwegian natural gas transportation. All requirements related to objectives and work processes are particularly identified. Further, technical and economic empirical data are identified for later usage. The result is documented in the information model printouts (from the computer program) and in the proceeding text.

Observation 5.5. The interviews identified the main requirements related to operations of Norwegian natural gas transportation. Similarly as above, all requirements related to objectives and work processes are

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[115] These requirements are also referred to as *the system requirements* in the work.

particularly identified. Another important goal of the interviews was to validate and verify the results from the literature assessment. The result is documented in the information model printouts and in the proceeding text.

5.3   Description of legal framework
5.3.1 *Supranational legislation*
The Norwegian legal system, governing the petroleum activities, complies with relevant international documents. Some relevant documents to be mentioned here are the United Nation Convention of the Law of the Sea (UNCLOS) and the EEA agreement. [116] As a result of the EEA agreement the Norwegian legislation has implemented general and specific internal market regulations of the EU [117] including the "licensing directive".

In this work the EU's Gas Directive is considered. In a White Paper (WP) no 46 (1997-98) "Petroleum operations" some comments are offered related to the implementation date of the Gas Directive. The WP states that the Gas Directive will be in force in Norway at the same time as it will be in force in the EU [118], provided the Gas Directive is included in the existing EEA agreement and implemented into Norwegian legislation. [119] A recently issued WP no 39 (1999-2000) states that the Gas Directive has not been included in the EEA agreement so far, and a 5 years transition period has be requested by the Norwegian Government.[120]

5.3.2 *Norwegian legislation*
5.3.2.1   *The licensing system*
The Norwegian petroleum legislation features a licensing system regulating all activities on the NCS. Information on the Norwegian licensing system is available in the public domain. [121] The following sub-sections highlight a few features of the licensing system pertinent to the natural gas production and transportation activities. These features are included here because it is of interest to test if the liberalization process influences on some

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[116] European Economic Area (EEA) decided on 5 April 1995

[117] See for example Fejø (1996) and Arnesen (1996) and Brautaset et al (1998)

[118] Which is summer year 2000, see WP no 46 (1997-98) page 32.

[119] See WP no 46 (1997-98) page 33

[120] According to several newspapers, see for example "Aftenposten" February 22, 2001 the commission has denied this request.

[121] Selvig (1995). This reference is some years old. An introductory to the issue is given in the Fact Sheet, issued by the Ministry for Petroleum and Energy (MPE) and in the IEA (1994) study. Dahl (1998-D) gives a general brief outline of the Norwegian legal system.

of these provisions. [122] By the same argument, these features are included in the systems engineering processes and the information modelling.

The Petroleum Act No 72 of 29 November 1996 regulates the licensing system. Pursuant to the Act, Royal Decree no 653 of 27 June 1997 stipulates detailed regulations. There are several other important acts and Royal Decrees, regulating topics such as safety or taxation. [123] The only act considered relevant for this work is the Petroleum Act.

According to section 3-3 of the Petroleum Act, the King awards the production license to the licensees. The key provision [124] of the Petroleum Act, regulating field development, is section 4-2 that requires the licensees to submit a plan for development and operation (PDO) [125] to the Ministry of Petroleum and Energy (MPE). MPE subsequently approves the plan.

The key provision [126] of the Petroleum Act, regulating natural gas transportation, is section 4-3 that requires the licensees to submit a plan for installation and operation (PIO) [127] of transport systems and related facilities to the MPE. On the basis of this plan MPE awards the transportation license to the licensees according to specified rules. Pursuant to the Decree no 653 of 27 June 1997, specific requirements are given related to the contents of the PIO. The licensees shall inform on subjects such as transport operations and the transport organization. Under section 4-10 of the Petroleum Act, the King decides where and how petroleum is to be brought ashore. Pursuant to section 4-8 of the Petroleum Act, MPE approves any use of installations by others than the licensees. This section is an important provision as it opens up, on MPE's discretion, a possibility for a third party access to the systems.

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[122] This work does not provide a comprehensive assessment of these topics, as this is left for the lawyers to undertake. The "bottom-up" approach of this work will however indicate whether any high level requirements ought to be amended. This work introduces changes into current operations and identifies any low level documents that are affected. By means of the requirement traceability model, traces are provided to higher-level requirements affected. In the real world case, the opposite procedure may likely occur. As soon as the outcome of the Norwegian implementation of the EU directive is known to stakeholders, a top-down decomposition of requirements can be performed, identifying any changes in all tiers of the document structure.

[123] See the Petroleum Taxation Act, please not that no aspects of taxation is treated here.

[124] See the Petroleum Act and Fact Sheet (1999)

[125] Called PUD (Plan for utbygging of drift) in Norwegian

[126] See the Petroleum Act and Fact Sheet (1999)

[127] Called PAD (Plan for anlegg of drift) in Norwegian

5.3.2.2   The resource management policy

According to sections 1-2 and 4-1 of the Petroleum Act, "prudent and efficient resource management has always been a key objective of Norwegian petroleum policy" [128] and it is of interest in this work to assess whether the liberalization process affects this policy. [129] The resource management policy has a main bearing on the development plans for the NCS, but it also provides operational goals for the day-to-day transport operations. It is therefore interesting to clarify how the resource management policy affects the current transport operations. In the following sub-sections, the resource management policy is briefly reviewed.

White Papers (WP) no. 46 (1986-87) "The petroleum activity on medium long term" and WP no 46 (1997-98) and WP no. 39 (1999-2000) discuss the resource management topic. MPE also gives a comprehensive review of the topic in an official letter to the EFTA Surveillance Authority (ESA) (1997). The resource management is funded by Norwegian sovereignty on the NCS. [130] According to the letter to ESA, the management of resources remains within the national state.

One key element of the management is to pool the different production fields and coordinate the total development of the NCS. The objectives of the resource management are many and they include depletions plans, methods for enhanced oil recovery, coordination of associated gas logistic and gas injection, environmental aspects, provisions for enjoying economic of scale in field and transports system development and gas marketing and sale. The argument is that such goals can only be obtained by Norwegian authority control. Important means for achieving gas marketing and sale are the establishments of the Gas Negotiation Committee (GFU) and the Gas Supply Committee (FU).

5.3.2.3   GFU and FU [131]

The GFU was established in 1986, see WP no 46 (1986-87). The GFU system, however, is not directly regulated by the Petroleum Act. The Fact

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[128] This statement is quoted from "MPE's official letter to the EFTA surveillance Authority, dated 20.01.97"

[129] Whether liberalization affect the policy is limited to whether future (new) forms of transport operations affect the policy. The work does not assess the effect of liberalization in relation to for example investment policies and overall field development planning.

[130] See United Nation (1982) Convention of the Law of the Sea, article 76, 77 and 80.

[131] For a more detailed assessment of the arrangements see Hammer (1998).

Sheet (1999) [132] gives a brief overview of the topic, while Brautaset et al. give a comprehensive description. Gas sales are based on commercial negotiations performed by the GFU. Statoil and Norsk Hydro constitute normally the GFU. The GFU-parties enter into a gas sales contract.

Different types of gas sales contracts are developed over the years such as the depletion contracts and the delivery contracts. The delivery contracts are the dominant type of contracts.

MPE approves all commercial deals, pursuant to paragraph 19 of the Decree and designate contract volumes to individual fields. MPE's designating activities are called *allocation* of field and transportation system development *and assignment* of gas sales contracts to *contractual* field or *supply* fields. A contractual field is assigned the contractual responsibility for the gas deliveries to the customers, while the actual physical gas supplies may be assigned to other fields called the supply fields. The FU was established in 1993 and comprises a number of Norwegian and international oil companies that are involved in activities on the NCS. The committee advises MPE on issues related to allocation of field and transportation systems development.

According to Stern [133], a liberalization process in the EU gas market may affect the Norwegian system for gas marketing and sales. Rune Pedersen in Brautaset et al. discusses the sales arrangement (i.e. the GFU) in light of the EEA agreement's competition rules. It falls outside the scope of this work to recapture and comment on these conclusions. [134]

WP no 46 (1997-98) and the MPE's letter to EFTA express the Norwegian governmental view on this topic. The WP confirms the governmental view that the existing system (GFU and FU) is important means to secure a high level of exploitation and cost effective systems and a means to support resource management. Similar views are expressed in the WP no 39 (1999-2000).

This work does not aim to analyze the establishment of GFU and FU. However, by the same argument as stated before, the systems engineering processes will inevitability identify the current lower level documents and requirements affected by any introduction of liberalization measures. By a bottom-up aggregation of requirements, it is possible to easily identify new operational conditions, which contradict prevailing requirements derived from the GFU or FU.

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[132] See Fact Sheet page 48.

[133] See Stern (1997) and the discussions in Brautaset et al.(1998)

[134] For any interested reader see Brautaset et al. (1998) page 78-79.

5.3.2.4   Policies for natural gas transportation

Several WP are issued throughout the years, discussing topics related to gas transportation, tariff and toll stipulations. [135] These WP give valuable information on how the Government and the Parliament evaluate petroleum related topics from time to time. Two WP of special interest are WP no. 46 (1986-87) and WP no 46 (1997-98).

WP no 46 (1986-87) section 12 incorporates some main policy objectives for the transportation activities. The paper states that licensees shall collect the main portion of their profit from the petroleum activities "*at the field and not from gas transportation.*" In order to understand this statement one needs to remember the vertically integrated nature of Norwegian natural gas activities. In most cases, the owners of the production facilities own the natural gas transportation systems as well (see Fact Sheet). Gas transportation is thus only "*a means*" and the transportation activity is not supposed to be a separate area for profit optimization by pipeline owners.

The WP 46 (1986-87) discusses principles for stipulations of transport tariffs and tolls in Norwegian natural gas transportation systems. The toll principles are rooted in the policy objective described above. In order to limit the pipeline owners' rents from transport operations, the paper specifies that profitability in transportation shall be limited to a specified rate of return on invested capital. This rate is 7% on capital invested before taxes. [136] These principles are referred to as the "Zeepipe-principles". [137] In the transportation agreements, entered into by transportation system owners and shippers, tolls are calculated to yield this rate of return to the owners. The tolls are based on an agreed throughput obligation called "Ship or Pay" (SOP). The SOP volume typically equals the Take or Pay (TOP) volume specified in the pertinent gas sales contracts. [138]

The WP 46 (1986-87) also discusses general considerations regarding tariff principles and toll calculations. The WP recognizes that tariff principles and tolls affect questions like the profitability in development of marginal fields and tail production at fields. Tolls affect co-production among fields and they influence on the share of profit amongst transport system owners and shippers. The WP also recognizes that the tariff and toll system influences the

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[135] See the Fact Sheet or the web: *http://odin.dep.no/html/english/*

[136] Nielsen (1999) and IEA (1994)

[137] See Nielsen (1999) page 112. Nielsen provides a review of the prevailing transportation agreements tariff system. The IEA (1994) study also refers to these principles, see page 251.

[138] Note that the pipeline lifecycle is normally longer than the gas sales contract periods.

willingness to make investments in transport systems. Many of these arguments are of a universal nature and they have relevance for tariff stipulation in the context of liberalization.

WP no 46 (1997-98) section 5 concludes that the best incentives for obtaining cost efficiency in transportation as well as less conflicts among stakeholders are to balance the owner shares and shipper shares. MPE draws this conclusion based on experience. This normally means that any individual party in a specific field production license shall have the same share in the ownership of the transportation system as the share of his gas volume handled by the transportation system.

A final observation to be made here is a clarification of who normally are the shippers. Nielsen (1999) states that the shippers are those who are owners of natural gas tendered for shipment in the system and to be delivered under a Gas Sales Agreement defined in the Transportation Agreement. [139]

5.3.3 Summary – legal framework

Finally, to sum up the main observations obtained by the assessment of the legal framework the following can be concluded:

Observation 5.6. The detailed assessment of the prevailing Norwegian legislative requirements has provided the work with legal insight. This insight is quite useful in relation to the research activities to follow. Based on the assessment of legal issues, the work has identified the governing documents and requirements, and the prevailing organizational set-up of the industry. The legal knowledge is also required in order to understand and evaluate how the Gas Directive may impact on existing working processes and economic, technical and operational conditions.

Observation 5.7. Normally only defined shippers who have an obligation to deliver gas according to a defined Gas Sales Agreement have a right to ship gas in the natural gas transportation system according to the existing Transportation Agreements. The tariff and toll regime is normally designed primarily to support such long-term shipping needs.

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[139] See also HA #1, Article 1.20

5.4 Results - effectiveness measures
5.4.1 Hypothesis B.2

The hypothesis B.2 states that "*it is possible to define effectiveness measures for the prevailing operations*". In the following work the hypothesis is tested. The hypothesis is true if the work succeeds in establishing the measures. An additional condition is that the stakeholders recognize the measures.

The measures are derived from the data obtained during the information assessment activity and the measures are ordered into three levels based on the three levels of document classification. The author has identified twelve effectiveness measures and they are ordered into these groups:

- The authorities' measures (four measures)
- The licensees' and gas buyers' measures (three measures)
- The operators' measures (five measures)

The source document that specifies an effectiveness measure is termed a *main* document in the proceeding text. Effectiveness measures typically are "high" level requirements according to the definitions given in Section 3.2.4, and a number of lower tiers of requirements are developed and specified in order to find feasible solutions. Those documents that include lower tires of requirements are termed *incorporated* documents. In the following text the twelve effectiveness measures are assessed and references are provided to the documents specifying the requirements.

5.4.2 Authorities' effectiveness measures
Resource management

The first effectiveness measure derived relates to the management of petroleum resources on the Norwegian Continental Shelf (NCS) and it states: *The development of new transportation systems, the daily transport operations, and the tariff regime shall help optimize the exploitation of Norwegian petroleum resources.* This measure incorporates the following observations:

> *Observation 5.8.* Gas production facilities and transportation systems shall be treated as an integrated "production system" on the NCS, in order to enhance the total production of hydrocarbons.

> *Observation 5.9.* Resource management shall include planning of gas

production for injection purposes, phase-out of declining fields and phase-in of new production.

The Norwegian Petroleum Act (Act) and White Papers (WP) as clarified in Section 5.3.2.2 are the main documents that specify resource management. Relevant sections are 1-2, 4-1 through 4-4 and 4-7 and 4-8. Further, White Paper no. 46 (1997-98) and White Paper no. 39 (1999-2000) discuss the same requirements. Several lower tiers of documents incorporate similar provisions such as the transportation system owners' Heads of Agreements, Transportation Agreements and the transportation system operator's procedures for operational flexibility.

Coordinated gas sales

The second effectiveness measure relates to gas marketing, sales, and planning activities and it states: *Transport operations and the tariff regime must support the established regime governing: gas marketing, negotiations and sales, assignment of gas sales contracts to contractual fields, allocation of gas supplies to delivery fields, and planning and development of new transport capacities.* This measure incorporates the following observations:

Observation 5.10. Gas sales represent a continuing activity: gas shall be marketed, negotiated, and sold in a coordinated manner.

Observation 5.11. The assignment of gas sales obligations to the contractual fields, allocation of supply commitments to the delivery fields and planning of new transport capacity shall be coordinated.

Observation 5.12. A coordinated approach is best means to secure gas supplies for the mutual benefit of buyers and sellers.

Observation 5.13. The industry must be governed by stable, predictable rules to secure investments and reduce financial risks.

Observation 5.14. Efforts will be made to protect, over the long run, long-term contract provisions such as delivery obligations, take-or-pay obligations, and ship-or-pay obligations.

The main documents are the Act and Decree as clarified in Section 5.3.2.1. The White Papers previously identified discuss this topic as well. A number of lower tier documents specify related requirements. Such documents

are the Gas Sales Agreements, the transportation system owners' Participants Agreements, the PDO approvals and the PIO approvals.

> *Economically efficient development and utilization*
> The third effectiveness measure relates to economic theory and it states: *The development of new transportation systems, daily transport operations, and the tariff regime shall be economically efficient.* This measure incorporates the following points:

> *Observation 5.15.* Economies of scale shall be utilized at the time of investment and during operations.

> *Observation 5.16.* All available systems capacity shall be utilized as systems and facilities built cannot be reversed and the investments are sunk costs.

> *Observation 5.17.* Social welfare shall be optimized in a long run perspective recognizing that petroleum resources are limited resources and they are not renewable.[140]

This measure is relevant for the planning and development activities of new capacity and it also is relevant for day-to-day operations. The measure guides negotiations and development activities. The effectiveness measure is derived and based on the Act, sect. 1-2 and White Paper no. 46 (1997-98) and White Paper no. 46 (1986-87). In order to have the day-to-day transport operations complying, the measure has been broken down into a number of lower-tier requirements incorporated in a number of licensees' documents and operators' procedures. Some important ones are the Transportation Agreements, Participants Agreements, Upstream Agreements, and the Operational Flexibility Procedure and the Interface Manuals and the Operating Philosophy.

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[140] A related argument is that the state is the original owner of available resources; it is also the major stakeholder (in several roles: as approval body (MPE) and also as producer, gas owner, shipper, and seller (as a result of the state's direct financial interests (SDFI) and as owner of Statoil)). The state has the largest total owner's shares in the sector. According to Fact Sheet (1999), 88% of the net present value of cash flowing from the Norwegian petroleum sector represents the state's share. In 1999 money, the state's share is NOK 1620 billion of a total NOK 1840 billion. Further, the state is responsible for securing a cost-effective, optimal exploitation and utilization of facilities. See Act 1-1.

Right incentives

The fourth effectiveness measure relates to the incentive structure and it states: *The regulatory regime for development of new transport capacity, operations, and tariffs must have incentives which ensure that a company's optimal economic adaptation to the regime coincides with the economically efficient solution.* This measure incorporates:

Observation 5.18. The incentive structure must enhance cost effectiveness in project solutions and operations.

Observation 5.19. The incentive structure must be designed so that a company's economic adaptation to the regime coincides with the economically efficient solution.

Observation 5.20. Shippers' shares as well as ownership shares in production fields and transportation systems must be harmonized throughout the value chain and between old and new projects to reduce conflicts and optimize incentives for cost effectiveness.

Observation 5.21. Licensees' profit shall be earned "at the field and not in the transportation system": transportation is only "a means" (or an agent serving in a broader context).

Observation 5.22. The rate of return in transportation systems shall be based on a risk assessment (based on risks occurring during project development, operations, production, and execution of gas sales contracts); the current system imposes low risk on transportation system owners. [141]

Observation 5.23. Tariff regimes and ownership shares must align with taxation principles.

The effectiveness measure is derived basically based on White Paper no. 46 (1997-98) sect 5, the Transportation Agreement and the Participants Agreement.

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[141] See Brottemsmo et al. (1993), pp. 18-21 for a discussion of such risks.

5.4.3 Licensees' and buyers' effectiveness measures
Supportive agreements

All agreements such as sales-, transport- and upstream-agreements must be developed keeping the implementation stage in mind. An optimal operation is an optimization of the totality and all aspects of natural gas transportation must be considered including commercial, technical and operational aspects. This is a challenging task for the stakeholders and they find it difficult to do it right.

The present effectiveness measure focuses on the task described above and it is derived from the White Paper no. 46 (1997-98) and the transportation system owner and operators' Objective Document for 1999. [142] The effectiveness measure can be written as follows:

> *Observation 5.24.* Sales-, transport-, and upstream- agreements shall be negotiated and agreed upon by parties in such manners that the agreements support transport operations, and vice versa.

Reasonable and prudent

The term "reasonable and prudent" is normally defined in all transport and sales agreement and it has for some time been applied in the industry to express the rules of conduct for the parties. The term specifies the "best practice" and it encompasses an awareness of fairness and impartial conduct.

The operations shall not deteriorate the environment, be energy efficient, and be reliable and safe. Included here is an expectation that the operations do not jeopardize the integrity of the system. Further, stakeholders expect that the natural gas transport operations pay due attention to the production of oil and NGL as well and in such a way that the production of these hydrocarbons is optimized.

The effectiveness measure is derived and based on the Gas Sales Agreements and the Transportation Agreements. [143] The requirement is also incorporated in a document that regulates the coordination of activities between the representatives of sellers and shippers, called the Interface Procedure. The effectiveness measure can be written:

> *Observation 5.25.* Operations shall be conducted in a "reasonable and prudent manner," with due attention to safety and the environment.

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[142] The document is discussed later, see "Mål for D&P 1999, sect. 7"
[143] See *TA* # 2, STC art. 3

Gas buyer compliance

The gas buyers must act reasonable and prudent. The effectiveness measure is derived from the Gas Sales Agreements and the Sellers Representatives' Operating Agreements. This effectiveness measure can be written as follows:

Observation 5.26. The gas buyers must act in accordance with the sales agreements.

5.4.4 Operator's effectiveness measures
Regularity

Several of the interviewees stated that one of the most important objectives for the industry was to deliver gas at high regularity. This effectiveness measure is documented in the transportation system owner and operator's yearly objectives, termed: Objective Document for 1999. [144] Further, several lower tier documents have incorporated requirements to this effect as well. This effectiveness measure can be written as follows:

Observation 5.27. Dry gas deliveries shall be made to customers with 100% regularity.

Gas quality

The gas must be delivered with a gas quality that complies with the gas sales agreements. This requires that the transportation system operator monitors and blends gas at all times. The effectiveness measure is specified in the transportation system owner and operator's yearly objectives. Further, several lower tier documents have incorporated requirements to this effect as well. This effectiveness measure can be written as follows:

Observation 5.28. Dry gas deliveries made to customers shall meet gas quality specifications at all times.

Tariff and toll

This effectiveness is based on the Objective Document for 1999, the Transportation agreements [145], and the Measurement Manual. Several lower tier documents have incorporated requirements to this effect as well. This effectiveness measure can be written as follows:

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[144] See "Mål for TCC 1999, sect. 1"
[145] See *HA* # 1, sect. 3 and *TA* # 2, STC article 3 and GTC 3.8 and sect. 4 and 5.

Observation 5.29. The transportation system operator shall correctly produce and issue tolls to shippers in a timely manner.

Communication system availability
This effectiveness measures is documented in the Interface manuals, the Objective document for 1999, and the Transportation agreements. [146] Several lower tier documents have incorporated requirements to this effect as well. The effectiveness measure can be written as follows:

Observation 5.30. Communications and support systems shall never shut down.

Production field regularity
The production field operations affect the outcome of the transport operations in obvious ways. The ultimate success is dependent on the production units' capability to deliver gas according to instructions. Gas deliveries shall be made at the right quality, flow rate and pressure. The effectiveness measure is based on the Interface manuals and the PUD permissions. This effectiveness measure can be written as follows:

Observation 5.31. Natural gas producers must deliver gas of the agreed-upon quality in a timely fashion, according to the specified delivery instructions.

5.4.5 Summary - effectiveness measures

The author has summarized the effectiveness measures as suggested here, but there are probably other ways of expressing and formulating these criteria as well. Further, it may be argued that some measures overlap to some extent with other measures.

The list of measures has been presented to the interviewees for comments, review and acceptance. The hypothesis B.2 it thus argued here to be true. The main result of this activity can be summarized as follows:

Observation 5.32. The list of identified effectiveness measures presented here accumulates and summarizes the success criteria that were identified in the literature review and derived from the interviews.

Observation 5.33. Another observation is that the authorities' and

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[146] See TA # 2, GTC sect 3.9

licensees' effectiveness measures, unlike operators' measures, are not directly measurable.

This latter result is expected and the challenging task then becomes to verify or make certain that current operations really meet all the success criteria. In order to verify this task the highest tiers of effectiveness measures have to be decomposed into lower-tier requirements in order to permit testing.

Traces of such decomposing are therefore expected to be visible in lower tiers of effectiveness measures. This is apparent in the results shown above. For example, one may argue that the "regularity measure" is derived from the "reasonable and prudent" measure, which again is a derivative or interpretation of the "coordinated gas sale" measure.

The main means however to verify that prevailing operations meet the success criteria will be the information models. In this manner, the way in which operations fulfill the above-noted twelve measures is easily documented. The last observation can thus be expressed as follows:

Observation 5.34. The final verification and proof that current transport operations really meet all the success criteria is an object and a result of the detailed information models.

5.5 Results - the information models
5.5.1 Hypothesis B.3
The hypothesis B.3 relates to the information modelling and it states: *"It is possible to create information models that unambiguously specify the system".* In the following sub-sections the hypothesis is tested. The hypothesis is true if the work succeeds in creating these information models. A second condition is that the stakeholders shall recognize and accept the models.

The following sub-sections present the result of the modelling work and the results are presented in the following manner. First, each one of the subsequent sub-sections focuses on the specific contributions offered by the individual model. This is done by means of presenting a typical figure that illustrates the structure of the model. This structure is composed according to the principles laid down in Section 3.2.5.

Secondly, the information modelling applies the "RDD-100" computer program and large printouts are produced as the main means of documentation. These printouts are enclosed in a separate Volume II of the work. [147] The contents-list of this volume is reproduced in Appendix 11.6.

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[147] These printouts are available for Statoil employees only. These printouts are needed in

Finally, for the benefit of the reader who does not have access to the computer printouts, the core contents of these printouts are synthesized into some few figures, lists and tables followed by some main conclusions at the end of each of the following sub-sections.

5.5.2 *Requirement traceability*

The first decision to be made was to decide a starting point or a source document for the models. Three possible starting points were identified, the Petroleum Act, the effectiveness measures or the White Papers. The Petroleum Act was chosen because it was assumed, and later also shown, that the Act represents the highest level of source document for the prevailing regime. By using the Act as a starting point, incorporated requirements were identified and lower tiers of documents and requirements were sorted out. Eventually, leaf-level requirements were obtained.

The next step was to test if the identified effectiveness measures and the White Papers introduced other requirements than those already identified. No such unidentified requirements where disclosed.

In the work that followed all other identified documents were modelled and the documents were arranged into a hierarchy structure. The tier of documents that followed the Petroleum Act was documents related to the transportation licenses approval process *(PAD),* the production field licenses approval process *(PUD)* and the gas sales negotiations, assignment and allocation process *(GFU and FU).* [148] Thereafter the modelling of transportation licensees' documents followed, [149] and finally the lowest tier of documents was modelled including all the documents as identified in Table 3 (see page 81).

In connection with the modelling work a carefully designed classification of the information was deemed necessary. For the reader interested in further details of this classification and categorization of information, see Appendix 11.7.1. In Appendix 11.7.2 a list of all documents included in this work is presented accompanied by a minor description of each of the documents.

On the following pages the requirement traceability model is summarized and a conceptual illustration is presented in Figure 6. This figure

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order to obtain an accurate and detailed understanding of the results.

[148] These processes comprise comprehensive procedures and the models presented here are significant simplifications of reality. The interesting point of view in this work, however, is not to assess how these processes are carried out, but to identify the documents and requirements that are produced by the processes.

[149] A detailed descriptive review is given by Nielsen (1999).

shows what the RDD-100 printouts look like. Figure 7 and Figure 8 synthesize the core requirements that are incorporated in the documents assessed in this work. The requirements are called "rules" in these two figures. This is done to pinpoint the fact that the requirements looked for in this work are those requirements that specify rules of conduct for the Norwegian natural gas transport operations.

Based on the requirement traceability model the following conclusions can be drawn at this stage in the work:

Observation 5.35. A requirement traceability information modelled is developed. 3 major source documents are applied: the Petroleum Act, Decree and White Papers. Approximately 10 different types of licensee's agreements are incorporated and approximately 9 different types of company documents are incorporated.

Observation 5.36. 55 leaf-level requirements are identified and they specify 55 functions that subsequently are allocated to stakeholders. The Transportation System Operator and the Shippers' Dispatching Representative were jointly allocated 75% of the functions, the Sellers Dispatching Representative 18% and the Production Field operators some 7% of the functions.

Observation 5.37. As the models have identified that the 55 leaf-level requirements are actually allocated to functions and to stakeholders who carry out the functions, a proof is provided that the effectiveness measures are indeed complied with. [150]Another way of saying is that current transport operations fulfill the success criteria specified.

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[150] In figure 1.10 - 1.13 in the "RDD-100" printouts this fact is shown, see the separate volume of the work.

Table 3.   Documents specifying effectiveness measures

M: Main / I: Incorporated — Public documents (Italic script) / Licensees' documents (Roman script) / Operator's documents (Garamond script)	Authorities' E. Measures				Licensees' E. Measures			Operators' E. Measures				
	Resource management	Economic efficiency	Right incentives	Coordinated gas sale	Supportive agreement	Gas buyer compliance	Reasonable, prudent	Regularity	Gas quality	Tariff and toll	Communication	Production regularity
Petroleum Act	M	M		M								
White Papers	M	M	M	M	M							
PUD approval				M								M
PAD approval				M								
Transportation A. *	I[151]	I	I				M	I[152]		M	I	
Participants A.		I	I	M								
Upstream A.	I	I						I	I			
Gas Sales A.				M		M	M	I	I	I	I	
*Op. Flex. P. *	I	I						I	I			
Objectives					M			M	M	M	M	
*Interface M. *		I						I	I	I	M	M
Operating Philosophy		I						I	I			
Measurement M.										I		
Tariff P.										M		
Identification P.							I	I				
Interface P. [153]								I		I	I	
Operating A.					M							

*Note; A: Agreement, P: Procedure, M: Manual

---

[151] See HA # 1, sect. 6.1 and TA # 2, GTC sect 2.9

[152] See HA # 1, sect .6.1 and TA # 2, STC sect. 2.2.4 and GTC sect 2.9

[153] The full name is: "Interface procedure between Sellers rep. and Shippers rep. and transportation system operator", ("koordineringsprosedyre" in Norwegian).

Norwegian Petroleum Act, Regulations
Source

documents   documents

Application for production field license	Application for transport system license
Requirement	Requirement

incorporates   incorporates   incorporates

Operational requirements for physical handling of gas flow	Dispatching requirements	Requirements for tariff calculations and issuing of tariff
Requirement	Requirement	Requirement

2   specifies   3   specifies   7   specifies

Receive production field availability	Issue seller's availability	Trade-off, calculate instruction
DiscreteFunction	DiscreteFunction	TimeFunction

allocated to   allocated to   allocated to

Transport operator	Contractual gas seller	Transport operator
Stakeholder	Stakeholder	Stakeholder

Figure 6. Main principles of requirement traceability model

```
The Petroleum Act and Decree
    └── Transportation license application and approval process (PAD)
            ├── Participants Agreements
            ├── Transportation Agreements and Heads of Agreements
            │       ├── Interface Manuals
            │       │       ├── Rules for handling of availabilities
            │       │       ├── Rules for handling of gas delivery instructions and nominations
            │       │       ├── Rules for shortfall handling
            │       │       └── Rules for trade-off calculations – nominations and instructions
            │       ├── Measurement Manuals
            │       │       └── Rules for verifying gas energy contents of gas delivered
            │       ├── Operations Philosophy Manual
            │       │       ├── Rules for handling of physical gas
            │       │       ├── Rules for gas quality monitoring and control
            │       │       └── Rules for trade-off calculations – valve set points and compression
            │       ├── Tariff procedure
            │       │       └── Rules for tariffing
            │       ├── Upstream Agreements
            │       │       ├── Modeling agreements
            │       │       ├── Regularity support agreements
            │       │       ├── Substitution agreements
            │       │       ├── Supply agreements
            │       │       └── Storage agreements
            │       │               ├── Rules for upstream agreement handling *1
            │       │               └── Rules for trade-off calculations – UA,
            │       │                   OpFlex, linepack optimization *1 *2
            │       └── The shipper's dispatching representative appointment procedure
            │               ├── Rules for upstream agreement dispatching
            │               └── Rules for field imbalances handling and dispatch
            └── Procedure for linepack arrangement between transportation
                systems and operational flexibility arrangement between fields
                        ├── Rules for optimization of gas sales and resource management
                        └── Rules for dispatching of operational flexibility

    *1 Note: These two rules apply for all upstream agreements
    *2 Note: This trade-off includes optimization of both upstream agreements and
    operational flexibility
```

Figure 7. Extract of the requirement traceability model

The Petroleum Act and Decree
  └── Field licenses application and approval process (PUD)
        ├── Interface Manuals
        │   ├──── *Rules for issuing field availabilities*
        │   └──── *Rules for receiving field gas delivery instructions*
        └── Participants agreements

The Petroleum Act and Decree including White Papers
  └── The gas sales negotiations, assignment and allocation process (MPE, GFU and FU)
        ├── Gas sales agreements – from GFU
        │   └── *The agreements "trigger" PUD and PAD processes
        │   and MPE's allocation and assignment of contracts*
        ├── Gas sales agreements – contractual fields
        ├── Gas sales agreements – supply fields
        └── Gas sales agreements – depletions contracts
              ├── The gas sales agreements' appendixes *
              │   ├── *Rules for gas quality compositions*
              │   └── *Rules for gas delivery terms*
              ├── The sellers identification procedure *
              │   ├── *Rules for shortfall handling*
              │   └── *Rules for prioritizing gas deliveries*
              ├── The sellers operating agreements *
              │   ├── *Rules for dispatching*
              │   └── *Rules for reporting*
              ├── The seller and shipper administration procedures *
              │   └── *Rules for acting on behalf of other shippers*
              └── The sellers invoicing manual *
                    └── *Rules for gas invoicing to customers*

  * Note: The rules are pertinent to all types of sales agreements

Figure 8. Extract of the requirement traceability model

5.5.3 Systems architecture

The systems architecture information model shows how the physical facilities are interrelated and decomposed according to the principles defined in Section 3.2.5.3. The Transportation Agreements specify these facilities. In the proceeding work, only the dry gas system is specified, as already mentioned.

Figure 9 illustrates schematically the Norwegian dry gas transportation system. Borders are defined such that the system consists of two treatment terminal facilities (Kollsnes and Kårstø), two riser platform facilities (Sleipner riser platform, or SLR, and Draupner riser platform, or Dr), four shore terminal facilities on the European continent, and 11 pipelines. Belonging to external systems are three production fields (Sleipner, Heimdal and Ekofisk) and a number of production fields upstream from the treatment terminals (not shown). Customer facilities downstream from the shore terminals also belong to the external system (not shown). The external systems are also referred to as the context systems.

At each facility, a gas input and/or output valve is installed; between the output valve at one facility and the input valve at another facility, a pipeline is installed, connecting the facilities. This fairly obvious observation has some implications guiding subsequent modelling and later research. First, the pipeline's configuration (length, diameter, internal coating condition, etc.) unambiguously defines its gas-flow capacities. Knowledge of these capacities and of how to optimize flow in the total pipeline network will be useful later in this research.

Secondly, many economic topics relating to the transport owner's tariffs are linked to gas flow in each pipeline.

Thirdly, from an operational point of view, many interesting actions focus on the set point values of flow and pressure at each valve: in fact, all operational behavior eventually devolves to decisions about how to set each valve's gas pressure and gas flow values.

Figure 10 displays schematically the system architecture modelled for this project and this figure illustrates how the RDD-100 printouts look like. Figure 11 synthesizes some parts of the architecture information model.

The following can be inferred by studying the architecture model:

Observation 5.38. The systems architecture model presented here is quite simple and the basic purpose of the model is to identify a system boundary and to capture the components comprising the system assessed in this work.
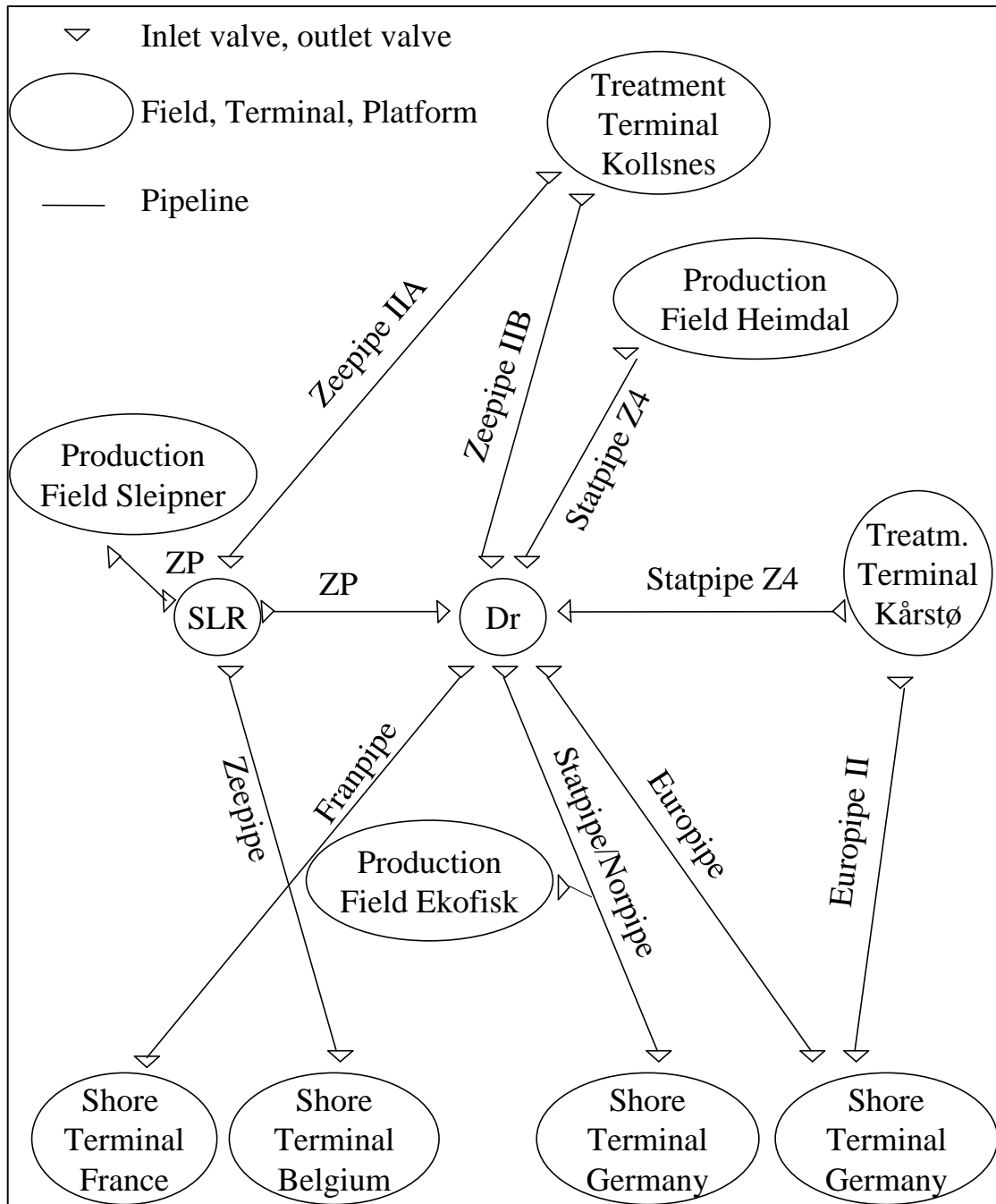
Figure 9. The physical components of the system

Dry gas transportation system
Component

built from | built from | built from

Treatment terminals	Riser platforms	Shore terminals
Component	Component	Component

built from | built from | built from

Platform operator	Output valve	Input valve
Stakeholder	Component	Component

connected to | connected to | connected to

Message system	Pipeline X	Pipeline X
Interface	Interface	Interface

Figure 10.   System architecture

```
The dry gas transportation system
   ├── Platforms
   │      ├── Draupner Platform
   │      │      ├── Input valve
   │      │      │      └── Pipeline "from and to"
   │      │      │             └── Gas stream "from and to"
   │      │      └── Output valve
   │      │             └── Pipeline "from and to"
   │      │                    └── Gas stream "from and to"
   │      └── Other Platforms
   ├── Shore terminals
   │      ├── Dunkerque terminal
   │      │      └── Input valve
   │      │             └── Pipeline "from and to"
   │      │                    └── Gas stream "from and to"
   │      └── Other terminals
   └── Treatment terminals
          ├── Kollsnes terminal
          │      ├── Input valve
          │      │      └── Pipeline "from and to"
          │      │             └── Gas stream "from and to"
          │      └── Output valve
          │             └── Pipeline "from and to"
          │                    └── Gas stream "from and to"
          └── Other terminals
```

Figure 11.   Extraction of the system architecture model

5.5.4 Behavior

Main purpose

The main objective of the behavior information model is to organize the identified functions into processes and to introduce the entities of inputs and outputs. Functions normally require some kind of input, which is processed

and returned as some kind of output. The modelling work presented here follows the principles given in Section 3.2.5.4.

Three major processes have been included and the processes are described in the following sub-sections. The author thinks that the behavior model is the most difficult one to summarize here and the RDD-100 diagrams are the only appropriate means to obtain a complete understanding of the behavior. But as before, for those readers who have no access to these printouts, an extraction of the results is given in the sub-sections to follow. The main processes included are:

- the dispatching process
- the optimization process
- the handling of physical gas process

The dispatching process

The dispatching process consists of four sub-processes called *the buyers' dispatching process, the sellers' dispatching process, the transportation system operator's dispatching process* and *the fields' dispatching process*. In these processes, much information is transmitted between the stakeholders. The information transmitted relates to availability information regarding facilities and production capacities, and nominations and delivery instructions. The processes consist of daily transmittals as well as weekly or long term planning activities. In this work, only the day-to-day [154] dispatching is modelled and the planning activities have been left out. [155]

The Transportation System Operator calculates and performs trade-offs between different possible solutions in order to meet a specific gas buyer' gas daily nominations. There is a need to do trade-off calculations due to the fact that production units and pipelines may be un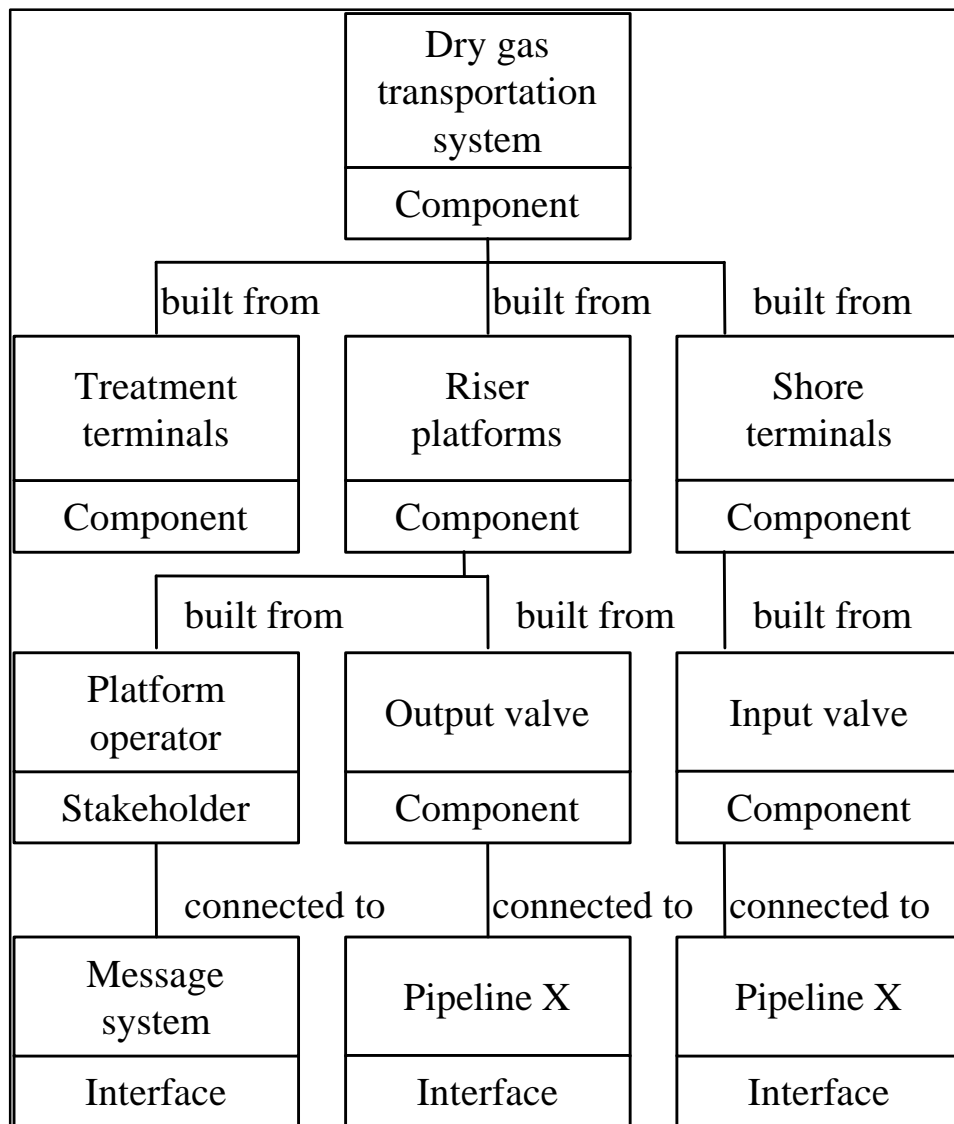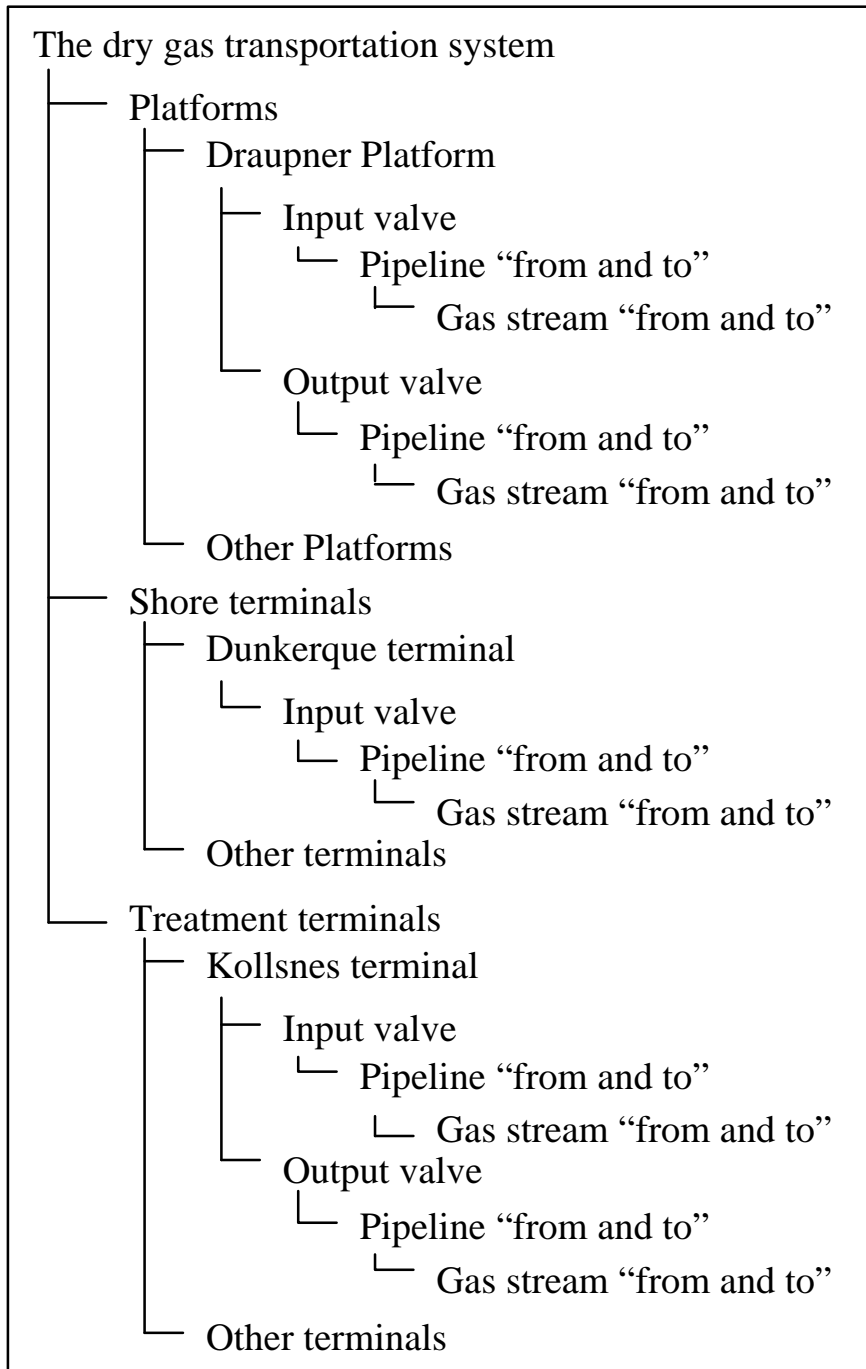available and imbalances must be corrected for, and so on. The processes are thus designed to cope with both normal days as well as days with shortfall situations. A shortfall occurs if the sellers are unable to meet the buyers' requests for daily gas deliveries.

In Figure 12 below the dispatch processes are illustrated based on their appearance in the RDD-100 printouts.

---

[154] According to the gas sales contracts a gas day is a 24-hour period starting at 06.00 am. During this period a given nominated gas volume shall be delivered. If the seller fails to meet the obligation a contractual shortfall situation has occurred, see Brautaset et al. (1998)

[155] The planning activities are identified in the requirement traceability model, but they are not included in the behavior model.
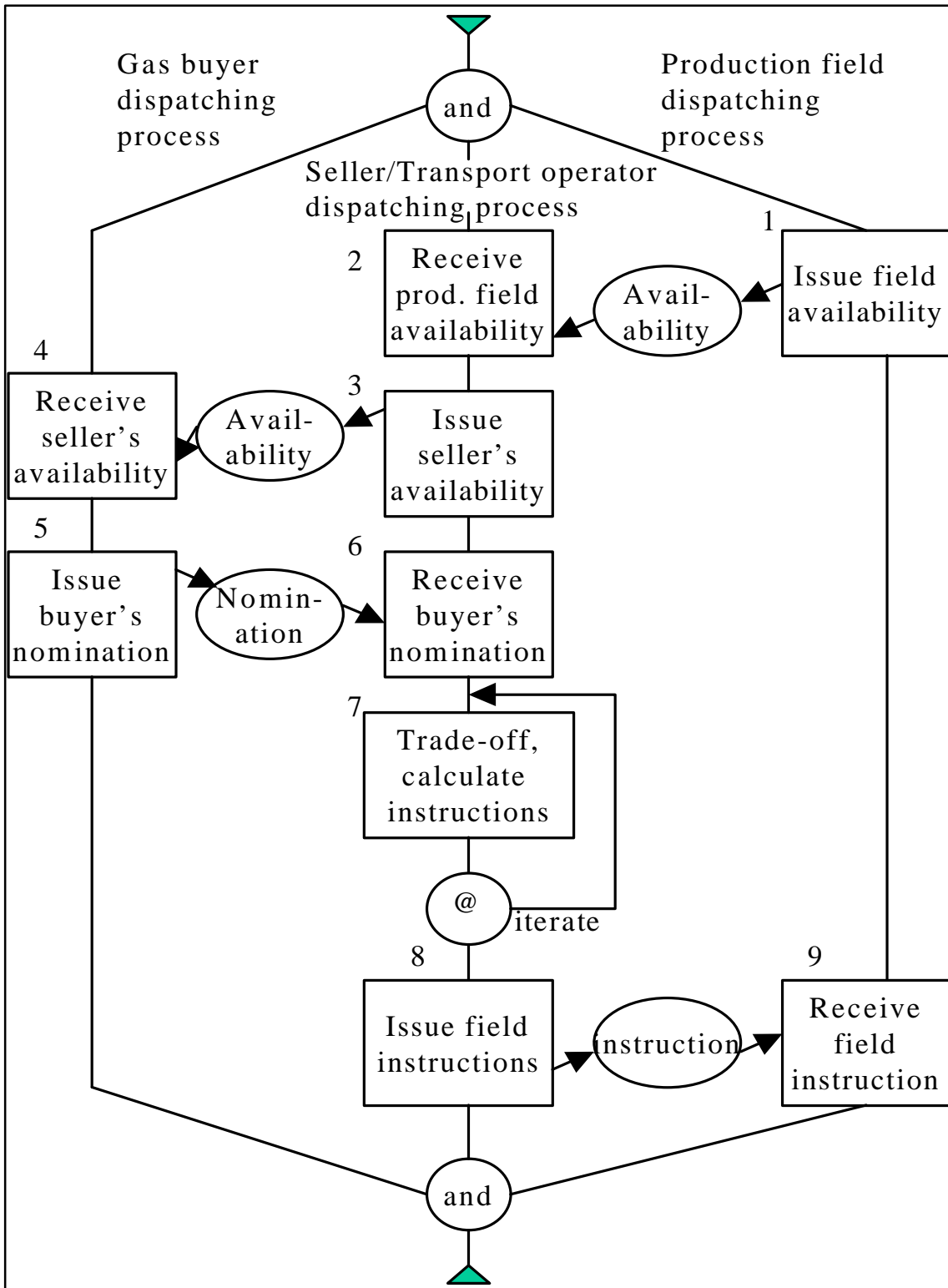
Figure 12.   Behavior model of some of the dispatching processes

Based on the figure above, one observation can be stated:

Observation 5.39. In order to facilitate the gas deliveries a comprehensive dispatching process is developed. The process makes sure that information regarding availability, requests and so on is conducted in a timely manner.

The optimization process

The optimization process comprises trade-offs between several requirements and considerations derived from three major means for daily optimization. The first means is to utilize provisions of five different Upstream Agreements. The second means is utilization of Operational Flexibility, and the third one is utilization of Linepack. In Appendix 11.7.3, 11.7.4 and 11.7.5 these three different means for optimizing daily operations are described in further details, respectively.

The main observation to be made here is:

Observation 5.40. In order to optimize the gas transport operations so that gas delivery commitments are met and resource management on the NCS is obtained in daily operations, many formal and informal arrangements have been developed.

The process for handling of physical gas

This process is covering the procedures for physical handling of gas in the pipeline systems. First, this process collects information on all gas flow rates, pressures and gas compositions from the SCADA[156] system. Then the process takes into consideration the results of the optimization process and the results from the dispatching process. As there are many considerations and contradicting requirements yielding some trade-off iterations must be performed. The rules for so doing are basically given in the two documents called *Procedure for linepack arrangement between transportation systems and operational flexibility arrangement between fields*, and *Operations Philosophy Manual*.

Upon collection of SCADA information and following the successful trade-offs, final decisions are made with respect to the sizes of flow rates and pressure set points in the systems. The control valves are remotely adjusted and instructions are given to field and terminal operators.

---

[156] Supervisory Control and Data Acquisition System, part of the "communication and data system".

In Figure 13 below an extract of the entire behavior model is given. The figure indicates the trade-offs performed and how information is passing on between the different sub-processes. Finally, it shall be noted that these processes run continually, 24 hours a day.
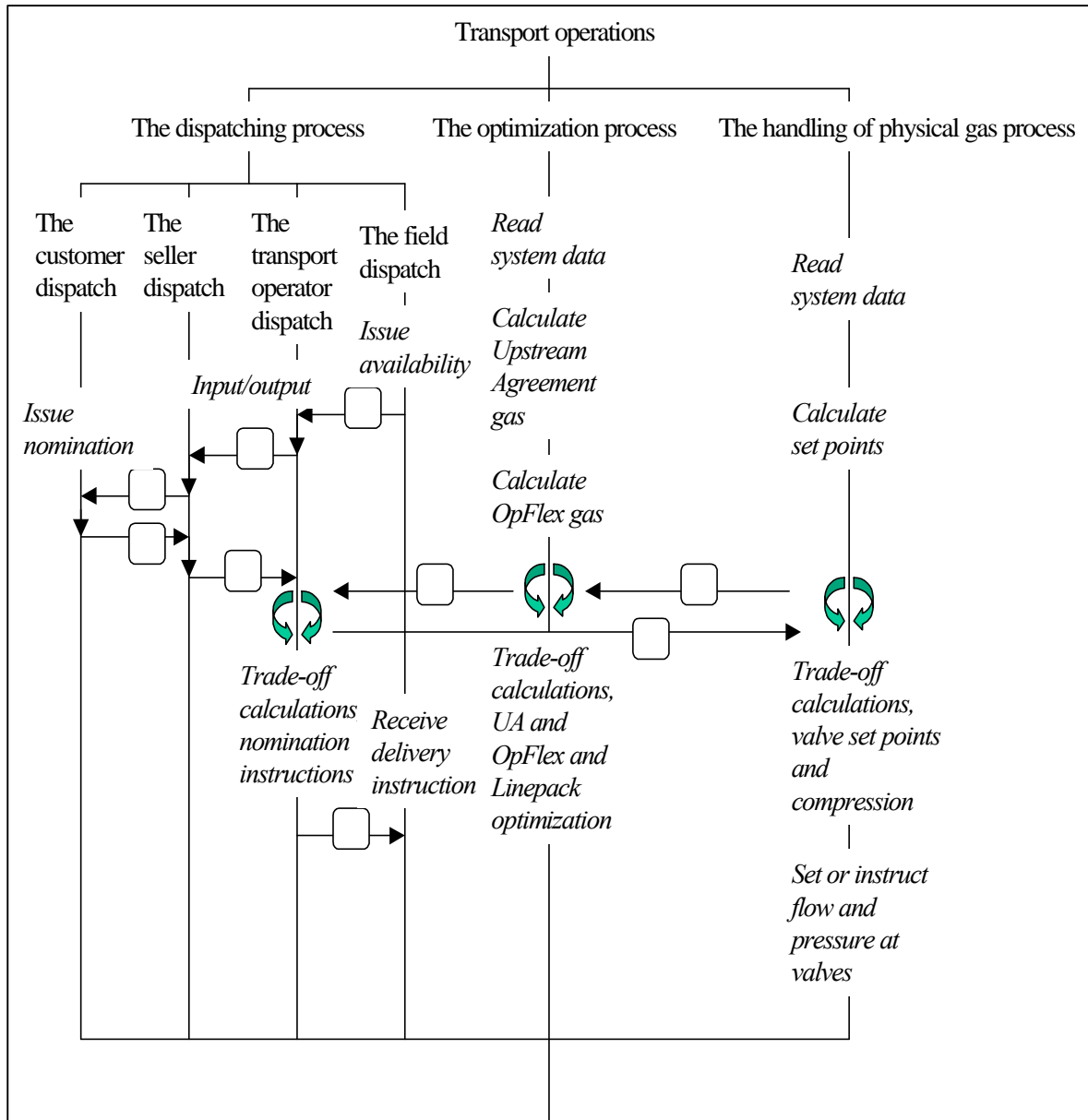
Figure 13.   Extract from the behavior information model

Two observations are made based on a study of the behavior models:

Observation 5.41. The Transportation system operator monitors and routes the physical gas in the transportation system by two major

means. First he remotely controls several key control valves at the two riser platforms, and secondly he instructs the terminal and platform operators to adjust control valves, flow and pressures on their respective installations.

Observation 5.42. The instructions on how to change physical conditions in the systems are derived based on careful evaluations of the information obtained in the dispatching process and the optimization process. As there typically are several contradicting wishes, the Transportation system operator conducts trade-offs in order to settle on final instructions.

5.5.5 *Context*

The last conceptual model is the context information (or "interface") model that identifies the system's interfaces with surrounding systems and the environment. The systems boundary is defined around the dry gas transportation system and the model identifies all major input and output crossing the system boundary.

The context information model derived in this research is displayed in Figure 14 below. The main conclusion is:

Observation 5.43. The context model identifies how requests, availabilities and instructions, the gas itself and toll are crossing the system boundary. The model shows how these entities interfere with other systems in the context. This model is useful in the later analyses of the work when effects of the Gas Directive on the prevailing regime shall be discussed.
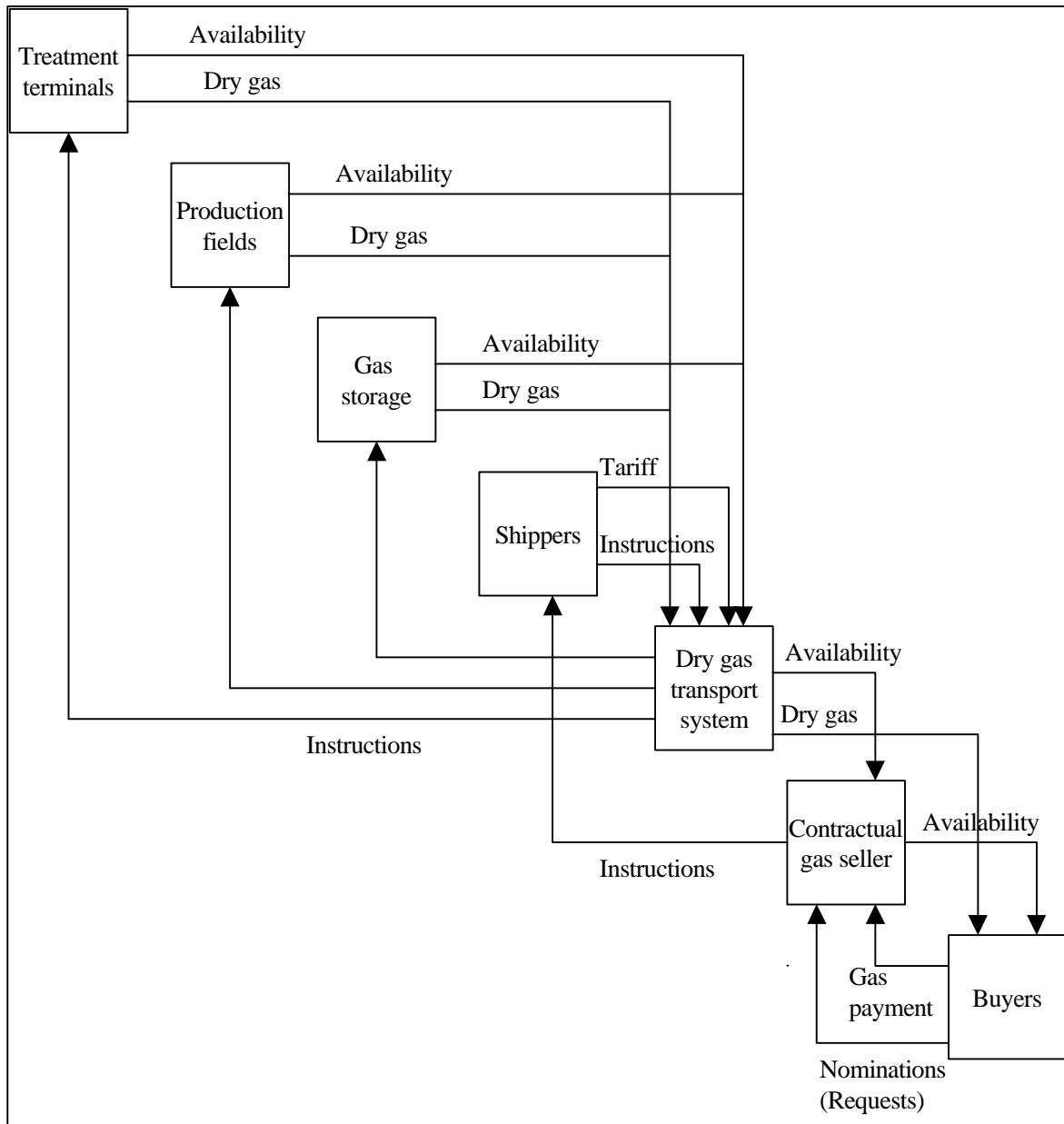
Figure 14.   The context system

5.5.6 *Trade-offs in the modelling work and hypothesis B.4*

The hypothesis B.4 relates to the trade-offs done in order to create the information models. The hypothesis states: *"The systems re-engineering process will provide means for making satisfactory trade-offs between identified requirements in order to obtain consistent information models and unambiguous descriptions"*.

The systems engineering program was the main means to test the

hypothesis and to do the trade-offs. [157] The hypothesis is true because this activity turned out successfully and the stakeholders accepted the effectiveness measures and the information models.

The following observation can be concluded:

Observation 5.44. By applying the computer tool an accurate description of the behavior of current operations is obtained (i.e. ordering of current working processes). This is a main reason for applying the tool. Another important aspect is that the tool makes it possible to accurately trace requirements to source documents and to identify how specified functions are allocated to stakeholders.

Observation 5.45. The computer program also "forced" the data to be entered according to defined rules. This helped the author to think logically, systematically, and holistically, as well as creatively. The author believes that the same level of data accuracy and creativity would have been very difficult (or at least time consuming) to achieve, had the work been done manually.

5.5.7 Summary – information models

The hypothesis B.3 states*: "It is possible to create information models that unambiguously specify the system".* Section 5.5.1 specifies that the hypothesis is true if the work succeeds in creating these models and the stakeholders subsequently accept the models.

The work has produced the four types of information models called for in hypothesis B.3 and the systems theory. The models have subsequently been reviewed and commented by most of the representatives of the stakeholder group. In particular the Transportation System Operator has reviewed and commented the models and he has accepted them. The author will thus argue that the hypothesis B.3 is true.

5.6 Summary
5.6.1 The hypothesis B.5

The hypothesis B.5 reads: *"The systems re-engineering process will document valuable information, identify complex interactions, and clarify the main features of current transport operations".* Based on this hypothesis, the overall results of the work so far must satisfactorily answer at least three questions:

---

[157] See also Malcolm et al. (1993).

- Is valuable information documented?
- Are complex interactions identified?
- Are the main features of current transport operations clarified?

In the following sub-sections each of the three questions are discussed and the main lessons learned are identified together with the main conclusions. These sub-sections - in sum - document and test the hypothesis B.5 and confirm that the hypothesis is true.

5.6.2 Documentation of valuable information

The following main conclusions can be inferred by reference to the observations made throughout the preceding text:

Conclusion 5.1. By means of the literature review and the interviews all main documents and requirements that govern Norwegian natural gas transport operations are identified. *See Observation 5.4 through Observation 5.6.*

Conclusion 5.2. All main success criteria (the effectiveness measures) are identified for Norwegian natural gas transport operations. See *Observation 5.8 through Observation 5.31.*

Conclusion 5.3. The systems boundary and system components are identified and ordered into system architecture. *See Observation 5.38.*

Conclusion 5.4. Empirical data has been collected, systemized and categorized in the assessment process. This information will be applied during analytical analyses later to be carried out in the work. *See Observation 5.2.*

5.6.3 Identification of complex interactions

The following main conclusions can be inferred by reference to the observations made throughout the preceding text:

Conclusion 5.5. A quite complex task is to verify that the effectiveness measures are complied with and that current operations actually meet the success criteria identified. The requirement traceability model has documented and verified these relationships in broad terms. *See*

Observation 5.32 through Observation 5.34, and Observation 5.37. [158]

Conclusion 5.6. There are several complex processes undertaken by the stakeholders. Further, the Transportation System Operator conducts several complex and comprehensive trade-offs. These are all identified and modelled. *See Observation 5.35 through Observation 5.37.*

Conclusion 5.7. Complex interactions between the system and its context systems have been identified. *See Observation 5.43.*

5.6.4 Main features of current operations
The following main conclusions can be inferred by reference to the observations made throughout the preceding text:

Conclusion 5.8. All requirements are broken down into leaf-level requirements and all leaf-level requirements are allocated to stakeholders. Further, all functions are ordered into processes. The functions and the processes define unambiguously the current operations and describe the complex interactions that take place between the stakeholders. *See Observation 5.39 through Observation 5.42.*

Conclusion 5.9. Domestic suppliers of gas do normally not compete in the gas market. *See Observation 5.10 through Observation 5.14.*

Conclusion 5.10. Access to the transportation system is normally granted only for those shippers who are identified in the existing Heads of Agreements and Transportation Agreements. These shippers are all companies that own gas to be delivered under specified Gas Sales Agreements. By the same token the existing tariff and toll regimes support normally only these types of transportation needs, *see Observation 5.7.*

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[158] On the NCS the ownership shares are not aligned and harmonized 100 % between the different parties' interests in production field licensees and transportation licensees. This causes some conflicts and sub-optimizations from time to time, source: Statoil and law cases in recent years.

5.6.5 Discussion of the results

Some comments to the data collected.

First, some asymmetry exists in the data collection, as the interviews were conducted on Statoil personnel only. Some main stakeholders were not interviewed and these are representatives of MPE and representatives of other companies participating in the licenses. Finally, no representatives of the gas buyers were interviewed.

The author predicts however, that the chosen group of interviewees was able to provide representative information as this group represents the management of approximately 90 % of Norwegian natural gas transport operations. The major issues of operations are covered and the models can easily be corrected if misunderstandings or discrepancies are identified at a later stage.

Improved results due to systems approach in the research work.

In the master strategic approach (A.1 and A.3) and in the INCOSE 1999 paper [159] it was argued that a systems approach would yield more correct solutions to the problems than those we would have obtained by using traditional approaches only and not focusing on systems thinking and multidisciplinary research. To verify this assumption is a challenging task and the later work of this dissertation will address this topic in detail (see Section 8). There are however some few results obtained so far that fully support this statement. The main ones are discussed below.

Traditional methods do not capture traceablility to requirements.

In this industry no similar assessments of information have been conducted, as far as the author knows. In order to study working processes the typical approach in the industry so far, is an assessment based on "value chain" thinking. [160] This means that subsequent work tasks are identified and described as we follow the physical gas stream from wellhead to burner tip. These methods lack some essential features, which are however included in the methods, applied in this work. These features can be summarized as follows:

Conclusion 5.11. The systems engineering approach presented here applies recognized methods into a new field, according to INCOSE [161]

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[159] Dahl (1999-B) page 793
[160] Source: Statoil
[161] Written comments given by INCOSE reviewers related to paper: Dahl (1999-B)

and the work develops tailored information models for this industry. These models provide traceability between requirements, stakeholders and processes *and this level of traceability goes beyond what is obtained by traditional methods*. Information asymmetry is thus reduced more effectively compared to applying traditional methods only.

Stakeholders consider the operations as complex, multidisciplinary and difficult to document. One particular reason for this experience is the fact that there are many agreements governing the industry. There are only a few stakeholders that find themselves in a position to have detailed knowledge of all agreements. More than a thousand different agreements exist, comprising transportation-, gas sales-, and upstream agreements. The conceptualization and documentation of the relationship between these agreements, as presented in this work, have therefore an intrinsic value for the stakeholders.

Conclusion 5.12. The work also contributes to the literature dealing with Norwegian legislative issues regarding the oil and gas industry. The work aims to clarify how current legislative requirements are implemented, understood and adhered to by stakeholders.

For further details see the discussion and concluding remarks sections of Dahl (2000) INCOSE paper (enclosed).

Core results from the B.0 activity
The following core results are obtained from the B.0 activity:

Conclusion 5.13. The system re-engineering process has documented that the Norwegian natural gas transport operations are "intimately" vertically integrated and that the transportation system is an integral part of the entire NCS hydrocarbon production "machinery". It is thus not feasible to think of the transportation system solely as an independent system for natural gas transportation only. *See Observation 5.8.*

Conclusion 5.14. The services to customers are "bundled" (i.e. the seller provides all services associated with the sale such as gathering, transportation and storage activities). Further, the services are "merchant" (i.e. the seller owns the gas all the way through the system from production until final sale in the downstream market thus offering security of supply and a high level of nomination rights for the buyer).

See Observation 5.12, Observation 5.25, Observation 5.28, Observation 5.29 and Observation 5.31.

Conclusion 5.15. One last observation to be made here is that vital features of operations optimization are based on requirements stated in documents issued at company levels, but higher-level documents only briefly specify relevant requirements. These documents are very little transparent and there is asymmetry in information. This complicates external bodies' assessment of transport operations' optimization, and limits understanding of the nature of bundling services currently being provided. This work, however, has modelled the optimization process conceptually, thus clarifying the matter. This topic is further discussed in Section 7.6. *See Observation 5.40 and Observation 5.42.*

The overall main conclusion is therefore that the hypothesis B.0 stating: "*It is possible to develop a systems re-engineering process for assessing, specifying, and documenting current operations*" is true based on the successful outcome of testing hypotheses B.1 through B.5.

6 Assessment of regimes in transition

6.1 The hypothesis C.1

The hypothesis C.1 states: *"It is possible to assess relevant liberalized regulatory regimes and extrapolate some possible conditions that may prove applicable to future Norwegian transport operations"*. This section applies three distinct sources for assessing regimes in transition: the North American experience, the Gas Directive and the recently issued Norwegian public document called St. prp. nr. 36 (2000-2001) "Ownership in Statoil and future management of SDFI" [162]

The first source of information assessed in this section is experiences from the natural gas industry in North America. It is not the intention here to present a comprehensive and detailed overview of the development of this industry or to list every important lesson learned from these experiences, as this would be an overwhelming task. The main objective is to point at some basic lessons, theoretical notions and the like that may be argued to be applicable in a European and Norwegian context given the requirements of the Gas Directive. The basic idea here is to test whether the suggested and assumed implications of the Gas Directive are supported by experiences from North America. Two methods were applied here for assessment of information, first a literature review and secondly, interviews.

The second part of this section assesses the Gas Directive and the third part reviews the Norwegian St. prp. nr. 36 (2000-2001).

6.2 Assessment of available information
6.2.1 Literature review

There is a rich literature discussing natural gas regulation in North America. In order to prevent this dissertation to become too lengthy the major documents assessed are discussed in the text below, rather than being identified here separately.

The Gas Directive is reviewed and supported by the descriptive assessment of Dyrland et al. (2000) and finally the recently issued Norwegian St. prp. 36 (2000-2001) is briefly discussed.

6.2.2 Visits to selected companies in North America

Several companies working with natural gas transportation have been

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[162] The author has translated the title. The Norwegian title is: Eierskap i Statoil og fremtidig forvaltning av SDØE", SDFI means The States Direct Financial Interests

visited in the period of fall 1999 to fall 2000. These companies are:

- Statoil Energy, Washington
- Columbia Gas, Fairfax
- Colombia Gas, Charleston
- TransCanada, Calgary
- National Energy Board, Calgary
- Canadian Association of Petroleum Producers, Calgary
- Tabors Caramanis & Associates, Cambridge

Appendix 11.3 shows the visit schedule and a typical questionnaire applied, is reproduced in Appendix 11.4. The results of the assessment activities focus on some core issues that are quite apparent, such as supplier competition, vertical separation and cost of service regulation and these results are documented in the proceeding text.

6.3   Results - assessment of regimes in North America
6.3.1 Supplier competition
Countries like the USA and Canada have, for many years, adopted approaches to move away from a regulated gas price (which was often set at the wellhead). The Canadian experience offers particular clarity on this issue. In the Canadian National Energy Board (NEB)'s[163] May 1986 document outlining its "reasons for decision," the governments of Canada and its provinces agreed, with respect to the domestic market, "that purchase and sale of natural gas will be freely negotiated, and prices will no longer be prescribed." Further, the governments "anticipate that the reviews of surplus tests … will result in significant freer access to domestic and export markets and will thus contribute to the achievements of the market-oriented pricing system."

It is interesting to note that, prior to the NEB's May 1986 agreements, several resource management-related measures were in effect in Canada, and the liberalization process relaxed these. The standard view of the Canadian governments and regulatory bodies was that Canadian reserves were fixed and more or less known, and any increase in production and export would only result in a more rapid drainage of these resources, causing gas shortages sooner. Several measures, or "tests," were designed to secure national control of gas resources and prevent uncontrolled gas exports. The NEB's May 1986

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[163] National Energy Board (1986).

agreements eliminated several of these tests.[164]

Interestingly, history shows that both reserves and production increase rapidly following liberalization. Mansell and Church (1995)[165] summarize this effect as "perhaps the most important implication of these earlier experiences," noting that the gas supply's responsiveness to market signals has resulted in a growth in Canadian gas production of approximately 3.5% annually, for many years. In Canada, for example, since liberalization, shippers have constantly requested more capacity, and existing systems have been utilized at near 100% capacity year-round.

It must be noted here that gas production on the NCS differs markedly from that in Canada, in such aspects as exploitation offshore versus on-land production, production unit size, number of producing units, cost per unit of production, and owner structure. Further, Canada has both foreign and domestic customers, while Norway has basically only foreign customers. No indication is meant to be given here that Canadian experiences will necessarily apply to Norway.

The main observation to be concluded here is simply:

Observation 6.1. North America has for long aimed for supplier competition between producers and suppliers of natural gas. The buyers can purchase gas at the wellhead, or at any other defined location (hub) in the transportation, transmission and distribution system.

6.3.2 *Open access*

Open access is a key element in the de-regulation process that has taken place in North America. Carpenter, Jacoby and Wright (1983 and 1986)[166] may serve here as two examples of literature references analyzing how the natural gas pipeline industry responded and was transformed in the early stages after field price decontrol. A key question was access to pipeline transportation and much focus was on the formal status and duties of the pipeline to transport gas on behalf of other shippers not being pipeline owners.

In a course given by the Canadian Association of Petroleum Producers, see Schultz (1998) is this issue pointed out quite clearly. All observations

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[164] See NEB (1986) and its Appendix II, Article 17: "the governments of Canada will take appropriate steps to amend its existing policy on short term export sales of natural gas. Specifically: I) the "incremental test" shall be eliminated, II) the "competing fuels test" shall be eliminated; and III) "Regulations…shall be amended to allow export of natural gas by order without volume limitation for terms not exceeding 24 months."

[165] Mansell and Church (1995), p. 23.

[166] Carpenter et al. (1983) and Carpenter et al. (1986)

listed below are borrowed from this course and they are quotations from the handout material of the course.[167] These observations may thus summarize the material assessed by the author on this issue.

> *Observation 6.2.* Open access involves the *functional separation* of gas transmission from gas buying and selling. Open access is distinguished from the "merchant" pipeline that buys gas in the production area and sells gas in the market area such that transmission is just one component "bundled" into a single transaction.

> *Observation 6.3.* Functional separation is *achieved by creating a tariff* for transmission services with access rules, services, tolls, terms of service.

Schultz (1998) also discusses the ownership structure versus functional separation and he concludes as follows:

> *Observation 6.4.* Separation of ownership of transmission from buying and selling is not necessary. If the owner of the pipeline also markets gas, then some form of *separation* of the activities is required.

> *Observation 6.5.* Separation may involve *separate divisions* of the same company, or the creation of *separate companies* with common ownership. The key is to avoid conflicts of interest, preferential treatment, or other unfair dealing. This is achieved by separating the transmission employees from the marketing employees and by implementing codes of conduct to ensure all customers of transmission services are treated equally.

> *Observation 6.6.* Functional separation of transmission from marketing is essential for a competitive gas commodity market. Functional separation of transmission from marketing is compatible with monopoly gas buying and selling.

6.3.3 Diversified transportation services

Some illustrations from the U.S. market may indicate some aspects of how gas market contacts may develop, even though there are many differences

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[167] Course given by Mr. Nick Schultz of CAPP at the CIPID Natural Gas Regulatory Framework Course, July 1998.

between the US gas industry and the European context.

The Energy Information Agency (1994) outlines a variety of independent services developed in the deregulated U.S. market after so-called "Order 636."[168] For example, at any given "City Gate" several independent services are designed such as "firm, bundled firm notice, interruptible, capacity release, managing for peaking, swing and balancing."[169] A glance at the transportation services offered by Colombia Gas and TransCanada fully supports this observation. [170]

Sutherland (1993)[171] states that an efficient gas supply requires increased contracting options and reduced regulatory approval of contracts. He specifically suggests that spot purchase and short-term contracts have become more efficient than the long-term fixed price contracts that typified U.S. industry before the 1980s. Further, Wilson (1997)[172] examines and documents how deregulation in the U.S. gas market significantly impacted Canadian gas producers.

Again Schulz (1998) of CAPP [167] summarizes the issue and the following observation is a quotation taken from the course:

> *Observation 6.7.* Services must be *adequate and suitable for the desires or needs* of shippers.

Schultz lists several different types of services in a conceptual manner. Some shippers may require the ability to demand services each and every day (*firm service*). Others may require an *annual service* i.e. on some days the shipper will not be served but in total over the year the demand is met. This may be a feasible service for shippers who have access to gas storage. Some shippers want *interruptible supplies* as they may burn oil as an alternative energy source. Some shippers want *seasonal services* for example during winter heating seasons. Some shippers want *peaking services* to meat a peak heating demand.

6.3.4 *Main elements of "cost-of-service" (COS) regulations*

Mansell and Church (1995) provide an informative overview and

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[168] Department of Energy, USA, Energy Information Administration, "Natural Gas 1994: Issues and Trends."

[169] In the "old days," security of the supply was typically part of a U.S. pipeline's standard services, which were often referred to as merchant pipeline functions.

[170] See for example web sites: https://www.columbianavigator.com/Ebb/Default.asp

[171] Sutherland (1993).

[172] Wilson (1997).

analysis of traditional cost-of-service regulations, as applied in North America. The COS regulation is an extension to a general ROR regulation (as given in (Eq. 7.4.17), in such a way that the regulator will make decisions regarding every element in the formula. Major issues are how to calculate capital cost tolls based on different rules for depreciation, how to calculate the tolling base, and how to estimate and measure other cost-related activities. The regulatory body usually applies a number of standards in order to secure fairness in the evaluation process.

The main political decision inherent in the COS regime is that shippers shall cover all costs for serving them; that is, they must cover average costs plus a regulated profit. This fact recognizes an economic distortion, and Khan and Mansell and Church (1995) discuss reasons for doing so. A few arguments can be mentioned here: COS is in line with a general public recognition of "fairness," it provides rate stability, and it secures company credibility. From what the author has observed, most regulatory regimes that are currently in force in this industry recognize such principles.

The following observation summarizes this topic:

Observation 6.8. It seems to be a general preference for a cost-based toll in North America. The cost-based tolls are intended to assign to shippers the costs that shippers cause the pipeline to incur when providing services to those shippers. This principle is referred to as *cost causality* according to Schultz (1998).

6.3.5 *Regulatory boards*
In Canada a national regulatory board is established. The USA has established a similar institution known as the U. S. Federal Energy Regulatory Commission (FERC). By referring to the Canadian National Energy Board's Annual Report of 1999 the purpose, vision and goals are expressed as follows – and this statement may serve here as very short summarization of the objectives of these institutions.

"The NEB's purpose is to promote safety, environmental protection and economic efficiency in the Canadian public interest while respecting individuals' rights within the mandate set by Parliament in the regulation of pipelines, energy development and trade."

A major lesson learned is that the liberalization process brought into focus the need for a strong regulatory body. As the industry became more competitive, and the costs of transportation more transparent, experiences have shown that stakeholders have much attention on costs. Therefore, a strong independent regulator is often needed in order to settle disputes and to

make finial judgements of the acceptable level of toll.

6.3.6 Standardization of the industry

As de-regulation has advanced and the industry has responded a growing need for standardization has occurred. In order to meet this need a Gas Industry Standards Board (GIBS) has been established. This Board publishes a "Business Practice Standards" [173] that specifies standards covering a wide range of topics. Some examples are standards related to nominations, invoicing, electronic delivery mechanism, and capacity release related standards, contracts and so on.

6.3.7 Differences - North American and European gas industry

A last issue to be mentioned here – for the sake of completeness – is to point out some of the many differences between the industries in these two continents. As can be seen from Table 4 below Continental Western Europe is largely dependent on some few major suppliers, and the buying nations are net importers. Further the lead-time for new gas projects for Continental Western Europe is significantly longer than elsewhere.

Table 4. Natural gas market differences [174]

	North America	UK	Continental Western Europe
Market size, BCM/yr.	700	80	280
Number of suppliers	> 5000	30-40	4 majors
Import dependent	0%	0%	40% rising
Development cost	Low	Medium	High
Lead time new gas	1-2 years	2-3 years	> 5 years
Primary energy share	27%	30%	18%

6.4   Results - EU's Gas Directive
6.4.1 Comments by other authors

In the following sub-sections some few core provisions of the Gas Directive relevant to our discussion are identified and commented upon. Some few authors have commented on the Gas Directive and pointed at several

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[173] See for example a GIBS's Business Practice Board Version of July 31, 1998
[174] Source: Holm (1999)

shortcomings and unsolved matters. [175] WP nr. 36 (1999-2000) and the recently issued St. prp. nr. 36 (2000-2001) both refer to the Gas Directive but give few details regarding it's implementation in a Norwegian context.

Several authors have commented the Gas Directive and have offered views that are relevant for the discussion. Such comments and views are also identified in the text below. Another interesting report is also "The Brattle Group" (2000) which discusses the Gas Directive and it suggests many practical solutions to questions related to implementation in a European context.

6.4.2 Access to the system

"System" is defined in article 2.13 of the Gas Directive and it means "any transmission network and/or distributions network". An interesting question is whether the Norwegian natural gas transportation systems are included in this definition. We notice that "transportation systems" or "upstream pipeline networks" is not included in the definition and Dyrland et al. (2000) thus conclude that "upstream pipelines" are not included in this definition. The Gas Directive has some special provisions covering the "upstream pipeline networks", see sub-section 6.4.4 below.

The main provisions may be summarized as follows: access shall be given to the "system" with "objective, transparent, and nondiscriminatory criteria" (Article 14), either as negotiated access with published commercial conditions (Article 15) or as regulated access based on published terms and tariffs (Article 16).

One key question here is what service obligations the "systems" have under capacity constraints. Dyrland et al. (2000) and also Stern (1992) discuss this issue. The interpretation offered by Dyrland et al. (2000) is that the Gas Directive does not require "Common Carriage" [176] obligations but it allows the

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[175] Percebois (1999) analyses the Gas Directive and discusses the different measures introduced in order to enhance liberalization in the European gas market. He points to a number of unsolved questions and obstacles. See also Brautaset et al. (1998). Readers interested in unbundling and related implications within a European context are referred to IEA (1994), pp. 93-99, or IEA (1995), pp. 106-107, as well as IEA (1995), pp. 221-236, where Øystein Noreng discusses this topic. Radetzki (1999) discusses related questions. She argues that market forces will result in competition in any case, and that commercial development may undermine existing monopolies.

[176] See Stern (1992) page 23-24 and Carpenter, Jacoby and Wright (1983) for a clarification of the term "common carrier". A common carrier pipeline is normally obliged to serve all shippers even under capacity constraints by reducing capacity pro rata to all parties in proportions to the shippers tender in the first place.

"system" to refuse access to new requests if the system capacity is already fully utilized.

Another key question is of course the terms and conditions for access to the "system". Two possibilities exist, either negotiated access or regulated access. The Gas Directive leaves it to the Member State to choose which principles they will go for. Lijesen [177] has analyzed the issue by means of a game theoretical model and indicates that under given assumptions "the regulated access-pricing regime is likely to be superior to the negotiated access-pricing regime", as the former will yield the highest welfare. There are however many parameters and assumptions influencing on the results above and detailed analyses ought to be carried out case by case prior to concluding on a preferred solution.

6.4.3 Eligible customers, natural gas undertakings and market opening

Access shall be given to "natural gas undertakings" (defined in Article 2) and "eligible customers" (defined in Article 18), and the provisions shall lead to specified levels of "market opening" over a ten-years period (Article 18). "Natural gas undertakings" means any legal natural person carrying out at least one of the fowling functions: Production, transmission, distribution, supply, purchase or storage of natural gas". "Eligible customers" are gas fired power stations and other final customers consuming more than 25 million cubic meter of gas per year on a consumption site".

Article 18 also stipulates the minimum requirements for levels of "market opening". This provision aims for creating a competitive European market in natural gas. The main objective is that gas suppliers must compete in the marketplace in order to obtain a gas price set by the market. This, of course, is a new approach to setting the price, an alternative to the existing gas-pricing mechanism in Europe.[178]

6.4.4 Upstream pipeline networks

Article 23 specifies provisions applicable for "upstream pipeline networks". One question is whether the Norwegian natural gas transportation systems fall into this category of systems. Dyrland et al. (2000) discuss this issue and they conclude that in their view it seems fairly reasonable to assume

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[177] Lijesen (2000)

[178] Austvik (1997) provides an overview of prevailing pricing principles. He also discusses differences between U.S. experiences and European development, and assesses the importance of taxation. Brautaset et al. (1998) provides a detailed description of the pricing formula and gas sales contracts. See also Dyrland et al. (2000) page 21 who clarify the matter of competing suppliers.

that all of the Norwegian natural gas transportation systems used to convey natural gas to a final coastal landing terminal[179] are included by this provision.

Another question is whether all provisions of the Gas Directive apply for the upstream pipeline network. On this issue Dyrland et al. (2000) express that there are some uncertainties regarding the extent to which all provisions of the Gas Directive are applicable for the upstream network and it seems that Article 23 introduces less stringent requirements for access. The same conclusion is suggested by Brautaset et al. (1998).

Article 23 specifies that member States shall take necessary measures to ensure that natural gas undertakings and eligible customer "are able to obtain access to upstream pipeline networks…in accordance with this Article".

6.4.5 *Unbundling of accounts*

An integrated natural gas undertaking shall unbundle its internal accounts i.e. keep separate accounts for their natural gas transmission, distribution and storage activities. (Article 13). The reasons for so doing are specified in Article 13.3 which states that this shall be done "with a view to avoiding discrimination, cross-subsidization and distortion of competition". Dyrland et al. interpret these provisions to require the same level of separate accounting as would have been done if the companies actually were separate companies.

> *Observation 6.9.*   The Gas Directive specifies unbundling of internal accounting. It may be assumed that this provision will be applicable for Norwegian natural gas transportation.

6.4.6 *Other provisions*

There are many more articles in the Gas Directive and some few are briefly mentioned here. Articles 25 and 26 specify provisions pertinent to specific difficulties that may be encountered during the transition stage. The Gas Directive also specifies rules for the establishment of a competent authority for dispute settlements (Article 21). Technical rules and interoperability are specified in Article 5.

Article 25.1 specifies that only if "a natural gas undertaking encounters or considers it would encounter serous economic and financial difficulties because of its take-or-pay commitments" a temporary derogation for access to the system can be filed as an application to the Member State. The derogation can be accepted only on the condition that "it is impossible to find

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[179] "Ilandføringsledninger" in Norwegian.

economically viable alternative outlets." In article 23.3 this provision is constrained by "serious difficulties shall in any case be deemed not to exist when the sales of natural gas do not fall bellow the level of minimum offtake guarantees contained in gas purchase take-or-pay contracts". For a more detailed discussion of the topic see Dyrland and Moe (2000) page 26.

6.5   Brief assessment of St. prp. nr. 36 (2000-2001)

On December 15, 2000 a Norwegian public document was released called St. prp. nr. 36 (2000-2001) "Ownership in Statoil and future management of SDFI". [162] This document presents the Government in Office's view on the future ownership of Statoil and related issues. The document is pending final approval by the Parliament presumably later this year.

This document proposes several legislative changes regarding the conduct of the Norwegian natural gas transport operations and a brief review of the document is given here.

The document refers to the Gas Directive as a force of change and it points to the Gas Directive's intention of having more direct competition between suppliers in the downstream market.

The document states that the resource management objective remains a main objective for the Norwegian oil and gases policy, see page 13 and page 116. The document specifies that competition between Norwegian stakeholders is important on issues such as geological knowledge and exploration, development of production fields and transportation systems and environmental issues.

The document discusses the future role of Statoil, but these discussions are left out here. The main focus of the text that follows here is the proposal of a new organization for natural gas transport operations.

The Norwegian Government suggests that a new transportation company shall be established (see page 17 and page 109). The new company shall be responsible for the natural gas transportation systems including those terminals that constitute parts in the transportation system. All parts of the transportation system that are "integral parts" in operations and that secure the resource management shall be included in the new company's scope of responsibility.

The "technical" operations, meaning essentially inspection and pipeline repair contingency shall not be part of the new company's work responsibilities, see Section 7.4.2.3 on page 139 for a break down of such work tasks. The State shall own the company, at least initially.

The reasons for establishing a new transportation system company are based on some main conditions as follows:

- The transportation systems and the treatment terminals shall serve all producers of natural gas in order to enhance resource management on the NCS.
- The natural gas transportation system operator shall behave in a neutral manner (being impartial) to all systems users (the shippers).
- The transportation system operator shall have a significant role in connection with the development of new transportation systems.

The transportation company shall have no other business functions than natural gas transportation. The document states that the Norwegian natural gas transportation systems are highly integrated and the transport operations are complex achievements. The integrated structure also makes possible a high production of oil and NGL from the different production fields and terminals.

Two more important rules are suggested. First, the prevailing ownership structure shall remain. The toll shall be based on a 7% real rate of return before taxation. There are some provisions for the pipeline owners to increase their revenues slightly if increased throughput is obtained.

Secondly, the prevailing tariff and toll regime shall remain. The transportation services shall be negotiated between parties, i.e. shippers and pipeline owners, and the Ministry shall approve all agreements. The Ministry shall also continue to allocate sales contracts to the production fields. The Ministry has thus an overall function for the allocating the systems usage.

The Government lists several major reasons why they suggest that a new transportation system operator shall be established. These are:

- The company who operates the transportation systems shall not participate in production and sale of natural gas.
- The company who operates the transportation systems shall enhance resource management in a neutral manner. This is also, according to the government the best way of securing a further development of the pipeline systems as the transportation company is neutral and has a unique information of capacity constrains and so forth.
- Information asymmetry. No company on the NCS shall have a benefit of information asymmetry related to the transportation system operations or other conditions related to the pipeline systems. This is an argument of having the transportation operations conducted by a separate company. See also Section 3.4.3.4.
- Cross-subsidizing. This is the classic argument as clarified in Section 3.4.3.3.

As we have seen the arguments listed above are all quite common arguments that are often applied in modern regulatory regimes and as outlined in Section 3.4.

The document has caused substantial political debate and involvement by stakeholders. The debate is often politically influenced. All parties however, seem to agree that some kind of a new company is needed in order to allocate capacity between shippers impartially.

> *Observation 6.10.* The Norwegian government has suggested that an independent organization unit (operator) shall conduct parts of the transportation system operations, limited to the dispatching and administration of the systems. This company shall not participate in production or sale of natural gas or any business development based on natural gas.

6.6 Summary

This section has reviewed the North American experiences related to deregulation of the natural gas industry and some few, but important lessons are listed in the preceding text. The Gas Directive has been reviewed together with a recently issued Norwegian public document expressing the view of the government on the issue. The author will argue that the hypothesis C.1 is true and the following main conclusions are stated:

> *Conclusion 6.1.* Competing suppliers of natural gas is a crucial element of the liberalization process both in North America and it is also called for in the Gas Directive, *see Observation 6.1* and the Gas Directive Article 18.

> *Conclusion 6.2.* Access to the system is an imperative element for enhancing competition in North America and it is called for in the Gas Directive, *see Observation 6.2* and the Gas Directive Article 15 and 16.

> *Conclusion 6.3.* All shippers (i.e. all natural gas undertakings and eligible customers) shall have access on equal terms, *see Observation 6.5* and the Gas Directive Article 14. It is somewhat uncertain to what the extent all shippers shall have access to the Norwegian dry gas systems, by if they are granted access it shall be impartially and equally.

> *Conclusion 6.4.* The company who offers transportation services (in a Norwegian context) shall have their internal accounts unbundled if

vertically integrated and it must have separate and transparent accounts for the transportation services. Alternatively – and conceptually – the transportation services may be offered by an independent transportation system "operator" [180] that is not involved in gas production, marketing and sales. The latter view has recently been suggested by the Norwegian government, *see Observation 6.5, Observation 6.6, Observation 6.9 and Observation 6.10.*

Conclusion 6.5. The functional separation shall be supported by a tariff and toll regime that ensures adequate services that meet the shippers demand, *see Observation 6.3 and Observation 6.7.*

Conclusion 6.6. The toll regime in North America is generally cost-based and it is just and reasonable, *see Observation 6.8.*

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[180] The term "operator" as used here does not necessarily mean the formal "Operator" role as defined in the stakeholders' documents such as the Transportation Agreements. The term used here is to be understood simply as an independent organizational unit.

7 Norwegian transport operations in a new regime

7.1 Introduction

The first activity conducted here is testing of hypothesis C.2 that redefines effectiveness measures. According to system theory and well-known principles of systems engineering stakeholders must define their effectiveness measures at an early stage in the systems engineering process. Such principles have to be observed here as well. The hypothesis C.2 expresses an assumption that the prevailing effectiveness measures must be redefined to some extent. This is needed in order to specify feasible measures for transport operations in a liberalized regime. The hypothesis is tested and shown to be true, and redefined measures are inferred.

The second activity is to test the hypothesis C.3 related to test case scenarios of change. The Gas Directive is still not implemented into Norwegian legislation [17] and any specification of future requirements for Norwegian natural gas transportation, done here, will inevitably have to be based on assumptions containing uncertain factors. In order to reduce the uncertainty of these assumptions, the suggested assumptions are assessed and tested. The applicability of the two test case scenarios suggested initially (see Section 2.4) is verified and it is concluded that they are relevant, albeit the text had to be slightly rephrased.

Hypothesis C.4 tests how new economic methods can be developed so that future operations comply with the new requirements assumed to be enforced. The first activity analyzes the extent to which the existing toll formula and incentive structure for rationing and cost efficiency are compatible with the new requirements. The analyses conclude that the prevailing toll formula and incentive structure only partly meet the requirements of a liberalized regime. New toll methods are thus developed regarding firm and interruptible supplies.

It has already been mentioned that an objective of this work is to apply system thinking and multidisciplinary approaches to enhance the correctness of the solutions suggested. One important issue is thus to test that the suggested new economic tariff and toll rules are compatible with the physical operations of the transportation network. Hypothesis C.5 comprises such important testing and it documents the extent to which the suggested new economic tariff and toll methods are feasible technically and operationally. In particular a tariff and toll regime for allocation of spare capacity is studied.

In order to perform the latter task a computer expert system is applied, known as the *GassOptTKL* program. The program applies linear programming for optimizing the physical gas streams in the Norwegian natural gas network. The program however, has never been applied to solve problems as identified here, and the program was tested on empirical data in order to verify its accuracy prior to being applied.

Throughout Section 7, the technical and economic theories identified in Section 3 are applied and combined. The analyses are also constrained by the statutory requirements inferred from our discussion of the Gas Directive in Section 6. Further, the analyses are enhanced by blending the theoretical analyses with empirical data, the *attribute* information from activity B.0, thus obtaining validation of the discussions and bringing into focus the core problems to be solved.

The last major task in this Section is amendment of the information models. This will call for updating and changes to be introduced into existing organizations and working processes as well as documents and requirements. The hypothesis C.6 and C.7 deal with such questions. Finally, hypothesis C.8 summarizes the results of these analyses and draws some conclusions.

7.2   Redefined effectiveness measures
7.2.1 The hypotheses C.2

The hypothesis C.2 states: *"It is possible to redefine the effectiveness measures applicable to future operations."* In the following sub-sections the hypothesis is tested. Based on the information obtained during the system re-engineering process (B.0) and the subsequent assessment activity C.1, the twelve effectiveness measures are revisited and their applicability in a liberalized context is analyzed. The measures are amended or changed as deemed necessary.

The hypothesis is true provided the analyses produce redefined measures that unambiguously specify success criteria for conduct of Norwegian operations in a liberalized European regime – and provided that the stakeholders accept the measures. The author recognizes however, that the final verification and acceptance by stakeholders is difficult to obtain as there are many uncertainties present, ultimately related to a still pending Norwegian implementation of the Gas Directive. The author also recognizes that different stakeholders may have different preferences and they may focus on different success criteria that are contradictory by nature. This assumption is based on the prediction that liberalization will cause a more competitive business environment.

7.2.2 Results – redefined effectiveness measures

7.2.2.1 Resource management

This effectiveness measure stated: *"The development of new transportation systems, the daily transport operations, and the tariff regime shall help optimize the exploitation of Norwegian petroleum resources."*

No evidences have been found in the assessment activities B.1 and C.1 of a Norwegian political desire to change this effectiveness measure. Actually, governments and MPE have repeatedly reconfirmed the topicality of this measure as documented in much of the literature assessed, such as White Papers and official letters. The resource management is an ultimate objective of the Norwegian petroleum activities and it is applicable in a liberalized context. These are the arguments as listed in Section 5.4.2.

A recently issued White Paper, no. 39 (1999-2000) and a Norwegian St. prp. 36 (2000 – 2001) emphasize that the transportation systems and their operations are integral parts of petroleum production on the NCS. The transportation system is thus a major tool for enhancing resource management. According to WP No. 39, Section 5.2.1, "production of natural gas" is defined as exploration, exploitation, blending, and transportation in the dry gas transportation system.[181]

The final treatment of natural gas is performed at the shore terminals. This treatment [182] focuses on extensive properties (e.g., volume, mass composition, heating value, and tracers) and intensive properties (e.g., pressure and temperature). The aim of the treatment is to bring the dry gas into compliance with gas sales specifications and delivery requirements.

In order to obtain resource management on the NCS efficient development of the transportation systems is needed. The centralized planning and licensing system is the main mechanism to secure a successful development of new capacity.

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[181] A note is to be made here: The WP No 39 (1999-2000) seems to define "transportation in pipelines" as being part of "production", see Sect 5.2.1. This definition is apparently not in agreement with the provisions of the Petroleum Law. Sect. 1-6 g) of the Law defines exploration, exploitation etc as part of production but does not include "transportation of petroleum in pipeline systems". Sect. 1-6 h) defines "transportation" as "shipping of petroleum in pipeline systems". The licensing system is featuring this distinction as well, as separate licenses are issued; one pertinent to the exploration, exploitation and production of petroleum and the other pertinent to transportation of petroleum in pipeline systems: the transportation license. Ulf Hammer pointed out these relationships for the author.

[182] The interpretation of "treatment" is based on the author's experiences with daily operations. See also Thaule and Postvoll (1996), who provide an overview of several operational aspects of gas deliveries in Norwegian systems.

One main concluding observation is thus made here:

Observation 7.1. It is assumed for the course of this work that the main components of the current framework for planning, developing and licensing of new production fields and transportation systems remain intact as no major reasons for changing them have been identified.

It falls outside the scope of this work to conduct a detailed assessment and testing of the above observation. Nor does this work evaluate whether or not liberalization will call for changes in the existing legislation.

If we now turn to the economic theory outlined in Section 3.4 it is argued that resource management – and the prevailing mechanisms to secure it – is a long-term task that also enhances dynamic and allocative efficiency. This industry has significant conditions for economy of scale [183] and these conditions are especially noticeable in the Norwegian high pressure, long distance sub-sea pipeline systems. Further, huge "one of its kind" projects characterize the development of the industry. As a consequence of these facts it is argued here that any planning and development of new production and transportation systems can not be done in small incremental steps and in an uncoordinated manner.

Based on the Observation 7.1 above and the economic facts stated above another observation is thus suggested here:

Observation 7.2. A centralized planning and licensing system remains to be a necessary tool for securing allocative and dynamic efficiency even in a liberalized context.

Two derived observations may be stated here as a consequence of Observation 7.2:

Observation 7.3. The tariff and toll regime will not constitute a major or prime tool for securing allocative and dynamic efficiency in a liberalized Norwegian context.

Observation 7.4. Daily natural gas transport operations and the tariff and toll regime must not prevent or hamper an efficient physical

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[183] See Sections 7.4.2.2 where some empirical data related to economy of scale is documented.

production of all petroleum products from the NCS.

To conclude, the transportation system including its operations is currently treated as an integral part of the development and production of the nation's petroleum resources on the NCS, both with respect to long-term development and in daily operations. The author has found no arguments opposing the validity of this effectiveness measure in a liberalized context nor has he found any reasons to argue that this effectiveness measure ought to be changed as a consequence of the liberalization process.

Further, in the current regime the operations are vertically integrated but as we have seen in Section 6.5, the Government has suggested to segregated operations into a separate operator entity. This however, does not oppose the resource management objective.

The main observation to be made is thus:

Observation 7.5. The resource management effectiveness measure remains valid.

7.2.2.2 Coordinated gas sales

The next effectiveness measure stated: *"Transport operations and the tariff regime must support the established regime governing: gas marketing, negotiations and sales, assignment of gas sales contracts to contractual fields, allocation of gas supplies to delivery fields, and planning and development of new transport capacities"*.

The main notion here is that the legislation governing the transport operations shall support the principles governing gas negotiating and sales. Phrased somewhat differently we may say that there shall be no conflict of interests between the rules governing transport operations and the rules specifying gas sales activities. In the prevailing regime, the licensing system and the centralized sales and planning functions by means of GFU and FU, as well as the prevailing tariff regime cause few conflicts, at least conceptually.

The core question here – in the context of this analysis – is whether the established mechanism for gas negotiation and sales, the GFU, will remain in a liberalized context or whether it has to be changed. If it has to be changed the subsequent question is whether this will cause an effect on the current regime for gas transportation and whether this regime must be altered and transformed.

If we turn to the literature, several authors have in recent publications discussed this topic. Brautaset et al. (1998) offer a juridical discussion of the

topic and especially relate the GFU, FU, and Norwegian resource management establishments to European competition law. Sunnevåg [184] offers an economic discussion of the topic, approaching the issue by assessing inefficiencies and externalities caused by these establishments. He indicates in his concluding remarks that "with separation and transactions through the vertical chain at transparent prices, decisions on exploration and field development can be decentralized and based on expected market prices for the compound product consisting of transport access and a unit of natural gas." As can be seen from Observation 7.2 above this author does not fully support such a view.

Another author, Stern (1997 and 1998),[185] discusses the GFU and argues, much in line with the Canadian experience described earlier, that the current Norwegian system may "curtail expansions of Norwegian gas exports, beyond what has already been contracted." Hannesson (1998) [186] expresses similar views.

Two recent White Papers [187] assess the implications of the Gas Directive and indicate possible implementation measures in relation to the prevailing Norwegian legislation. In particular in the former of the two White Papers mentioned, Norwegian authorities argue that GFU is an important means to secure resource management.

It is not the intention of this work to evaluate the impact of new market conditions on GFU; nor does this work aim to comment on the effectiveness of provisions introduced by the Gas Directive. [188] The following observation is thus made in relation to this work:

> *Observation 7.6.* The validity of the Norwegian means for gas sales (GFU) in light of the Gas Directive and other EU provisions has been assessed in the literature. Many different arguments are raised and several authors are questioning and analyzing the validity of the

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[184] Sunnevåg (1999) and Sunnevåg (2000)

[185] Stern (1998), pp. 164-170.

[186] See Hannesson (1998), page 59.

[187] WP No. 46 (1997–98) and WP No. 39 (1999-2000).

[188] For readers interested in such issues, a large number of published books and articles relate to the possible development of the European gas market. Estrada et al. (1995), Stern (1998), Mestmeacker (1993), and several studies issued by IEA (1994, 1995, 1997, the 1998 Distribution study, and the 1998 Gas Pricing study) discuss these topics. Further, the United Nations, as economic commission and gas center for Europe, has issued a series of articles on the subject. Stoppard (1996), together with a number of books published by Financial Times (FT), give overviews and insights on many European-related natural gas market issues. See the reference list for information on these publications.

arrangements. It falls outside the scope of this work however, to assess and conclude on whether this establishment endures liberalization and whether the effectiveness measure identified here is valid in a liberalized context.

There are however, one important observation that can be argued to be applicable based on the discussion above and the discussions to follow in Section 7.3 (which relates to new modes for transport operations). This observation thus constitutes an essential element in order to conduct the research as outlined in this work. This observation is:

Observation 7.7. It can be inferred that domestic suppliers of dry gas must compete – this is a prerequisite for competition.

The observation above can be derived from the Gas Directive as the Gas Directive specifies that a competitive natural gas market is an important element of the internal energy market in Europe. [189] Further, basic principles of economic theory generally call for competing suppliers as a prerequisite in order to obtain competition in a given market that is characterized by an elastic market demand.

Observation 7.8. As a consequence of the above observation, and as will be discussed later in the work, it follows that transport operations will be affected in different ways because competing suppliers will cause that shippers will request new gas transportation services.

Observation 7.9. The core challenge then becomes to secure economic and operational efficiency under these new assumptions. One major means to do so is to revise the tariff and toll regime keeping in mind that it must be compatible with technical and operational constrains.

7.2.2.3 *Economically efficient development and utilization*

This measure states: *"The development of new transportation systems, daily transport operations, and the tariff regime shall be economically efficient"*.

This effectiveness measure reflects universal economic objectives as they were outlined in the discussion of economic efficiency criteria in Section 3.4.4. The observation to be made is simply:

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[189] See the Gas Directive, "whereas" no. 3

Observation 7.10. Economic efficiency is a valid effectiveness measure in a liberalized regime.

7.2.2.4 Right incentives

The fourth measure states: *"The regulatory regime for development of new transport capacity, operations, and tariffs must have incentives which ensure that a company's optimal economic adaptation to the regime coincides with the economically efficient solution."*

This measure reflects the incentive objectives applicable for the vertically integrated structure of today, but it is must be rephrased to cover the effects caused by liberalization. In Section 7.4.3 the key features of the prevailing incentive structure are analyzed. It will become apparent in the analyses that liberalization will call for new incentive structures in order to improve on rationing efficiencies in a liberalized context.

The incentive structure is to a large extent dependent on political decisions. No new incentives are formally introduced into the Norwegian legislation so far except for those suggestions specified in the recently issued Norwegian St. prp. nr. 36 (2000-2001). The document is still pending final approval. [17] This document emphasizes – in relation to the effectiveness measure stated here – the importance of having the transport operations conducted impartially and in such a way that all shippers are treated in an equal manner. Based on this information and the assessment activity C.4 and the discussion of Section 7 some observations are made here and summarized below:

Observation 7.11. The transport operations shall treat all shippers impartially and equally and the transportation system operator shall conduct its activities in an independent (neutral) manner.

Observation 7.12. New incentives for improving economic efficiency must probably be introduced as a consequence of the Gas Directive and in order to treat all shippers equally. It is especially argued that a new incentive structure is needed for securing rationing- and potentially also cost- efficient daily transport operations in a liberalized context.

Observation 7.13. The main means to achieve a proper incentive structure, an efficient allocation of existing capacity and cost efficient operations are the tariff and toll regimes and an efficient product selection of transportation services. This therefore constitutes a revised

effectiveness measure and it will be the subject for research work later in this dissertation.

Further, by reference to Section 6 and the lessons learned from liberalization in other regions, a liberalization process will typically result in disputes between stakeholders related to cost and tolls. All gas industries studied in this work have established a resolute and independent regulator who is entitled to settle disputes. Such regulators are established by virtue of national legislation.

> *Observation 7.14.* It may be assumed that stakeholders will experience disputes and conflict of interests related to transportation services, access, and tariff and toll to a larger extent than what has been common so far. It may therefore be a need to establish a dispute settlement arrangement in order to settle such disputes. [190] This topic is not pursued any further by this work.

7.2.2.5 Supportive agreements

This measures states that: *"Sales-, transport-, and upstream-agreements shall be negotiated and agreed upon by parties in such manners that the agreements support transport operations, and vice versa."*

In a liberalized regime this effectiveness measure will still be valid. There is however one important noteworthy distinction. Given the assumption that the transportation services are transparent and access to the transportation system is made available as specified in the Gas Directive, the transportation system operator must include in his product portfolio services that support such upstream transportation. Such services must be made more transparent than what is the prevailing practice. One observation is thus stated here:

> *Observation 7.15.* The future tariff and toll regime must support upstream arrangements and provide transparent services for such arrangements.

7.2.2.6 Reasonable and prudent

This measure states: *"Operations shall be conducted in a "reasonable and prudent manner," with due attention to safety and the environment."* This requirement is valid in a liberalized regime. The conditions for operations will

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[190] The Gas Directive has provisions to this effect, see Article 23.3-4

probably change as a consequence of liberalization, but the conduct must always remain reasonable and prudent. One specific related argument can be made here, derived from experiences of regulatory regimes elsewhere, and as was discussed in Section 6 namely that:

> *Observation 7.16.* The tariff and toll regime shall be designed in a just and reasonable, prudent and fair fashion.

7.2.2.7 Gas buyer compliance

The gas buyers must act in accordance with the sales agreements. In Section 6 it has been documented that gas buyers in a liberalized market diversify their contracts and in Section 7.3 this topic is further discussed. But regardless of the contracts entered into, this effectiveness measure remains the same assuming that the gas buyers must act prudently according to the contracts made.

One special situation regarding the existing Take-or-Pay contracts is regulated in the Gas Directive. If any parties encounter "serious economic and financial difficulties" because of these commitments, Article 25 of the Gas Directive specifies some counter measures. These topics however, are not discussed any further in this work.

7.2.2.8 Regularity

Dry gas transport system deliveries shall be made to gas buyers with 100% regularity. Based on the current gas sales commitments, this effectiveness measure is an ultimate goal. If new types of gas sales contracts will be introduced in a liberalized regime such as interruptible contracts, this measure obviously is irrelevant for those contracts. However, a high technical regularity of the facilities will always be attractive and aimed for, especially in periods of full capacity usage. The effectiveness measure is thus relevant in a liberalized regime. [191]

7.2.2.9 Other measures being unchanged

The remaining effectiveness measures related to *gas quality, tariff and toll, communication system,* and *production filed regularity* remain valid as specified.

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[191] Reference is also made to the Canadian experience, where the regularity of gas transportation became imperative in the time that followed the introduction of deregulation.

7.2.3 Summary

The main lesson learned here is that many of the effectiveness measures remain the same, especially those related to the resource management, *see Observation 7.1 and Observation 7.2, Observation 7.4 through Observation 7.6 and Observation 7.10*. Some of the effectiveness measures however, must be changed – or be rephrased somewhat – in order to reflect valid effectiveness measures in a liberalized regime and to incorporate essential *new* legislative requirements caused by the Gas Directive. In the preceding text these changes are summarized based on the observations identified in this sub-section. The revised effectiveness measures, relevant for this work can be summarized as follows:

Conclusion 7.1. In order to facilitate competition in the downstream market – a pre-requisite for competition according to the Gas Directive, domestic suppliers may be required to compete (between themselves) in the gas market*, see Observation 7.7.*

Conclusion 7.2. In order to facilitate such competition shippers of gas will require new transportation services, *see Observation 7.8.*

Conclusion 7.3. New transportation services must be developed in order to meet the shippers' new demands and the main means for providing such services is a new tariff and toll regime, *see Observation 7.9.*

Conclusion 7.4. The new tariff and toll regime must enhance rationing efficiency and cost efficiency and provide an incentive structure to this effect, *see Observation 7.12, Observation 7.13 and Observation 7.15.*

Conclusion 7.5. Transport operations must be transparent and secure all shippers access to the services, *see Observation 7.11.*

Conclusion 7.6. The new tariff and toll regime must be compatible with an efficient physical transport operation and it must support upstream agreements in order to enhance production of natural gas, oil and NGL, *see Observation 7.15.*

Conclusion 7.7. A new toll regime must be just and reasonable, transparent and fair, *see Observation 7.16.*

The revised measures have been review by a representative of the Transportation System Operator and found reasonable. The author will thus argue that the hypothesis C.2 is true, given the uncertainty that exists due to lack of political decisions regarding the implementation of the Gas Directive into Norwegian legislation.

7.3 New modes for future transport operations
7.3.1 The hypothesis C.3

The hypothesis C.3 states: *"It is possible to unambiguously specify some future economic and technical requirements, and to express and treat these requirements as test-case scenarios in the succeeding work"*.

In the following sub-sections this hypothesis is tested. The hypothesis is true if it is possible to make probable some requirements for future operations by deriving and inferring such requirements from *three* distinct sources. The first source is obviously the revised *effectiveness measures* as concluded in the sub-section 7.2.3 above. Secondly, the assumptions regarding future operational modes are checked against *the economic theory and related literature*. Finally *experiences learned from similar situations elsewhere* are applied to see whether the new modes look reasonable.

The author recognizes that such requirements for new operational modes under all circumstances will be uncertain to some extent as the final outcome of the Gas Directive's implementation process in a Norwegian context is still pending political decisions and judgements. [17] The validity of the suggested requirements is also influenced by the way the industry chooses to respond to the Gas Directive – an experience still largely unknown.

In the initial stages of the dissertation work two assumptions were made:

- *Scenario 1*: The dissertation shall analyze and suggest possible means to include short-term sales agreements in addition to the existing take or pay agreements, taking into consideration the effect of possibly varying natural gas market prices.

- *Scenario 2*: The dissertation shall analyze and suggest possible means to incorporate access of "third party shippers" in the transportation system.

The results of the work that has been done since these test scenarios were suggested have shown their validity. But the work has also shown that a slight rephrasing of the text will reflect future operational modes more accurately regarding transportation services and transport operations. A

rephrasing of the scenarios is therefore given at the end of this sub-section.

In relation to the first scenario it is show in the following text that liberalization will introduce supplier competition. This is an argument derived from the economic theory as pointed out in Section 3.4.3. The work shows that literature and experiences support this conclusion. As a subsequent notion diversified gas sales contracts will probably develop, again, derived from theoretical assumptions and supported by experience. The next logical step here is that the transportation costs shall be unbundled and made transparent. This will result in a need to develop "stand-alone" transportation services that support the shippers' (and gas sellers') need for diversified gas sales contracts, eventually resulting in "firm, interruptible and peak load transportation."

The second scenario is derived directly from the Gas Directive.

7.3.2 *Firm and interruptible transportation*
7.3.2.1 *Introduction of supplier competition*

From an economic point of view, competing suppliers in one way or another represent a prerequisite to any alternative to regulated price - a fact that has been noted by several journal and textbook authors over the years and has been borne out by experiences around the world. Bjerkholt et al. (1990),[192] for example, recognize this fact in their analysis of how liberalization would affect the European gas market. Their analyses consider three major national gas suppliers' battle over market share in Europe. They apply a specific simulation model calculating market share based on individual suppliers' cost functions and estimated demand functions, concluding that the results are very sensitive to exogenous change.[193]

Golombek et al. (1995)[194] also evaluate the effects of a radical liberalization in Europe. They assume various possible approaches to selling gas: sellers are considered in one case to be profit-maximizing Cournot producers, in another case to be traders exploiting arbitrage, and so on. Their conclusion is that economic welfare in Western Europe could increase by 15% to 20% in the long run. In a more recent publication, the same authors [195] extend their study to include domestic suppliers, concluding that "once the

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[192] Bjerkholt et al. (1990 and 1992).

[193] Yves Smeers (1997) offers an overview of the key elements of the European legislative process, noting the diversity of the institutional contexts. He concludes that market liberalization will probably be an intricate process. He also discusses how computable equilibrium models can be applied to assess the market.

[194] Golombek et al (1995).

[195] Golombek et al (1998).

demand side of the market is liberalized, each gas-producing country has an incentive to break up its gas sellers." The authors do, however, recognize several obstacles to such a development, among the most important of which are the possibilities of reductions in gas prices as well as in national profits.

In a recent paper, Ellis et al.[196] follow up on the above discussions and explore the effect on the market of three possible company strategies. They claim that the Gas Directive alone is insufficient to create a competitive market. Significant structural changes in the market depend on the strategic positions taken by the stakeholders, who may pursue the particular market structures that they prefer. Finally, an important point to note is that in all the above studies, ideal "third-party" access to transportation systems is assumed.

The question of how to introduce competing suppliers on the NCS — if competition should become a reality — is a very complex issue, indeed. One difficult question is whether or not a structure of competing suppliers on the NCS is compatible with the prevailing resource-management objective and the extent to which such an objective must be altered. A related question is how new licenses shall be awarded in a new regime.

Another legal question is who shall actually be the competing suppliers; shall they be, for example, the field licensing group as a whole versus other licensing groups, or shall it be based on a company level?

The above questions will not be perused any further here as they basically are legal questions subject for political decisions. The outcome of such questions will give rise to some other complex questions related to field-production planning and over/under lifting of gas in the fields. These questions will not be discussed either.

7.3.2.2 *Introduction of diversified gas sales contracts*

While existing Norwegian gas sales contracts may generally be characterized as offering bundled services,[197] new contracts might be expected to relax any "premium delivery" conditions and be much more diversified. Existing agreements typically provide buyers with a high degree of security in supply, gas quality, and flexibility in nominations over a long time period. New contracts, however, may seek to include fewer services, and buyers may consequently argue for a diversified pricing regime, as well. These assumptions are also discussed in Section 5.2.2 of WP No. 39 (1999–2000).

According to economic theory, diversification can be understood as

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[196] Ellis et al. (2000)
[197] See Section 7.4.2.11 on page 162.

"freedom to enter and independence of action." [198] New contracts typically specify different provisions for total contract duration (in terms ranging from days to years) and when deliveries shall start and stop (e.g., immediate deliveries, as in the spot market, [199] or future deliveries). New rules may be specified regarding the right to nominate how much variation is permitted in daily contract quantity (DCQ) and where the gas is to be delivered and re-delivered (the "hubs"). Finally, new requirements for the level of backup arrangements to be utilized, such as gas storage, regularity of support, modulation, hedging, and so on may be agreed to.

In Section 6 it is documented that the above assumptions are supported by experiences from North America.

7.3.2.3 Introduction of firm and interruptible transportation services

The existing transportation service generally features only one service, namely guaranteed transportation for all shippers.[200] A liberalized regime, to the contrary, would likely require significant diversification of the transportation services. Such a split of transportation services into new products is a core effect of the liberalization process as reflected in the Conclusion 7.1 through Conclusion 7.3 on page 125.

This observation is based on experiences from other regions. These lessons [201] tell us that the market may develop into different basic categories of services identified as: *non-interruptible service*, *interruptible service* and may be also *peak load service*. The first one is often also referred to as firm supply or firm capacity. A similar development is also partly suggested as relevant by the "The Brattle Group" (2000). [202]

This conclusion is also supported by economic theory because an efficient rationing will require all available capacity to be used if there is a willingness to pay the costs of being served. If available off-peak capacity is released at a lower toll than firm capacity some shippers will utilize this capacity – in theory. These are the shippers who have a lower willingness to pay for transport services than those requiring firm supply. One feasible major way to distinguish between transportation services and thus costs of transportation is by the level of security of supply.

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[198] Kahn (1988).

[199] Roeber (1996) indicates the importance of spot markets in the UK.

[200] So far, interruptible transportation agreements have been used only to a very limited extent and they are agreed case by case.

[201] See Section 6 and the experiences from TransCanada and Colombia Gas.

[202] See Table 1 page 15 of The Brattle Group (2000)

To sum up, the first test case requirement for future transport operations is thus rephrased as shown in Conclusion 7.8 of the summary of this sub-section, see page 131.

7.3.3 *Equal access to transportation systems*

In Section 6 a detailed assessment of the Gas Directive was conducted. The Norwegian view of the implementation process is to some extent discussed in White Paper no. 39. Section 5.3 of this White Paper refers to Article 23 of the Gas Directive and states that the scope or range of Article 23 needs to be further clarified. [203]

At least two outcomes or scenarios of such clarification can be suggested. In the first, the prevailing Norwegian regulatory regime continues to a large extent. The assumption is that an insignificant number of eligible customers and natural gas undertakings, other than the current ones, will request access to the dry gas system. In this scenario, domestic suppliers on the NCS will not compete. The current tariff and tolling system, therefore, is assumed to largely serve shippers' needs.

Some minor distortions, however, may occur of the type indicated in the discussion of Section 7.4.3. These distortions are caused by uneven ratios of a company's share of ownership in a given pipeline system versus its share of gas shipment in the same system. This may require some adjustments in tariff and tolling rules, as indicated in WP No. 39 (1999-2000), Sect. 2.1.1, but no major structural changes are envisaged.

The second outcome proposes a development discussed by Golombek et al. (1998) and Ellis et al. (2000) (in their "pull-the-plug scenario"), involving a radical liberalization, competing domestic suppliers, and access to the Norwegian dry gas system for any eligible customer and natural gas undertaking. In addition, all shippers ideally shall have access on equal terms to natural gas transportation, transmission, and distribution system services. Ellis et al. (2000) might serve as representatives for a large number of authors expressing this view.[204] They conclude, "competition is unlikely to emerge in supplies to end-users unless access is unrestricted to existing gas networks."

If we now finally turn to the experiences obtained from the assessment of the conditions in North America, "open access" to the transportation

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[203] The interpretation and translation of the WPs and the Gas Directive, offered here, represent the author's best understanding and summarization of the material; the adjudicated Norwegian text and the text of the Gas Directive, of course, supersede any statements made here. Brautaset et al. (pp. 36–40) offer some interpretations of the applicability of Article 23.

[204] Jensen (1992) also discusses the importance of "open access," as do the IEA studies.

systems is a recognized notion as was clarified in Section 6.3.2 on page 103.

This latter scenario is thus applied in this work as a research requirement. The work does not evaluate the extent to which this will be the outcome of the Norwegian political process, but the work shows that this development is realistic based on experiences from other regions and based on analytical discussions founded on economic theory.

To sum up, the second test case requirement for future transport operations based on the discussion above and also based on the revised effectiveness measures, see Conclusion 7.5 in sub-section 7.2.3, is thus rephrased as shown in Conclusion 7.9 below.

7.3.4 Summary

Two test cases are defined in the preceding text and they are based on the test cases suggested initially in the work. The hypothesis C.3 is therefore argued to be true. The test cases reflect that if the Gas Directive will have any impact on Norwegian dry gas transport operations at all, a development as identified here may be envisaged.

The two test cases are rephrased as follows:

Conclusion 7.8. Test case scenario one can now be written as follows: The dissertation shall analyze and suggest possible methods to include firm, interruptible and peak load transportation in addition to the existing ship or pay transportation agreements, taking into consideration the effect of an elastic demand for transportation services.

Conclusion 7.9. Test case scenario two can now be written as follows: The dissertation shall analyze and suggest possible means to incorporate equal access to the transportation system for all eligible customers and natural gas undertakings.

7.4   New economic methods and principles for future operations
7.4.1 The hypothesis C.4

In sub-section 7.4 hypothesis C.4 is tested stating that: *"It is possible to develop new economic methods and rules in order to fulfill the future economic requirements".*

In the *first* sub-section empirical data for the Norwegian natural gas transportation systems is analyzed by means of economic and technical theory. The purpose of this analysis is to derive some observations that may support the later discussions of how to design new tariff and toll regimes and organizational changes and so on. The empirical data and formulas are related

to economy of scale and scope, costs of investments and energy consumption, line packing and prevailing principles for gas pricing and gas quality.

The *second* sub-section contains an analytic discussion of the prevailing tolling regime and incentives for profit maximization and cost reductions. Several provisions are stated and some conclusions are drawn regarding the extent to which the prevailing regime will be feasible in a liberalized context.

In the *third* sub-section the different tariff and toll principles described in Section 3.4.5 are revisited and differentiated into some analytically preferred tolling rules. This sub-section discusses implementation of toll rules and conducts some analyses of different options. A number of theoretical and practical questions are assessed. Some examples are: how shall a toll base for tolling be established - shall old or new costs be considered, and is it a feasible approach to calculate the toll by means of a "postage-stamp" approach or is a toll based on the distances shipped a better solution?

7.4.2 *Analytical assessment of empirical information*
7.4.2.1 *Validation of economy of scale and scope*

The first bulk of empirical data analyzed here are used to evaluate *economies of scale.* The existence of economy of scale is an imperative economic fact. In order to support and document its validity some costs were calculated for five main Norwegian transportation pipelines. The data applied here are collected from MPE's publications [205] and they are tabulated in Table 5. The table presents some data for these pipelines, along with the ratio between investment and capacity over a typical licensing period. The licensing period is set equal to 20 years.

Economies of scale can be realized during investment and is defined as changes in cost with and equal proportional change in all input factors (the long-run average cost). In a nutshell, it is cheaper to build, operate, and maintain one large pipeline with a given capacity than two (or more) smaller pipelines with the same total capacity. According to the International Energy Agency (IEA), [206] "as a pipeline grows in capacity, its costs increase less than linearly while throughput increases exponentially." Bjørkvoll [207] concludes that a doubling in installed compressor effect and pipeline diameter quadruples pipeline capacity.

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[205] See Fact Sheet (1999)
[206] IEA Transportation Study (1994).
[207] Bjørkvoll (1994).

Table 5.   Some economic and technical data for five major pipelines

Pipeline	Start-up year	Dia. (in)	Length (km)	Annual Capacity (GSm^3)	Daily peak capacity [208] (MSm^3)	Invest-ment, 1999 money (GNOK)	Invest-ment/ capacity (NOK/ Sm^3)
Norpipe	1977	36	440	19.0	53.8	34.4	0.0905
Zeepipe	1993	40	814	12.0	34.0	15.3	0.0638
Europipe	1995	40	716 [209]	17.0	48.2	15.0	0.0441
Franpipe	1998	42	840	15.0	42.5	7.6	0.0253
Europipe II	1999	42	653	18.0	51.0	7.5	0.0208
Total			3463	81.0	229.5	79.8	
Average [210]							0.0493

As can be seen from the last column in the table above, the ratio of investment to capacity has fallen in price over the years. Some of the explanation is due to technological change, and some is attributed to economies of scale. A detailed assessment is not conducted here to determine the portion that is due to economy of scale.

A comparison of the ratio of steel volume to gas volume per unit length for two Norwegian pipelines, Statpipe (30") and Zeepipe (40") illustrates the latter. This comparison is made for locations at which the specified water depth and internal pressures are in the same range, approximately 100 m and 160 bars, respectively. The pipe wall thicknesses are 22.2 mm and 26.1 mm, [211] respectively and this causes the ratio to reduce from 0.1165 to 0.1028. In the IEA transportation study [212] similar conclusions are derived from a study of the US natural gas transportation industry where economies of scale were identified by calculating the pipeline construction costs/capacity for a number of pipeline projects.

Observation 7.17. There are significant conditions for economy of

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[208] Daily peak capacity = yearly capacity/(365 – M), for M equal to some small specified number of days the facility is shut down for scheduled maintenance.

[209] Including pipes on land. Source: Statoil.

[210] Weighted average, by volume

[211] Source: Statoil.

[212] See fig 3 of the IEA (1994) study

scale in Norwegian natural gas sub sea pipeline systems. One major reason for reduced investment costs is caused by the fact that the relative required volume of steel reduces as the diameter increases.

Observation 7.18. Any future development of such systems must seek to fully utilize these conditions in order to save investment costs.

Economy of scale can also be illustrated by calculating and comparing the required inlet pressures for different pipelines in order to transport the same amount of gas, with all parameters the same except for diameter. Equations (Eq. 3.3.1-3) of Section 3.3 will produce such results and as show in Figure 15. Here different inlet pressures are calculated for different pipeline diameters as shown, while pipeline length (800 km), delivery pressure (80 bar), and flow (25 MSm^3/day) all are kept constant. [213] All other parameters are as specified in Section 3.3. As can be seen a smaller pipe requires more compressor power than does a larger one, increasing variable operating costs unfavorably for smaller pipes.
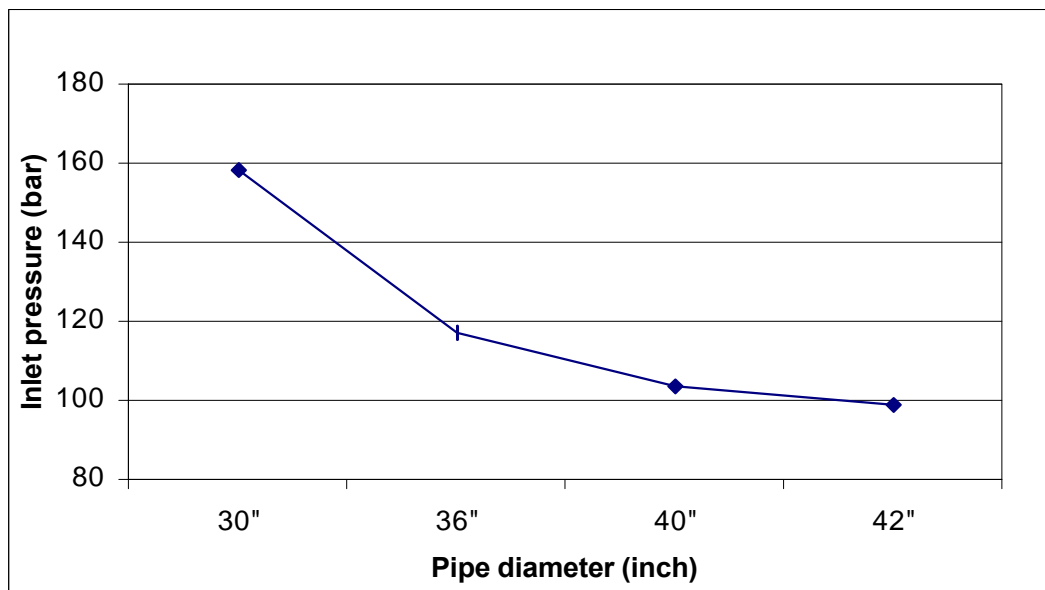

Figure 15.   Required inlet pressures for different pipes transporting same amount of gas and delivering at same pressures

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[213] In these calculations the compressibility factors and the friction factors were calculated for each case and the values ranged from 0,67- 0,68 for the *Z*-factors and from 0,0021-0,00199 for the *f*-factors.

Observation 7.19. There is economy of scale in operations as the variable cost reduces as the diameter increases.

Observation 7.20. Any new development of new capacity must take into considerations such effects.

A minor aspect of economies of scale is also present due to the nature of compressor work equations. At a constant throughput, the required incremental energy consumption increases less than linearly as delivery pressure increases.

Economy of scope occurs in transport operations when the same organization unit undertakes new task of different nature with less cost compared to the option of having another organization unit doing the task. A typical example [214] of this economic condition is to transfer as many tasks as possible from "day personnel" to "shift personnel" in a 24 hours operated control room. If we assume that this can be done without increasing the workforce in the control room the net effect is a reduction in total number of employees.

Statoil has utilized this possibility in their daily operations. Some few examples are transfer of planning NGL shipments, general planning and reporting activities, conduct of night-time security checks on the premises and so on.

The significance of economy of scope is probably difficult to calculate and quantify. The Statoil organization is currently handling approximately 90% of the Norwegian natural gas transport operations. Any calculations of potential benefits or losses due to economy of scope must be based on an assumption of a different organizational set-up on the NCS and no attempts are made here to stipulate such costs.

Observation 7.21. Economy of scope has been utilized in the industry and it can be achieved by having different operational task centralized into one organizational unit. If the liberalization process calls for re-organizing of the industry such conditions should be carefully assessed in order not to create unintentional adverse effects.

7.4.2.2 Investment costs

An important component of the tolling regime is the fixed cost, largely

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[214] Source: Author's experience

comprising irreversible costs but also some reversible costs. The fixed cost is derived from the investments and these investments are sunk costs as was described in Section 3.4. The following sub-section takes a closer look on these costs and it shows how to calculate annual coverage of such cost under given assumptions for the five chosen pipelines specified in Table 5. These discussions will provide valuable information later to be utilized when new toll regimes are discussed.

In the calculations presented here the irreversible fixed annual capital cost is calculated based on annual equivalent criterion calculations: [215]

$$FC_I = I_{pipe} * \left[\frac{i(1+i)^N}{(1+i)^N - 1} \right] * \left(Q \right)^{-1}$$

(Eq. 7.4.1)

Here,

FC_I is the annual fixed capital cost, NOK/ Sm^3
i is the real discount rate
N is number of periods, years
I_{pipe} is the net present value of the pipeline investment in 1999 money, NOK
Q is the annual throughput, Sm^3

A number of sources are applied here in order to assign appropriate values to the parameters specified in (Eq. 7.4.1). The first parameter assessed is the interest rate.

The interest rate is of course a quite essential parameter as its size is proportional with revenues for the pipeline owner. In a Norwegian context the rate is specified by means of the PAD licensing approvals. The rate has in recent years been limited to 7% *real* rate of return on capital invested before taxes as documented in Section 5.3.2.4. In North America the rate of return is typically between 12-14%. Many financial factors influence on the size of the rate of return figure such as whether it is to be understood as the net rate of return or not. Further, different aspects of risk exposure may influence on its size.

The next parameter assessed is the investment figures. These are derived from the Fact Sheet (1999) and they are tabulated in Table 5.

In a similar manner as how the rate of return is specified in licensing

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[215] See for example Park and Sharp-Bette (1990) page 204.

document is the number of years of the licensing period specified in the same document. In a Norwegian context this figure is typically ranging from 20 – 25 years. In North America the allowed depreciation period typically could last much longer, for example 40 years.

The last parameter to decide is the annual throughput. White Paper no. 39 (1999–2000) clarifies that the peak capacity in a Norwegian context is normally 110% of an annual contract quantity (ACQ). On average, customers nominate approximately 90% ACQ, according to the White Paper, which yields an 80% average annual utilization of the transportation system. The yearly throughput is thus simply specified as 80% of the pipelines' maximum capacities. The maximum capacities are specified in Table 5.

In Figure 16 different values of annual fixed and irreversible costs FC_I are calculated for different sets of parameters for the five pipelines chosen. As can be seen the choice of interest rates, and the licensing periods, or years for depreciation, significantly influence on the results. The pipeline utilization is fixed in all calculations at a level of 80% utilization.
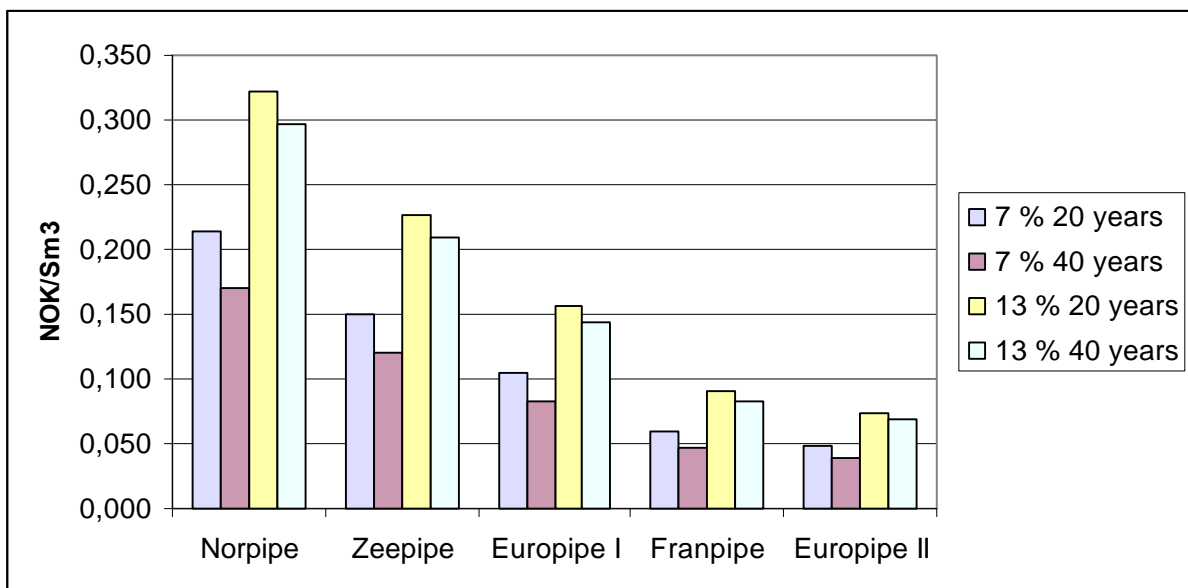
Figure 16. Annual fixed costs (FC_I) for different pipelines at 80% utilization

Based on the assessment above some few observations can be concluded:

Observation 7.22. The irreversible costs - as they appear for shippers in a Norwegian context – are significantly influenced by several

parameters being politically decided. These parameters are the regulated rate of return, the time period of depreciation or the licensing period and the level of utilization applied as the base load. In connection with liberalization and deregulation elsewhere, several of these parameters are brought up as objects for discussions between shippers, owners and regulators. The Norwegian rate of return is low compared to typical values applied in North America.

Observation 7.23. Due to the very fact that Norwegian authorities have published cost figures for the relevant pipeline system, the level of fixed costs are already fairly transparent to external observers.

Observation 7.24. The fixed cost comprises in the range of 88-90% of total average costs (see sub-section 7.4.2.6).

These irreversible costs contribute significantly to the declining short-run average cost as shown in Figure 17. Here Europipe I is taken as an example showing the FC_I at 7% interest rate and 20 years of depreciation. As average annual throughput increases the FC_I reduces accordingly, as there are more and more units of gas "to share" the costs.

Figure 17.   Declining irreversible costs in Europipe I

One main observation can be concluded:

Observation 7.25. Irreversible costs feature significant declining average costs as throughput increases and this fact ought to be taken

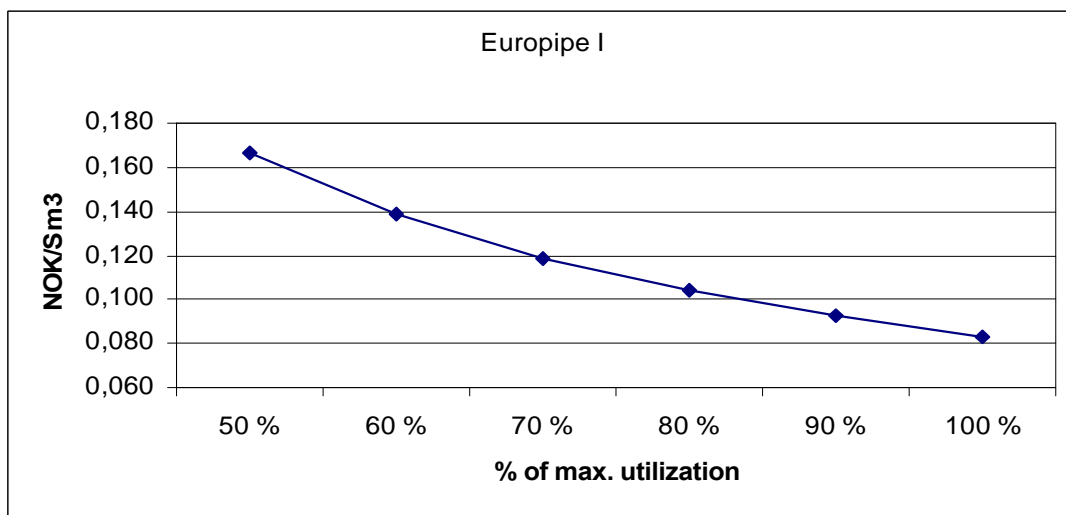into consideration in the incentive structure of a future toll regime. (The tariff and toll regime and regulatory incentive structures must be designed so that they enhance full and optimized utilization of the pipeline systems. See Section 7.4.4 where such issues are discussed).

7.4.2.3   Operational and maintenance costs

Operational and maintenance costs are *reversible costs* but they stay fixed for a limited short period of time, typically a budget year. In this sub-section these costs are looked into.

There are six categories of reversible short-run fixed costs and these are in sum noted FC_O. The unit is NOK/Sm^3. All these costs are related to operations and maintenance of the natural gas transportation systems. The total annual budget for year 2000 covering these costs for the Statoil operated systems is as a whole approximately 540 MNOK. [216] These costs are split into six categories as follows:

- 10% for dispatching, termed FC_d
- 25% for pipeline inspection and repair contingency, termed FC_i
- 20% for shore terminal operations, termed FC_t
- 25% for riser platform operations (two platforms), termed FC_p
- 10% for administration, corporate overhead, R&D funding, property tax, and the carbon dioxide emissions tax, termed FC_a
- 10% for insurance, termed FC_s

In mathematical terms the reversible fixed costs can be formulated as:

$$FC_O = FC_d + FC_i + FC_t + FC_p + FC_a + FC_s$$

Observation 7.26. As can be verified evidently from the figures displayed above, the current Statoil policy is to make the reversible cost figures transparent.

Observation 7.27. The reversible costs comprise in the range of 8-10% of total average costs (see sub-section 7.4.2.6).

The reversible costs are normally declining as throughput increases. If

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[216] Source: Statoil, year 2000 budget. Norpipe operation is not included in this figure.

we assume that approximately 51 GSm^3/yr will be transported in year 2000, [217] the FC_O yields a unit cost of 0.0106 NOK/Sm^3. If costs remain the same until year 2006, but the yearly throughput is increased to 72 GSm^3/yr, the FC_O will yield a unit cost of only 0.0075 NOK/Sm^3. Or in other words, if a constant return to scale is applied (producing a linear increase in costs), these total annual costs *(FC_O *Q)* will have increased by an annual incremental cost of approximately 224 MNOK in 2006.

In several of the cost categories listed above, declining average costs are present. In the first category, the *dispatching,* these conditions are observed if spare capacity is present and more work can be performed without increasing costs. The dispatching costs consist basically of manning costs and computer/software costs. Provided excess capacities exist in these recourses new additional tasks (but equal in nature) may be added on without increasing costs. The unit cost is thus decreasing for a given pipeline as throughput increases in the pipeline. But there is also declining average cost in the sense that the unit cost for dispatching of the total network decreases when new pipelines are taken into an existing organization's portfolio with no or only minor additional costs. [218]

Pipeline inspection and repair contingency programs are costly activities also exhibiting declining average costs. In order to inspect the pipelines internally, inspection tools are sent through the pipelines, and the gas streams power them. Such tools are often termed "intelligent inspection pigs". External pipeline inspections require survey by sophisticated subsea tools lowered into the sea from ships sailing the pipeline routes. It is obviously cheaper to inspect one large pipeline rather than several minor pipelines as the cost of inspection is linear with the pipeline length being inspected.

Further, the pipeline repair systems and contingency facilities (PRS) are designed to repair existing pipelines by means of divers and tools remotely controlled from a service ship. The repair equipment, tools and habitats are design to fit all existing pipeline sizes. If a new pipeline is put into operation and this pipeline has a size within the service range of the PRS the average repair contingency costs are declining. These conditions are caused by the fact

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[217] Annual flow data is taken from WP No. 39 (1999-2000), Sect. 5.

[218] Another related and similar issue is the learning effect in the organization. This effect makes the organization more effective over time, creating the possibilities to take on new tasks without increasing the costs linearly. One example derived from the author's experience may serve to illustrate the point. The dispatch and control center's training costs for commissioning of Zeepipe IIA (1996) was approximately 50 % of the training cost of Europipe (1995), which again was 50% of training costs for Zeepipe (1993).

that the average cost per pipeline length is decreased the more pipelines that are included in the scheme.

Platform- and terminal - operations and administration costs exhibit declining average costs by the same token as listed above. As long as there are excess capacities in these resources additional tasks can be included causing declining average costs.

A final and quite significant observation is that managerial discretion over the operations and maintenance costs is limited, as a majority of the tasks performed are required by statutory documents. In a Canadian context, the management typically has less than a 50% influence in such matters, according to Mansell and Church (1995). This figure is probably applicable to a Norwegian context, as well. This observation supports the author's view as previously expressed in Section 3.4.4, namely that dynamic and allocative efficiency is achieved basically during the planning and development stages of a pipeline system, and not during the operational stage.

Observation 7.28. There are declining average costs in the reversible costs due to the centralized organizational set-up of the transport operations.

7.4.2.4 Variable cost

The next cost element assessed here is *variable cost* and it is termed *VC(Q,P)*. Its numerical size is basically dependent on throughput, delivery pressures and fuel costs. Theories of fluidmechanics and thermodynamics are applied in order to calculate this cost. In the proceeding text the required compressor power is calculated for transporting gas in a pipeline system. In order to illustrate and validate the calculations data from the Kollsnes plant and Zeepipe IIB are applied.

Several major parameters influence on the variable costs. The three most interesting ones to be studied here are the throughput (or mass flow of gas through the compressor), the compressor suction- and exit- pressures and the fuel costs. In order to assess these relationships the equations in Section 3.3 are applied and empirical data is applied in the analyses.

In the following example three flow rates are chosen; $Q_{100} = 100$ MSm^3/d, $Q_{70} = 70$ MSm^3/d, and $Q_{56} = 56$ MSm^3/d. These figures represents approximately full export capacity from the Kollsnes plant,[219] maximum flow in Zeepipe IIB and 80% flow in Zeepipe IIB, respectively.

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[219] Source: Fact Sheet (1999) section 17 specifies Kollsnes; max. capacity at 100 MSm^3/d.

In order to calculate the compressor power, the compressor's suction pressure and delivery pressures must be defined. These values are assumed to be, *Ps* = 76 bar and *P₁* = 120 to 186 bar, respectively. [220] Based on (Eq. 3.3.6) through (Eq. 3.3.9) the theoretical compressor power requirements are calculated for different outlet pressures and the results are shown in the Figure 18 below.
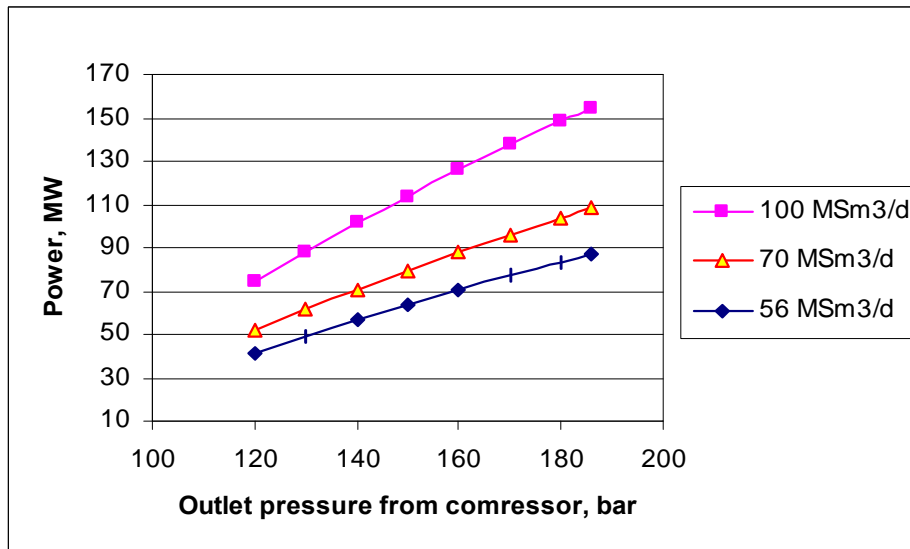
Figure 18.   *Theoretical compressor power*

At full capacity i.e. at a flow of 100 MSm³/d and at an outlet pressure of 186 bar from the compressor the power requirement is approximately 154,7 MW. This figure corresponds well with actual values. [221]

The last step here is to calculate the variable costs as a function of the fuel consumption. The compressor drives can either be electrical motors, which is the case at Kollsnes or they can be gas-fired turbines. The fuel costs are thus dependent on the type of drives that is installed. Further, in the case of gas fired turbines the fuel costs are dependent on the location of the installation, being either offshore or onshore. In the case of an offshore installation the owners must pay a carbon dioxide tax on each cubic meter of gas burned, while this is not required for onshore installations. Taking such considerations into the analyses, the following costs for electricity and fuel gas

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[220] Source: Statoil

[221] At Kollsnes, 5 electrical driven compressor packages are installed. Each compressor package delivers 25 MSm³/d and requires 38 MW at maximum capacity. The total power requirement is thus 4*38= 152 which is some few percentage lower than the figures calculated in this example. Source Statoil.

are stipulated:

> Onshore el-costs: $c_{el} = 2928$ NOK/MWday $= 12,2$ øre/kWh [222]
> Offshore gas fuel costs: $c_{gt} = 0,85$ NOK/Sm³ [223]
> Onshore gas fuel costs: $c_{gt} = 0,60$ NOK/Sm³ [224]

The variable costs for compressing gas into the pipeline for the three different fuel cost alternatives can thus be found by multiplying the fuel costs with the power requirements calculated for the drives according to (Eq. 3.3.10) and (Eq. 3.3.11). This will yield the following equations:

$$VC_{el} = c_{el} * \frac{\dot{W}}{h_{el}}$$
(Eq. 7.4.2)

$$VC_{gt} = c_{gt} * \frac{24 * 60 * 60}{GCV_{fuel} * h_{gt}} * \dot{W}$$
(Eq. 7.4.3)

Here, the terms have the following meaning:

> VC_{el} is the variable cost based on electricity, NOK/d
> VC_{gt} is the variable cost based on fuel gas, NOK/d
> GCV_{fuel} is the heating value of the gas, assumed to be $40*10^6$ J/Sm³

The variable costs for transporting a maximum flow of 70 MSm³/d in Zeepipe IIB is shown in Figure 19, calculated for the three fuel alternatives as listed above. The variable costs for delivering gas at a flow rate of 70 MSm³/d, at the outlet pressure of 186 bar is 0,602 MNOK/d if we use the carbon tax as fuel cost (equal to the offshore fuel cost of 0,85 NOK/Sm³). The figure is reduced to 0,425 MNOK/d if we use the sales gas price as the cost of fuel (assumed here to be 0,60 NOK/Sm³).

Another way of expressing these costs is to compare the variable costs with the revenues from gas sales. If we, for example, assume an offshore

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[222] In the report NOU 1998: 11 "Energi- og kraftbalansen i Norge mot 2020", issued by MPE, at page 97, table 7.8, the value of electricity in the Norwegian market for large industrial purposes is specified at: 12,2 øre/kWh. Actual values may likely be somewhat higher from time to time.
[223] According to the Petroleum Law
[224] The fuel cost is set equal to the gas price as applied in this work, see Section 7.4.2.10.

installation and a corresponding carbon tax as the fuel cost, the total revenue of selling 70 MSm^3/d will yield 42 MNOK/d while the *VC* will yield 0,6 MNOK/d or approximately 1,4 % of the gas sales value.

As a note here it can be mentioned that according to the rules laid down in the prevailing regime and transportation agreements the fuel gas is provided "free of charge" by the shippers. Any inclusion of cost of fuel gas consumption is thus not included in the tariff formula.

VC in Zeepipe IIB at maximum flow of 70 MSm3/d
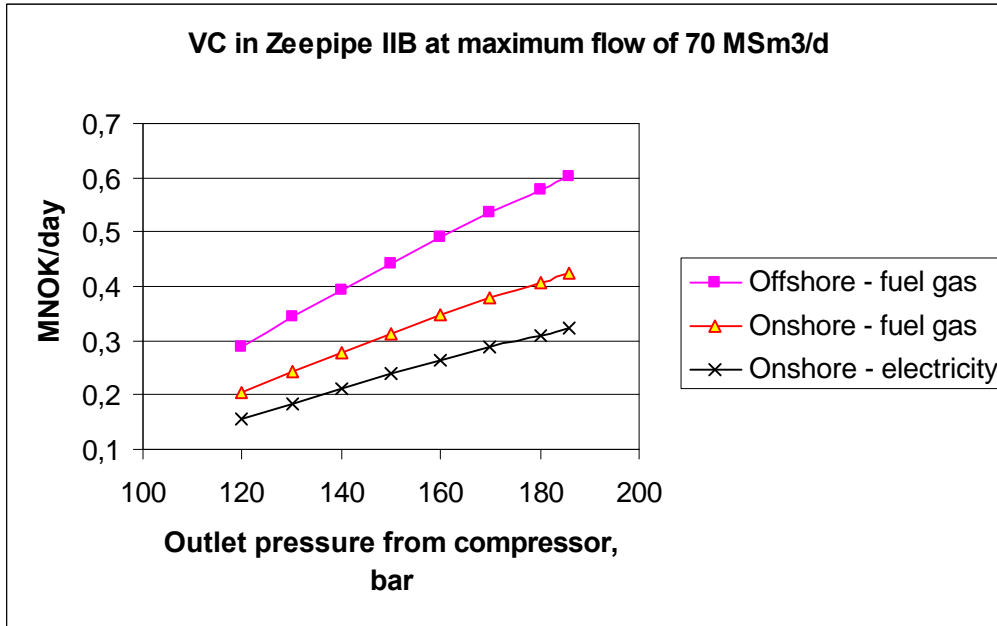
Figure 19.   Theoretical VC for transporting gas in Zeepipe IIB

Observation 7.29. The variable costs are large in absolute terms, but small in relative terms as they comprise typically less than 3,8 % of total average costs (see sub-section 7.4.2.6). As many of the compressor drives are gas fired, there will always be incentives to reduce the fuel gas consumption due to environmental and economic reasons. These facts are considered in later analyses of the work.

For the sake of completeness and for use in the next sub-section the equations (Eq. 7.4.2) and (Eq. 7.4.3) can be written as shown below.

$$VC_{el} = c_{el} * \frac{\dot{m}}{h_{el} * h} * \frac{c}{c-1} * \frac{RTZ}{M} * 10^{-6} \left[\left(\frac{P_1}{P_s} \right)^{\frac{c-1}{c}} - 1 \right] \qquad \text{(Eq. 7.4.4)}$$

$$VC_{gt} = c_{gt} * \frac{\dot{m}}{GCV_{fuel} * h_{gt} * h} * \frac{c}{c-1} * \frac{RTZ}{M} * 8,64 * 10^{-2} \left[\left(\frac{P_1}{P_s} \right)^{\frac{c-1}{c}} - 1 \right]$$

(Eq. 7.4.5)

7.4.2.5 Short-run marginal cost and average variable cost

Marginal cost pricing constitutes an important base case for tolling and it gives proper incentives for optimal usage of the system (provided there is sufficient capacity). Economic literature often refers to marginal cost pricing as the first best solution, see Section 3.4.5.3 on page 46. In order therefore better to understand how the marginal cost function behaves and how to quantify and assess its numerical values as flow rates and pressures changes, some formulas for marginal costs are developed below.

Marginal costs in the short run, when no new capacity is being developed, can be found from the partial derivatives of the compressor cost functions (Eq. 7.4.4) and (Eq. 7.4.5) with respect to flow and pressure. All other cost elements being parts of the total cost function are treated as fixed costs and they contribute nothing to marginal costs.

Marginal costs are often referred to as short run or long run marginal costs. In order to specify the difference between "short run" and "long run" some few definitions are suggested here. The short run period is defined to be a time period where no new investments are done and this period may typically be thought of as one year.

The long run may be understood as the licensing period or alternatively the systems technical lifetime. A long run perspective may thus typically be 20-25 years or even 50 years. During this period of time new investment or unexpected maintenance and repair may occur.

The last unit of time to be suggested here is the time span of 1 "time unit" set equal to 24 hours. This time frame is equal to the time it takes to deliver the lowest level of a transportation service to a customer. The lowest time unit is defined as the "gas day" according to the provisions of the prevailing transportation agreements.[225]

In order to calculate numerical marginal cost values the short run marginal cost can be approximated as the incremental cost defined as the costs of increasing the flow by 1 Sm^3 and simultaneously increasing the pressure by 1 bar from any given delivery condition. These definitions thus constitute the lowest level of a transportation service provided. The lowest level of an

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[225] In later years hourly delivery rates are becoming common, but this is not included here.

incremental transportation service is thus a flow of 1 Sm^3 of dry gas with a delivery pressure of 1 bar during a time period of 1 day. [226]

As can be seen from the equation (Eq. 7.4.4) and (Eq. 7.4.5) above, the variable compressor costs are dependent both on the compressor delivery pressure as well as the mass flow assuming that all other parameters are kept constant. The short run marginal cost and average variable costs can be calculated by either keeping the mass flow constant and calculating the cost for changing the delivery pressures or by keeping the outlet pressure constant and calculating the marginal cost for changing the mass flow. This will give the following two pares of short run marginal costs and short run average variable costs: [227]

$$SRMC_{gtp} = \left. \frac{\partial VC_{gt}(\dot{m}, P_1)}{\partial P_1} \right|_{\dot{m}=const.}$$

(Eq. 7.4.6)

$$SRMC_{gtm} = \left. \frac{\partial VC_{gt}(\dot{m}, P_1)}{\partial \dot{m}} \right|_{P_1=const.}$$

(Eq. 7.4.7)

$$SRAC_{gtp} = \left. \frac{VC_{gt}(\dot{m}, P_1)}{P_1 - P_s} \right|_{\dot{m}=const.} \qquad P_1 > P_S$$

(Eq. 7.4.8)

$$SRAC_{gtm} = \left. \frac{VC_{gt}(\dot{m}, P_1)}{\dot{m}} \right|_{P_1=const.}$$

(Eq. 7.4.9)

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[226] In the USA's gas industry, the lowest production unit is defined as 1 Dth/day = $1*10^6$ Btu/day = 1055 MJ/day = 0,293 MWhr/day = 12,21 KW = 26,38 Sm^3/day. (1 Sm^3/d yields 40 MJ/day). Source: Columbia Gas verbal information and Christensen (1998) appendix 6 and Katz (1990) page 707.

[227] In this case the gas turbine cost function is chosen. The following considerations will remain the same if the electrical motor cost function had been chosen instead.

Constant pressure, changing mass flow

The short run average (variable) costs and the short run marginal costs (per day) can be found by partial derivation of equations (Eq. 7.4.7) and (Eq. 7.4.9), which can be written:

$$SRMC_{gtm} = \frac{\partial \left(A * \dot{m} \right)}{\partial \dot{m}} = A$$

$$SRAC_{gtm} = \frac{A * \dot{m}}{\dot{m}} = A$$

Here A has the following term:

$$A = c_{gt} * \frac{8{,}64 * 10^{-2}}{GCV_{fuel} * h_{gt} * h} * \frac{c}{c-1} * \frac{RTZ}{M} \left[\left(\frac{P_1}{P_s} \right)^{\frac{c-1}{c}} - 1 \right] \qquad \text{(Eq. 7.4.10)}$$

In Figure 20 below A-values are calculated for different values of pressures, $P_1 = \{120,186\}$ and the fuel cost is set equal to the carbon dioxide tax at 0,85 NOK/Sm³. In the figure the A-values are plotted on the "y-axis" and the values have been converted into units of øre/Sm³ (rather than øre/kg).
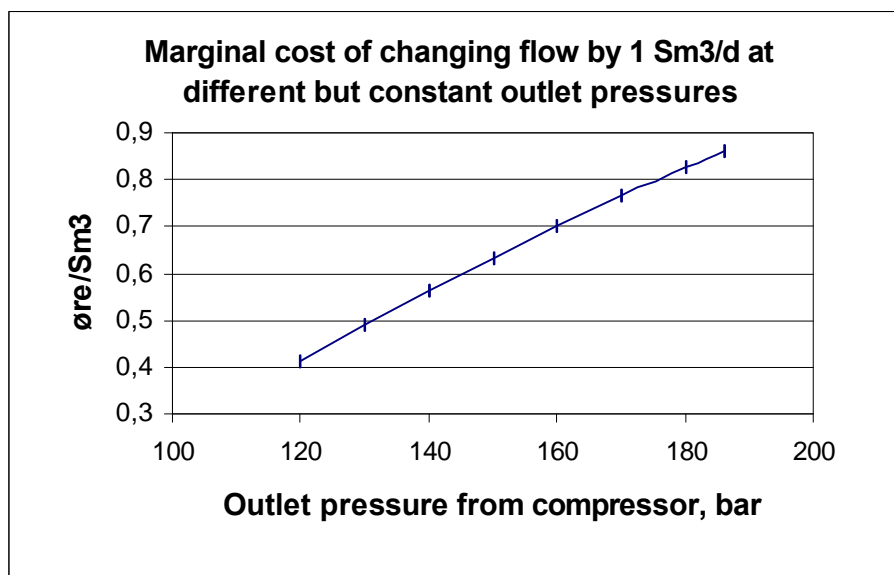
Figure 20.   Marginal cost of increasing flow at constant outlet pressures.

In these equations, *A* (øre/kg) is a constant for each choice of P_1 and the marginal cost and the average costs are constant for all values of the throughput. This conclusion simply means that the variable costs are proportional to the mass flow at a constant delivery pressure. Further, $SRAC_{gtm}$ = $SRMC_{gtm}$ = *A*, which means that the variable cost function exhibits constant return to scale. [228]

Constant mass flow, changing pressure

The next step in the analysis is to develop formulas for marginal and average variable costs in the case where the mass flow is kept constant but the pressure is changing. Equations (Eq. 7.4.6) and (Eq. 7.4.8) can be written accordingly:

$$SRMC_{gtp} = \frac{\partial}{\partial P_1}\left(B\left[\left(\frac{P_1}{P_s}\right)^{\frac{c-1}{c}} - 1 \right] \right) = \frac{B\left(\frac{c-1}{c}\right)}{P_S^{\frac{c-1}{c}}} * P_1^{\frac{-1}{c}} \qquad \text{(Eq. 7.4.11)}$$

$$SRAC_{gtp} = \frac{B*\left[\left(\frac{P_1}{P_s}\right)^{\frac{c-1}{c}} - 1 \right]}{P_1 - P_s} \qquad P_1 > P_S \qquad \text{(Eq. 7.4.12)}$$

Here B is a constant as follows:

$$B = c_{gt} * \frac{8,64*10^{-2}*\dot{m}}{GCV_{fuel}*h_{gt}*h} * \frac{c}{c-1} * \frac{RTZ}{M}$$

The values of $SRAC_{gtp}$ and $SRMC_{gtp}$ are calculated and shown in Figure 21 for a constant flow of 1 Sm^3/d.

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[228] See Nicholsen (199) page 357
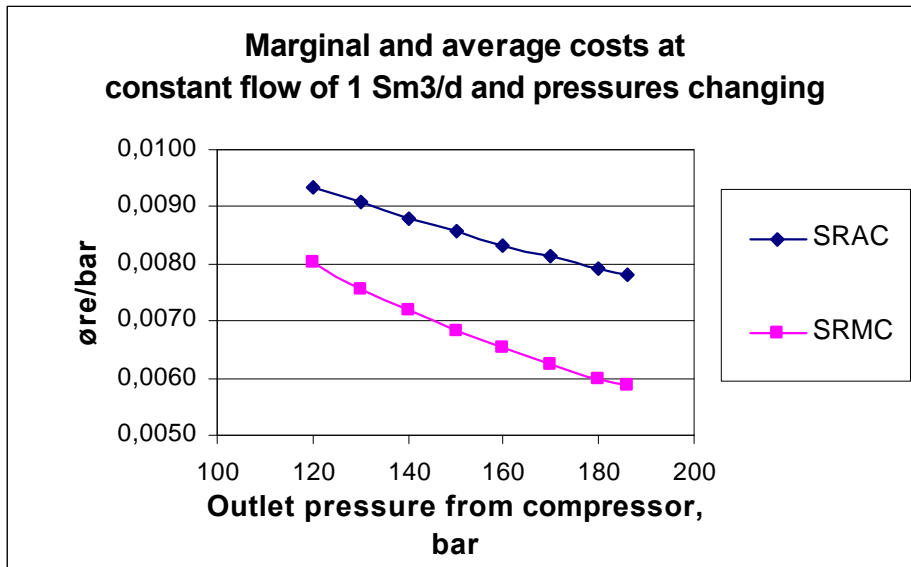
Figure 21. SRMC and SRAC for compressor at constant flow

The total marginal cost function can now be found by considering both these contributions as shown below:

$$SRMC_{gt} = \left. \frac{\partial VC_{gt}(\dot{m}, P_1)}{\partial \dot{m}} \right|_{P_1 = const.} + \left. \frac{\partial VC_{gt}(\dot{m}, P_1)}{\partial P_1} \right|_{\dot{m} = const.} \quad \text{(Eq. 7.4.13)}$$

$$SRMC_{gt} = A + \frac{B\left(\dfrac{c-1}{c}\right)}{P_S^{\frac{c-1}{c}}} * P_1^{\frac{-1}{c}} \quad \text{(Eq. 7.4.14)}$$

The equation (Eq. 7.4.14) will thus give the total marginal cost (or incremental cost) of increasing the flow and pressure with one unit equal to 1 Sm^3 and 1 bar per day from any given output condition. Figure 22 illustrates this situation by reference to the Kollsnes plant and the numerical example chosen is calculated as incremental costs at full capacity.

In Figure 22 the two incremental contributions are calculated and combined. At an output of 100 MSm^3/d it costs 0,86094 øre to increase the flow with 1 Sm^3/d at constant delivery pressure. This situation is illustrated by moving from point 1 vertically up to point 2 in the figure. This cost element is the same as illustrated in Figure 20. The next contribution is the incremental

cost by increasing the outlet pressure by 1 bar calculated to yield 0,00585 øre/Sm^3. This situation is illustrated as moving from point 2 to point 3 in the figure – also illustrated separately in Figure 21. The total marginal cost is thus the sum of these two contributions yielding 0,86679 øre/bar/Sm^3.
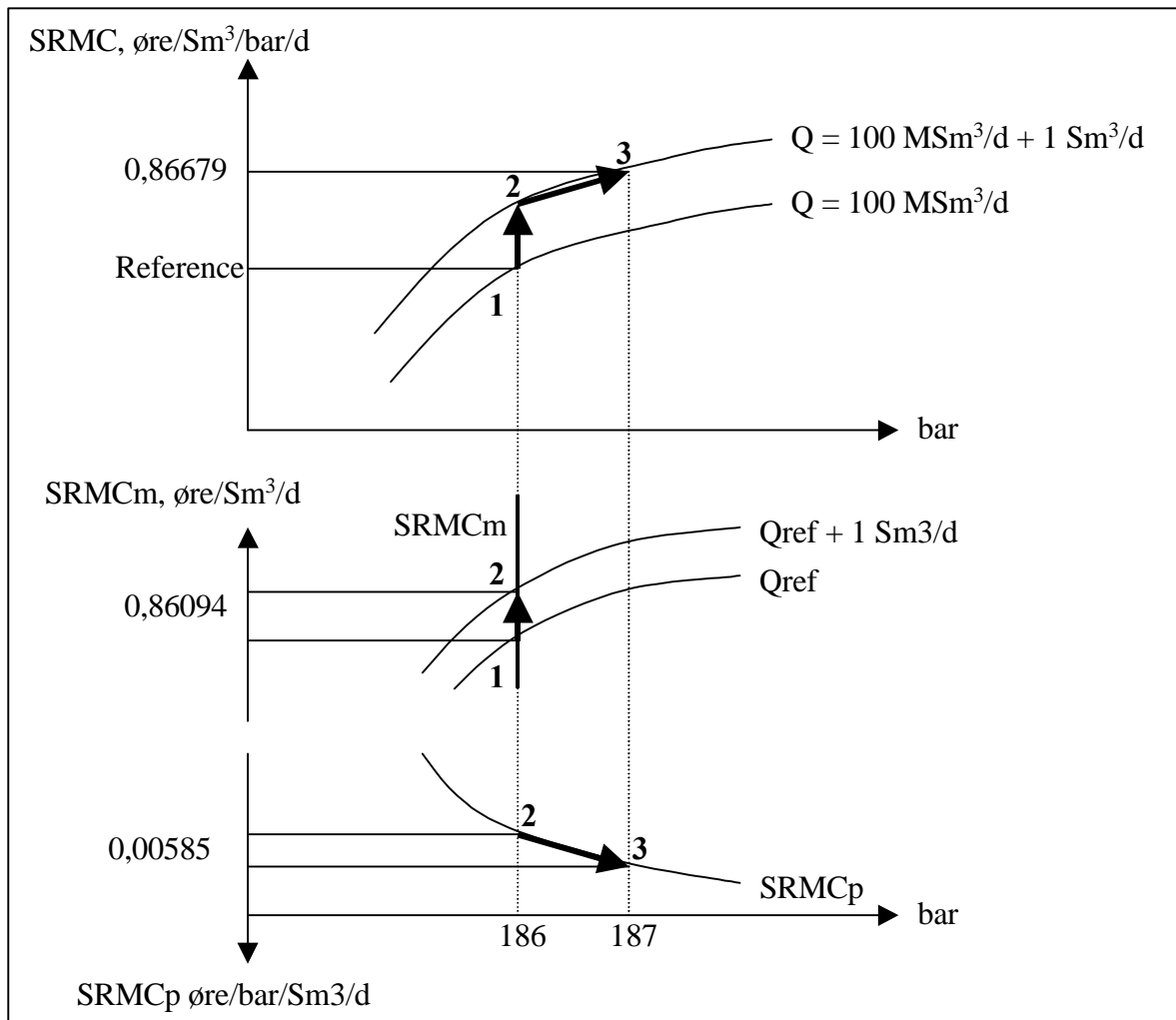
Figure 22.   Total incremental cost

These results of course are equal to the differences in *VC* between the two operating modes. The same incremental values are obtained directly from equation (Eq. 7.4.5) and as shown by principles in Figure 19, by first calculating the *VC (100 MSm^3/d + 1 Sm^3/d, 186 bar)* minus *VC (100 MSm^3/d, 186 bar)* which represents the step from point 1 to point 2. This will yield the numerical values in øre: 86.094.236,58160 - 86.094.235,72066 = 0,86094 (as calculated above). Then the *VC (100 MSm^3/d + 1 Sm^3/d, 187 bar) - VC (100 MSm^3/d + 1 Sm^3/d, 186 bar)* is calculated, representing the move from point 2

to point 3. The result is divided by the total flow in order to find the incremental cost per unit of flow. This will yield the following results: (86.679.222,35850 - 86.094.236,58160)/100.000.001= 0,00585 øre/bar/Sm^3 (yielding once again the same result as above).

The following three observations are suggested based on the analyses above:

Observation 7.30. The short run marginal cost comprises less than approximately 3,8 % of total average costs. This figure is based on 100% utilization. At 80% utilization the short run marginal cost is approximately 2,2 % of total average costs.

Observation 7.31. The short run marginal cost is dependent on the flow rates, the outlet pressures and the fuel costs. These parameters are all constantly changing.

Observation 7.32. The marginal cost is different from system to system, albeit these differences are small.

7.4.2.6 Total and average costs

Average cost is defined as the total cost of gas transportation divided by the volume of gas being transported. If we for simplicity disregard pressure as a variable parameter but treat it as a constant, the total cost of transportation will comprise the following cost elements:

- Irreversible costs due to investments, termed FC_I [229]
- Reversible costs due to operation and maintenance, termed FC_O [229]
- Variable cost due to fuel consumption, termed $VC(Q)$

In mathematical terms the total cost function can be expressed in a general form as follows by applying the notations as defined in this work. The unit is in NOK (per year):

$$TC(Q) = (FC_I + FC_O + VC(Q))*Q \qquad \text{(Eq. 7.4.15)}$$

The average costs can thus simply be expressed as follows and with a

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[229] Note that fixed cost strictly considered, also dependans on the volume as a given annual throughput volume is specified in order to calculate the fixed costs.

unit of NOK/Sm^3 (per year):

$$AC(Q) = FC_I + FC_O + VC(Q) \qquad\qquad \text{(Eq. 7.4.16)}$$

In the preceding text all the cost elements that are included in the total and average cost functions have been discussed and quantified and they can now be combined to show average costs for selected pipeline systems. The pipelines presented here are the five pipelines listed in Table 5. For each pipeline three sets of cost elements are calculated. Please also note that the level of maximum capacity for each pipeline is derived from the Fact Sheet (1999) and as tabulated in Table 5. [230]

In Figure 23 below the costs are compiled and shown for each of the pipelines assessed.

Cost elements at 80% utilizaton
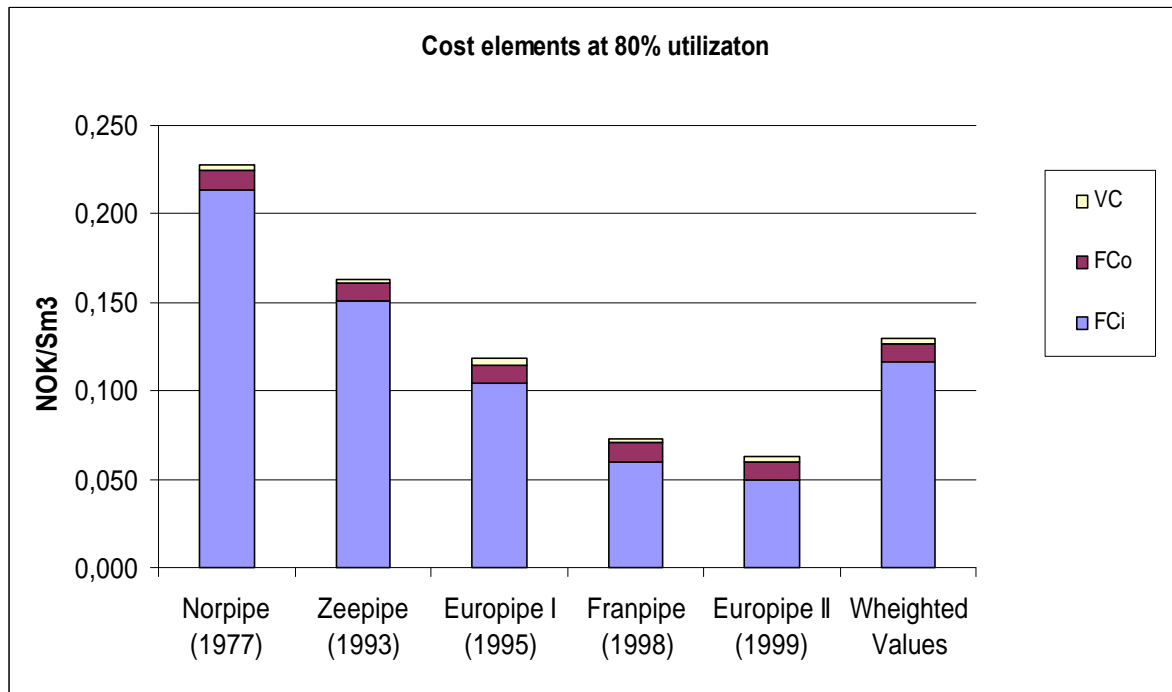
Figure 23. ***Indication of costs for five Norwegian pipelines*** [231]

Several calculations had to be carried out in order to establish the

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[230] The exact maximum transportation capacity for a given pipeline is dependent on a number of factors and the capacity may thus vary from one operational mode to another. The figures that are stated in Table 5 might thus be somewhat different from those applied elsewhere in this work.

[231] The "weighted values" are based on the volumes shipped in the different pipeline systems.

variable costs shown in the figure above. For each pipeline the required input pressure is calculated so that the corresponding compressor's outlet pressure can be established. The pipeline's outlet pressures are all set at the lowest values possible based on contractual requirements. Further, the pipeline inlet pressures are calculated here at an 80% utilization level. In order to do these calculations the Wheymouth's equation (Eq. 3.3.1) is applied. Having calculated all required outlet pressures from the compressor the variable costs are calculated for each case.

A few points about the Figure 23 are worthy of note. The FC_I element is calculated based on an interest rate of 7% before taxes and with a licensing period of 20 years. Further, if the FC_I element were calculated based on a 100% load factor, the capital cost would be reduced accordingly as was illustrated in Figure 17. A 100% load factor would result in a 20% reduction in the capital costs, yielding a weighted average capital cost element of 0.093 NOK/Sm^3 rather than 0.116 NOK/Sm^3.

Thirdly, the FC_O are spread equally across all pipeline systems. This is a simplification and minor error, since operational costs of Norpipe are not included in the FC_O. Should they be included FC_O would be somewhat higher.

Finally, the VC calculated here are based on 80% load factor. If a higher load factor applies, these costs will, of course, be somewhat higher. The VC element as given in Figure 23 above is, as it is defined, equal to the average variable cost. According to equation (Eq. 7.4.10) the average variable cost is equal to the short-run marginal cost when we keep the pressure constant (i.e. the gas is delivered at a constant pressure). In other words, short-run marginal costs are 2.2 % or less of *average costs*, considering the dry gas system as a whole.

> *Observation 7.33.* Total average costs are differently spread among the different pipelines primarily due to different historic investment costs. The above analyses still give a fairly adequate overview of the total costs of transportation and these figures may add valuable information to be utilized later when different toll regimes are discussed and analyzed.

7.4.2.7 Cost and revenues from "Linepack"

In order to get an indication of the linepack volumes that are available for storage in the pipeline system, an example is provided below. This is due to the assumption that in a liberalized regime such gas volumes may play a role in connection with gas spot sales and the like.

In the example to follow, the calculations are based on the Zeepipe system and we assume that the gas deliveries are requested at a rate of 80 % of maximum pipeline capacity. It is also assumed that the gas is delivered to the customers at the minimum contractual delivery pressure. Given this situation, the pipeline has a capacity to store some additional gas. The limiting factor for how much gas that can be stored is the maximum inlet pressure of the pipeline. These conditions are illustrated in Figure 39 of Appendix 11.7.5, see page 282.

Three questions must be answered. First how much additional gas can be stored in the pipeline? Secondly, how much does it cost to inject the additional volume of gas into the pipeline, and thirdly how much value does this gas represent if sold?

Size of linepack volume. The first question assessed is the size of the linepack volume. Again the Weymouth's equation is applied to calculate the inlet pressures and outlet pressures for the different operational modes shown in Figure 39 of Appendix 11.7.5. The results are shown in Table 6 below. [232]

Table 6.   Flow, inlet and outlet pressures at different operational modes

Mode	Flow rates, MSm^3/day	Inlet pressures, bar	Outlet pressures, bar
Maximum allowable flow	$Q = 34$	$P_{1,max} = 122$ [233]	$P_{2,min} = 80$
80 % flow, no linepack	$Q = 27,2$	$P_1 = 108$	$P_{2,min} = 80$
80 % flow, max linepack	$Q = 27,2$	$P_{1,max} = 122$	$P_2 = 98$

For each of the two latter operational modes, *80% flow, max linepack* and *80% flow, no linepack*, the corresponding pipeline inventory at standard conditions are calculated according to equations (Eq. 3.3.4) and (Eq. 3.3.5). These volumes yield 105,3 MSm^3 and 90,0 MSm^3, respectively and the linepack volume available is thus: 105,3 – 90,0 = 15,3 MSm^3.

Cost of storing. The additional volume of gas to be stored is thus 15,3 MSm^3/d. The maximum rate available for injecting additional gas is 6,8

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[232] Please note that linepack volumes as calculated here are theoretically values based on an assumption of a *steady state flow* condition. In the real world there will normally be *transients* that will affect on the usefulness of the linepack volume and the rate of withdrawal and injection, see Dahl (1998-B)

[233] In reality the actual maximum allowable pressure is higher. The listed maximum flow in the Fact Sheet (1999) is lower than actual value.

$MSm^3/d = (34,0 - 27,2 \ MSm^3/d)$. By this rate of injection 2,25 days are needed in order to inject 15,3 MSm^3.

Further the variable cost of increasing the inlet pressure from the original mode (108 bar, 27,2 MSm^3/d) to the required maximum allowable inlet pressure and flow (122 bar, 34 MSm^3/d) [234] is calculated by means of the variable cost function (Eq. 7.4.5). These costs are 84,9 kNOK/d and 145,5 kNOK/d, respectively. The incremental cost is thus 60,6 kNOK/d which will yield a total cost of (60,6*2,25) = 136,4 kNOK. In these calculations we have assumed a cost of fuel equal the CO_2 tax, and all other parameters are as specified earlier in the work.

Revenues of selling linepack gas. The linepack volume of 15.3 MSm^3 equals 56 % of a full gas day delivery. At a delivery rate of 27,2 MSm^3/d the linepack volume equals thus a "survival time" of approximately 13,5 hours. The pipeline can "supply" gas delivery to a customer for these hours in case a full curtailment in gas production should occur. The economic value of the linepack volume is 9,18 MNOK, assuming a gas border delivery price of 0.6 NOK/Sm^3. In other words, an investment in additional variable costs of 0,136 MNOK will potentially yield additional revenue of 9,18 MNOK.

Another way of visualizing the attractiveness of linepack is the fact that it will pay off to hold the linepack stored in the line for as much as approximately 290 days before a potential gas sale takes place! [235]

Observation 7.34. One important observation to be made here is the assumption that, in liberalized regime, the transportation system operator will seek to store linepack to a larger extent than what is common today, especially if spot sales become a normal event. Even though the linepack volumes are small in sizes they are inexpensive to obtain and they have the potential of significant gains. They also represent an inexpensive tool to optimize daily operations.

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[234] In the calculations performed here a constant pipeline pressure of 122 bar is applied. The actual pipeline inlet pressure (equal to the compressor exit pressure) will however increase over time as the linepack volume increases. The results presented here will thus give somewhat too high energy consumption. This effect is neglected here.

[235] The daily compressor costs at the conditions (flow: 27,2; pressure 108) and (flow: 27,2; pressure: 122) are 84,9 kNOK and 116,4 kNOK respectively, yielding a daily incremental cost of 31,5 kNOK. It will take 290 days before the accumulated incremental costs are rising above the sales figure of 9,18 MNOK.

7.4.2.8 *Linepack, energy consumption and variable cost reductions.*

In Section 3.3.4 the author suggested a technical efficiency criteria for measuring the level of efficient utilization of the pipeline system from an energy consumption point of view. The notion here is that an efficient operation seeks to deliver the gas flow through the pipeline systems at the lowest consumption of fuel gas possible. In order to measure such conditions an efficiency criterion was designed as expressed in equation (Eq. 3.3.12) stating that $h_{tech} = Q_{SC} / \dot{W}$.

The *higher* the value of h_{tech} is, the more efficient the operation is. We immediately see that if the operator increases the linepack the efficiency will be reduced, as flow remains constant, but power increases. This fact visualizes one of the many trade-offs to be done in daily operation. The use of linepack may prove to be quite attractive from an economic point of view as it may increase the revenues significantly, but its usage on the other hand requires more energy consumption. The latter is contradicting the efficiency measure expressed in the reasonable and prudent effectiveness measure which specifies energy conservation, see Section 5.4.3.

Finally, a last question is at what throughput level is the operation most energy efficient? In the proceeding text a numerical example is provided to answer this question. In Table 7 below different values of h_{tech} is listed against the throughput, required outlet pressures from the compressors and the power requirements. In the numerical example Zeepipe is applied and in all of the calculations the compressor suction pressures are set constant at 76 bar and the pipeline delivery pressures are set constant at 80 bar.

Table 7. Power requirements, pressure and flow

Flow in pipeline, MSm^3/d	3,4	6,8	10,2	13,6	17	20,4	23,8	27,2	30,6
Outlet pressure from compressor, bar	80,5	82,1	94,5	88,0	92,1	96,9	102,3	108,2	114,5
Power consumption, MW	0,3	0,8	1,7	3,1	5,1	7,8	11,2	15,3	20,2
"Quasi" efficiency, h_{tech} Sm^3/Wd	*11,4*	*8,4*	*6,1*	*4,4*	*3,3*	*2,6*	*2,1*	*1,8*	*1,5*

This little exercise shows a trivial conclusion; namely that the most energy optimal operation is "not to transport gas at all". Based on this purely theoretical approach the results indicate that transportation of natural gas becomes more and more energy inefficient the higher the flow is. In reality there are several other conditions that influence on this result to some extent. One important factor is the design of the compressors and the compressor characteristics and utilization curves. The compressors may be designed for example to work most efficiently at a high level of utilization.

Several observations of a general nature can be suggested here based on the result in Table 7 above.

Observation 7.35. If there is a possibility to reduce the flow, energy consumption will be reduced accordingly.

Observation 7.36. Energy efficiency is generally improved if flow is equalized as much as possible in the different pipelines, assuming that the pipelines and compressors have the same configuration and design.

In the Norwegian natural gas transportation systems there are some few pipeline systems that can be utilized as alternative transportation routes - to some extent - in order to ship gas between the same entry and exit locations especially at lower rates of total utilization of the total system. These are some of the pipelines to Germany and the two pipelines from Kollsens.

To illustrate the Observation 7.36 a numerical example is provided. In this example we apply the data from Table 7 and we assume that a total flow of 34 MSm^3/d shall be shipped between the two points. We assume that there are two alternative routes comprising two equal pipelines with physical characteristics as Zeepipe between the entry and exit points. If the flow is split at a ratio of 90/10 % between the two pipelines the total power requirement would be 20,2 + 0.3 = 20,5 MW (equal to the flow of 30,6 + 3,4, respectively). If the flow is split at a ration of 50/50 the total power requirement would have been 5,1 + 5,1 = 10,2 MW which is only 49 % of the power requirement of the former option.

This latter conclusion thus leads to a subsequent argument namely:

Observation 7.37. To the extent the organization setup of the operations may affect this issue, a coordinated operation may be preferable. This is a valid argument provided the organization has been given a mandate to conduct such overall physical transport optimization.

This topic may be quite essential when it comes to optimizing spare capacity – a topic to be discussed in Section 7.5.

7.4.2.9 Transaction costs

A well-defined and quantitative understanding of the level of *transaction costs* is considered to be important in relation to discussing liberalization in utility industries. [236] In a traditional regime a high degree of vertical integration is typically present and one positive effect of integration, according to Teece (1990), may be the low transaction costs. If the industry liberalizes, segregation of services into independent entities may be required as discussed earlier in the work. This will often increase transaction costs. Some authors like the IEA (1994) study report and Teece (1990) point to this fact, also saying that little research is available identifying how these transaction costs increase as integration splits up.

The political judgement often concludes that increased transaction costs are accepted in order to obtain reduced costs elsewhere. It is believed that such cost reductions will exceed the increments in transaction costs. Some authors believe that the total effect of gas-to-gas competition increases welfare, even though some parts of the industry experience increased costs. A related argument is that equal access to transportation services may enhance competition between suppliers causing ultimately enhanced competitive power on the NCS. [237]

The Norwegian dry gas transport operation's transaction costs may be defined to consist of the sum of *administration costs and dispatching costs*. Transaction costs may also be defined to include *costs related to negotiating* sales-, transportation- and upstream agreements. The former of these costs is included in the *VC*-element as defined in this work. As can be seen from Figure 23 these costs are fairly low in the current regime in relative terms and the irreversible costs will remain to play the most dominant cost element in the future as well.

As there are presently a number of uncertainties related a future Norwegian organization of transport operations no further work is done here in order to stipulate future transaction costs, except for offering some few observations collected from the assessment activities.

The first observation is simply a recognition of the fact that much of the transaction costs are caused directly by the choice of a regulatory regime, and these costs are thus to a large extent independent or outside managerial

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[236] Teece (1990), IEA (1994)

[237] This argument is listed in St. prp. nr 36 (2000-2001) page 13.

influence of the transportation system operator. [238] This leads to the following observation:

> *Observation 7.38.* The regulatory body must carefully evaluate how different regulatory regimes result in different levels of transaction costs.

Secondly, if the current vertically integrated transport operations are segregated into an independent transportation company (as suggested by the Norwegian St. prp. 36 (2000-2001)) increased transactional costs may probably occur due to increased costs of knowledge and information transfer between different organizational units. If the prevailing integrated organizational structure is broken up into two or more independent business units, the author assumes that other and more expensive and cumbersome routines for technology and information transfer will arise. Some few prominent examples of efficient interdepartmental knowledge transfer in Statoil are:

- transfer of knowledge between transport operations and engineering support
- transfer of technical gas composition data from daily gas operations into pipeline inspection program development
- transfer of operational experiences into transport and project development
- transfer of operational experiences into field allocation recommendations and gas sales assignment recommendations (FU)
- transfer of operational experiences into negotiations of agreements (upstream-, transport- and sales- agreements (GFU)).

Based on these observations the following observation is suggested by the author:

> *Observation 7.39.* The author is of the opinion that transfer of information as listed above will inevitably be more cumbersome and more costly in a liberalized context due to several reasons.

These reasons are firstly that much of the information above is

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[238] Kolbe et al.(1993) examine the risk of different regulatory principles

considered to be proprietary. If this information shall be released to external shippers that are not pipeline system owners, a much closer filtering of information is called for to prevent release of proprietary information. Secondly, the information must be free from all kinds of contractually related information. This will once again call for a screening of information to a more detailed extent.

7.4.2.10 *Prevailing Norwegian toll regime*

Little information has been published about tolls in Norwegian dry gas transportation systems. [239] Brottemsmo et al. (1993) [240] refer to some average costs applicable to Statpipe and Europipe I, but offer no detailed breakdown of the toll structure. They do indicate a toll in the range of 0.10–0.39 NOK/Sm^3, and predict the toll for Europipe to be approximately 0.13 NOK/Sm^3 at a load factor of 75% utilization. Bjerkholt et al. (1990) refer to the transportation cost for Norwegian gas as being in the range of 0.044–0.435 NOK/Sm^3. [241] Golombek et al. (1998) indicate a toll to Germany of 0.20 NOK/Sm^3. [242]

Transportation agreements specify the transportation toll formula. Nielsen [243] offers a description of the formula, and a general outline is also provided in the IEA transportation study. The formula typically takes the following form:

$$T_{xn} = C * I_{pipe} * E_n * Q_{xsn} + \frac{O_n}{Q_n} * Q_{xn} \qquad \text{(Eq. 7.4.17)}$$

$$t_{xn} = (C * I_{pipe} * E_n) + (\frac{O_n}{Q_n}) \qquad \text{(Eq. 7.4.18)}$$

Here, the terms have the following meaning:

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[239] Such data is specified in stakeholders' transportation agreements.

[240] Brottemsmo et al. (1993); see Table 2.3. The costs are based on annual operating costs and an annualized total investment cost at a 7% real discount rate.

[241] Bjerkholt and Gjelsvik (1992) in Table 7 specify costs in the range 0.14–1.38 USD/MBtu. 1 USD = 8 NOK, 1 Btu = 1.055 KJ, and 1 Sm^3 = 40 MJ.

[242] Golombek et al. (1998, Table 1) specify costs for offshore gas transportation to Germany equal to 3.75 USD per 100 km per TOE. 1 TOE = 42300 MJ, 1 USD = 8 NOK, 1 Sm^3 = 40 MJ. In the above example, Europipe is applied at a length of 716 km.

[243] Nielsen (1999), p. 109. The information provided here is basically taken from this reference.

n is year n,

x is shipper x,

T_{xn} total tariff for year n for shipper x (NOK/yr),

t_{xn} unit tariff for year n for shipper x (NOK/ Sm^3/yr),

C capital cost element ($1/Sm^3$),

I_{pipe} Investment (NOK) in the pipeline system,

E_n escalation factor for year n,

O_n total operating cost for year n (NOK),

Q_n total quantity transported for year n (Sm^3/yr),

Q_{xn} actual quantity transported for shipper x for year n (Sm^3/yr),

Q_{xsn} the higher of the actual quantity transported or the ship-or-pay (SOP) quantity for shipper x for year n (Sm^3/yr).

The capital cost element, FC_I shown in Figure 23 equals the term $C*I_{pipe}*E_n$ (assuming $E_n = 1$), and the O_n/Q_n equals the term FC_O. The *VC(Q)* for fuel gas consumption is not part of the toll formula and is set equal to zero. The gas consumption is measured and treated as loss. A number of observations can be concluded based on the characteristics of this particular toll formula and the formula's inherent tolling characteristics: [244]

Observation 7.40. The formula secures the pipeline recovery of all costs plus a given rate of return.

Observation 7.41. The formula gives a constant tariff over time (provided throughput is according to plan).

Observation 7.42. The formula secures the transport owner against reduced throughput by means of the SOP provision.

Observation 7.43. The toll formula may offer incentives to increase throughput if shippers are favored with rebates on additional volumes, essentially passing on to them the declining average costs benefit.

Observation 7.44. The prevailing toll formula may be characterized as a combined "rate of return regulation" and an "average cost pricing formula", even though the ship-or-pay requirement may act as a booking charge element and thus indicating that the formula may look like a two-part toll. The function of the formula however is to be

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[244] See IEA (1994), pp. 139–140.

considered basically as an average cost pricing mechanism.

For a more detail discussion of the prevailing toll formula see Section 7.4.4.4 on page 201. The shippers also pay for the variable operational costs, i.e. the fuel gas as they supply the gas "in kind" and pro-rate their volumes shipped. A rebate or refund system is in force based on an annual post calculation of all revenues. As the pipeline's return is regulated excess revenues from tolls are transferred back to the initial shippers (i.e. the firm shippers).

7.4.2.11 Prevailing gas pricing principles and delivery conditions

The gas price is calculated based on a netback market value pricing formula, linked to the price of other alternative energy sources, as for example oil products. The IEA distribution study of 1998 discusses this pricing mechanism. Austvik (1997) provides an overview of these matters as well. [245] In Figure 24 below the netback market value pricing principles are shown.

The price formula is specified in the sales agreements. Brautaset et al.[246] give a description of this formula and a typical gas price formula in a Norwegian gas sales contract reads:

$$P = P_0 + 0{,}6 \, (AE1 - AE1_0) * EK_{AE1} * 0{,}85 \qquad \text{(Eq. 7.4.19)}$$
$$+ \, 0{,}4 \, (AE2 - AE2_0) * EK_{AE2} * 0{,}90$$

Here the above terms have the following interpretation: P is the gas price, P_0 is an agreed initial basis gas price, $(AE1 - AE1_0)$ is actual minus historic price of an alternative energy source, and $(AE2 - AE2_0)$ is actual minus the historic price of another alternative energy source. EK_{AE1} and EK_{AE2} represent energy conversion factors. The gas price is calculated based on the current prices of the alternative energy sources. There is a typical time lag of 3 to 5 months of the gas price adjustment. The gas price is subject to re-negotiations every three to five years, according to Brautaset et al.

Figure 25 illustrates these relationships in a conceptual manner.

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[245] IEA distribution study (1998), see page 76, figure 4. See also Austvik (1997) page 1001-1004

[246] See Brautaset et al. (1999) page 250

Figure 24.   Netback market value pricing
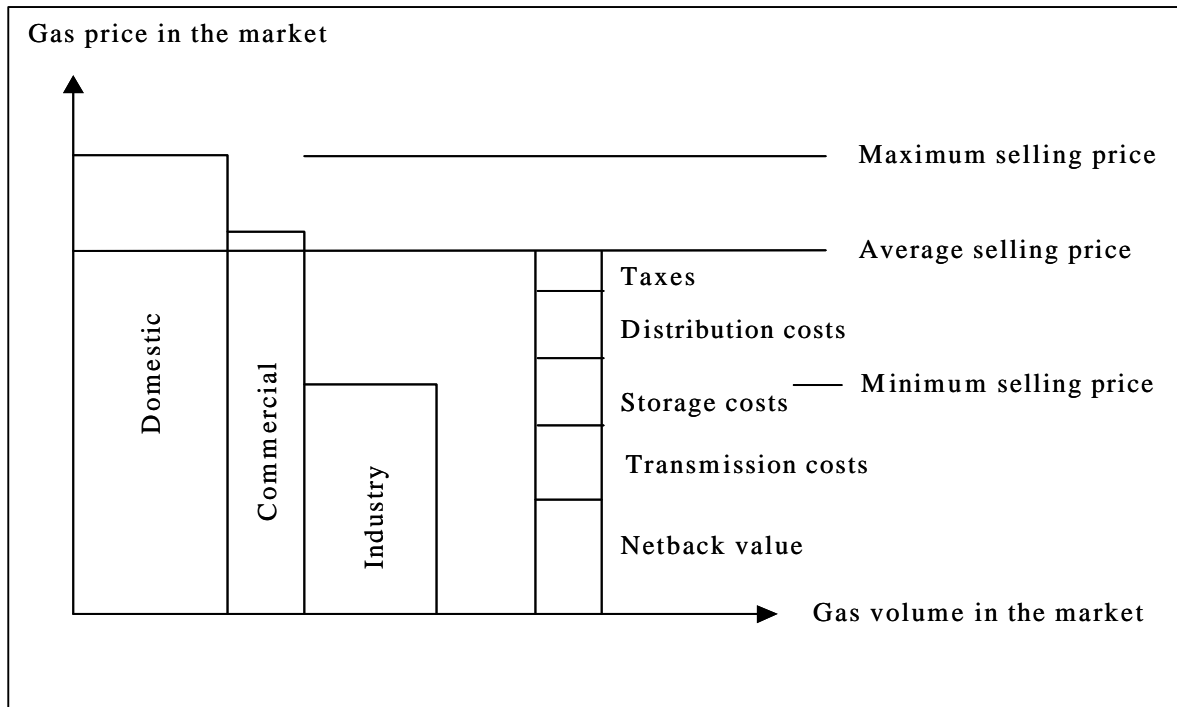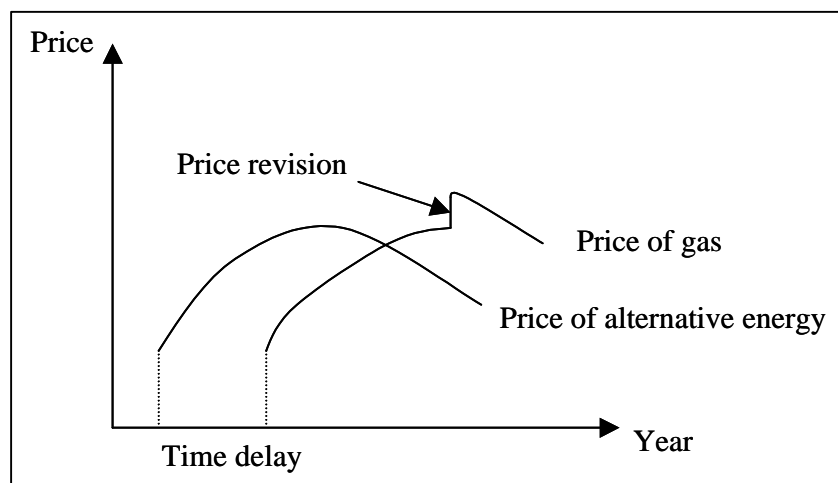

Figure 25.   Gas pricing principles

No further review of the prevailing gas pricing principles is given here except for specifying some main observations noteworthy in relation to the research conducted:

Observation 7.45. As a result of GFU negotiations and signing of gas sales contracts, gas prices are fixed for given periods of time, typically three to five years.

During the "fixed price" periods, the gas price may fluctuate, since it is linked to the price of alternative energies, usually oil; from a practical point of view, however, the gas price is exogenously given in the short run. Prices remain those specified in gas contracts, regardless of the gas quantity taken by buyers under normal delivery conditions. [247] There are no ways to utilize the pricing regime established by a contract after it has been signed to discriminate between customers or markets, or to exercise market power. There are also no means for buyers to obtain rebates or reduced prices in periods of excess production capacity or the like.

> *Observation 7.46.* Negotiated long-term "take-or-pay" (TOP) gas sales contracts constitute the backbone of gas transportation system development and much field development, as well. Take-or-pay contracts and ship-or-pay (SOP) provisions in transportation agreements have established a measure of risk sharing between stakeholders that insures pipeline owners against high risks. [248]

Finally, the gas sales agreements specify the gas price and no stakeholders publish these prices. However, some indicative figures are available in the literature. Stern, for example, quotes some border prices for six different European countries for the year 1996. In Germany, for example, a border price of approximately 1,35 Pf/kWh or 0,62 NOK/Sm^3 is listed, [249] and the end user prices for domestic households are 4,62 Pf/kWh (equal to 19 øre/kWh) or 2,12 NOK/Sm^3. The domestic price is thus 3,4 times the border price. The quoted German figures were also specified in the same range in a Norwegian newspaper "Dagens Næringsliv" on Nov 7, 1997. The information was based on released data from the German Ministry of Commerce and "Bundesverband der deutschen Gaswirtschaft". [250]

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[247] Special provisions cover unexpected events such as curtailment and "force majeure."

[248] This paper does not discuss or analyze how to optimize risk sharing between the stakeholders.

[249] Stern (1998) page 75, table 3.13. In the conversion calculations above, the following rates are applied: 100 DEM = 413 NOK and 1 Sm^3 yields 40 MJ.

[250] Two other examples are: "Finansavisen", Jan 22 1997, in which Statoil President P. Mellbye indicates that 6 Gm^3/year over a 25 years period was sold for approximately 90 GNOK. Assuming equal and average deliveries for 25 years, the average price is thus 0.60 NOK/m^3. According to "Aftenposten", Jan. 6, 1997 the Statoil transportation system operator indicates that the daily value of approximately 100 MSm^3/day is 65 MNOK/day, giving a gas price of 0.65 NOK/Sm^3.

7.4.2.12 The Norwegian bundled and merchant gas sales services

The bundled service offered by the TOP contracts is a product of complex relationships and interactions between stakeholders. In order to understand how the final gas sales product is achieved an analysis of the different stakeholder roles is presented below. In Figure 1 on page 5 some of these relationships are illustrated.

The *production field owners* are owners of all hydrocarbons produced in the field, according the production license. In order to sell the gas or store the gas, agreements have to be made to this effect. These agreements are the agreements identified earlier in Section 5 and they comprise the upstream agreements, the supply agreements, the contractual gas sales agreements and the gas sales agreements negotiated by GFU. Based on these agreements, the companies became *gas owners* and they need to enter into transportation agreements with the transport system owner, in order to transport the gas. The gas owners now act as *shippers.*

The transportation system owner receives the shippers' gas at a given location, handles and transports the gas to a given delivery point, and re-delivers the gas to the shipper. If this redelivery takes place at the shore terminals the shippers acts as *sellers.* The seller sells the gas to the buyers according to the conditions specified in the sales agreement entered into by GFU.

Some observations can be concluded here:

Observation 7.47. In the current regime there are close relationships between the production fields, gas owners, gas shippers and gas sellers. These relationships are all regulated by a large number of agreements. These agreements are largely proprietary and the arrangements are largely non-transparent.

Observation 7.48. An organizational segregation of any of these stakeholder positions (for example like the one suggested by St. prp. 36 (2000-2001)) will inevitably cause that several of the agreements must be renegotiated or revised. An overview how liberalization impacts the documents is indicated Section 7.6.

One essential issue in the context of this work is the vertically integrated pipeline ownership structure combined with the gas sales function. Many companies are simultaneously owners in the production facilities as

well as the transportation facilities, [251] and they own the gas. As indicated in Figure 1, a specific company's revenue is thus the aggregated revenue obtained from oil, NGL including heavier petroleum products and dry gas sales. As the companies normally also are transportation system owners, they receive tariffs (as system owners), but at the same time they also pay tariffs (as shippers).

> *Observation 7.49.* In a Norwegian context the majority of gas shippers simultaneously act as gas transportation system owners. This is a quite special regulatory regime that according to the knowledge of the author is not the case anywhere in North America. Due to this specialty some distinct incentives for cost efficiency and rationing efficiency are established. The magnitude of the incentives is quite dependent on the individual company's specific share of ownership versus shipper share in a particular pipeline. These relationships must be further analyzed in the proceeding work. [252]

Owners of gas enter into transportation agreements with transportation system owners and thereby become shippers. Such agreements are negotiated and entered into, in many cases, "internally" within a given company. This is due to the fact that the same company is often the owner of the gas (and thus, represents the shipper) as well as owner of the transportation system (and thus, represents the system owner with whom the shipper must negotiate).

> *Observation 7.50.* The prevailing transportation agreements differ somewhat from traditional agreements in the legal sense. Normally the parties are independent and have different interests while the parties' interests often are coinciding in said agreements. This fact is discussed and commented upon by Nielsen (1999, see page 6). A potential segregation of stakeholder roles may alter these relationships and agreements significantly.

> *Observation 7.51.* In connection with the St. prp. 36 (2000-2001), which suggests a segregation of transport operations into an independent company, the legal validity of the transportation

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[251] Fact Sheet (1999)

[252] A long lasting debate has been the debate on finding the right owner share versus the shipper shares in a given pipeline in order to create right incentive for economic efficiency. This topic is discussed in Section 7.4.3.

agreements and incorporated documents must be assessed.

Observation 7.52. The transportation system itself never owns any gas; the gas is always the property of the shippers.

7.4.2.13 *Regularity in gas deliveries and daily utilization of the systems.*

The delivery goal is set to 100% regularity in gas deliveries to customers as was pointed out in the effectiveness measures. The regularity is calculated as aggregated daily regularity. The daily regularity is defined as the actual delivery figure divided by the gas buyer's specified nomination figure. In Table 8 below, the regularity figures for the period 1991 – 1999 are shown.[253] Based on these figures some few observations are concluded.

Observation 7.53. The coordinated planning and development of facilities and systems, together with centralized system operations, have resulted in very high delivery and quality regularity over the years — typically close to 100%.

Table 8.   Annual regularity and utilization in Norwegian dry gas systems

Regularity and (Utilization)	1991	1992	1993	1994	1995	1996	1997	1998	1999
Statpipe/ Norpipe	99.2	93.8	97.7	99.6	100 (85)	99.8 (85)	99.7 (87)	99,96 (71)	100 (52)
Zeepipe			100	100	100 (48)	99.99 (70)	100 (80)	100 (82)	100 (69)
Europipe I						100 (54)	100 (77)	99,99 (73)	100 (92)
FranPipe								100 (50)	100 (59)

Vastly diverse agreements are developed to secure individual and mutual needs for gas storage, modulation, regularity support, and swap and supply arrangements. These are the agreements assessed in Section 5 of this work. One observation may be suggested here:

Observation 7.54. The stakeholders - at least to some extent - enjoy many economic benefits caused by a vertically integrated industry

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[253] Source: Statoil

ultimately resulting in high delivery results, as noted by Teece. [254] Such benefits, or economic efficiencies, are related to capital utilization; aggregation economics; transactional, informational, and operational efficiencies; and credible supply commitments. The difficult question is to what extent these benefits will be adversely affected by liberalization. As this is largely a political question no further work is done here to assess the question.

The utilization of the systems has varied largely over the years as shown in Table 8. In some periods the utilization has been low and this fact contributes to the high regularity. The system is highly utilized during the winter periods and curtailments in deliveries, if they occur, usually come during these periods.

A major reason for the general low utilization of some systems is explained by the fact that the overall system capacity has been increased regularly over the years to meet an ever-increasing demand. The capacity is increased in steps as the Figure 26 below illustrates.[255] Figure 26 shows the level of annual throughput (the line drawn) versus the aggregated transportation systems' capacity for the time period 1992 through 2003.
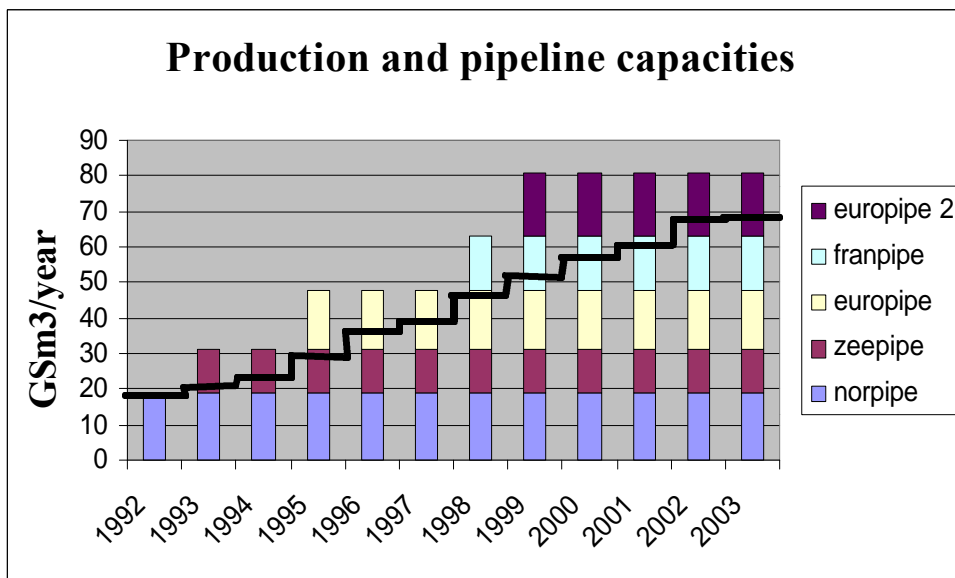

Figure 26.   Yearly production and pipeline capacities

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[254] Teece (1990).

[255] Source: Pipeline capacities: Fact Sheet (1999), Production curve: Statoil (See Appendix 11.1)

One observation can be concluded:

Observation 7.55. The utilization of the systems will increase in the years to come as full delivery commitments are approaching. This will result in a more stringent operation. The need for offering interruptible supplies may be found advantageous in order to utilize the systems at a high level, rather than offering firm capacity and thus limit the transportation to a lower level of average annual utilization.

7.4.2.14 Gas requests, oil and NGL production.

An interesting consideration is to identify the sensitivity of oil, condensate and NGL production from the NCS, versus fluctuation in dry gas nominations. If one considers the dry gas system as defined in this work, the gas customers' nominations will be aggregated as delivery instructions at the four entry locations shown in the architecture model, see Figure 9 of Section 5 on page 86. A brief overview of the sensitivity of reduced dry gas requests on oil and NGL production is displayed in Table 9 below, aggregated to the four entry locations.[256]

As can be seen from the Table 9 the current system is fairly robust against reductions in dry gas requests with regards to the oil production. The condensate and NGL production is a direct function of the rich gas production, and it will be reduced linearly with reduced dry gas nominations. Broadly speaking, the total revenues gained from the selling NGL as a separate product is approximately 150% the revenues of selling NGL as blended into the commingled dry gas stream.

Observation 7.56. A high production of dry gas out of the treatment terminals is always an attractive objective, as any reduced dry gas deliveries will reduce NGL production almost linearly.

Another observation, visualized in Table 9 is the fact that the sensitivities of oil cuts due to declining dry gas nominations are differently spread between the four locations. This fact causes challenges for negotiators, production planners, and day-to-day operations, in order to optimize the total production on the NCS, especially during periods of (extremely) low buyers

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[256] Source: Statoil. The data is based on year 2005 forecasts. Please note that these figures are of an indicative nature only and that changes occur continually. The data is dependent on issues such as different operational modes, injections modes and new facilities put on stream.

nominations or system interruptions. A last observation is thus concluded:

> *Observation 7.57.* In order to optimize simultaneously the dry gas operations and oil, condensate and NGL production, an integrated operation is imperative. This observation supports the view that only one transport organization unit must be in charge covering all transportation systems.

Table 9.   *Effects of reduced dry gas requests on oil and NGL production*

Four locations where dry gas enters into the dry gas system	*Request, q_n, for gas delivery at this location (% DCQ) [257], [258]*	*Reduced oil and condensate production at the location and/or aggregated losses on production units upstream the location*	*Reduced NGL production at the location and/or aggregated losses on production units upstream the location*
Kårstø	*$A < q_n < 110$* *$q_n < A$*	*No effect* *Oil and condensate production reduces*	*Linear effect* *Linear effect*
Kollsnes	*$B < q_n < 110$* *$q_n < B$*	*No effect* *Oil and condensate production reduces*	*Linear effect* *Linear effect*
Sleipner	*$C < q_n < 110$* *$q_n < C$*	*No effect* *Condensate production reduces*	*Linear effect* *Linear effect*
Oseberg/ Heimdal	*$D < q_n < 110$* *$q_n < D$*	*No effect* *Oil production reduces*	*Linear effect* *Linear effect*

7.4.2.15 Gas quality

An important and a last issue analyzed here is "gas quality". The gas quality issue has its root in some basic facts. First, the different fields deliver gas with different gas heating value. Secondly, the gas production at the fields may contain H_2S and CO_2 from time to time.

The gas sales contracts specify limits for contamination as well as

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[257] Daily contract quantity (DCQ)

[258] The parameters A, B, C and D are proprietary information. The values are all fairly low.

ranges of acceptable heating values. This range is subject to nominations according to specified rules.

Experience has shown that the gas quality issue requires close daily operational attention and the Transportation System Operator must always keep the blending of gas aspect in mind.

In order to illustrate the magnitude of this task, an example is provided below. Two different fields are considered and the heating values from the fields, termed A and B are assumed to be:

$$GCV_A = 38,7 \text{ MJ/Sm}^3$$
$$GCV_B = 42,4 \text{ MJ/Sm}^3$$

If we assume that field A delivers 40 MSm^3/d and field B delivers 20 MSm^3/d, the commingled gas stream will have a heating value of (40*38,7 + 20*42,2)/60 = 39,9 MJ/Sm^3. We may assume for example, that the allowable range is $\pm$2% deviation from the mean value. The acceptable range of heating values will thus be 39,1 - 40,7 MJ/Sm^3. Given this constraint a production curtailment at field B of approximately 75% can be accepted. But if field A's production is reduced more than 56%, the field B production must be held back, in order to prevent off-specification gas.

Two observations can summarize this issue:

Observation 7.58. In daily operations the transportation system operator must blend the different gas streams into commingled gas streams so that the gas delivered to customers meets sales specification. This task requires an integrated operation and once again, an efficient organizational set-up is to have only one operator conduction the work.

Observation 7.59. To blend gas correctly may from time to time be a challenging task for the operator and it may introduce significant constraints on operations. From a conceptual and an analytical point of view however, the task is fairly strait forward and this issue is thus not treated any further in this research.

7.4.2.16 Summary of this sub-section

Based on the observations listed in the preceding text some main conclusions can be synthesized and suggested here. These are as follows:

Conclusion 7.10. The future development of the industry in a

liberalized regime must continue to utilize the natural gas transportation system's significant economies of scale and declining average cost benefits. A comprehensive and centralized planning function that includes experiences from transportation system design and operations will enhance such a development. *See Observation 7.17 through Observation 7.20 and Observation 7.25 and Observation 7.53.*

Conclusion 7.11. If the future operation of the highly integrated Norwegian natural gas pipeline systems is organized into one (and only one) organization unit the following features are enhanced:

- cost efficiency (i.e. minimization of variable and fixed operational and maintenance costs), *see Observation 7.21 and Observation 7.28.*
- energy efficiency (i.e. an operation that causes as little fuel consumption as possible), *see Observation 7.29 and Observation 7.35 through Observation 7.37.*
- optimized utilization so that the deliveries have high regularity, *see Observation 7.34 and Observation 7.53 through Observation 7.55.*
- optimized blending of gas streams so that the deliveries meet gas sales specifications and thus avoiding penalties and maximizing revenues, *see Observation 7.58 through Observation 7.59.*
- enhancement of resource management on the NCS in daily operations. *See Observation 7.56 through Observation 7.57.*

Conclusion 7.12. The irreversible cost is the largest contributor to the transportation cost and it comprises approximately 88-90 % of this cost. The reversible operation and maintenance cost contributes with approximately 7-8 % and the variable cost contributes approximately with less than 3-4 %. The latter cost may also be interpreted as short run marginal cost. The empirical data on costs derived here is interesting background information when it comes to designing a future tariff and toll regime. *See Observation 7.24, Observation 7.26 through Observation 7.27 and Observation 7.29 through Observation 7.33.*

Conclusion 7.13. Most of the transportation cost can not be influenced by the owner or operator's managerial decisions. Nor do they have much influence on the revenues (in the short term and considering no new sales or investments). The costs are however, largely influenced by

political decisions and the level of costs are implicitly specified by regulatory bodies. This conclusion is based on the fact that the regulatory body specifies the level of rate of return, licensing periods and volume of gas that constitutes the ship or pay volume. Further, the regulatory regime highly and in an indirect manner affects the level of transaction costs. Liberalization may affect on these issues. *See Observation 7.22 though Observation 7.23 and Observation 7.38 through Observation 7.46.*

Conclusion 7.14. The current regime is based on a vertically integrated structure. If transport operations shall be segregated into an independent organization unit a number of documents will be affected and they must be revised in order to maintain a valid and legal framework and hierarchy of requirements governing the operations. *See Observation 7.47 through Observation 7.52.* This topic is further discussed in Section 7.6.

7.4.3 Feasibility analyses - prevailing incentive structures and liberalization
7.4.3.1 Objectives and the economic background

On the NCS today there are several transportation systems owners and owner groups (joint ventures) as well as many shippers. The pipeline system owners are assigned a specific owner's share in the different pipeline systems. This assignment takes place in the licensing process. In addition to being owners the majority of the participating companies also act as shippers in the same pipeline systems. Further, many of these companies are vertically integrated and they are owners in field production licenses. They consequently have revenues and costs associated with oil, NGL and gas sales and production and transportation of said products, as indicated in Figure 1.

The prevailing Norwegian regulatory regime specifies that the toll to be paid by shippers shall be based on a typical toll formula as discussed in Section 7.4.2.10 on page 160. This toll formula acts basically as an average cost pricing formula, based on a regulated rate of return (even though it may look like a two-part toll and it actually acts like one given some quite specific conditions). [259]

The toll is based on the historic investment costs for the particular pipeline system in question. The pipeline systems were developed in the first place based on a defined annual throughput volume (i.e. the ship-or-pay volume) and the shippers are obliged to ship this volume of gas, effectively

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[259] This is discussed in more detail in Section 7.4.4 on page 191

ensuring a financial security for pipeline owners.

But as was stated above, the fact that the majority of the pipeline system owners simultaneously are shippers leads to some quite specific economic and regulatory advantages and disadvantages. In general, conflicts may arise between different companies caused by uneven ownership shares versus shipper shares in a specific system. Uneven shares combined with the given toll formula may cause that different (vertically integrated) companies have *different preferences related to two important issues* in the context of this work. These two important issues are studied in the proceeding text and they are:

- A given company's incentives for cost efficient investments and operations
- A given company's preferences for which pipeline system to utilize (i.e. where to route the gas).

Why is it important to analyze these questions in an analytical manner? The first striking answer is that the Norwegian authorities repeatedly confirm that this regime shall persist even in a liberalized context. WPs have been issued stating this fact and the latest publication issued by the Norwegian Government reconfirms that this part of the prevailing regime shall continue unchanged. The recently issued Norwegian St. prp. 36 (2000-2001) documents that the prevailing tariff regime and ownership structure shall continue as a regulatory principle.

Another reason for performing this analysis is, as far as the author has observed, the lack of such analysis in the literature. [260] There are however, many authors that indicate that average cost pricing is not a preferred solution in a liberalized regime due to many reasons. Actually, economic literature has taught for long that average cost pricing is associated with several disadvantages. Nese (1998) may serve as an example of such an author and he summarizes these disadvantages as follows: "inefficient use of capacity, incorrect investment signals and weak incentives for cost efficiency". Further, according to Nese (1998), page 43: "Average cost pricing will give the pipeline owner weak incentives for cost efficiency since financial costs are recovered by the price under any circumstances. An example of average cost pricing is rate of return regulation, which is the usual way of regulating the natural gas transportation on the NCS."

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[260] Brottemsmo (1994-A and -B) give some quite similar analyses. The focus of Brottemsmo's analyses however is somewhat different from the one presented here.

There is however one important distinction that apparently seems to have been overlooked, or at least not mentioned, in the indicated conclusion given by Nese. Nese's comment regarding the average cost pricing rule's improper incentives for cost efficient investments and operations may be true in general terms, but it is not fully correct in the Norwegian case. The core issue here seems to be that the analysis has not taken into consideration the fact that the pipeline owners are also the users of the system. This fact usually shifts the incentives for cost efficient investments and operations from improper to proper.

In order therefore to fully understand how the prevailing regulatory regime causes incentives for proper or improper investments and cost efficient operations and how it influences on the shippers' preferences for where to route the gas in the system, a detailed analysis is carried out here. The ultimate objective is to clarify if this regime may be recommended as an appropriate regime fit for a liberalized context, or whether it has to be adjusted or changed to some extent.

7.4.3.2 Assumptions and constraints

In the analysis conducted here the following assumptions are made:

- The gas price and the gas volumes to be shipped are exogenously given and they are kept constant.
- The transportation toll is given by the toll formula as specified in equation (Eq. 7.4.17) which is the prevailing formula. In these analyses *we do not evaluate* the functionality of the toll regime as such nor its ability to enhance rationing efficiency.
- No taxation considerations are considered here. Further no profit or toll considerations are analyzed considering a fully depreciated system.

The economic background for the assumption made in the first bullet point is taken from the prevailing gas sales contracts. This assumption is based on the fact that the gas is sold under take-or-pay contacts. In these contracts both the volume and the price are fixed for a substantial period of time.

The economic background for the second bullet point above is taken from the prevailing toll formula. The only issue of interest here is to study how shippers will respond given that there exist different tolls in different systems and provided they have different levels of owner shares in these systems. The assumption made here is that the total capacity of the system is set equal to its predefined ship-or-pay throughput level and thus there is

always sufficient total capacity in the total system. In the analyses we do not treat the total flow through the system as a variable. The only issue to be analyzed here is where a given company will prefer to route his gas only on the conditions of different tolls in different systems and his owner interests in the systems. (i.e. we assume that the shipper has a need to ship in the system and that the systems considered by the shipper are equal geographical alternatives). The assumption made here means in practical terms that if there are only two shippers and one shipper is allowed to chose the routing of his gas first, the second shipper has no choice but is forced to ship the gas where the first shipper decided not to go. The toll is therefore treated as exogeniously given but different from one pipeline system to another.

Are the above realistic assumptions? Given the prevailing regime they are, and as will be shown, there are some inherent problems associated with the practice.

7.4.3.3   The basic profit function

Figure 1 on page 5 illustrates the vertically integrated structure of the Norwegian gas industry. We now introduce a given company, *x*, and we assume that this company is vertically integrated meaning it is an oil and NGL producer and seller, gas producer, shipper, transportation system owner, and gas seller combined. This company will have costs and revenues associated with sales, production and transportation of the hydrocarbon products.

Based on (Eq. 3.4.1) in Section 3.4.3.1 a general profit function for the company can be developed. This profit function must include all the revenue and cost elements. In order to ease the set-up of the function Table 10 may assist the thought.

Table 10.   Revenues and costs for company x in year n

Stake-holder roles:	Oil producer	NGL producer	Gas producer	Ship-per	Transportation system owner	Gas seller
$TR_{xn} =$	$Q_{oil}*P_{oil}$	$Q_{NGL}*P_{NGL}$			T_{xn}	$Q_{xn}*P_{gas}$
$TC_{xn} =$	$Q_{oil}*C_{oil}$	$Q_{NGL}*C_{NGL}$	$Q_{xn}*C_{gas}$	T_{xn}	$\dfrac{Q_{xn}}{Q_n}(O_n + r^f I_n)$	

The total profit function for the company, *x*, in year, *n*, can thus be written as follows:

$$\Pi_{xn} = TR_{xn} - TC_{xn}$$
(Eq. 7.4.20)

Here the terms have the following meaning:

TR   is total revenue from sale of hydrocarbon products and transportation services, NOK/yr

TC   is total cost of production and transportation of hydrocarbon products, NOK/yr.

The terms for total revenue and total cost are thus defined as follows:

$$TR_{xn} = Q_{oil} * P_{oil} + Q_{NGL} * P_{NGL} + Q_{xn} * P_{gas} + T_{xn} \qquad \text{(Eq. 7.4.21)}$$

$$TC_{xn} = Q_{oil} * C_{oil} + Q_{NGL} * C_{NGL} + Q_{xn} * C_{gas} + T_{xn} + Q_{xn} / Q_n * (O_n + r^f I_n)$$
$$\text{(Eq. 7.4.22)}$$

Here,

I_n is the (annual) investment for the pipeline company in year *n*.

r^f is the interest rate in the capital market (or financial opportunity costs)

The toll is given by the toll formula as follows (reproduced here):

$$T_{xn} = C * I_{pipe} * E_n * Q_{xsn} + \frac{O_n}{Q_n} * Q_{xn} \qquad \text{(Eq. 7.4.17)}$$

In order to simplify the analyses we stylize the formulas slightly. The first formula to be simplified is the toll formula above (Eq. 7.4.17) and we may write it in a stylized form as follows:

$$T_x = \frac{Q_x}{Q}(r^r I + O)$$

$$T = \sum T_i = \sum \frac{Q_i}{Q}(r^r I + O), i = x, y$$

Here *x* and *y* represent two companies: *x* and *y*. The equation above will thus simply read:

$$T = r^r I + O \qquad \text{(Eq. 7.4.23)}$$

Here,

r^r is the regulated rate of return as specified by the regulator

O is the total (annual) operating costs

The next step is to introduce an expression for the owner shares by specifying that the company x has an ownership share in the transportation system equal to a percentage share a. This will have the following two implications for the company. First, the company is entitled to collect a percent of the total toll received by the transportation company (in which he is an owner). Secondly, the company must pay a percent of the total costs that the transportation company has to cover.

We now assume for simplicity that there are only two owners, company x and company y. This implies that company y will be entitled to (1-a) percent of total toll and cost coverage.

Further, we assume that company x ships gas in the system equal to b percent of the total gas volume shipped. Applying now the assumptions listed above the following relationships can be listed for the two companies:

$$T = T_x + T_y, \qquad T_x = b\,T, \qquad T_y = (1- b)T \qquad \text{(Eq. 7.4.24)}$$
$$Q = Q_x + Q_y, \qquad Q_x = b\,Q, \qquad Q_y = (1- b)Q \qquad \text{(Eq. 7.4.25)}$$
$$I = I_x + I_y, \; I_x = a\,I, \qquad I_y = (1-a)I \qquad \text{(Eq. 7.4.26)}$$

The revenues and costs for these two companies can now be tabulated as shown in Table 11. Again, the expressions are somewhat simplified and stylized here without loosing coherence and continuity. All revenues and costs related to production of oil and NGL are disregarded as well, and the gas production costs and gas sale prices are assumed to be the same for both companies. The latter assumptions may be perfectly true as the shippers may be two companies in the same production field and they may sell their gas in the same market.

Table 11. Revenues and costs for company x and company y

Stakeholder roles:	Gas producer	Shipper	Transportation system owner	Gas seller
$TR_x =$			$a\,T$	Q_x*P
$TC_x =$	Q_x*C	T_x	$a\,(O+r^fI)$	
$TR_y =$			$(1-a)T$	Q_y*P
$TC_y =$	Q_y*C	T_y	$(1-a)(O+r^fI)$	

If we now consider the profit, revenues and costs for company x, by applying the elements of Table 11 and the profit function (Eq. 7.4.20), the following profit function can be specified for this case:

$$\Pi_x = Q_x*P + a*T - \left[Q_x*C + T_x + a(O + r^f I)\right]$$

Inserting equations (Eq. 7.4.24) through (Eq. 7.4.26) into the equation above and simplifying, the equation will now yield:

$$\Pi_x = b\left[Q(P-C)-T\right] + a\left[T - O - r^f I\right] \qquad \text{(Eq. 7.4.27)}$$

Equations (Eq. 7.4.27) now represents a stylized profit function for the company x and several propositions can be concluded from it by changing the values of a and b. These propositions are summarized and discussed in the following sub-sections.

7.4.3.4 Case one: the company is only an owner

The first case to be studied is specified by ($a = 1$, $b = 0$). This means that the company is the only owner and it does not ship at all in the system. Equation (Eq. 7.4.27) will now read as follows:

$$\Pi_x = T - r^f I - O \qquad \text{(Eq. 7.4.28)}$$

Three propositions can be made:

Proposition 7.1. If a company is solely a transportation company that does not ship any gas in the system it has an incentive to increase its profit by increasing the toll, provided $r^r > r^f$. The toll may be increased by excessive investments in pipeline systems (gold plating and the "Averch and Johnson" effect [261]).

Proposition 7.2. If a company is solely a transportation company that does not ship any gas in the system it is indifferent to the level of transport operations and maintenance costs.

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[261] See Hope (1994) chapter 3.1 (or Hope (2000) page 253) where a more detailed discussion is given of this effect.

Proof: These two propositions are shown directly from equation (Eq. 7.4.28) by inserting (Eq. 7.4.23) into the equation. A positive profit is obtained provided $r^r > r^f$, as seen directly from the equation (Eq. 7.4.29) below.

$$\prod_x = r^r I + O - r^f I - O = I(r^r - r^f)$$
(Eq. 7.4.29)

The higher value of *I* the higher the profit will be. This conclusion is the classic argument as stated by Nese (1998). We also see that the company is indifferent to the operations costs as these are cancelled out. This simply means that operations costs are passed on to the shippers. Faced with these facts the following observation is made:

> *Observation 7.60.* If the Norwegian regulatory regime should assign all of the pipeline system ownership to an independent transportation system company that is not allowed to ship own gas in the system the current regulatory regime must be changed in order to create correct incentives for cost efficient investments and operations. [261]

7.4.3.5 Case two: the company is only a shipper

The second case to be studied is specified by ($\boldsymbol{a} = 0$, $\boldsymbol{b} = 1$). This means that the company is the only shipper and it does not own the system at all. The equation (Eq. 7.4.27) will now read as follows:

$$\prod_x = Q(P - C) - T$$
(Eq. 7.4.30)

The following proposition can be made:

> *Proposition 7.3.*   If a company is solely a shipper and it does not own the pipeline system the company has an incentive to have the toll reduced in order to increase its profit.

Proof: This conclusion is seen directly from equation (Eq. 7.4.30) and it is a quite obvious and trivial conclusion.

There are however some few comment to be made here. Generally we may assume that most shippers are also pipeline owners in a Norwegian context. But this may not always be the case and there may be requests for transportation from shippers who do not own the pipeline. This latter situation may particularly arise as a consequence of the Gas Directive.

One interesting question is to analyze if the toll formula as specified in (Eq. 7.4.17) is an appropriate toll formula, for firm capacity, for a potential shipper who is not a pipeline owner, provided the other (vertically integrated shippers) pay the same toll for the same service – and still assuming there is sufficient capacity.

If we assume and stick to the notion that those shippers who request firm capacity shall cover the fixed costs (see Section 7.4.4 where this notion is discussed) the following can be argued. The "third party shipper" will be in no worse or better situation than any other shipper, as the users of the system shall cover the fixed cost regardless of who owns the system. Actually, and assuming that most of the other shippers are "over-shippers" or balanced this situation will benefit him as the incentive structure forces the other shippers (and the owners) to focus on keeping the costs a low as possible (see the next two sub-sections). The independent shipper will thus know that the toll is at its lowest possible level and the rate of return regulation makes sure that no pipeline system owners are in the position of exercising excessive tolls.

If the toll should be set at a higher or lower level for the "third party shipper" than the toll paid by the incumbent shippers, discrimination is introduced. Such discrimination will presumably be in conflict with the Gas Directive's requirements of equal access for all shippers.

7.4.3.6 Case three: the company is balanced

The third case to be studied is specified by ($a = b > 0$). This means that the company is balanced and his sipper share is exactly equal to his owner share in the given system. By rearranging the profit function (Eq. 7.4.27) the equation will read as follows:

$$\prod_x = bQ(P-C) - a(O+r^f I) + T(a-b) \qquad \text{(Eq. 7.4.31)}$$

Now the following relationships apply: $Q_x = aQ = bQ$. If these expressions are inserted into (Eq. 7.4.31) the profit function will yield:

$$\prod_x = Q_x * (P-C-\frac{O}{Q}-\frac{r^f I}{Q}) \qquad \text{(Eq. 7.4.32)}$$

In the special case of ($a = b = 1$) the equation will simply read:

$$\prod_x = Q * (P - C) - O - r^f I \qquad\qquad\text{(Eq. 7.4.33)}$$

Based on the equation (Eq. 7.4.32) or (Eq. 7.4.33) two essential features of the current incentive structure can easily be visualized.

Proposition 7.4.　If a company has even ownership shares and shipper shares the company will seek to reduce costs in gas production and gas transport operations in order to increase its profits.

Proposition 7.5.　If a company has even ownership shares and shipper shares the company will seek to reduce costs in pipeline system investments in order to increase its profit.

Proof: These two propositions are derived based on the assumption that the gas price and the gas volumes sold are exogeniously given in the short run and the only variables left for considering are transport operation costs, gas production costs and investments. The propositions are seen directly from equation (Eq. 7.4.32) and (Eq. 7.4.33).

Osmundsen (1999) reaches the same conclusions as stated above. [262] He states that "companies in general are cost minimizers and that the regulatory regime does not encourage for gold plating."

There are however some few comments to be made here. Some economists may argue that if the ownership share is relatively low, the company (which we now assume is the operator and the one that can influence on the operating costs) will have weak incentives for heavy cost reduction efforts. This is due to the fact that the "lions share" of these reductions will be taken by the other owners and the State in particular (tax on revenues), while the company itself must solely take all the unpleasant efforts as for example, discussions with the labor organizations and unions.

This argument was indeed stated by the Norwegian Minister of Petroleum and Energy. [263] His argument was that this observation is a prime reason for why the Norwegian oil companies shall be offered to buy higher owner shares in the different licenses on the NCS, as suggested in the St. prp. 36 (2000-2001). The ultimate goal is to increase the oil companies' incentives and efforts for cost efficient operations and thereby improving their

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[262] Osmundsen (1999) discusses risk sharing and incentives in Norwegian petroleum extraction.

[263] At a public meeting in Haugesund, Norway on the Feb. 15, 2001

competitive edge in a long-term perspective.

On the other hand, representatives of the oil companies may claim that the current incentives are proper in the present form, and proper incentives for cost efficient operations and investments are already in force.

7.4.3.7 *Case four: the company is over-shipper*

The fourth case to be studied is specified by ($a < b$). This means that the company is an over-shipper. Based on equation (Eq. 7.4.31) a new proposition can be stated:

> *Proposition 7.6.*   If a company has an ownership share that is less than its shipper share it has an incentive to reduce operational costs, investments and the toll in order to increase its profit.

> *Proof:* The statement is seen directly from (Eq. 7.4.31). We see that any increase in investment costs and operations costs and the toll will yield a reduced profit.

The above proposition is likely the cause of a notion that for long has been governing Norwegian regulation. The notion is that "the companies shall be allocated a less ownership share in the transportation system than in the production fields" (i.e. the shipper interests). The quotation is taken from the White paper no. 46 (1986-87) page 69. See also the next sub-section and Proposition 7.8.

7.4.3.8 *Case five: the company is over-owner*

The fifth case to be studied is specified by ($a > b$). This means that the company is an over-owner. By inserting the stylized toll formula (Eq. 7.4.23) into the profit function we derive a general formula for profit as a function of investments:

$$\textstyle\prod_x = bQ(P-C) - a(O + r^f I) + T(a - b) \qquad \text{(Same as: Eq. 7.4.31)}$$

$$\textstyle\prod_x = bQ(P-C) - a(O + r^f I) + (r^r I + O)(a - b)$$

$$\textstyle\prod_x = bQ(P-C) + (aO - aO) + a(r^r I - r^f I) - br^r I - bO$$

$$\prod_x = \boldsymbol{b}Q(P-C) + \boldsymbol{a}I(r^r - r^f) - \boldsymbol{b}(r^r I + O) \qquad \text{(Eq. 7.4.34)}$$

In equation (Eq. 7.4.34) the first term on the right hand side is the well-known expression for profit obtained from gas sale minus production costs. The second term shows that the company will yield a return on the investments according to his owner share. The last term expresses the costs for utilizing the system and from (Eq. 7.4.23) we see that this term is exactly equal to the total toll times the company's shipper share.

The interesting question is now to study whether an increase in investment costs would yield a higher profit for the company. This can be analyzed by studying the derivative of the profit function (Eq. 7.4.34) with respect to the investment *I*, which will yield:

$$\frac{d\prod_x}{dI} = \boldsymbol{a}(r^r - r^f) - \boldsymbol{b}r^r \qquad \text{(Eq. 7.4.35)}$$

When $\dfrac{d\prod_x}{dI} = 0$ the company is indifferent. This situation thus takes place when:

$$\frac{\boldsymbol{a}}{\boldsymbol{b}} = \frac{r^r}{r^r - r^f} \qquad \text{(Eq. 7.4.36)}$$

Based on (Eq. 7.4.35) and (Eq. 7.4.36) a proposition can be concluded:

Proposition 7.7. A company will only seek to increase investments in order to increase its profit if the ratio of ownership shares versus shipper shares is larger than the ratio $r^r/(r^r-r^f)$. In mathematical form this condition yields only if $\boldsymbol{a}/\boldsymbol{b} > r^r/(r^r-r^f)$.

Proof: Based on equations (Eq. 7.4.35) and (Eq. 7.4.36) we see that if $\left|\boldsymbol{a}(r^r - r^f)\right| > \left|\boldsymbol{b}r^r\right|$ the derivative of the profit function will yield a positive value, which means that the company has an incentive to increase the investments and thus the toll as this will increase his profit. If, however $\left|\boldsymbol{a}(r^r - r^f)\right| < \left|\boldsymbol{b}r^r\right|$ the opposite will take place and the company has an incentive to reduce the investments and thus the toll.

A corollary to Proposition 7.7: If we introduce some numerical values for the rate of return and the opportunity cost the proposition can be illustrated numerically. If for example, $r^r = 7\%$ and $r^f = 5\%$ the ratio between ownership share and shipper share will yield 3.5. If we for example, assume that the company owns the entire pipeline the company will be indifferent at ($a = 1$) and $b = 0.29$. As this case represents the ultimate ownership share, the corollary means that whenever a company is shipping approximately 29% or more in a pipeline it will have proper incentives for keeping the investment low. Or to put it somewhat differently, the "Averch-Johnson" effect is *eliminated* given this condition.

Finally and for the sake of completeness we can also verify the results and propositions derived above by means of equation (Eq. 7.4.35). If we specify $a = 1$ and $b = 0$ (the company is only an owner) this function will yield: $\dfrac{d\Pi_x}{dI} = r^r - r^f$, which complies with Proposition 7.1 and Proposition 7.12 (see case six below). The function will always be positive which means that excess investment is always attractive.

If we specify $a = 0$ and $b = 1$ (the company is only a shipper) the function will yield: $\dfrac{d\Pi_x}{dI} = -r^r$. This result complies with Proposition 7.3. The function will always be negative which means that excess investment will never be attractive.

If we finally specify that $a = 1$ and $b = 1$ the function will yield: $\dfrac{d\Pi_x}{dI} = r^r - r^f - r^r = -r^f$. This result complies with Proposition 7.5. The function will always be negative and constant at $-r^f$, which means that excess investment will never be attractive.

A last analysis of interest is to study how the profit seeking company will behave if it is allowed to negotiate the rate of return with the regulator. From (Eq. 7.4.34) we can calculate that:

$$\frac{d\Pi_x}{dr^r} = I(a - b) \tag{Eq. 7.4.37}$$

The following proposition can be suggested:

Proposition 7.8. A company that both owns and ships in a pipeline system will seek to increase the rate of return (if possible) only if its owner share is larger than its shipper share.

Proof: From (Eq. 7.4.37) we see that this equation will yield a positive value only if $a > b$.

7.4.3.9 Case six: two companies and two pipelines

In the proceeding analyses we expand the study case to include two different pipeline systems, termed a and b and written as subscripts in the equations. The two companies x and y mutually own the systems and they both ship in the systems. We now assume for simplicity that $P_a = P_b = P$ (i.e. an exogeniously given price) and $C_a = C_b = C$ (i.e. equal production costs for the gas).

We assume further that $Q_{xa} = b_{xa} Q_x$ and $Q_{xb} = b_{xb} Q_x$ and $b_{xa} + b_{xb} = 1$ yielding that $Q_{xb} = (1 - b_{xa}) Q_x$, and $Q_x = Q_{xa} + Q_{xb} =$ constant. We also assume that the total volume of gas shipped in both systems by both shippers (i.e.: $Q = Q_x + Q_y$) is constant and that the total volume is exactly equal to the total ship-or-pay volume. This is the volume applied (by the regulator) as the base volume for calculating the regulated rate of return.

This latter assumption subsequently yields that the toll elements T_a and T_b are constant. This is so due to the fact that the pipeline systems are assumed to be utilized at their regulated throughput levels which will yield a constant toll according to the toll formula (Eq. 7.4.17). Finally, we also assume that the ownership shares, a_{xa}, a_{xb} are exogeniously given as part of the licensing approval procedures. We will later relax this latter assumption.

The reason for suggesting these strict assumptions is to eliminate the toll formula's potential rationing efficiency capability (or lack of such capability). This will allow us to study the behavior of the shippers independently from their potential incentives to increase or decrease the shipped volume as a function of the toll formula. This means that we do not analyze the features of the toll formula as such. Another way of expressing this is that we do not analyze the toll formulas' capability to reduce deadweight losses caused by any inefficient rationing capability of the toll formula. This all means that the only question studied is the *shipper's preference for where to route gas as a function of his shipper share and owner share*.

By applying equation (Eq. 7.4.27) the profit functions for company x pertinent to systems a and b yield:

$$\Pi_{xa} = \boldsymbol{b}_{xa}\left[Q_x(P_a - C_a) - T_a\right] + \boldsymbol{a}_{xa}(T_a - O_a - r^f I_a) = \boldsymbol{b}_{xa}k_1 + k_2 \quad \text{(Eq. 7.4.38)}$$

$$\Pi_{xb} = (1 - \boldsymbol{b}_{xa})\left[Q_x(P_b - C_b) - T_b\right] + \boldsymbol{a}_{xb}(T_b - O_b - r^f I_b) = (1 - \boldsymbol{b}_{xa})k_3 + k_4$$
$$\text{(Eq.7.4.39)}$$

The task now is to *maximize total profit for company x* by manipulating the routing of the gas volumes to be shipped i.e. deciding the sizes of $\boldsymbol{b}_{xa}$ and $\boldsymbol{b}_{xb}$. We remember that $\boldsymbol{b}_{xb}$ is given implicitly by $\boldsymbol{b}_{xa}$ so the task can thus be expressed as follows:

$$\underset{bxa}{Max}\left[\Pi_{xa} + \Pi_{xb}\right] \quad \text{(Eq. 7.4.40)}$$

The derivative of the profit function (Eq. 7.4.40) with respect to $\boldsymbol{b}_{xa}$ can be expressed as follows:

$$\frac{d(\Pi_{xa} + \Pi_{xb})}{d\boldsymbol{b}_{xa}} = \frac{d}{d\boldsymbol{b}_{xa}}\left[\boldsymbol{b}_{xa}k_1 + k_2 + (1 - \boldsymbol{b}_{xa})k_3 + k_4\right]$$

$$\frac{d(\Pi_{xa} + \Pi_{xb})}{d\boldsymbol{b}_{xa}} = k_1 - k_3 \quad \text{(Eq. 7.4.41)}$$

From (Eq. 7.4.41) two propositions can be concluded.

Proposition 7.9. If a company ships gas in two pipeline systems it will seek to shift the gas volumes over to the pipeline system that has the lowest toll. This is a fairly obvious conclusion, though.

Proof: If we specify that $|k_1| > |k_3|$ then $\dfrac{d(\Pi_{xa} + \Pi_{xb})}{d\boldsymbol{b}_{xa}} > 0$ which will yield a positive profit. The inequality above can be simplified by inserting $P_a = P_b = P$ and $C_a = C_b = C$, yielding:

$$\left| Q_x(P-C)-T_a \right| > \left| Q_x(P-C)-T_b \right|$$

$$T_b > T_a \qquad\qquad\qquad\qquad \text{(Eq. 7.4.42)}$$

Proposition 7.10. The optimization decision of where to ship gas is independent of the company's owner shares in the pipelines in question.

Proof: This conclusion is derived from the fact that the ownership shares are constant and does not influence on the decision as shown in the inequality (Eq. 7.4.42).

If we now relax on the assumption that the ownership shares are exogeniously given, but we rather assume that the companies are allowed to increase or decrease their shares, a profit maximization behavior can be studied. The task is now once more to maximize the profit function by choosing the optimal values for a_{xa} and a_{xb}. We assume for simplicity however, that company x has a constrained investment possibility in such a way that $a_{xa} + a_{xb} = 1$, $a_{xb} = 1 - a_{xa}$.

We assume further that the operation costs are the same in both systems and they are constant. We also assume here *that even the toll is equal in both systems* (and the reason for so doing is given in the main conclusions specified at the end of this sub-section). The profit function can now be found from equations (Eq. 7.4.38) and (Eq. 7.4.39).

$$\underset{a_{xa}}{Max}\left[\Pi_{xa} + \Pi_{xb} \right] \qquad\qquad\qquad \text{(Eq. 7.4.43)}$$

The derivative of the profit function (Eq. 7.4.43) with respect to a_{xa} can be calculated and the result is as follows, applying the assumptions listed above:

$$\frac{d(\Pi_{xa}+\Pi_{xb})}{da_{xa}} = \left[T-O-r^f I_a \right] + \left[-T+O+r^f I_b \right] = r^f(I_b - I_a) \quad \text{(Eq. 7.4.44)}$$

Proposition 7.11. If a company can shift its owner shares between pipeline systems in which it ships gas and where the toll is equal in both systems, the company will seek to invest in the system that has the lowest investment cost as this will increase its total profit. If the

investments are the same in both systems the company is indifferent as long as the toll is the same in both systems.

Proof: If $|I_b| > |I_a|$ the derivative of the profit function is positive and the company will invest in system "a".

If the tolls however are not the same in the two systems the equation (Eq. 7.4.44) will have a more general form:

$$\frac{d(\Pi_{xa} + \Pi_{xb})}{d\boldsymbol{a}_{xa}} = \left[T_a - O - r^f I_a\right] + \left[-T_b + O + r^f I_b\right]$$
$$= T_a - r^f I_a - T_b + r^f I_b$$

(Eq. 7.4.45)

The following proposition can be stated based on (Eq. 7.4.45):

Proposition 7.12. If a company can shift its owner shares between pipeline systems in which it ships gas and where the toll is set at a regulated rate of return, it will seek to invest in those systems that have the highest investment costs (and toll) as this will increase its total profit.

Proof: If we study the inequality $\dfrac{d(\Pi_{xa} + \Pi_{xb})}{d\boldsymbol{a}_{xa}} > 0$ we find that this condition holds if $\left|T_a - r^f I_a\right| > \left|T_b - r^f I_b\right|$. If we now insert the simplified toll function of (Eq. 7.4.23) the inequality reads: $\left|I_a(r^r - r^f)\right| > \left|I_b(r^r - r^f)\right|$ or simply : $|I_a| > |I_b|$.

We note that Proposition 7.11 and Proposition 7.12 yield different results.

7.4.3.10 Summary of this sub-section

This sub-section has shown that dependent on the values of the two parameters $\boldsymbol{a}$ and $\boldsymbol{b}$ a vast variety of incentives are derived. Four main conclusions are suggested here as the main inferences from the analyses of this sub-section:

Conclusion 7.15. Generally all shippers will seek to ship in the pipeline system that has the lowest toll, if they are allowed to choose between equal transportation possibilities in systems where the sizes of the tolls are the only differences. Further, such preferences are independent of a shipper's owner shares in the systems. An introduction of a unitized toll would prevent such a behavior and eliminate such shipper preferences. *(See Proposition 7.9 and Proposition 7.10).*

This conclusion is quite interesting in relation to optimization of the systems at high levels of system utilization. As will be shown in Section 7.5 on page 203, it is important to have as few restrictions as possible that specify or dictate how to route the shippers' gas physically in the integrated network. If the shippers are allowed to specify where to route their gas in the systems, "internal" physical constrains are created that may effectively reduce an optimal overall utilization.

Based on this physical fact and the conclusion above the author will argue that the current regulatory regime and the prevailing toll formula hamper physical optimization of gas transportation, especially at high levels of utilization.

Conclusion 7.16. If a unitized toll *is* introduced in all pipeline systems but the owner shares are unevenly spread distortions are introduced resulting from reduced profit or excess profit for some pipeline owners. This conclusion is due to the fact that the pipeline systems have different (historic) investment costs, $I_a \neq I_b$. An introduction of a re-ownership arrangement into a unitized ownership scheme (i.e. all pipelines belong to only one owner group) or a similar arrangement of some kind or re-allocation of revenues, must be done if a unitized toll is introduced. *(See Proposition 7.11 and Proposition 7.12).*

Conclusion 7.17. If the Norwegian public authorities regulate that no shipper has an owner share larger than $r^r/(r^r-r^f)$ times his shipper share, incentives are created for cost efficient investments. The incorrect investment signals and weak incentives for cost efficiency usually associated with average cost pricing regimes are eliminated. As this condition is normally always fulfilled in the Norwegian context proper incentives for cost efficient investments and operations exist - in theory. *(See Proposition 7.4 through Proposition 7.7).* Further, only when the owner share is less than the shipper share a right incentive is created for simultaneously decreasing operations costs, investment costs and the

rate of return in order to increase the profit for a company that owns and ships in the same pipeline system. *(See Proposition 7.8).*

Conclusion 7.18. If an independent transportation company is established and this new company is assigned the entire ownership of the systems, the classic difficulties of the "Averch-Johnson effect" will occur. Under such circumstances alternative incentive structures should be sought for that – in theory – would be superior to the prevailing rate of return regime. *(See Proposition 7.1, Proposition 7.2 and Observation 7.60).*

7.4.4 *Analytical discussion of possible toll regimes in a liberalized context*
7.4.4.1 *Main features of applicable toll regimes – a summary*

If we now recapture the main elements of the economic tolling theory discussed in Section 3.4 we can summarize the theory shortly as follows:

- The main purpose of the toll regime for the Norwegian natural gas transportation system is to ensure:
  - rationing efficiency i.e. an optimal usage of existing capacity.
  - cost recovery i.e. coverage of the fixed costs.
  - cost efficiency i.e. the toll regime shall feature an incentive structure that enhances cost minimization.

Generally, a toll regime is often designed to capture several other important features as well. These features are not considered here due to several reasons as discussed in the preceding work. The features found not to be included here as prime objectives for a future toll regime in a Norwegian context are:

- Dynamic efficiency
- Allocative efficiency

The different toll regimes have different features that comply and capture the main objectives in different ways and to a different extent. This may be summarized as follows:

- Toll set equal to marginal costs of transportation secures an optimal usage of the system. Marginal cost pricing does not contribute to cover financial costs and fixed operational and maintenance costs i.e. fixed

costs in the case of natural gas transportation due to the fact that the marginal costs are always substantially lower than average costs.

- Toll set equal to average cost covers fixed costs, but it does not secure optimal usage of the system or it provides only sub-optimal usage. Further, such tolling will not give proper incentives for cost efficiency if an independent system operator operates the system and he also solely owns the system.

- Two-part toll can ensure both an optimal usage by pricing transport equal to marginal costs and also cost coverage by means of the fixed part of the toll. The shippers sort themselves into groups according to their willingness to pay toll and according to their needs for services. This may result in different values of the fixed part of the toll dependent on the different services offered.

- Ramsey pricing can ensure to some extent an optimal usage and also cost coverage provided the shippers demand functions are known. The rule is also known as the inverse elasticity rule and the shippers are discriminated in such a way that the fixed costs are charged in that portion of the market that can bear the costs the best. This is the market that is affected the least in utilizing the capacity when the toll is increased. This type of tolling is often referred to as second best tolling as it ensures cost coverage and at the same time minimizes the deadweight loss. Ramsey pricing will in theory also combine the two basic principles of tolling as written in the bullet points below.

The toll may be based on two basic principles, namely:

- costs based tolling
- value based tolling

The former principle is quite dominant in relation to natural gas transportation in several regions of the world. In North America cost based tolling has long been recognized as a basic principle, see Conclusion 6.6 on page 114. The Norwegian point of view has so far recognized the same principles, see Section 5.3.2.4 on page 69. Further, the Gas Directive requires that cost of transportation is made transparent, see Section 6.4.5 on page 110, indicating that a cost based toll regime is in compliance with the Gas Directive.

Further, a value based toll regime will require information that is currently not available to a large extent, see Section 3.4.3.4 on page 38. In

order to obtain such information significant legal and constitutional barriers are envisaged to occur simply because existing agreements and licensees all must be renegotiated. The main conclusion made here is thus:

> *Observation 7.61.* The future toll regime for Norwegian natural gas transportation must preferably be cost based in order to cover fixed costs in a foreseeable future. If a future evolution of the European gas market progresses a shift to value based tolling may prove necessary. This will however require paradigmatic changes into Norwegian law and regulations. Value based tolling is thus not considered in this work.

Ramsey pricing

Ramsey pricing was discussed theoretically in Section 3.4.5.8 and Ramsey pricing has in theory several promising and attractive features. As has been shown, the implication of Ramsey pricing is to set the toll closer to marginal cost in the elastic market and farther from marginal cost in the inelastic market. This means that the shipper with the most inelastic demand curve for transportation services is discriminated against others and he pays a higher toll than the shipper with a more elastic demand curve. This is an attractive feature as the transportation system owner may cover fixed cost with the least distortion on the system utilization.

There are however several difficulties regarding its applicability in a real Norwegian and European context. Similar difficulties are experienced in Canada as well and Mansell and Church (1995) list four of them. *Firstly*, the information requirements to implement Ramsey pricing are formidable. From the formula we see that there are two important parameters to be decided in order to calculate the toll for an individual shipper. The first parameter is the marginal cost. Even though marginal costs are constantly changing and differ somewhat from pipeline to pipeline these costs are manageable and some kind of average marginal cost can be applied for all shippers.

The largest difficulty is to set the individual shippers' elasticity of demand for transportation services correctly. We may assume for example, that the interruptible shipper has a more elastic demand than the firm shipper, but how much? Further, how stable are such elasticities if they are obtained in the first place – do they change from time to time or from season to season? How will for example, all the Upstream Agreements effect on a shipper's willingness to pay toll? Will for example, an Upstream Arrangement be a more attractive possibility in given situations as soon as the shipper has learned that his toll has been increased for a given transportation service? Is it likely that shippers will disclose such information – as a strategic move – if

the they know that the operator will use this information to discriminate shippers? These types of questions are hard to answer.

The *second difficulty* is that a move from the existing toll regime to Ramsey pricing will cause winners and losers. This can be seen by the fact that Ramsey pricing is discriminating shippers for example, in an off-peak situation where both firm and interruptible services are running concurrently. The notion would be to apply Ramsey pricing in such a way that the firm shippers should pay the higher toll. This principle could be expanded even further in such a way that there were different tolls between the individual firm shippers.

Assuming this situation, who is the shipper with an inelastic demand? If we apply the Gas Directive the shippers can be anyone – the "traditional producers" (i.e. sellers) or the downstream buyers. In a liberalized context we may assume for example, that the interruptible shipper will be the one who has an access to gas storage, typically the "traditional downstream buyer". This shipper may have a fairly elastic demand. The traditional producer, if being a shipper, may have a more inelastic demand, due to the fact that the gas being shipped may be associated gas. It is important for him to have the gas shipped so that he can collect revenues from his oil and NGL production. Given such assumptions, Ramsey pricing may discriminate Norwegian hydrocarbon producers – they may be the losers – and the downstream buyers may be the winners.

The *third implication* mentioned by Mansell and Church is that such prices are not strictly cost based and the *last* one mentioned is closely related to the former one, namely that Ramsey pricing may "run afoul of legislation". There are at least two issues noteworthy here. The first issue is whether tolls shall be allowed to deviate from a cost based toll whatsoever, and the second issue is whether discrimination is allowed as a recognized principle as such. In the prevailing regime neither of these possibilities are normally accepted. In a liberalized regime, and strictly following the Gas Directive the former issue is not fully clarified, see Dyrland and Moen (2000) page 20. The latter issue seems to be more clarified in the Gas Directive as rules based on discrimination are generally not accepted, see again Dyrland and Moen (2000) page 32.

A *fifth and last difficulty*, in the opinion of the author is the fact that Ramsey pricing would introduce different tolls for different shippers (and for different parts of the system) which will be counteracting the notion of a unitized toll. In Section 7.4.3 and Section 7.5.5 this author has argued that in order to enhance the physical utilization of the system it is important to eliminate any shippers' preferences for internal specified routing in the

integrated network. The benefits and disadvantages of Ramsey pricing must thus be compared with the substantially improved rationing efficiency of a unitized tolling regime.

As it has become apparent from the discussion above and based on the approach taken in this work, this author has not done any in-depth analyses based on Ramsey pricing. If that should have been done the difficulties identified above must be sorted out first. This leads to the following observation:

> *Observation 7.62.* This work has indicated that there are several difficulties in implementing Ramsey pricing as an applicable tolling mechanism in Norwegian natural gas transportation. This pricing mechanism is thus not evaluated any further here.

Two-part toll

The two-part toll based on a cost of service approach can be designed in such a way that different tolls are designed for different services. The shippers may then - according to their own preferences - decide which services they will go for and thereby disclose information of their willingness to pay. The shippers are thus not discriminated in the sense that they pay a different toll for the same transportation service (as Ramsey pricing would have done), but shippers simply sort themselves into groups according to their needs and willingness to pay for different services.

> *Observation 7.63.* Two-part toll based on a cost of service approach and a differentiated product selection (the transportation services, which comprise firm, interruptible and peak load supplies), will sort shippers into groups according to their needs and willingness to pay. If the services and the related tolls are correctly designed rationing efficiency is obtained and the fixed costs are covered.

The main task then becomes to design appropriate services for Norwegian natural gas transportation and to allocate the correct tolls to the services. The former task is already addressed as an efficient product selection. The latter task will call for further economic analyses and discussions. These two topics are therefore analyzed in the next two sub-sections.

7.4.4.2 Efficient product selection

The main services inferred by the work so far applicable for a liberalized regime are:

- Firm transportation
- Interruptible transportation
- Peak load transportation

All the prevailing "ship-or-pay" contracts may be categorized into the first type of service. It is a political goal to maintain these contracts as much as possible and we may assume that these contracts will tie-up a substantial portion of the system capacity for quite some time, see Observation 5.14 on page 72. We make one observation here:

> *Observation 7.64.* The existing ship-or-pay transportation agreement may be characterized as firm capacity and it may act as a two-part toll if the ship-or-pay volume it treated as a "booked capacity charge."

If spare capacity exists in the system and if the booked capacity is not fully utilized some capacity exists that in the current regime – as well as in a liberalized context – can be utilized for other transportation services. These services may be any of the three different types identified.

Several new types of services can be thought of for utilizing this capacity, see Observation 6.7 on page 105. In liberalized regimes elsewhere in the world the unused portion of the booked capacity plays a significant role in a capacity release market. Here transportation rights are traded. [264] Based on the existing transportation agreements specified rules exist in the prevailing regime for how to utilize the booked but not utilized capacity.

There are also other types of conceptually identified spare and scarce capacity as illustrated in Figure 27. In order to utilize this capacity in a liberalized context, and based on Conclusion 7.9 on page 131, the following observation can be suggested:

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[264] An observation is quite apparent in this respect. If the gas price is high in the downstream market the shippers will request high nominations and thus leaving less opportunities for the gas sellers to offer spot market sales. In periods of low gas sales prices in the downstream market the situation may be the opposite. The gas sellers thus become marginal suppliers. Denny Ellerman, MIT, addressed this observation as a likely effect of liberalization.

Observation 7.65. In a liberalized context, an independent transportation system operator must be given the right to allocate spare and scarce capacity in a rationing efficient manner and he must not be restricted by the regulator or the pipeline system owners or other shippers.
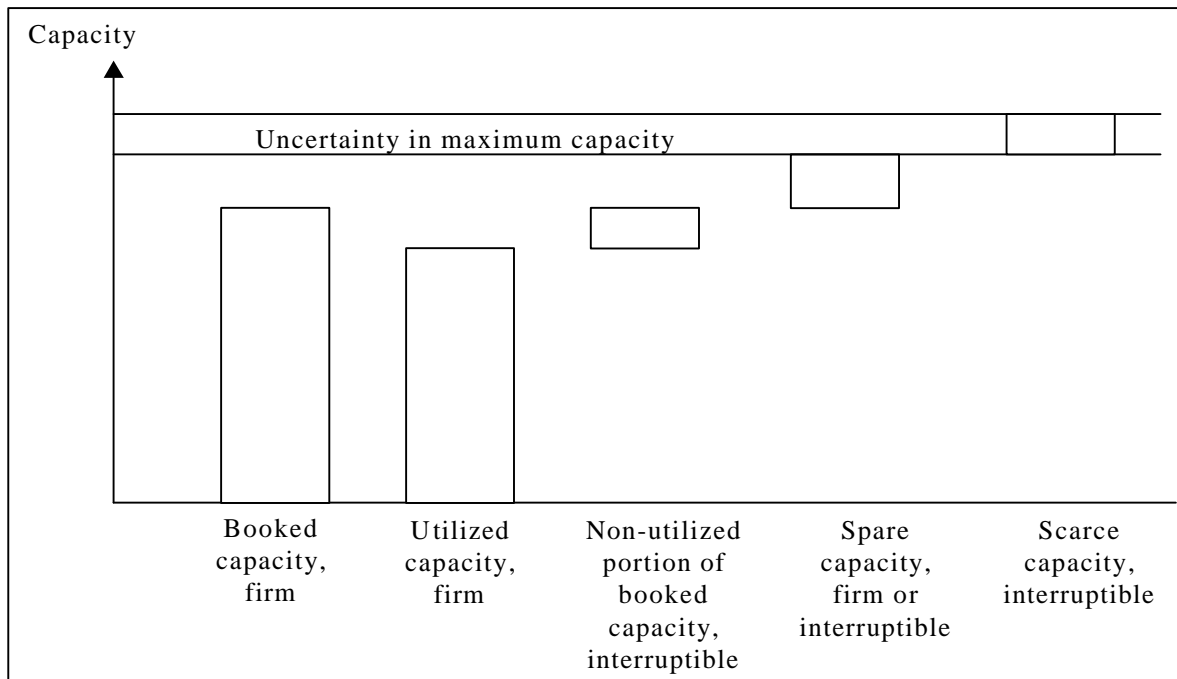
Figure 27. Different transportation services [265]

Interruptible transportation can – from a conceptual point of view as well as a practical point of view – be offered during off-peak periods and during peak periods. It may be difficult to find out in advance how much of the available capacity that actually will be requested as interruptible supplies or how much of the capacity that will be so attractive that shippers will "compete" for it in an auction. The final answer will probably not be revealed before an auction actually has taken place.

7.4.4.3 *Components of the future toll formula*

A major concern is how the toll shall be designed for the different services. One approach is to treat the firm capacity as the peak utilization of the system, while interruptible service is off-peak usage. Based on this approach some economic principles can be applied and some rules are defined

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[265] Source: Statoil

for how to allocate the fixed costs between the different types of services.

According to Kahn (1988), [266] the economic principle is absolutely clear, (provided that full coverage of average costs is the aim): "if the same type of capacity serves all users, capacity costs as such should be levied only on utilization at the peak." If this principle is used, firm shippers shall be charged a toll which – when integrated over all shippers - covers all fixed costs.

The fixed part of the two-part toll may be designed to cover these costs. This may thus be understood to be an access charge or a demand or capacity charge. In the fixed cost element a rate of return may be included in a similar manner as the current rate of return.

By the same token the interruptible toll shall not contribute to the coverage of fixed costs, but shall be charged only to cover marginal costs. This would imply a commodity toll equal to the marginal costs at peak demand (which equals the marginal cost or total average variable cost). Further:

> *Observation 7.66.* The variable part of the two-part toll may be set equal to the variable unit costs.

There are of course several caveats to the above suggestion. By applying the empirical data provided in this work the interruptible toll would be approximately 4% of the firm toll. If there is substantial excess capacity in the system a clear motivation is created for the shippers to shift their volumes from firm to interruptible transportation. The rule may thus be altered slightly to compensate for this effect by increasing the toll for interruptible services.[267]

These principles, applied in several regimes in North America, are called straight fixed/variable methodology (SFV). [268] Modifications to the rule are specified in such a way that peak users (i.e. shippers who compete for scarce capacity) also cover part of the capital costs, in essence shifting a larger portion of risk from shippers to transport system owners. The above discussion may be summarized as follows:

> *Observation 7.67.* A two-part toll may be designed in such a way that the fixed part covers fixed costs and this part is levied on the firm

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[266] See Kahn (1988), Chapter 4/I, page 89/I.

[267] In theory a tolling regime based on Ramsey pricing could have solved this problem, but as pointed out earlier, such tolling is difficult to implement.

[268] See Mansell and Church (1995), page 60.

capacity. This toll is based on a cost of service approach.

Observation 7.68. Variable costs plus a minor portion of the fixed costs may constitute the toll for interruptible transportation when no capacity constraints exist.

Observation 7.69. The existing toll regime and the ship-or-pay agreements comply – in a conceptual manner – with the above suggested toll principles regarding firm capacity, see the prevailing toll formula in Section 7.4.2.10 on page 160 and Observation 7.44 on page 161.

Observation 7.70. The fixed part of the toll for interruptible services may be set at a level that is less than the fixed part of the firm capacity when there is spare capacity in the system. When capacity constraints exist an auction of capacity is suggested, see Section 7.5 on page 203.

Another difficult economic consideration is how to treat old and new historic investment costs in the base rate for tolling and calculation of the fixed cost element (old or new "vintage" considerations). We may also include here the economy of scale effect. Table 5 on page 133 clearly shows the difference in fixed costs between old and new systems. Table 5 shows for example, that the ratio of investment/capacity in Europipe II is only 33% of the same ratio for Zeepipe. The question is then, shall shippers be discriminated depending on which system they use — the old or the new? Shall tolls be calculated based on past or present costs?

In addition to the differences in historic investment costs, older systems are depreciated to some extent and the capital cost element may thus have vanished or been significantly reduced – in theory. [269]

Kahn (1988) offers a clear view on this issue and he states that: "prices should reflect marginal costs at the time of sale – not at some time in the past"; similarly, he recommends "the use of reproduction instead of original cost as the basis for computing capital charges." [270] If this principle is applied, shippers' tolls should reflect costs in newer pipelines, and the owners of older systems would thus not fully cover their capital costs — a situation creating the well-known situation of stranded costs.

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[269] This assumption depends on how to calculate depreciation. In some regimes depreciation is not included.

[270] See Kahn (1988) page 109/I.

However, Mansell and Church (1995) for example, point to a number of arguments suggesting that tolls shall reflect an average capital cost for old and new systems considered as a whole. Such arguments relate to the fact that the aggregated demand of all shippers gives rise to the need for additional pipeline capacity, and no shipper (in a liberalized context) has an acquired right to ship in one particular pipeline system.

Operational considerations support the latter view, as well. In order to comply with the gas quality specifications some blending of gas must be performed in the transportation network. All shippers thus benefit from this possibility, and no shipper can claim that he utilizes only one single portion of the network independently. All shippers are benefiting from the integrated transportation system operations. Several empirical cases and operational considerations have been provided in this work supporting this view, see Conclusion 7.11 on page 172. The following conclusion is therefore suggested as a feasible approach in a Norwegian context:

> *Observation 7.71.* The fixed cost element for firm capacity shall generally be calculated as an average fixed cost based on historic costs (and potentially corrected for depreciation) for all pipelines that are included in the Norwegian dry gas system.

There are some objections to this rule. First, none of the rich gas pipelines are included here as these may impose costs on the shippers in the dry gas system that may not be appropriate for some shippers. Further, the Norpipe system inevitably distinguishes itself somewhat from the other pipelines as it is significantly more expensive in investments and in operations due to offshore compression.

A final important consideration is whether the toll shall be "mileage-based" or "postage-stamp" allocated. A typical consideration in many network utilities is whether tolls should be allocated based on distance utilized, or should serve essentially as postage stamps. Tabors et al. (2000) [271] identify some useful indicators for choosing between the two options in relation to natural gas transportation. Specifically, they suggest that a postage stamp toll is appropriate if:

- The cost of service does not vary significantly between customers using the system.

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[271] Tabors (2000).

This may be the case if the market is located at one end of a pipeline, with producers are located at the other. In a Norwegian context this condition is met to a large extent. The interesting cost here is the variable costs. As we have seen these costs contribute less than 4 % of total costs and there are only minor differences between the different pipelines.

- There is a clustering of all compressors at one end of a pipeline, with no intermediate compressor stations along the way. This condition is met with the only exception of Norpipe.

- There is an absence of receipt and delivery points along the way.

This condition is also met if we disregard some very minor deliveries of gas at Karmøy to a local distribution company (Gasnor). The following observation is thus made:

Observation 7.72. Norwegian systems comply to a large extent with the above criteria, suggesting postage-stamp tolling to be a feasible approach, at least for major parts of dry gas transportation systems.

7.4.4.4 *Summary of this sub-section*

The main conclusion of these sub-sections and the observations listed here can be summarized into the following conclusions:

Conclusion 7.19. The existing toll formula may partly be characterized as a combined rate of return regulation and a two-part toll if the ship-or-pay volume is taken as a fixed booking charge, or it may be characterized as an average cost pricing toll if the shipped volume exceeds the ship-or-pay volume, see *Observation 7.64*.

Conclusion 7.20. The prevailing toll regime should continue to constitute the base principles for a future toll for firm transportation provided sufficient capacity exists in the system and provided the fixed part is treated as a "booking charge". This latter provision means that the shippers shall pay a fixed unit toll for booking rights in the system, see *Observation 7.67*.

Conclusion 7.21. The fixed part of the toll may include the fixed (annual) operations and maintenance costs or these costs may

alternatively be charged separately as a variable part (per unit of gas), see *Observation 7.66*.

Conclusion 7.22. *Conclusion 7.15* through *Conclusion 7.18* in Section 7.4.3.10 at page 189 must be observed. These conclusions state in sum that a unitized toll for firm capacity must be established and it must be set equal for all pipeline systems that comprise dry gas system. The entire dry gas transportation system must be treated as one zone only and entry and exit points must be established. A unitized toll for firm capacity will require either unitization of the ownership structure or a payment mechanism that secures that no shipper receives extra profit or loss due to the unitization.

Conclusion 7.23. The fixed cost element of the two-part toll is set equal to the average historic costs for all pipelines in the dry gas system and the fixed part of the two-part toll is thus the same for all dry gas pipeline systems. New incremental investments if developed must be included in the fixed part of the toll, see *Observation 7.61, Observation 7.63 and Observation 7.69 to Observation 7.71.*

Conclusion 7.24. A two-part toll shall be treated as a postage stamp toll, meaning that the same toll will be charged regardless of the routing of the gas between the entry points and the exit points of the dry gas system, see *Observation 7.72*

Conclusion 7.25. The variable part of the two-part toll must be set equal to the marginal unit cost at full capacity for a representative pipeline times the volume transported by the shipper. Alternatively the variable part of the toll can be charged as per today – "in kind", see *Observation 7.69*.

Conclusion 7.26. A two-part toll formula for interruptible services must be developed on the same format as the toll for firm capacity, but the fixed part must be set somewhat lower than the fixed part of the firm capacity toll, see *Observation 7.70*.

Conclusion 7.27. The aggregated annual revenues from the tolls (firm, interruptible and peak load) must be balanced with the regulated allowable pipeline owners' return. If the revenues exceed regulated limits the firm shippers shall be refunded or charged accordingly and

pro-rata their firm capacity - at least in theory, see *Observation 7.69 and Observation 7.44.*

Conclusion 7.28. In order to enhance cost efficiency in operations and assuming that an independent transportation system operator is established, some new incentives must be introduced in order to ensure cost efficiency in operations and incentives for optimization of the transport operations, see also *Observation 7.65*. This topic is discussed in Section 7.6.

7.4.5 Summary
In this section the hypothesis C.4 has been tested. The hypothesis states: *"It is possible to develop new economic methods and rules in order to fulfill the future economic requirements."* The hypothesis is argued to be true given the assumptions of the work. Many observations are identified and several conclusions are drawn regarding future principles for regulation, tariff and toll in a liberalized context. (These conclusions are all documented in the preceding text so they will not be reproduced here).

7.5 Allocation of spare capacity – principles, methods and toll
7.5.1 The hypothesis C.5
The hypothesis C.5 states: *"It is possible to identify solutions that are feasible from a gas flow optimization point of view by applying the GassOptTKL program."* In this sub-section the hypothesis is tested. The main issues to be derived here are some technical and operational principles for allocation of spare (and scarce) capacity, provided there is not sufficient overall capacity in the system to serve all shippers. If such principles can be produced the hypothesis is true.

The *first* activity of this sub-section is testing of the *GassOptTKL* linear programming expert computer tool. The purpose of the testing is to verify the extent to which this program can be applied as an optimization tool for optimizing physical gas flows in the integrated pipeline system.

The *second* issue dealt with is the development of a case study concerning a future situation where shippers bid for spare capacity. The case study is based on principles suggested by Nese (1998) [272] concerning auctioning of spare capacity in a network. The basic idea is that different shippers bid for capacity by selecting different options for routing of the gas in the network. Each suggested routing is accompanied by a bid regarding the

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[272] Nese (1998) chapters 6 and 7.

shipper's willingness to pay a toll for utilizing the specified pipeline segments.

The *third* part of this sub-section analyzes the physical flow patterns in the system resulting from the different shippers' choices of routing. As will be shown, it is almost impossible for a shipper to select an optimal physical routing. Different routes will yield different flows that typically are lower than an optimized flow.

Fourth, a method for calculating shadow prices on capacity constraints is suggested.

Fifth, a study case is provided that assigns economic values to the shippers' bids. By assessing the total values of the different bids some plausible principles for auctioning of the spare capacity are inferred. Finally, the last sub-section derives some conclusions.

7.5.2 The GassOptTKL program
7.5.2.1 Test data and verification of the program's accuracy

The *GassOptTKL* program has never before been applied by Statoil to solve problems as identified here. In order therefore to solve such problems a testing of the program was deemed necessary in order to verify its usefulness to solve the task identified here. The main purpose of the testing is to obtain some information on how accurately the program calculates pressures compared to real pressures and taking into consideration *transient* conditions in the pipeline system.

In connection with transportation of natural gas in the very long and highly pressurized Norwegian natural gas pipelines *transients* occur regularly. Transients may be understood to be the pressure waves moving inside the pipeline due to the fact that the gas is a compressible fluid and caused by the fact that the operator increases or decreases the linepack. Transients are present during the time it takes for the system to move from one *steady state* condition into a new steady state condition. Transients are caused by the fact that the flow into the pipeline may be set differently at a given point in time than the flow out of the pipeline.

If the flow in the pipeline is at a steady state condition, meaning that the flow into the pipeline is exactly the same as the flow out of the pipeline, and the conditions are stabilized, the *GassOptTKL* will calculate pressures correctly. This is due to the fact that the program is calibrated based on such conditions. Data from steady state transport conditions are obtained and collected during comprehensive capacity testing of the pipeline systems done from time to time by the Transportation System Operator.

The test of the program was conducted by comparing calculated

pressures from *GassOptTKL* with on line data collected from the SCADA [156] system at the Bygnes Control Center, Karmøy in a random time period chosen to be Oct. 12-17, 2000. The program was tested on three individual pipelines, Zeepipe, Europipe I and Franpipe.

The test data contains the following information from each of these three pipelines using here the Zeepipe as an example: pressure and flow at the inlet of the pipeline at Sleipner: (P-SLR) and (F-SLR) and pressure and flow at the outlet of pipeline in Zeebrugge: (P-ZBR) and (F-ZBR). These sets of four data values were obtained from the SCADA system every minute. Five sets were taken for each day and fed into the *GassOptTKL*.

The data applied, as input for *GassOptTKL* is the flow (F-ZBR) and pressure (P-ZBR) at the outlet of the pipeline and the program calculates the pressure at the inlet of the pipeline at Sleipner (P-SLR). As *GassOptTKL* calculates only steady state conditions the flow is assumed to be constant all the time. The calculated inlet pressure is finally compared with the true value at that exact same point in time and the difference between true and calculated value is presented.

7.5.2.2 Test results

The results are displayed in Figure 28 below and we can see that there are differences between the calculated pressures at Sleipner and the true values in the range of +/- 2% most of the time, with one shorter peak value of + 6%. The test results from the two other pipelines are in the same range.

When the natural gas transportation system is utilized at high deliveries the pressures are very close to the maximum allowable working pressures. In this respect the range of deviation in pressures obtained by testing the program are significant due to the existence of transients. The following observations can thus be concluded:

> *Observation 7.73.* Based on the principles for calibration of the program and the testing conducted of the *GassOptTKL,* the program will give satisfactory results for situations that are very close to steady state transportation.

> *Observation 7.74.* In relation to the conceptual discussion conducted in this research the *GassOptTKL* program can be applied for analyzing the suggested principles for allocation of spare capacity in an auction.

> *Observation 7.75.* If the program shall be applied as a daily tool some

further testing is recommended on data deliberately chosen to contain large transient conditions in order to evaluate its usefulness for conducting such tasks. Presumably there will be a need for accurate methods and predicting tools in order to establish the exact capacity that is available for auctioning from time to time.

Observation 7.76. Transients will always be present to some extent and this will inevitably affect on the possibilities for predicting the existing spare capacity at any given point in time and definitely for any point in the future.
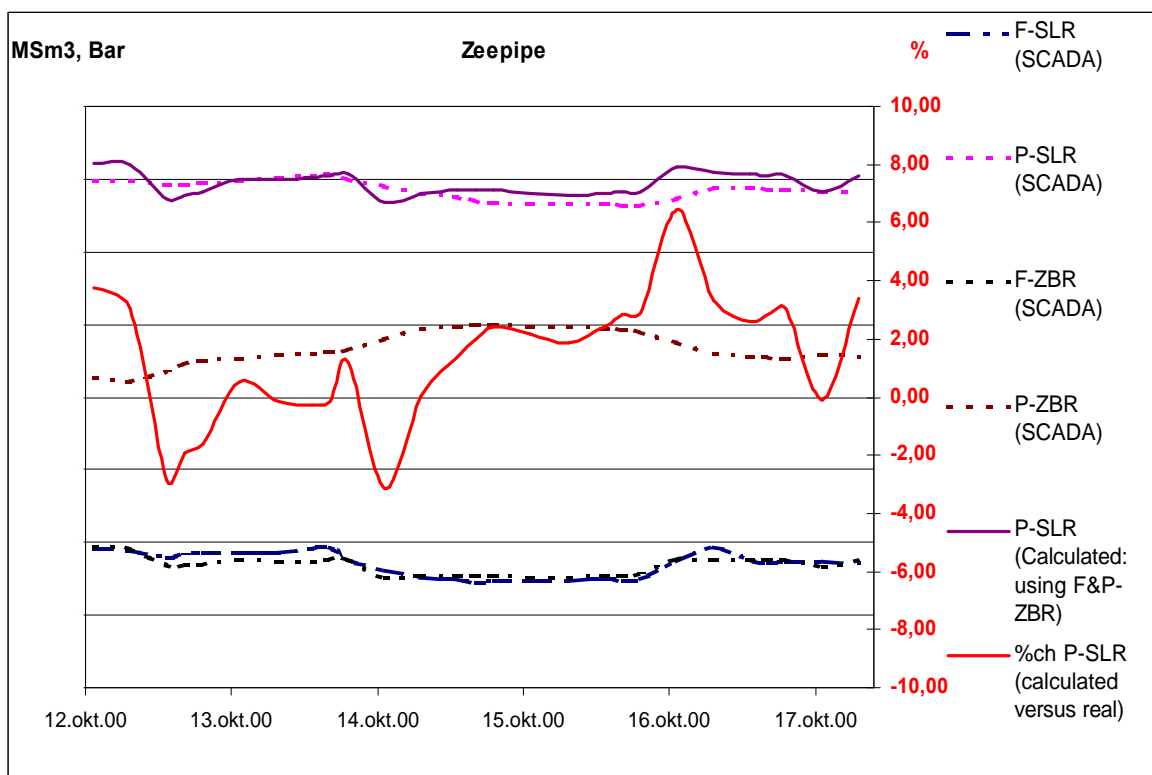
Figure 28. Testing results of GassOptTKL – Zeepipe [273]

7.5.3 Development of a test case

7.5.3.1 The initial flow conditions and stipulations of spare capacity

Prior to assessing how a specific auctioning of spare capacity can be conducted, a study case must be suggested. An initial base case is therefore suggested and presented in Figure 29 below (all flow data is in MSm^3/d).

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[273] Please note that the actual pressure and flow data are deleted on the left-hand side axis as they are proprietary information

Here, a very simplified section of the dry gas system is considered comprising the Kollsnes terminal and the pipelines shown. The spare production capacity and the pipelines' maximum design capacities are shown in Figure 29 together with the planned production forecasts for the following day.

The *GassOptTKL* has been applied to optimize the routing of the planned production from Kollsnes. This means that the presented flows in the figure below are those that cause the least pressure drops in the system. These flows are those that cause the most energy efficient routing.

If we study the information displayed in Figure 29, we see that there are apparently sufficient capacities in Zeepipe IIA and the "crossover" to transport the entire additional production capability at Kollsnes (i.e. 12) down to Draupner (Dr). It also seems to be almost enough capacity to transport this amount of gas through Zeepipe IIB as well (spare capacity is 11,6).

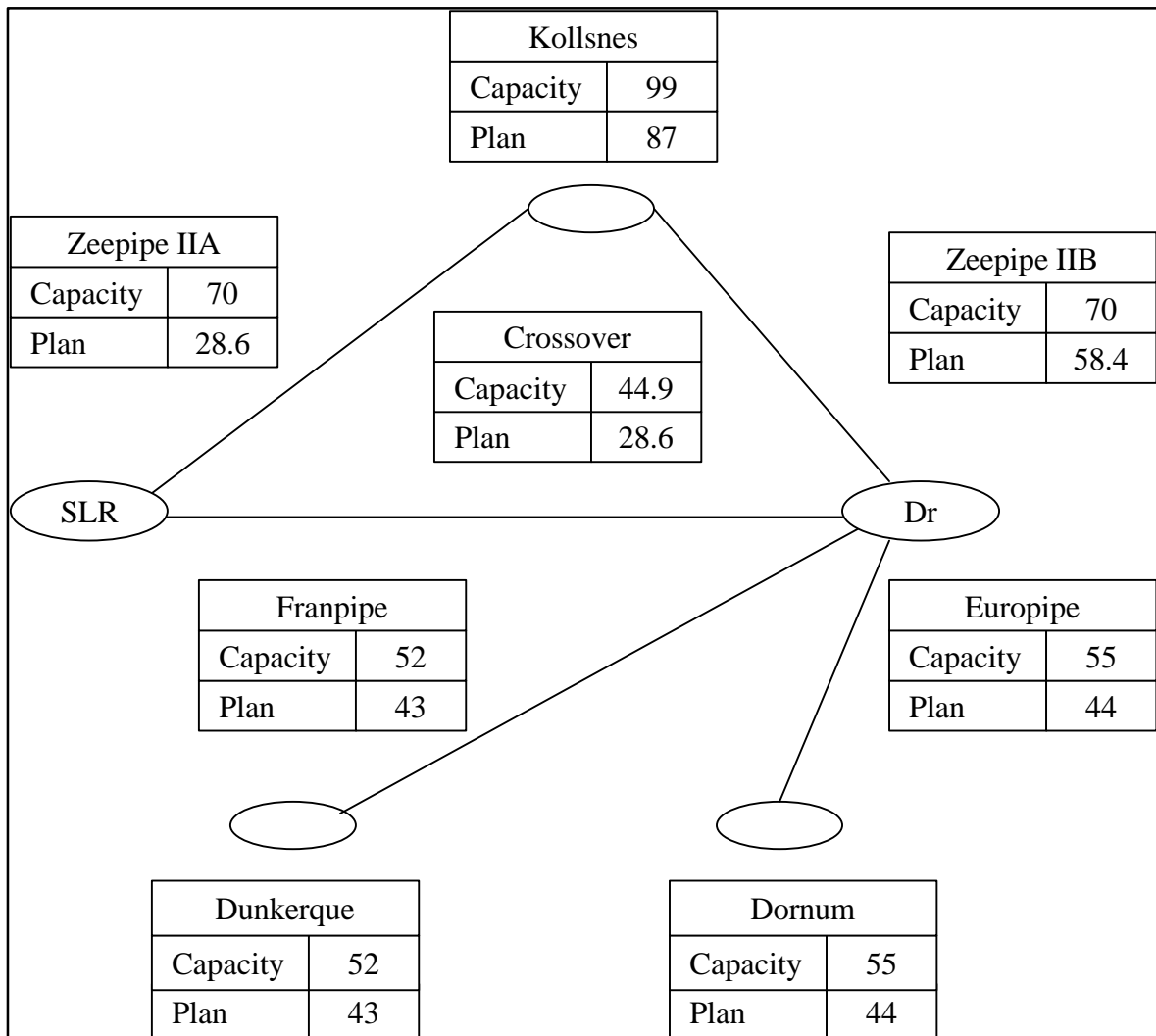**Figure 29.   *Planned transportation prior to auction of spare capacity***

7.5.3.2   The shippers bid and preferred routing

We now introduce three shippers, Shipper A, B and C. These shippers are all interested in bidding for the spare production capacity at Kollsnes and they would like to have the gas shipped to Dornum and Dunkerque. We now assume that the information displayed in Figure 29 is released to the shippers causing three bids as shown in Table 12 below.

Table 12.   Shippers' bids

	Max Cap.	Planned Prod.	Bid from Shipper A	Bid from Shipper B	Bid from Shipper C
Kollsnes	99	87	+ 12	+ 12	+ 12
Dunkerque	52	43	+ 6	+ 9	+ 3
Dornum	55	44	+ 6	+ 3	+ 9
ZP IIA	70	28.6	+ 12	+ 12	+ 1
ZP IIB	70	58.4			+ 11
Crossover	44.9	28.6	+ 12	+ 12	+ 1
Franpipe	70	43	+ 6	+ 9	+ 3
Europipe	70	44	+ 6	+ 3	+ 9

We see that Shipper A would like to bid for the total capacity at 12 and he would like to have it routed entirely in Zeepipe IIA and the "crossover" and then split in 6/6 into Franpipe and Europipe respectively. Shippers B and C have also put forward bids as shown.

7.5.4 Flow optimization

7.5.4.1   Flow results based on shippers routing

The interesting question is now to find out if it is possible – from a physical point of view – to successfully meet the shippers bids based on their suggested routing. In order to do so we have used the *GasOptTKL* program to calculate how much gas it is actually possible to transport through the system by transporting the gas in the pipeline segments specified by the bids. The results are displayed in Table 13 below.

We see that quite a substantial portion of the spare capacity at Kollsnes is not utilized due to technical constraints in the transportation system. These constraints restrict therefore a full production at Kollsnes. We also see that the different choices of routing will yield different results. In sub-section 7.5.4.3 below a detailed explanation of the results is given clarifying what is actually happening here.

Table 13. Shippers' bids and physical results

	Max	Plan prod	Bid A	Result A	Bid B	Result B	Bid C	Result C
Kollsnes	99	87	+ 12	**+ 5.3**	+ 12	**+ 5.3**	+ 12	**+ 7.2**
Dunkerq.	52	43	+ 6	**+ 3.2**	+ 9	**+ 3.2**	+ 3	**+ 3**
Dornum	55	44	+ 6	**+ 2.1**	+ 3	**+ 2.1**	+ 9	**+ 4.2**
ZP IIA	70	28.6	+ 12	+ 5.3	+ 12	+ 5.3	+ 1	+ 0
ZP IIB	70	58.4					+ 11	+ 7.2
Crossover	44.9	28.6	+ 12	+ 5.3	+ 12	+ 5.3	+ 1	+ 0
Franpipe	70	43	+ 6	+ 3.2	+ 9	+ 3.2	+ 3	+ 3
Europipe	70	44	+ 6	+ 2.1	+ 3	+ 2.1	+ 9	+ 4.2

7.5.4.2   Flow results of optimized routing

The next interesting assessment is to disregard the shippers specified routing and optimize the flow in the system only constrained by the shippers final wishes for delivery locations. Once again we optimize the flows in the system by means *GassOptTKL* and the results are displayed in Table 14.

Table 14. Optimized physical results

	Max	Plan prod	Bid A	Result A	Bid B	Result B	Bid C	Result C
Kollsnes	99	87	+ 12	**+ 9.1**	+ 12	**+ 7.3**	+ 12	**+ 8.4**
Dunkerq.	52	43	+ 6	**+ 3.9**	+ 9	**+ 4.3**	+ 3	**+ 3**
Dornum	55	44	+ 6	**+ 5.2**	+ 3	**+ 3**	+ 9	**+ 5.4**
ZP IIA	70	28.6		- 2.5		- 4.3		- 3.2
ZP IIB	70	58.4		+ 11.6		+ 11.6		+11.6
Crossover	44.9	28.6		- 2.5		- 4.3		- 3.2
Franpipe	70	43		+ 3.9		+ 4.3		+ 3
Europipe	70	44		+ 5.2		+ 3		+ 5.4

We see immediately that the optimization process will cause more gas to be transported in each case. Indeed, every optimized case yields a better result compared with any of the shippers suggested routes.

The results can be summarized as shown in Table 15 below by expressing how much of the spare capacity that is actually utilized and shipped under the different options. We clearly see that the optimized routes yield better results.

Table 15. Maximum volumes possible to deliver as percentage of bid

	Shipper A	Shipper B	Shipper C
Shippers specify route	44%	44%	60%
Optimized route	76%	61%	70%

7.5.4.3 Discussion of results

The example provided above is a simplification of reality in several quite significant ways. First, the case does not include the fact there are several other pipelines entering and exiting from the Sleipner riser platform and the Draupner riser platform. This fact means that the optimization algorithm must include the effects from all physical gas streams that enter and exit into other pipelines. These gas streams introduce pressures and back-pressures in the pipeline manifolds that are not included in the optimization done above.

Secondly, the gas quality issue is not considered at all in the example provided above. In the above example only Troll gas quality was considered. If gas streams coming from other sources are included, and the gas quality tolerance is set in such a way that it introduces constraints on the level of blending, the optimization task gets even more complicated.

Another observation to be addressed is simply the question: does this example show that it is not possible to utilize the entire production capacity at Kollsnes? The entire capacity at Kollsnes can of course be utilized if a portion of the gas is routed into other pipelines than those included here. The example however, clearly shows that it is not possible to route the entire gas stream from Kollsnes solely through the Draupner platform. This therefore inevitably leads to the recognition that the physical gas streams are all commingled gas streams comprising gas molecules originating from different sources.

Finally, what is the physical explanation of the events illustrated by this example? In order to give an explanation an illustration is provided in Figure 30 below. In this figure several lines are drawn illustrating pressures in the different pipelines.

The first step here is to study the pressures in the systems as they appear prior to the bidding process. The line between the points marked A and D represents the pressure drop line in the two pipelines Zeepipe IIB (from Kollsnes to Draupner) and Europipe (from Draupner to Dornum), see Figure 29. A and D represent the inlet pressure and the outlet pressure, respectively. At Draupner a resulting pressure equal to C will yield. Similarly, at Sleipner the pressure B is the inlet pressure in the crossover pipeline. The outlet pressure from the crossover pipeline is equal to C.

The optimization process will now start to increase flow in the system. At Kollsnes the pressure will thus start to increase and it moves from A in the direction of A*. The delivery pressure in Dornum is kept constant at D, but the resulting pressure at Draupner will increase and it moves from C to C*. The fact that the flow is increasing in the two pipelines between Kollsnes and Dornum is illustrated by the fact that the pressure drop line is shown to be more steep in the drawing (between A* and D).
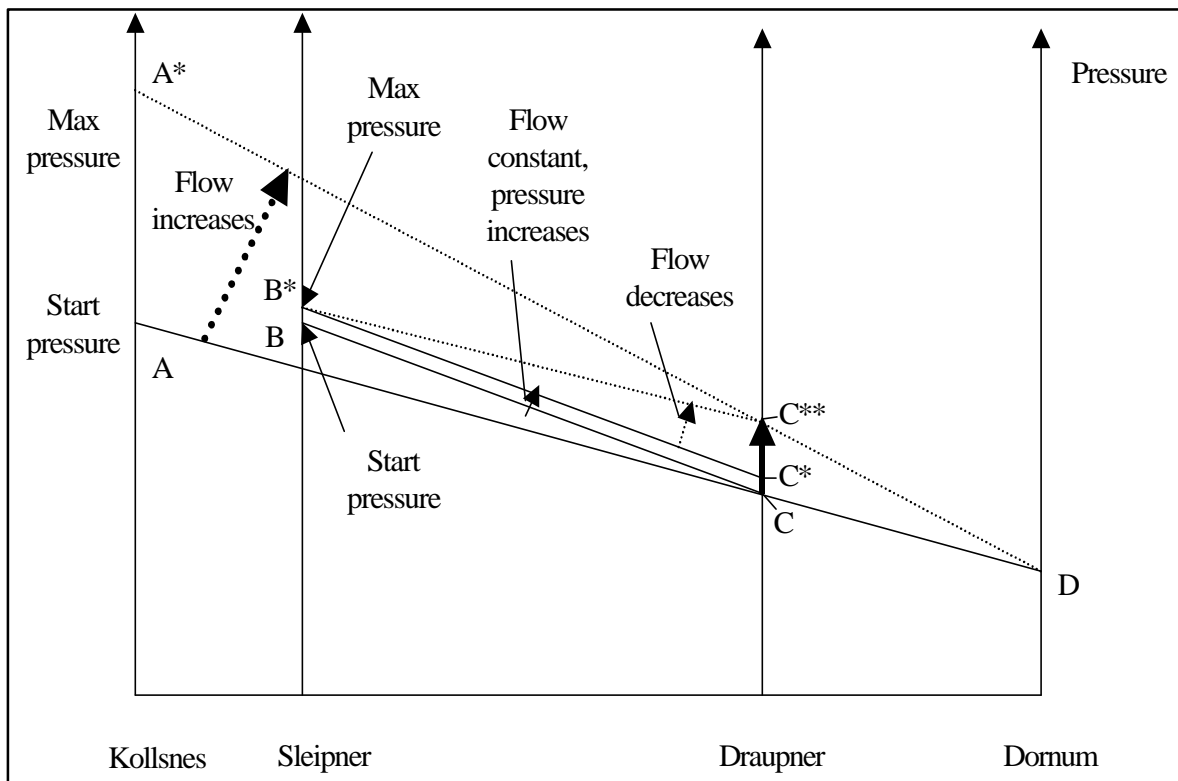
Figure 30.   Illustration of flow optimization

In order not to shut in the flow from Sleipner the pressure in the crossover pipeline must increase as well and the pressure at Sleipner moves from B to B* and the pressure at Draupner moves from C to C*. We see that at this point, and so far, no increase in flow has taken place in this pipeline, but only a lifting of the pressure (i.e. a higher level of linepack). This fact is illustrated by letting the pressure drop line between B* and C* run in parallel with the line B to C. When the pressure at Sleipner has reached the level of B* the maximum design capacity is reached in the crossover pipeline. We now realize a quite important fact:

The only physical way to increase the outlet pressure from the crossover line (from C to C**), as the pressure B* is kept fixed, is to reduce*

the flow in this pipeline. This is illustrated as the line B* to C** is less steep than the line B* to C*. The optimization challenge thus becomes to reduce the flow in the crossover pipeline simultaneously as increasing the flow in the pipeline Kollsnes to Dornum so that the outlet pressure from the crossover pipeline balances exactly the Draupner pressure at C**.

Having this technical knowledge in mind, we easily see why the resulting flows according to the shippers specified routing turned out as they did. In the case of shippers A and B, they "unfortunately" specified to have the gas routed in the "weakest link", namely the crossover pipeline. In this case the *maximum allowable pipeline design pressure* (B*) limited a higher total transportation, see Table 13. Shipper C to the contrary obtained a better result as he chose to route in Zeepipe IIB. But as the shippers, of course, are not allowed to suggest reductions in flows in specific pipelines, no optimization by means of flow reduction in the crossover pipeline took place, effectively limiting the outcome of all shippers' bids.

In the optimized case, see Table 14, Zeepipe IIB is fully utilized in all cases and the flow is at its maximum capacity of 70. We also see how *GassOptTKL* has reduced the flows in the crossover pipeline in each case. The differences between the three cases are now caused by differences in the pipeline configurations downstream Draupner, local pressure drop conditions at Draupner and the shippers' specified delivery requirements in Dornum and Dunkerque. Another way of putting it is that there is not sufficient total pressure "left" at Draupner to meet both delivery requests, and an optimization is conducted on how to use the remaining pressure capacity at Draupner. Based on these analyses, simulations and numerical examples some observations can be concluded as follows:

> *Observation 7.77.* It is not feasible or possible to let the shipper specify any preferred or optimized routing of spare capacity in the Norwegian natural gas transportation system.

> *Observation 7.78.* The Transportation system operator is the only stakeholder who shall decide how to physically route the gas in the network.

> *Observation 7.79.* The shippers are in no position to calculate and optimize the routing, as an optimization algorithm requires information that is not available to the shippers. If such information should be made available it must contain on-line SCADA information of the entire gas network and corresponding contractual delivery instructions, linepack

considerations and so on. Such information is only available to the Transportation System Operator.

A last question to be discussed here is to find out the extent to which the above observations are applicable for allocation of spare capacity that is well within capacity limits. Is it for example feasible to have the shippers suggesting specific routes for transportation of firm capacity? Again, if the shippers should be given such a right many "internal" constraints are introduced limiting the transportation system operator to optimize the total throughput in the system. The results will be the same, reduced total flow and an inefficient rationing of capacity.

Observation 7.80. The author will thus argue that the principles stated in Observation 7.77 through Observation 7.79 are valid under all circumstances, also for allocation of firm capacity.

7.5.5 *New auction principles – an example*
It has been argued in this work that liberalization will cause higher levels of system utilization or even full utilization of the entire transportation capacity during peak periods. When the system is fully utilized one difficult question is how to allocate spare capacity between shippers in a rationing efficient manner. In the proceeding text this question is analyzed by means of providing an illustrative example.

So far we have followed the idea suggested by Nese (1998) and have asked the shippers to bid a preferred routing of the gas. Nese (1998) however, identifies one possible caveat to the idea, but disregards its effect in his analyses; namely "the problem of interaction between pipelines where physical characteristics like pressure, diameter, capacity etc. of one pipeline influence on the transportation possibilities in other pipelines". As we have seen from the Observation 7.77 through Observation 7.79 above the idea of having the shippers specifying the routing is neither technically and implicitly contractually feasible nor rationing efficient.

In order therefore to suggest some possible auctioning principles that are compatible with physical characteristics and technical operations some other, very simple and basic principles for auctioning are suggested here.

The first principle is to define the level of information that shall be *released to shippers* in order to make an auctioning feasible. Based on the lessons learned above there is no reason to disclose information on pipeline pressures, internal flow rates and so forth. The only information needed is information on spare production capacity at defined production units and the

spare delivery capacities at defined delivery terminals. This implication may thus be formulated into another observation and it is shown in principle in Figure 31 below.

> *Observation 7.81.* The entire dry gas transportation system ought to be treated as one "black box" and the only information released for auctioning is the spare production capacities at defined entry points (i.e. the production platforms and terminals) and spare delivery capacities at defined exit points (i.e. the continental delivery terminals). All bidding shall take place as requests for gas to be shipped between any of these entry and exit points.
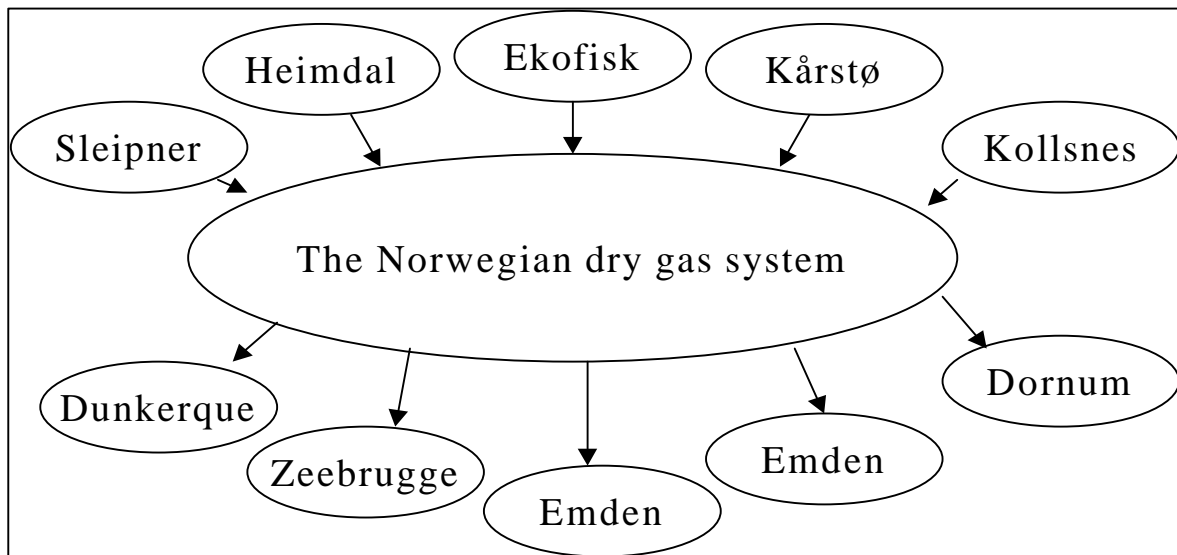
Figure 31.   The suggested entry and exit points for bidding of spare and scarce capacities in the Norwegian dry gas system

The next task is to decide *what information the shippers (the bidders) shall disclose to the Transportation System Operator*. We suggest here that they have to specify how much of the spare production capacity at a given production unit they would like to utilize. Then they have to instruct where they will have the gas delivered. Finally, they have to specify the size of toll they are willing to pay. Alternatively, they may also specify for how may days they would bid for the spare capacity.

If we now apply Shippers A, B and C's bids as posted in Table 12 and we introduce some additional information as suggested above the bids may now appear as shown in Table 16 below. We see that the shippers have included information on toll and days.

Table 16. Shippers' bids

Rate: MSm³/d	Shipper A			Shipper B			Shipper C		
Toll: øre/Sm³	Rate	Toll	Days	Rate	Toll	Days	Rate	Toll	Days
From Kollsn.	12			12			12		
To Dornum	6	20	5	9	30	5	3	28	5
To Dunkerq.	6	20	5	3	30	5	9	28	5

If no physical constraints in the transportation system should be considered (which will be a quite faulty approach as proven above) we immediately see that the successful bidder is Shipper B.

The physical constraints however are quite imperative and in each of the shippers' suggested routes, constraints are present reducing the values of the bids. For the sake of completeness, we may first see the values of the different bids given that the shippers are allowed to specify the routing. The results are displayed in Table 17 and we see that the successful bidder is shipper C.

Table 17. Value of the shippers' bids based on specified routes

Rate: MSm³/d	Shipper A			Shipper B			Shipper C		
Toll: øre/Sm³	Rate	Toll	Days	Rate	Toll	Days	Rate	Toll	Days
From Kollsn.	5.3			5.3			7.2		
To Dornum	3.2	20	5	3.2	30	5	3	28	5
To Dunkerq.	2.1	20	5	2.1	30	5	4.2	28	5
Total value	5.3 MNOK			8.0 MNOK			10.1 MNOK		

We now apply the principles suggested here and cancel out the possibility for specified routing. The flows are now optimized only on the condition that as much as possible of the production from Kollsens shall be delivered at the exit terminals (Dornum and Dunkerque) constrained by the shippers' preferences for deliveries here (i.e. this will yield the flow results shown in Table 14). The values of the bids are displayed in the Table 18.

Table 18. Value of the shippers' bids based on total flow optimization

Rate: MSm³/d	Shipper A			Shipper B			Shipper C		
Toll: øre/Sm³	Rate	Toll	Days	Rate	Toll	Days	Rate	Toll	Days
From Kollsn.	9.1			7.3			8.4		
To Dornum	3.9	20	5	4.3	30	5	3	28	5
To Dunkerq.	5.2	20	5	3	30	5	5.4	28	5
Total value	9.1 MNOK			11.0 MNOK			11.8 MNOK		

Given the assumptions listed here the successful bidder is shipper C.

Dependent on the individual bidder's choices we immediately see that a variety of outcomes are possible. We see for example, that the duration of the bid may significantly improve a given shipper's possibility for succeeding. We also see that the bid, which requires the highest level of gas production, is not necessarily the most valuable bid. We shall remember however, that even though this may take place, an optimized routing for the most valuable gas has been conducted. This simply means that there is no more transportation capacity left for other shippers to utilize.

Further, several auctioning techniques can be applied as suggested by Nese (1998). Such techniques may introduce other problem areas. For example, a recognized principle is to set the toll equal to the second best bid (the first looser), which in this case will yield a toll equal to 30 øre/Sm^3, which is higher than the successful bidder! This will presumably not be accepted and other principles must be worked out.

A detailed assessment and refining of auctioning principles will most likely call for a large debate among stakeholders and we leave this discussion here only summarizing some further observations.

Observation 7.82. The above analyses have shown that the Norwegian natural gas transportation system - to a very large extent - is to be considered as one integrated system and that actions conducted at one location in the system significantly may impact delivery conditions elsewhere in the system.

Observation 7.83. Auction theories or other theories for optimizing networks that may work well in other industries or even in other gas distribution systems may not necessarily be appropriate in a Norwegian context. Such theories and principles must be refined and they must take into consideration the specific physical and operational characteristics of the Norwegian natural gas transportation system.

Observation 7.84. In order to evaluate shippers' bid for auctioning of spare (and scarce) capacity in the Norwegian natural gas transportation systems an optimization algorithm of physical gas flows may improve the rationing task.

Finally then, and by referring to the discussions above a very basic tolling regime for spare capacity can be suggested here.

Observation 7.85. The toll for peak load capacity shall be based on an auction where shippers disclose their willingness to pay a unit toll for a specified upper limit of gas to be transported between selected pre-defined entry and exit points.

Observation 7.86. The auctioning principles must be further refined.

7.5.6 Calculations of shadow price of capacity constraints

A last topic to be discussed here is the issue of shadow prices on capacity constraints. In Hope (2000) [274] the notion of shadow prices is illustrated and discussed in relation to the power markets in Norway. By applying this notion into the present situation we may define the shadow price of capacity constraints as follows:

$$P^{SP} = Q_{NS} * T_{Auction} \qquad\qquad \text{(Eq. 7.5.1)}$$

Here:

P^{SP} is the shadow price in NOK/d.

Q_{NS} is the volume of gas that the system is not able to transport due to technical capacity constraints. This volume is thus equal to the difference between the maximum production capacity and the actual volumes shipped in each case. The unit is MSm^3/d.

$T_{Auction}$ is the value of the transportation toll offered in the bid in each case, in NOK/MSm^3.

If we apply the suggested formula in (Eq. 7.5.1) and introduce the numerical values applied in the example provided so far we obtain the shadow prices as displayed in Table 19 below. Please also note that the shadow prices are allocated to the physical facility that is representing the limiting factor as was clarified in connection with Figure 30 and the related discussion.

We see that the shadow prices yield higher numerical values for all cases where the shippers have suggested the routing, which is quite expected based on the foregoing analyses. This leads to the following observation:

Observation 7.87. The methodology suggested here might be a feasible approach in a future context for identifying the numerical values of the "bottlenecks" in the system. In this respect the auctioning principles may assist the decision making process regarding *allocative efficient*

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[274] See Hope (2000) page 75 and figure 2.

reinforcement of the facilities when and where needed. This recognition is also an argument supporting the Conclusion 7.10 on page 171, arguing that the transportation system operator must have a close liaison with those stakeholders who are responsible for the future development of the transportation systems.

Table 19. Shadow prices on capacity constraints for this example

Bids	Shadow price in "crossover" MNOK/d	Shadow price in Zeepipe IIB MNOK/d
Shipper A specified routing	(12-5.3)*.20=1.34	
Shipper A optimized routing		(12-9.1)*.20=0.58
Shipper B specified routing	(12-5.3)*.30=2.01	
Shipper B optimized routing		(12-7.3)*.30=1.41
Shipper C specified routing		(12-7.2)*.28=1.34
Shipper C optimized routing		(12-8.4)*.28=1.01

7.5.7 Summary

Based on the preceding discussions the hypothesis C.5 is true provided the gas flow is very near a steady state flow condition. If transients are present, which they are frequently, the analyses have shown that it is even more difficult to accurately predict the range of spare and scarce capacity. The lessons learned here however, and as expressed in the observations above are valid regardless of the existence of transients. If the influence of transients shall be included in the evaluations the considerations will be even more complex, a fact that reinforces the conclusion made here.

Conclusion 7.29. The *GasOptTKL* is a feasible tool for optimizing spare and scarce capacity given ideal steady state conditions. In reality, where transient conditions exist in the pipeline system, the optimization task gets more complex and a more accurate tool for flow optimization is needed. *See Observation 7.73 through Observation 7.76 and Observation 7.82 and Observation 7.84.*

Conclusion 7.30. The transportation system operator is the only stakeholder who shall decide how to route gas physically in the Norwegian natural gas transportation systems. *See Observation 7.77 through Observation 7.79.*

Conclusion 7.31. The entire dry gas transportation system must be

treated as one unit from an allocation of capacity point of view, and not as a collection of individual pipeline systems. Defined entry and exit points must be established. *See Observation 7.81.*

Conclusion 7.32. All transportation rights shall be allocated to the specified entry and exits points and the shippers shall not specify any "internal" routing. This principle applies for both firm, interruptible and peak load services. *See Observation 7.80 and Observation 7.85.*

Conclusion 7.33. Some kind of an auctioning system for spare capacity must be established. The transportation system operator discloses information on spare production and delivery capacities and the shipper discloses information on his willingness to pay toll, the volumes to be shipped between the selected entry and exit points and potentially also information on how many days he will ship gas. The auctioning principles must be further refined. *See Observation 7.83, Observation 7.84 and Observation 7.86.*

Conclusion 7.34. An auctioning of spare capacity will make the calculation of shadow prices for capacity constraints possible and thus enhance the procedures for future development of reinforcements in the system. This will also enhance allocative efficiency. *See Observation 7.87.*

7.6 Modified information models
7.6.1 The hypotheses C.6
Hypothesis C.6 specifies that *"It is possible to modify the information models so they unambiguously specify future operations".* In Section 5 information models were developed that described prevailing transport operations. The challenge is now to study how these models must be altered in order to describe the conduct of transport operations in a new regime.

The information models focused on requirement traceability and ordering of functions into working processes and the two core models applied are the requirement traceability model and the behavior model. The task now becomes to analyze how the identified new requirements will alter these two models.

There is however one significant obstacle here. As we have seen the models require detailed information and quite specific requirements in order to be constructed. The behavior model in particular is dependent on leaf-level requirements, which are the lowest level of requirements possible. Presently,

we do not have such detailed information about future requirements. This is due to the many uncertainties and pending political decisions regarding the implementation of the Gas Directive. [17] The hypothesis above has therefore not been fully tested in this work.

This work has however identified several presumable changes and new requirements demanded by liberalization and it has expressed these changes as revised effectiveness measures and test case scenarios. Further, these revised effectiveness measures and test case scenarios are analyzed. As a result of these analyses several observations are derived and these are aggregated into *conclusions*, see Section 4.3.6 and Figure 4 on page 59. Based on all the inferred conclusions the most relevant conclusions are chosen and discussed in the proceeding text. Even though it is not possible to conduct a full information modelling at this stage, an assessment of the work's conclusions – so far – will yield some insight with respect to the directions in which working processes and documents must be altered.

7.6.2 Results – modified information models
7.6.2.1 Documents and requirements that must be altered

Figure 32 is a synthesis of some of the documents and requirements that will be affected by the liberalization process addressed in this work. The results presented in Figure 32 are derived based on an assessment of Fig 1.1 – Fig. 1.10 in Volume II of the work. [147] Representatives from the Transportation System Operator have briefly reviewed the results. A detailed assessment of how to change the requirements and documents identified in Figure 32 is premature at this stage and no further detailed work on this issue is reported here. The observation made here can simply be summarized as follows:

> *Conclusion 7.35.* A majority of the documents assessed in this work must be revised and amended in order to incorporate the requirements of change caused by the Gas Directive.

C? The Petroleum Act and Decree

C? └── Transportation license application and approval process (PAD)

C? ├── Participants Agreements

C ├── Transportation Agreements and Heads of Agreements

    C ├── Interface Manuals

       C ├─ *Rules for handling of availabilities*

       C ├─ *Rules for handling of gas delivery instructions and nominations*

       C ├─ *Rules for shortfall handling*

       C └─ *Rules for trade-off calculations – nominations and instructions*

    ├── Measurement Manuals

       └─ *Rules for verifying gas energy contents of gas delivered*

    ├── Operations Philosophy Manual

       ├─ *Rules for handling of physical gas*

       ├─ *Rules for gas quality monitoring and control*

       └─ *Rules for trade-off calculations – valve set points and compression*

  C ├── Tariff procedure

    C └─ *Rules for tariffing*

  C ├── Upstream Agreements

    ├── Modeling agreements

    ├── Regularity support agreements

    ├── Substitution agreements

    ├── Supply agreements

    ├── Storage agreements

      C ├─ *Rules for upstream agreement handling [1]*

      C └─ *Rules for trade-off calculations – UA, OpFlex, linepack optimization [1] [2]*

  C └── The shipper's dispatching representative appointment procedure

      C ├─ *Rules for upstream agreement dispatching*

      C └─ *Rules for field imbalances handling and dispatch*

C └── Procedure for linepack arrangement between transportation systems and operational flexibility arrangement between fields

    C ├─ *Rules for optimization of gas sales and resource management*

    C └─ *Rules for dispatching of operational flexibility*

[1] Note: These two rules apply for all upstream agreements
[2] Note: This trade-off includes optimization of both upstream agreements and operational flexibility
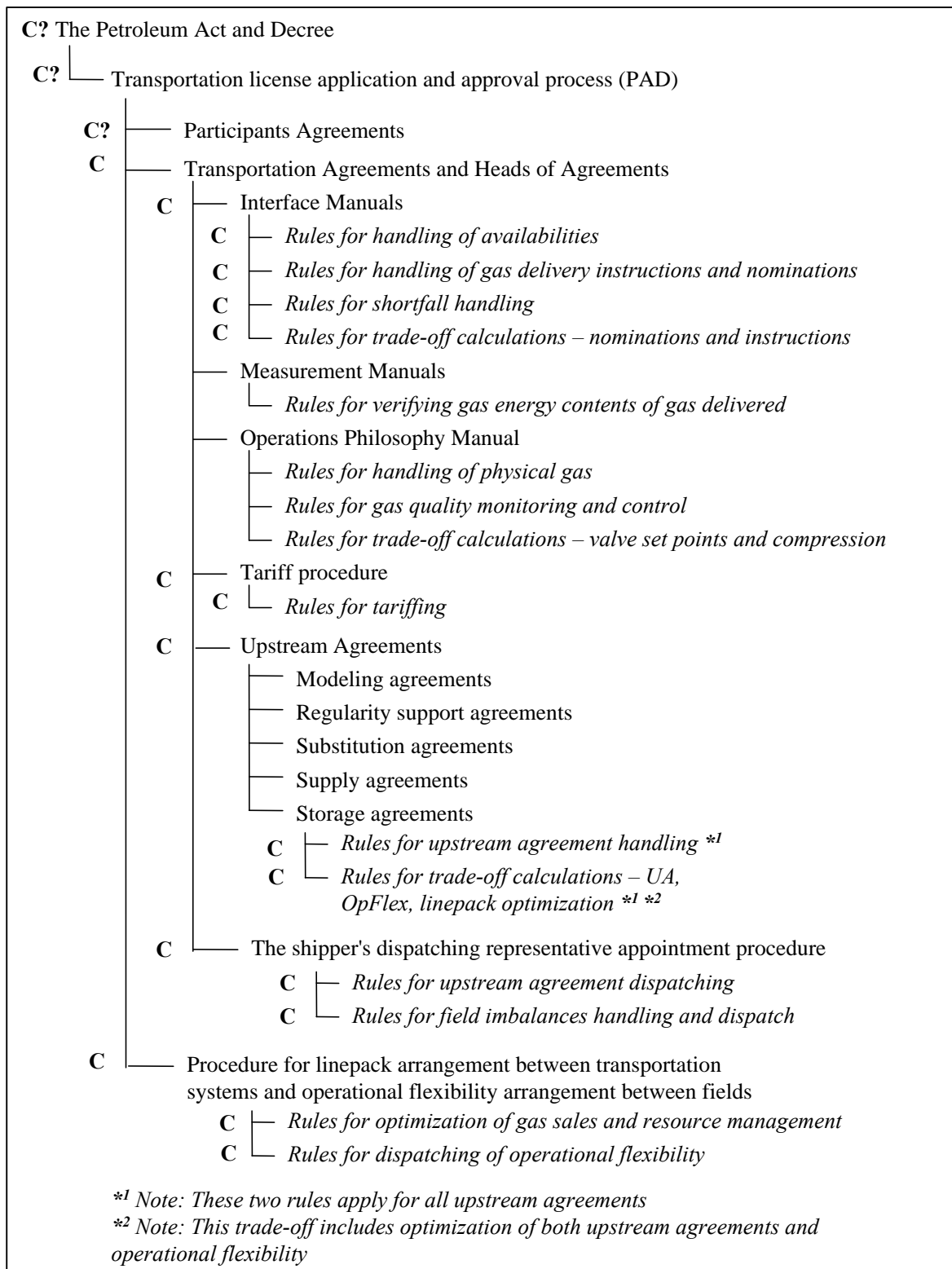
Figure 32. Indications (C) of which documents to change due to liberalization

7.6.2.2 *Organizational considerations and working processes*

The Norwegian legislation specifies a regulatory regime that causes the transport operations to be vertically integrated - as outlined in Section 5. In the current regime Statoil conducts several of these integrated functions and processes. Different stakeholders carry out different functions, but many of the stakeholder roles are allocated to the same business unit in Statoil.

The chairman of GFU is employed by this business unit, as is the secretariat in the FU. The business unit is a significant seller and it is appointed as many seller groups' representative and dispatching representative. The same organization is a major transportation system owner and it acts as the transportation system operator and shipper. It also acts as the shippers' representative and shippers' dispatching representative. The same organization unit also does similar functions regarding the gas storage currently available.

This work has clearly shown that the natural gas transport operations shall be conducted in a neutral manner, see Section 9.1 on page 236. This requirement of change will inevitably affect the existing organization one way or another. One particular area of interest for this work is the relationship between *the transportation system operator and the shippers (and sellers) including their representatives and their dispatching representatives.*

In a liberalized regime the transportation system operator and the shippers representative will represent counterparts and their interaction must be clearly defined. Today these interactions are interwoven, non-transparent and conducted by the same company in many cases. Further the transportation system operator currently carries out many of the shippers' dispatching representative functions (i.e. the same individuals hold both stakeholder positions). It is noteworthy to remember that the B.0 activity concluded that these relationships were difficult to identify clearly and accurately in the present regime.

By studying the requirement traceability model (Fig. 1.6 of volume II) and the behavior model (Fig 3.2 of volume II) we identify another issue of interest. We see that the optimization process is quite dependent on *the successful dispatching of the upstream agreements and the dispatching of the operational flexibility and use of linepack.* There are many documents developed to support this optimization and dispatching. The transportation system operator must probably develop more transparent services for handling of Upstream Arrangements and the like to meet the requirements of liberalization.

Further, if the transportation system operator shall handle and keep

accounts of the gathering of gas at the field for each individual shipper a new and quite expanded accounting system must be developed together with new balancing rules.

The above observations lead to the following conclusions:

Conclusion 7.36. The current organization must be changed and a more specific regulation is required regarding the future roles of the transportation system operator and the shipper/seller representatives and dispatching representatives. These stakeholders will be formal counterparts in a liberalized regime and no longer members of the same organization unit as they often are in the prevailing regime (in Statoil).

Conclusion 7.37. As the above stakeholder relationships closely interact with quite essential and complicated working processes for optimization of transport operations and resource management in daily operations, new working processes and means for interactions between stakeholders must be carefully designed so that these goals are still met in a liberalized regime.

7.6.2.3 Incentives for conduct of work

In Section 7.4.3 it has been shown that the current regime normally features incentives for cost efficient investments and operations – at least conceptually. Further, this work has shown that the vertically integrated structure gives incentives of optimizing operations in order to achieve a high regularity in gas deliveries and optimized production of hydrocarbons from the NCS.

The interesting question is now to study how these incentives will be altered if an independent transportation system operator is established. The following incentives may probably be affected:

- Incentives for cost efficient development of new capacity.
- Incentives for cost efficient operations (dispatching and administration) and product management.
- Incentives for cost efficient inspection, repair and maintenance of the pipeline systems.
- Incentives for optimizing operations during periods of capacity constraints and peak periods.

Generally, the problems identified here are of the principal/agent type,

as discussed by Pratt and Richard (1985). [275] No detailed analyses will be presented here of these types of problems and their solutions. In the following text only a brief review of some of the issues is presented and some indicative solutions are suggested in order to correct the distortions. These topics will definitely be subject for further analyses when future requirements are settled.

Proper incentives for the task identified in the *first bullet point* may largely be maintained as they are today, provided the regime of having shippers also being owners persists. This assumption is based on the fact that regardless of who operates the system, the toll (as suggested in this work) will be a function of costs. As long as the majority of the shippers at the same time are owners the incentive for cost efficient investment, as discussed in Section 7.4.3, is in place.

There is however one important note to be made here. This work has identified that there is a need to have a well functioning transfer of operational information to the developers of new capacity. This is true whether the capacity needed is removal of bottlenecks or substantial development of new capacity. As liberalization may split the currently integrated organization into two or more functionally separated organizational units some new routines must be developed so that important operational aspects are communicated to the development projects. For further details see Section 7.4.2.9 on page 158 that discusses transaction costs in relation to liberalization and Observation 7.39 on page 159.

The incentive mentioned in the *second bullet point* is of less importance, as the cost contributors are small numbers in relative terms and they contribute very modestly to the toll. Further, such costs are quite transparent and they are subject to limited managerial influence.

The topic identified in the *third pullet point* however, may cause some conflict of interests under given situations and ought to be closely looked into. These costs also represent large portions of the daily operations and maintenance costs, see Section 7.4.2.3 on page 139.

If we assume that an independent inspection and repair agent on behalf of the transportation system operator conducts this activity, but is paid by the shippers, improper incentives exist for cost efficient work by the agent. This may be so if the transportation system operator is allowed to pass on to shippers the agent's fee. The transportation system operator will then be indifferent with respect to the agent's size of the fee. Conceptually one may also argue that he may be indifferent to the quality of the agent's work, as the pipeline system itself does not belong to the company, but to the

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[275] Pratt et al. (1985)

shippers/pipeline owners. As such inspection is closely related to the safety and integrity of the facilities, correct lines of responsibilities and incentives must be sorted out.

The *fourth and last bullet point also represents a condition that should be carefully looked into*. The costs of potential losses of wrong operations may be significant. A potential lack of motivation to optimize the operations under periods of capacity constraints may in a similar manner cause reductions in revenues for shippers and gas sellers. See Section 7.5.6 on page 217 where some numerical data was presented illustrating the value of constraints. Today there are good incentives for operational optimization due to the vertically integrated structure of the industry.

In the future, proper incentives for optimization of the throughput must be designed, as this probably will be more important than ever before. If we assume that the transportation system operator should be functionally separated from the gas sales activities, his only revenues will be the toll or part of the toll. This will cause reduced incentives for optimization if the operator's revenues and costs are regulated and his performance is no longer directly influencing on his revenues and profit.

The incentives for optimal usage may be even further deteriorated if the independent transportation system operator shall have its cost covered by annual budgets from, let us say, the Norwegian State [276] – with no linkage to performance at all.

The author will therefore suggest that an incentive structure must be introduced in such a way that the operator is measured and rewarded based on his ability to optimize operations. In this respect, at least two issues are of concern. The first issue is to make sure that the shippers obtain deliveries according to their daily instructions. Here, a feasible method can be to reward the operator according to his ability to meet the shipper's request for deliveries. A possible mechanism can be to apply the regularity measure. A high annual regularity may thus trigger a reward.

The second issue is to create an incentive that motivates the operator to utilize the spare capacity of the system, see Figure 27 on page 197 - whenever needed. Here, for example a reward can be offered as a function of the volumes being auctioned. The higher the aggregated annual value of the auctions is the higher the reward. For further details regarding incentive regulations see for example Mansell et al. (1995). [277]

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[276] This is suggested in the St. prp. 36 (2000-2001) page 122 – 123.
[277] Mansell and Church (1995) and Armstrong et al. (1994) provide an overview of alternative regulations that aim to improve the performance of regulated firms.

To summarize this discussion a simple conclusion is drawn:

Conclusion 7.38. The regulator must carefully design proper incentives that enhance optimization of the physical flow in the transportation system given a liberalized regime.

7.7 Trade-offs performed

The hypotheses C.7 states that: *"The systems engineering process will provide means for making satisfactory trade-offs between identified requirements and solutions in order to obtain consistent information models and unambiguous descriptions and solutions"*. There are at least two implications of this hypothesis. First, and as was discussed in connection with the system re-engineering process, there will always be a need for doing trade-offs in order to develop information models, see Section 5.5.6 on page 94. As no detailed information modelling of future operations is conducted, no such trade-offs are identified.

The second implication relates to all the trade-offs that have become apparent throughout the conduct of this multidiscipline work. Several such trade-offs are identified and are noteworthy. The author will thus argue that the systems approach features a possibility to identify and treat such trade-offs in an efficient manner. Some prominent trade-offs are listed below accompanied by a short description. As all these tradeoffs are analyzed and discussed in the work, no detailed review is repeated here.

- *Energy conservation and profit maximization.*
  As we have seen from our discussion with linepack considerations the potential profit from gas sales far exceeds the variable fuel costs, making energy conservation a second priority in most cases.

- *Shippers freedom to select routing versus physical optimization of routing.*
  Ideally, one may argue that shippers shall have the freedom to choose their own routing of where to ship gas in the network. As we have seen, this may however cause physical constraints and reduce overall throughput. The shippers must therefore be offered a limited possibility for choosing the routing of the gas in the network.

- *Cost coverage versus first best tolling rules.*
  As we have discussed in great detail many arguments and contradicting

requirements must be balanced in order to obtain a feasible tariff and toll regime. Such discussions are also largely influenced by the outcome of political decisions and as specified in the legal and statutory documents.

- *Reduced efficient tolling due to information asymmetry.*
  Another area of concern is asymmetry in information. As has been discussed several times in this work toll rules that by nature feature attractive qualities are in many cases simply not applicable. The main reasons are lack of information or restricted possibilities for release of such information due to many reasons.

- *Improper incentive structures due to information asymmetry.*
  By the same token as specified in the preceding bullet point, may it be difficult to create incentive structures that motivate an agent to comply with all of the principals' whishes.

- *Constraints given in legal documents and the Gas Directive and political outcome versus ideal solutions.*
  In this work the legislative documents identified are treated as a matter of fact, and the solutions suggested are incremental steps that are building on these documents. The solutions suggested may thus be categorized as an "evolution" rather than a dramatic "paradigmatic" change. From an analytical point of view it can be interesting to perform analyses based on ideal conditions alone by disregarding existing law and regulations and all the stakeholders' existing documents such as gas sales agreements, transportation agreements and upstream agreements. A "trade-off" has therefore to be done in order to decide whether the research shall largely be based on ideal cases rather than the real cases. The latter has been focused in this work, as the former option would have broadened up the scope of the work too much. See Section 8.2 on page 231 for further discussions of this topic.

- *The producer interests versus consumer interests.*
  Another major issue is of course the classic difference in interests between the producer and the consumer. In this industry these stakeholder interests largely follow the national borderlines. These type of conflicts are not discussed in this work in great detail, and again, the prevailing legislative documents, including the Gas Directive is treated as a matter of fact with respect to the research activities conducted.

7.8   Summary

The hypothesis C.0 states that: *"It is possible to develop a systems engineering process for assessing, specifying and documenting future operations"*. The process is documented in the preceding text and a very brief summary of the process is captured below.

As we have seen by the discussions and analyses of Section 6 hypothesis C.1 is true. In Section 7 the remaining hypotheses have been tested, and C.2 was argued to be true as redefined effectiveness measures were developed. This statement is made on the condition that the Gas Directive will be implemented in a Norwegian context. By the same token, hypothesis C.3 is true and two scenarios of change were developed.

In Section 7.4 many analyses are conducted based on empirical data and by applying technical and economic theory. The main purpose of these analyses has been to derive some plausible methods and basic principles for suggesting a new or revised tariff and toll regime applicable for Norwegian dry gas transportation in a liberalized regime. Given the uncertainties caused by the still not implemented Gas Directive the hypothesis C.4 has still been tested. The testing has suggested that new tariff and toll rules including amendments to the existing tariff regime should be enforced and hypothesis C.4 is argued to be true.

Similarly, new tariff and toll rules are suggested for allocation of spare capacity and the hypothesis C.5 is thus argued to be true. Finally, the hypothesis C.6 and C.7 are looked into, but these hypotheses are not tested fully.

Given the above conclusions the author will argue that the hypothesis C.8 is true as far as it is possible to conclude given the uncertainties that exist in the present situation.

8   Discussion of results

8.1   A systems approach for solving complex problems

It is tempting to begin this sub-section by borrowing some few words from Carpenter, Jacoby and Wright's (1986) report "Adapting to changes in natural gas markets." This report starts out with the following quotation taken from Morris A. Adelman's work of 1962:

"With constant changes in supply, demand and technology, relative advantages must change, and some fuels or demands or sellers are under pressure to give ground to others… An orderly retreat is, of all military maneuvers, the hardest to carry out."

The above quotation seems to reflect – and so do also the conclusions of the said report – that liberalization in energy markets will not come easily. Such processes are difficult to handle and conflicts may arise between stakeholders.

As we have seen in this work, there certainly are many stakeholders involved and many questions and analyses are needed to get a comprehensive understanding of the tasks at stake. It is thus assumed that the lesser asymmetry in information there is between stakeholders, the easier the transition may be. This, solely is of course no guarantee of a smooth transition (e.g. the information can deliberately be misused by the counterpart). A reduced level of asymmetry however, may contribute to reduce the level of misunderstandings and it may point to what is considered as relevant discussions and analyses and so forth.

Further, in the INCOSE' 99 paper (Dahl 1999) the author concluded that the strength of a systems approach lies in its ability to identify the stakeholders' needs and systemize many requirements. Based on the systems approach real problems are identified and in the systems engineering process appropriate methods and analyses are conducted in order to find solutions to the problems. The process includes multidisciplinary analyses and these are needed since the decision-making and the trade-offs done in this industry – and particularly during transition stages – involve multidisciplinary characteristics.

This work has therefore focused on collecting, assessing and systemizing information. The information is used to identify the real problems as accurately and comprehensively as possible. Having identified the

problems, a search for relevant analyses and models is conducted so that the problems can be solved adequately.

The main reason for why the chosen systems approach has been applied may be summarized in the following statement, which also may be understood as a presumption governing this work:

"A systems approach will yield more comprehensive, accurate and relevant analyses and results that satisfy the stakeholders' needs, compared to what is obtained by field specific methods and "stand alone" approaches."

This statement is argued to be true because the systems approach has an inherent feature of assessing all information and requirements relevant and it includes multidisciplinary research. These points are illustrated in Figure 33 below.
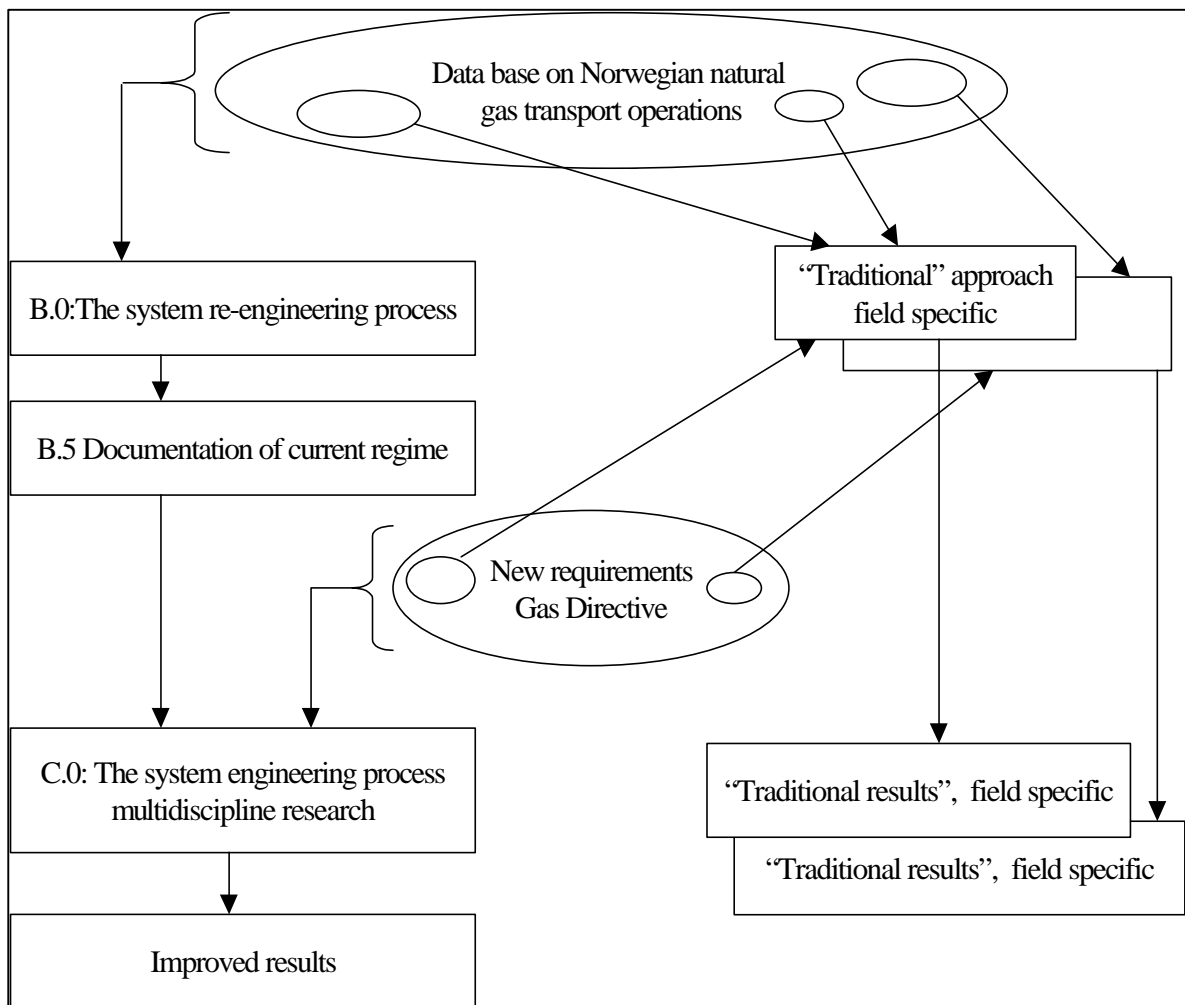
Figure 33.   *Improved results caused by a systems approach*

There exist technical, legal, institutional, economic, public and private information and requirements that all together may be characterized as an entire database regarding prevailing Norwegian natural gas transport operations. Then it exists an information domain related to the forces of change such as those given by the Gas Directive. "Traditional field specific approaches" will then – at least conceptually – make a selection in the information domains and pick out those requirements, which are deemed relevant for the field considered. Such approaches will therefore not include solutions based on considering *all* requirements mutually. The outcome is field specific results that only partly solve the problem, or they solve it inaccurately or insufficiently.

The systems approach however, seeks to assess all information and requirements available and then identify the most important problems to be solved multidisciplinary. The brackets in the figure indicate this idea.

8.2   Improved results caused by the systems approach

The question now becomes: is the statement above true – has the systems approach really yield more correct results than what we could expect as the outcome of a traditional field specific analysis? This is a difficult question to answer because the topic chosen in this work is very complex and the academic fields applied are all huge and complex disciplines. A full assessment of the validity of the statement above will thus be – in the author's opinion – a major task to prove. A full assessment of the issue would go beyond the scope of this work. There are however several observations made throughout the course of this work that indicate the correctness of the statement above. These observations are summarized and listed below.

Observation 8.1: The systems approach has made it possible to supplement economic models with relevant technical knowledge and analyses, and thereby improving the analyses and the results.

Many network utilities are constrained in specific ways due to the nature of the technology applied. Transportation of natural gas in pipelines has some quite specific characteristics in general and the integrated Norwegian sub-sea pipeline transportation system has its own fairly unique features in particular. These features must inevitably be observed when a regulatory regime shall be designed for tariff and toll purposes.

One illustrative example to this effect is the discussion of auctioning principles for spare capacity. As was pointed out in Section 7.5.5 a recent economic research report by Nese (1998) has suggested some auctioning principles based on the assumption that there are *no* "interactions between

pipelines." The technical analyses conducted here have shown that there are indeed significant interactions. This work has therefore suggested some methods for auctioning of spare capacity, which observe the effects of interacting pipelines.

Another topic often discussed in the literature is the marginal cost of transportation. There is however no detailed analysis in the literature assessed by this author, clarifying the exact nature of the marginal cost function for transportation of natural gas in a pipeline system. This work has therefore developed some general equations of marginal cost based on the compressor power equations.

The exact marginal cost equation has enlightened the discussions as it provides answers to several interesting questions. It has been shown for example, that it is no difference in marginal cost for shippers in the same pipeline system. It has been shown that three parameters typically influence on marginal cost, i.e. the fuel cost for the compressor drive, the gas delivery rate and the delivery pressure. It has been shown that the marginal cost largely exhibit constant return to scale. And lastly, having developed the marginal cost function, true marginal costs for some selected Norwegian pipeline systems are calculated by applying empirical data.

Observation 8.2: The systems approach has made it possible to supplement economic models with relevant empirical data and operational experiences, and thereby improving the analyses and the results.

The systems approach has provided the research with correct empirical data and relevant operational experiences. [278] This has made it possible to obtain more knowledge on specific problems. Such problems have so far been treated only conceptually in the literature or in some cases have the issues not even been identified as potential problems that must be solved.

Some illustrative examples are the analyses of the break down of costs into average costs, marginal costs, fixed costs, operational costs, and so on. Other illustrative analyses are carried out based on empirical data such as for example the linepack calculations, which compare costs, revenues and energy consumption or the calculations of economy of scale and declining average cost benefits.

Operational experiences are also relevant for other discussions initiated by liberalization. Based on operational experience it has been shown for example, that no shipper is a solely independent shipper in a pipeline, not

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[278] Please note that the data applied is normally taken from the public domain, see Section 2.4

benefiting from services of other pipelines. Similar arguments, based on operational experience, are used to suggest important tolling principles such as unitized toll and postage stamp tolling.

Observation 8.3: The systems approach has made it possible to supplement economic models and analyses with legal insight

This topic is considered by the author to be quite essential as the systems approach effectively clarifies and narrows down the research into relevant problems derived from the given legal requirements.

In the economic literature many potential effects of liberalization are discussed. These discussions range typically from very broad analyses to quite specific assessments and they are related to many key questions such as regulation, organization and economic efficient development and utilization of the industry. It is also a fairly comprehensive literature available discussing and documenting foreign experiences. Finally, it is also a rich literature available regarding related topics in other utility industries such as for example the power industry.

A researcher seeking concrete solutions, that can be implemented practically and realistically in a given context, may find it difficult to identify which research issues that are most relevant and significant. Faced with the huge scientific background and collection of experiences is it not straightforward to identify neither the most important problems to be solved nor their solutions.

The systems approach copes with such challenges as it narrows down the research domain by identifying current and future legislative requirements. These requirements are taken as a matter of fact (i.e. the requirements of the Gas Directive must be complied with and the applicability of the requirements as such are *not* subject for the research).

This method implies that prior to initiating a specific economic in-depth analysis an initial evaluation is done regarding the applicability of the analysis. If for example the *input* information required by the analysis is proprietary or unavailable, difficulties may arise regarding its applicability and the analysis may rather not be performed.

An illustrative example to this effect is the discussion of Ramsey pricing. As we have seen, any introduction of Ramsey pricing will result in many negotiations and legal discussions caused by the fact that Ramsey pricing is a move away from the existing agreements, legal foundation and licensing system. Further, Ramsey pricing is likely not compatible with the Gas Directive. The discussion of the Ramsey pricing thus illustrates the importance of including legal aspects into the analyses if the aim is to find

practical solutions.

The last issue to be mentioned is the fact that the systems approach incorporates a detailed assessment of the legal and constitutional aspects and this may prevent misunderstandings and too simplified perceptions of the problems to be solved. One illustrative example was given in Section 7.4.3. Here it was shown that the typical economic notion of weak incentives for cost efficient investments caused by average cost pricing is not necessarily always true. Even though some authors claim that this fact is yielding in a Norwegian context, a closer look has revealed that this condition does not exist as long as the pipeline system owners are also pipeline system shippers. And as this normally is a matter of fact in a Norwegian context, proper investment incentives exist even tough average cost pricing is applied. This regime will also continue to give proper incentives for cost efficient investments in a liberalized context, if this regulatory principle is maintained.

Observation 8.4: Information models.

In Conclusion 5.11 on page 98 it was argued that the information models were able to capture and describe more correctly the working processes of the current operations than any other method applied by the stakeholders of the industry in Norway so far. The requirement traceability model and the behavior models provide an overview of the complexity of transport operations that has not been documented before.

The systems approach has produced results that more comprehensively and accurately than traditional methods specify which working processes and functions that must be changed, given the Gas Directive. Similarly, an indication is provided of where to change documents.

Summary of this sub-section

The analyses conducted in this work have been constrained by requirements of prevailing and future regulatory regimes. The discussions are tried to be quite specific and focused on the identified problems. In other words, the analyses are not "opened-up" too broadly or made too general by nature. This has been done quite deliberately in order to adhere to the main objectives of the work.

In the author's opinion the chosen approach both represents a potential weakness as well as strength. Due to the fact that the analyses are kept fairly close to what is assumed to be a realistic development, potential benefits and insights from more general and basic analyses are not included in this work.

As an example, "in depth" analyses could have been carried out regarding toll principles. One suggestion is a transfer of the ownership of the

pipelines fully to the State. In this case the effect of tolling versus revenues obtained by taxation could have been analyzed. Such analyses could evaluate the effects on state revenues under different assumptions of national and international shippers being served.

On the other hand, the author thinks that the chosen approach represents strength. This view is based on the fact that the discussions conducted are relevant for the present problems. The topics chosen are carefully derived by means of the systems approach. The analyses conducted and the solutions suggested are also supported by relevant experiences from elsewhere. [279] The suggested solutions may therefore be thought of as minimum solutions representing incremental steps in the evolution of the European gas market.

A final note to be made here is that some authors in the "economic" literature domain also recognize the importance of the above observations. Such authors point to the importance of holistic, multidisciplinary and systems approaches. Some few examples are Megdal (1998), Kaijser (1988) and Smith (1998). These authors point to fact that several different disciplines must be approached in order to analyze effects of de-regulation in energy markets.

Hobbse et al. (1997) point to the importance of multi-criteria decision-making approaches in order to quantifying stakeholder values. Blumstein et al. (2000) in their abstract state that such approaches "stresses the importance of theory-based market transformation, with tight linkages between existing theory, program design, empirical testing of crucial assumptions, evaluation, and theory development. Feedback and iterative learning are involved at all stages. Because a clear understanding of market dynamics is crucial to this approach, multidisciplinary research plays a key role".

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[279] In a report prepared for the European Commission by "The Brattle Group" (2000) similar ideas as those derived here (i.e. two-part tolls) are discussed as possible recommendations in a European context. See
http://www.brattle.com/articles/method_gas_europe.pdf

9 Conclusions and future research

9.1 Conclusions

The main hypothesis tested in this work is:

"It is possible to operate future Norwegian natural gas transportation systems at a level that is approximately optimal, technically and economically, with major stakeholders duly attending to requirements specified in the Norwegian statutory framework and in the implemented "Gas Directive."

Based on the testing of the preceding sub-hypotheses, the analyses conducted and the conclusions derived in this work, the author hereby concludes that the main hypothesis above is true provided the following five *recommendations* are observed.

Recommendation 1 - regarding implementation of the Gas Directive

The prevailing regulatory regime governing Norwegian natural gas transport operations has been assessed and analyzed in a systematic manner [1.1]. [280] It has been documented that the current transport operations enhance resource management [1.2] and that the operations comply with all major success criteria identified [1.3]. It has been documented that the transport operations are vertically integrated with production and sales activities [1.4] and that the services to the customer are "bundled and merchant" [1.5].

It has been documented that the prevailing Norwegian legislative regime does not generally comply with two distinct and imperative conditions *assumed in this work* to be required by the Gas Directive:

- The prevailing regime does not normally feature a possibility for domestic gas sellers to compete in the downstream market by marketing and selling their gas individually [1.6].
- The prevailing regime does not normally feature access to the transportation systems for those shippers who according to the Gas Directive are defined as "eligible customers" and "natural gas undertakings" [1.7].

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[280] The figures in the brackets refer to the bullet list below where all conclusions supporting the statement are listed.

Therefore, and provided it is a Norwegian political objective to comply with the requirements of the Gas Directive, the Gas Directive must be implemented into Norwegian legislation in order to comply with the new requirements.

The above recommendation is inferred from the following conclusions of the work:

- [1.1] Conclusion 5.1 through Conclusion 5.4 on page 96.
- [1.2] Conclusion 5.13 on page 99.
- [1.3] Conclusion 5.5 on page 96.
- [1.4] Conclusion 5.6 through Conclusion 5.8 on page 97.
- [1.5] Conclusion 5.14 on page 99.
- [1.6] Conclusion 5.9 on page 97, Conclusion 6.1 on page 113, and Conclusion 7.1 on page 125.
- [1.7] Conclusion 5.10 on page 97, Conclusion 6.2 and Conclusion 6.3 on page 113 and Conclusion 7.9 on page 131.

Recommendation 2 - regarding development of new transportation services

In order to facilitate access to the Norwegian natural gas transportation systems for all eligible customers and natural gas undertakings (i.e. the stakeholders qualifying to be future shippers) the future regulatory regime must observe the following recommendations:

- An organization unit that has a transparent account of its transportation services must operate the transportation systems. Alternatively, the operations must be carried out by an organization that is functionally separated from, and does not participate in, any gas marketing and sales activities [2.1].
- Due to the fact that the Norwegian natural gas transportation systems are highly physically integrated [2.2] having one and only one transportation system operator is normally the best solution for enhancing cost efficiency in daily operations, energy efficiency, resource management in daily operations, optimized utilization and optimized gas blending [2.3].
- The transportation services must be designed to meet the future needs and requirements of the shippers and they must be offered to all

shippers [2.4].

The above recommendation is inferred from the following conclusions of the work:

- [2.1] Conclusion 6.4 on page 113.
- [2.2] Conclusion 5.13 on page 99.
- [2.3] Conclusion 7.11 on page 172.
- [2.4] Conclusion 7.2 on page 125.

Recommendation 3 – regarding development of new tariff and toll regimes

The future transportation services must comprise firm service i.e. booked and guaranteed transportation, and interruptible service i.e. transportation being interrupted either during off-peak periods or during peak periods and presumably also peak load service [3.1]. The services must be offered to all shippers in an equal and impartial manner [3.2]. The services must be supported by a transparent and feasible tariff and toll regime [3.3]. The toll regime must feature several properties that ensure cost recovery of fixed costs, cost efficiency in operations and maintenance, and rationing efficiency [3.4]. The toll regime suggested in this work must be just, reasonable and fair [3.5] and cost-based [3.6].

This work has identified that the existing toll regime does not feature all of the above properties [3.7]. This work therefore suggests that the existing toll regime is re-designed and extended to include new elements so that the future toll regime features these properties. Such properties are needed in order to meet the future shippers' requests for services.

The future toll regime must support services offered as firm transportation
- The existing toll formula may partly be characterized as a combined rate of return regulation and a two-part toll if the ship-or-pay volume is taken as a fixed booking charge, or it may be characterized as an average cost pricing toll if the shipped volume exceeds the ship-or-pay volume [3.8]. This toll regime may continue to constitute the base principles for a future toll for firm transportation provided sufficient capacity exists in the system and provided the fixed part is treated as a "booking charge". This latter provision means that the shippers shall

pay a fixed unit toll for booking rights in the system [3.9].

- The fixed part of the toll may include the fixed (annual) operations and maintenance costs or these costs may alternatively be charged separately (per unit of gas) [3.10].

- The variable part of the toll may be set equal to average marginal costs per unit of gas, or be paid "in kind" as done in the current regime [3.11].

- New incremental investments in system capacity, if developed, must be included in the fixed part of the toll [3.12].

- A unitization of the fixed part of the toll is suggested here. The unitization schema shall include the existing ship-or-pay contracts and any new firm contracts. The unitization will accomplish a possibility for eliminating specific shippers' preferences for where to physically route gas in the system. This will subsequently improve *rationing efficiency at high levels* of utilization of the system when there is a concurrent need for auctioning of spare and scarce capacity [3.13].

- The unitized toll for firm capacity must be set equal for all pipeline systems that comprise the entire dry gas system. The dry gas transportation systems must be treated as one zone only and specific entry and exit points must be established. [3.14].

- The fixed part of the toll must be calculated based on average historic investment costs of all dry gas systems included in the unitized schema. Further, the fixed part of the toll formula as well as the variable part shall be allocated as a postage stamp toll (i.e. the same toll applies regardless of the transportation route in the system) [3.15].

- A unitized toll for firm capacity will require either unitization of the ownership structure or a payment mechanism that secures the shippers no extra profit or loss due to the unitization [3.16].

- In the prevailing regime the individual companies act normally both as shippers and pipeline system owners. This regime ensures proper incentives for cost efficient development of new capacity and cost efficient operations and this regime may continue to exist in a liberalized context [3.17].

The future toll regime must support interruptible services for off-peak periods

- A new two-part toll formula that in its form is equal to the firm capacity toll must be developed for covering interruptible off-peak services. The fixed part of the interruptible toll must be set lower than the fixed part

of the firm toll [3.18].

The future toll regime must probably provide services for peak load periods
- A new toll must probably be developed and be based on auctioning principles for allocation of spare and scarce capacity in the system during peak load periods [3.19].
- In order to facilitate the auction a tool is required for predicting the level of spare capacity that is available from time to time and for optimizing the total throughput based on the different auction bids [3.20].
- The auction bids shall refer to the pre-specified entry and exit points and no shipper shall have a right to specify "internal" routing in the dry gas systems [3.21].

The transportation system operator's total revenues must be harmonized regularly
- Total revenues shall not yield higher profits than the regulated return and the balance (i.e. the balance can yield either a surplus or a deficit) shall be levied – at least in theory – the firm transportation shippers only [3.22].

The above recommendation is inferred from the following conclusions of the work:

- [3.1]. Conclusion 7.3 on page 125 and Conclusion 7.8 on page 131.
- [3.2]. Conclusion 7.5 on page 125.
- [3.3]. Conclusion 6.5 on page 114.
- [3.4]. Conclusion 7.4 on page 125.
- [3.5]. Conclusion 6.6 on page 114 and Conclusion 7.7 on page 125.
- [3.6]. Conclusion 6.6 on page 114, Conclusion 7.12 on page 172 and Conclusion 7.23 on page 202.
- [3.7]. Conclusion 5.10 on page 97 and Conclusion 7.9 on page 131.
- [3.8]. Conclusion 7.19 on page 201.
- [3.9]. Conclusion 7.20 on page 201.
- [3.10]. Conclusion 7.21 on page 201.
- [3.11]. Conclusion 7.25 on page 202.
- [3.12]. Conclusion 7.23 on page 202.

- [3.13]. Conclusion 7.15 on page 190, Conclusion 7.22 on page 202 and Conclusion 7.31 on page 218.
- [3.14]. Conclusion 7.22 on page 202 and Conclusion 7.31 on page 218.
- [3.15]. Conclusion 7.23 on page 202 and Conclusion 7.24 on page 202.
- [3.16]. Conclusion 7.16 on page 190 and Conclusion 7.22 on page 202.
- [3.17]. Conclusion 7.17 through Conclusion 7.18 on page 191.
- [3.18]. Conclusion 7.26 on page 202.
- [3.19]. Conclusion 7.32 through Conclusion 7.33 on page 219.
- [3.20]. Conclusion 7.29 on page 218.
- [3.21]. Conclusion 7.30 on page 218.
- [3.22]. Conclusion 7.21 on page 201.

Recommendation 4 – regarding documents, organizational issues, working processes, and incentive structures

An implementation of the Gas Directive will introduce several requirements that will affect existing regulation and provisions regarding documents, organizational issues, working processes, and incentive structures. The work has briefly discussed these issues, but due to the many uncertainties no detailed assessments are conducted. Based on the assessments carried out in the work some conclusions are made however, and these are listed below.

- *Documents.* A majority of the documents assessed in this work must be revised and updated to reflect new requirements caused by liberalization [4.1].

- *Organization.* More information is required in order to assign detailed responsibilities to the future transportation system operator, especially if an independent transportation system company shall conduct transport operations. Given this assumption a comprehensive assessment is needed in order to split the existing vertically integrated functions into new and re-assign working processes and responsibilities. This is particularly relevant for the future transportation system operator's, and the shipper and seller dispatching representatives' functions. Finally, it shall also be mentioned here that the Gas Directive, strictly taken, does not require an independent transportation system company. This is only a requirement of St. prp. 36 (2000-2001). [4.2].

- *Working processes.* A detailed specification of the future working

processes must be clarified. This especially applies for how to optimize the operations in a liberalized context. [4.3]. See also the former bullet point, which is much related to this issue.

- *Incentive structure.* Carefully designed incentives are needed especially for enhancing optimal usage of the network during capacity constraints and peak load operations, given that an independent transportation system operator shall conduct transport operations. [4.4].

The above recommendation is inferred from the following conclusions:

- [4.1] Conclusion 7.14 on page 173 and Conclusion 7.35 on page 220.
- [4.2] Conclusion 7.36 on page 223.
- [4.3] Conclusion 7.37 on page 223.
- [4.4] Conclusion 7.13 on page 172 and Conclusion 7.38 on page 226.

Recommendation 5 – related to how to ensure allocative and dynamic efficient development of new capacity
In order to ensure allocative and dynamic efficiency on the Norwegian Continental Shelf and in the transportation systems a centralized planning and development system must be in force, such as the existing FU. No reasons or arguments have been found in this work that liberalization contradicts such an establishment. A centralized planning function is required to secure resource management and utilization of the significant possibilities for economy of scale. Further, the transportation system operator must have a close liaison with these functions in order to share information about operational experiences, capacity constraints and shadow prices. [5.1]. The above recommendation is inferred from the following conclusions of the work:

- [5.1] Conclusion 7.10 on page 171 and Conclusion 7.34 on page 219.

9.2   Future research
Throughout this thesis several topics have been touched upon that may be the subject for future research. In the list below these topics are summarized.

- The tariff and toll regime must be further studied. This is especially relevant for the allocation of numerical values to the different components of the toll formulas, such as the fixed part components of

the firm and interruptible tolls. Such studies will however be closely related to actual cost figures and they will contain proprietary and strategic information. The way, in which such information shall be made transparent, as called for by the Gas Directive, must be further clarified as well. The auctioning principles for spare and scarce capacity, including a tailored tolling regime, must be further studied as well.

- Revised and changed rules for allocation and balancing of pipeline inventory imbalances must probably also be worked out.
- The principles for periodical calculation of the transportation system owners' revenues and the re-allocation and balance mechanisms for toll surpluses and deficits must be worked out.
- The incentive structures for enhancing cost efficient operations and optimized utilization of the gas transportation systems must be looked into – especially given that an independent transportation system operator is established.

The recommendations given in this work may be considered as "minimum" solutions. They represent incremental steps that as far as possible are aligned with the prevailing regime. Simultaneously, they comply with requirements of change as specified by the Gas Directive. As liberalization develops however, more dramatic changes may be envisaged compared those identified here. Future research may thus open up for more paradigmatic analyses and in-depth analyses of issues that are only briefly discussed here. Provided the future European and Norwegian legislation will make it relevant, tomorrow's research prospects may focus on issues as:

- *"The capacity release market"* where shippers are allowed to trade their non-utilized booked capacity in the market. Such capacity can be utilized in different ways. For example, it can be "sold" to other shippers at a regulated or non-regulated price, or the "booked capacity owner" can utilize this capacity to offer "bundled" services to gas buyers.
- *New ownership structures.* The ownership of the pipelines can be re-assigned party or as a whole to specific stakeholders, for example to an independent company that also is the operator. Alternatively, the State may take over the entire ownership of the pipelines. Such re-allocations of the ownership structures will inevitably cause a shift in the incentive structures that must be carefully analyzed.

If the future European liberalized regime allows for even more dramatic changes in the regulation, compared to those issued identified in this work, new and substantially different tolling methods may be looked into, such as:

- Value based tolling.
- Price capping of some of the services.
- Long-term marginal cost tolling for some specific systems or regions.
- Detailed incentive regulation for specific services.

All of the above methods will call for a substantial new European and Norwegian legislation and they will introduce new elements of uncertainty which again raise difficult questions regarding how such regimes ensure long-term security of supply.

10 References

"Aftenposten," Jan. 6, 1997.

Albrechtsen, R. A., (1998), "Gas distribution and transport", *Course no. Pr 067* at the Haugesund/Stord college, Norway, (in Norwegian).

Armstrong, M., Cowan, S., and Vickers, J. (1994), *Regulatory Reform, Economic Analysis and British Experience*, The MIT Press, Cambridge, USA.

Arnesen, F., (1996), *Statlig styring og EØS-rettslige skranker*, Universitetsforlaget AS, Oslo. (*Governmental control*, in Norwegian).

Asbjørnsen, O.A., (1992), *Systems engineering principles and practices,* Department of Thermal Energy and Hydro Power, Norwegian University of Science and Technology (NTNU), Trondheim.

Austvik, O.G. (1997), "Gas pricing in a liberalized European market: Will the rent be taxed away?" *Energy Policy*, Vol. 25, No. 12, pp. 997-1012.

Bahill, A. T., Dean, F. F, (1996), "What Is Systems Engineering? A Consensus of Senior Systems Engineers", *Proceedings of the Sixth Annual International Symposium of the International Council on Systems Engineering (INCOSE),* (Boston, USA, July) vol. I, pp 503-508.

Bjerkholt, O., and Gjelsvik, E. (1992), "Common carrier for natural gas: The producers' perspective," Energy Markets and Environmental Issues: A European Perspective, *Scandinavian University Press*, pp. 131–162, Oslo, Norway.

Bjerkholt, O., Olsen, Ø., and Visle, J. (1990), *Recent Modelling Approaches in Applied Energy Economics*, Chapman and Hall, London, UK.

Bjørkvoll, T. (1994), Natural gas pipeline transport: Costs, tariffs and capacity dimensioning, *Doctoral dissertation, Norwegian University of Science and Technology*, Trondheim, Norway (in Norwegian).

References

Bjørkvoll, T. (1996), "Regulation of gas transportation", *Report STF38 A 96603, SINTEF,* Trondheim, Norway (in Norwegian).

Black, J. (1997), A dictionary of economics, *Oxford university press*, Oxford

Blanchard S.B., Fabrycky W.J., (1990), Systems Engineering and analysis, *Prentice Hall,* New Jersey.

Blumstein, C., Goldstone, S., and Luthzenhiser, L. (2000), "A theory-based approach to market transformation," *Energy Policy*, Vol. 28, pp. 137–144.

Brautaset, A., Høiby, E., Pedersen, R.O., and Michelet, C.F. (1998), Norwegian gas sales: Legal framework, *Sjørettsfondet, University of Oslo*, Norway (in Norwegian).

Brottemsmo, J., Haugland, D., Nansve, A., Stensland, G., and Sunnevåg, K. (1993), "Pipeline and processing tariffs: Problems and possible solutions," *SNF-report 28/93, Norwegian School of Economics and Business Administration*, Bergen, Norway.

Brottemsmo, J., (1994-A), "Tariff systems in offshore Norway" *SNF-report 6/94, Norwegian School of Economics and Business Administration*, Bergen, Norway.

Brottemsmo, J., (1994-B), "Incentives in offshore Joint Ventures" *SNF-Working Paper 12/94, Norwegian School of Economics and Business Administration*, Bergen, Norway.

Carpenter, P. R., Jacoby, H. D., Wright, A. W., (1983), "Natural gas pipeline regulation after field price decontrol", *Center for Energy Policy Research*, MIT-EL 83-013WP, Massachusetts Institute of Technology Cambridge, USA

Carpenter, P. R., Jacoby, H. D., Wright, A. W., (1986), "Adapting to changes in natural gas markets", *Center for Energy Policy Research*, MIT-EL 85-007WP, Massachusetts Institute of Technology, Cambridge, USA

Cave, M., and Doyle, C. (1994), "Access pricing in network utilities in theory and practice", *Utilities Policy*, No 4(3), pp. 181-189.

Christensen, L.-S. (1998), *"An industry in transformation, A closer look at the current changes in the natural gas industry in the United States"*, Rotterdam School of Management", Rotterdam, Holland

Dahl, H.J., (1998-A), "Operating procedure for a common carrier natural gas transport system", *Statoil/NTNU, report no. 24909*, (Working report).

Dahl, H.J., (1998-B), "Systems engineering and the Norwegian natural gas value chain", *Statoil/NTNU, report no. 64904*, (Working report). (In Norwegian)

Dahl, H.J., (1998-C), "Tariff systems for natural gas transport", *Statoil/NTNU/NHH, report no. 99991*, (Working report). (In Norwegian).

Dahl, H.J., (1998-D), "Legal aspects, natural gas production, transport and sale", *Statoil/NTNU/UiB, report no. 99992*, (Working report). (In Norwegian).

Dahl, H.J., (1999-A), "Perspectives on Technological Change and Innovation in Norwegian Natural Gas Transport Industry", *Statoil/NTNU, report no. 91905*, (Working report).

Dahl, H.J., (1999-B), "Systems engineering and Statoil natural gas transport operations," *Proceedings of the Ninth Annual International Symposium of the International Council on Systems Engineering (INCOSE),* (Brighton, UK, June), Vol. II, pp. 791–798.

Dahl, H.J., (2000-A), "Information modeling and system re-engineering: An efficient approach to assessing complex current Norwegian natural gas transport operations," *Proceedings of the Tenth Annual International Symposium of the International Council on Systems Engineering (INCOSE),* (Minneapolis, USA, July), pp. 49-56.

Dahl, H.J., (2000-B), "A European natural gas market in transition: Is a new tariff regime in Norwegian dry gas transportation needed? Overview of a complex issue," *Annual European Energy Conference 2000 (IAEE),* (Bergen, Norway), Conference Proceedings.

Department of Energy, USA (1994), Energy Information Administration, Natural Gas 1994: Issues and Trends.

De Vany, A.S., and Walls, D.W., (1994), "Natural gas industry transformation, competitive institutions and the role of regulation: Lessons from open access in US natural gas markets," *Energy Policy*, No. 22 (9), pp. 755-763.

De Vany, A.S., and Walls, D.W. (1995), *The Emerging New Order in Natural Gas: Markets versus Regulation*, Quorum Books, London.

Dyrland, S., Moen, K. B., (2000), "Market opening and third party access", *Marius, 257/2000,* University of Oslo, Sjørettsfondet, Oslo, Norway (In Norwegian).

Ellis, A., Bowitz, E., and Roland, K. (2000), "Structural change in Europe's gas markets: Three scenarios for the development of the European gas market to 2020," *Energy Policy,* No. 28, pp. 297–309.

Estrada, J., Moe, A., and Martinsen, K.D. (1995), *The Development of European Gas Market*, John Wiley & Sons, Chichester, England.

European Union (1998), *"Directive 98/30/EF, dated 22 June 1998, of the European Parliament and of the Council concerning common rules for the internal market in natural gas."*

Fact Sheet (1999), *Norwegian Petroleum Activity*, Ministry of Petroleum and Energy, Oslo, Norway. See <http//odin.dep.no/oed/eng/>.

Fejø, J., EU-konkurrenceret, 2.udgave, Jurist- og Økonomforbundets Forlag, Copenhagen Denmark. (in Danish)

Financial Times, London, UK:
— (1990), Cameron, P., "Gas regulation in Western Europe: A country-by-country guide."
— (1991), Kalim, Z., "Natural gas in the European community."
— (1995), Cameron, P., "Gas regulation in Europe: From monopoly to competition, Vols. 1 and 2."
— (1996), Johnson, D., "Trans-European Energy Networks: Europe's gas and electricity into the 21st century."
— (1997), Johnson, D., and McCann, K., "EU Energy Policy: An evolving agenda."
— (1997), Madden, M., "The Network Code: Commercial and operational

implications for the UK gas industry."

— (1997), Milner, R., "Privatising European Energy: Policy developments and progress."

— (1998), Gurney, J., "Gas Deregulation in North America."

— (1998), Madden, M., "The Interconnectors: The commercial and operational implications for the European gas industry."

GIBS (1998), Gas Industry Standard Board, Business Practice Board Version, Houston, Texas, USA.

Golombek, R., Gjelsvik, E., and Rosendahl, K.E. (1995), "Effects of liberalizing the natural gas markets in Western Europe," *The Energy Journal*, Vol. 16, No. 1, pp. 85-111.

Golombek, R., Gjelsvik, E., and Rosendahl, K.E. (1998), "Increased competition on the supply side of the Western European natural gas market," *The Energy Journal*, Vol. 19, No. 3, pp. 1-18.

Golombek, R., and Hoel, M. (1987), *Natural Gas Markets and Contracts*, Elsevier Science Publisher B.V., Amsterdam, Netherlands.

Grønn, E. (1996), *Mikroøkonom, Formler og oppgaver, 3. utgave*, Cappelen Akademiske Forlag, Oslo, Norway

Gundersen, G., Statoil, (1999), "Open access and market liberalization", 6'Th International Symposium on the Operation of Gas Transport System, Haugesund, Norway, April 1999, *Conference proceedings*.

HA#1, TA#1, refer to proprietary Heads of Agreement and Transportation Agreements

Hammer, U., (1998), "Petroleum law Compendium, Book 1", Part II, The petroleum sector", *Scandinavian Institute of Maritime Law*, University of Oslo, Oslo – Norway.

Hammer, U., (1999), "Tilrettelegging av kraftmarkedet", Cappelen Akademiske Forlag, Oslo. ("Structuring of the electricity market", in Norwegian).

Hannesson, R. (1998), *Petroleum Economics, Issues and Strategies of Oil and*

References

Natural Gas Production, Quorum Books, London, UK.

Hitchins, D. K., Boarder, J. C., Moore, Borgan, I., (1999), "Guide to the Practice of Systems Engineering", *Structured Software Systems*, Henley-on-Thames, UK.

Hobbs, B.H., and Horn, G.T.F. (1997), "Building public confidence in energy planning: A multimethod MCDM approach to demand-side planning at BC gas," *Energy Policy*, Vol. 25, No. 3, pp. 357–375.

Holm, T., (1999), Shell International Gas, "European Experiences after the Gas Directive on the Business", 6'Th International Symposium on the Operation of Gas Transport System, Haugesund, Norway, April 1999, *Conference proceedings.*

Hope, E., (1994), "Optimal regulering av nettmonopoler i kraftomsetningen", *SNF-report no. 51/94.*

Hope, E., (2000), *Studier i markedsbasert kraftomsetning og regulering,* Fagboklaget, Bergen, Norway (in Norwegian)

Hunt, S., and Shuttleworth, G. (1996), *Competition and Choice in Electricity*, John Wiley & Sons Ltd., Chichester, England.

INCOSE (1998), "Systems Engineering Handbook," Release 1.0, January 1998, *San Francisco Bay Area Chapter,* USA.

International Energy Agency (IEA) (1994), Transportation Study: "Natural gas transportation, organization and regulation," Organization for Economic Co-operations and Development, OECD, Paris, France.
—(1995), "The IEA natural security study," OECD, Paris, France.
—(1997), "Energy policies of IEA countries: Norwegian 1997 Review," OECD, Paris, France.
— (1998), "Natural gas distribution, focus on Western Europe," OECD, Paris, France.
— (1998), "Natural gas pricing in competitive markets," OECD, Paris, France.

Ilstad, Steinar, (1998), "Lecture in Methodology", Course: "Psychology in organisation and management". *Department of Industrial Economics and Technology Management,* Norwegian University of Science and

Technology (NTNU), Trondheim

Jensen, J.T. (1992), "Open access – the new market approach to natural gas policy," *Energy Policy*, Oct. 1992, pp. 1005-1014.

Joskow, P.L., and Schmalensee, R. (1983), *Markets for Power: An analysis of Electric Utility Deregulation*, The MIT Press, Cambridge, Massachusetts, USA.

Kahn, A.E. (1988 revision of 1970 edition), *The Economics of Regulation: Principles and Institutions*, The MIT Press, Cambridge, Massachusetts, USA.

Kaijser, A., Mogren A., Steen P. (1988), *"At ändra riktning, Vilkår för ny energiteknik,"* Allmänna Förlaget, Stockholm, (In Swedish).

Katz, D.L., and Lee, R.L. (1990), *Natural Gas Engineering*, McGraw-Hill, New York, USA.

Kolbe, A.L., Tye, W.B., and Myers, S.C. (1993), *Regulatory Risk: Economic Principles and Application to Natural Gas Pipelines and Other Industries*, Kluwer Academic Publishers, Boston, USA.

Kotas, T. J. (1995), *The energy method of thermal plant analysis*, Krieger publishing company, Malabar, Florida, USA.

King, G., Keohane, R.O., and Verba, S. (1994*), Designing Social Inquiry: Scientific Inference in Qualitative Research*, Princeton University Press, Princeton, New Jersey, USA.

Letter from MPE to the EFTA Surveillance Authority, dated 20.01.97.

Lijesen, M. G., (2000), "The Effect of the Access-Prising Regime on Wholesale Natrual Gas Prices", *Annual European Energy Conference 2000 (IAEE),* (Bergen, Norway), Conference Proceedings.

Malcolm, N., Alford, M. (1993), "Systems Engineering: Its Roots, Its Future", *Ascent Logic Corporation*, San Jose

Mansell, R.L. and Church, J.R. (1995), *Traditional and Incentive Regulation,*

References

Application to Natural Gas Pipelines in Canada, The Van Horne Institute, Toronto, Ontario, Canada.

Megdal, L. (1998), "Integrated Perspectives from Alternative Disciplines to Understand Market Transformation Policy in Energy Markets," *IAEE Conference Proceedings*, May 13–16, Quebec, Canada.

Mestmeacker, E.J. (ed.), (1993), *International energy and Resource Law and Policy Series, Natural Gas in the Internal Market: A review of Energy Policy*, Graham & Trotman, London, England.

National Energy Board (1986), "Reasons for decision in the matter of TransCanada Pipelines Limited, Availability of Services, May 1986," *Regulatory Support Offices*, Ottawa, Canada.

Nese, G. (1998), "Pricing of Natural Gas Transportation", *SNF-report no. 64/98.*

Nicholson, W. (1995), *Microeconomic Theory, Basic principles and extensions*, Sixth edition, The Dryden press, Harcourt Brace College Publishers.

Nielsen, J. (1999), *Introduction to Norwegian Natural Gas Transportation agreements*, Sjørettsfondet, University of Oslo, Norway. (In Norwegian).

NoU no 11, (1998), "Energi- og kraftbalansen mot 2020", *Ministry of Petroleum and Energy*, Oslo, (In Norwegian), See: http//odin.dep.no/nou/

Oliver, D. W., Kelliher, T. P., Keegan, J. G., (1997), "Engineering Complex Systems with models and objects", *McGraw-Hill,* New York

Oliver, D. W. (1999), "Concept Analysis: Modelling and Organisation Transformation", *Proceedings of the Ninth Annual International Symposium of the International Council on Systems Engineering (INCOSE),* (Brighton, UK, June) vol. II, pp 1445-1451.

Osmundsen, P. (1999), "Risk sharing and incentives in Norwegian petroleum extraction", *Energy Policy*, Vol. 27, pp. 549-555.

References

Park, C. S., and Sharp-Bette, G. P. (1990), *Advanced Engineering Economics*, John Wiley & Sons, Inc., New York, USA.

Percebois, J. (1999), "The gas deregulation process in Europe: economic and political approach", *Energy Policy*, No. 27, pp. 9-15.

Pratt, J.W., and Richard, J.Z. (1985), *Principal and Agents: The Structure of Business*, Harvard Business School Press, Boston, USA.

Purves, B., and Baker, L. (1998), "Information Models as a Prerequisite to Software Tool Interoperability," *INCOSE Insight*, Fall 1998, Vol. 1, Issue 3, Seattle, Washington, USA.

Radetzki, M. (1999), "European natural gas: market forces will bring about competition in any case," *Energy Policy*, No. 27, pp. 17-24.

RDD-100 User Manual, (1996), " ALC Training Course 101, Introduction to RDD-100, Student Workbook, version 1.3", *Ascent Logic corporation*, San Jose, USA.

Roeber, J. (1996), "The Development of a UK Natural Gas Spot Market," *The Energy Journal*, Vol. 17, No. 2, pp. 1-15.

Rosenberg N. (1991), "Critical issues in science policy research", S&T interfaces, *Science and Public Policy*, volume 18, number 6, Dec, pp 335-346

Rosenberg N. (1994), "Path-dependant aspects of technological change", *in Exploring the Black Box: Technology, economy and history* (Cambridge: CUP), pp 9-23

Royal Decree No. 653 of 27 June 97, Article 19.

Schultz, N. (1998), "Canadian Institute for Petroleum Industry Development, 1998 Summer Program, Natural gas regulatory framework course", Hand out materials, CAPP, Calgary, Canada

Sejersted, F., Arnesen, F., Rognstad, O.-A., Foyn, S., Stemshaug, H., (1995), *EØS-rett*, Senter for Europa-rett, University of Oslo, Universitetsforlaget, Oslo Norway (in Norwegian).

References

Selvig, E. (1995), *Petroleum Law*, Sjørettsfondet, University of Oslo, Norway (in Norwegian).

Sintef report STF38 A99613, (1999), "*Leveransesikkerhets-, Metodeutvikling, system-spesifisering og implementering. Brukerveiledning for GassOptTKL.*", Trondheim, Norway, (In Norwegian).

Sjøen, K. (1998), "Gas transportation", *Course at NTNU*, (In Norwegian)

Smeers, Y. (1997), "Computable Equilibrium Models and the Restructuring of the European Electricity and Gas Markets," *The Energy Journal*, Vol. 18, No. 4, pp. 1–31.

Smith, K. (1998), "Innovation as a systemic phenomenon: rethinking the role of policy", *Report to European Commission*, Step group, Oslo.

Sproles, N. (2000), "Coming to Grips with Measures of Effectiveness," *Journal of the International Council on Systems Engineering*, Vol. 3, No. 1, pp. 50–58.

Stern, P.J. (1992), Third Party Access in European Gas Industries, Regulation-driven or Market-led? *The Royal Institute of International Affairs*, London.

Stern, P.J. (1997), "The British Gas market 10 years after privatizations: a model or a warning for the rest of Europe?" *Energy Policy*, Vol. 25, No. 4, pp. 387-392.

Stern, P.J. (1998), *Competition and Liberalization in European Gas Markets: A Diversity of Models*, The Royal Institute of International Affairs, London, UK.

Stevens, Brook, Jackson, Arnold, (1998), "Systems Engineering, Coping with Complexity", *Prentice Hall Europe*, London.

Stoppard, M. (1996), A new order for gas in Europe? *Oxford Institute for Energy Studies*, Oxford, UK.

Stortings Proposisjon nr. 36 (2000-2001), "Eierskap I Statoil og fremtidig forvaltning av SDØE", 15.12.2000, *Ministry of Petroleum and Energy*, Oslo, Norway (in Norwegian). See http//odin.dep.no/nou.

References

Sunnevåg, K.J. (1999), "How sustainable is the framework for Norwegian gas sales under European gas market liberalization?" *Conference proceedings, June 1999, 22nd IAEE Annual International Conference*, Rome, Italy.

Sunnevåg, K.J. (2000), "How sustainable is the framework for Norwegian gas sales?" *Energy Policy*, No. 28, pp. 311–320.

Sutherland, R.J. (1993), "Natural gas contracts in an emerging competitive market," *Energy Policy*, No. 12, pp. 1191-1204.

Tabors, R.D. (2000), "Energy and economic development" - TPP 126, *MIT Sloan course*, spring 2000", Talk given by a representative of Enron.

Teece, D.T. (1990), "Structure and Organization of the Natural Gas Industry: Difference between the United States and the Federal Republic of Germany and Implications for the Carrier Status of Pipelines," *The Energy Journal*, Vol. 11, No. 3, pp. 1–35.

The Brattle Group, (2000), "Methodologies for establishing national and cross-boarder systems of pricing of access to the gas system in Europe", see http://www.brattle.com/articles/method_gas_europe.pdf

Thome, B., (1993), "Systems engineering, Principles and Practice of Computer-based Systems Engineering", *Wiley,* Chichester.

Thaule, S.B., and Postvoll, W. (1996), "Experience with computational analyses of the Norwegian Gas Transport Network," *Pipeline Simulation Interest Group PSIG, Conference proceedings*, San Francisco.

United Nations (1982), Convention of the Law of the Sea (UNCLOS).

United Nations (1996), Economic Commission for Europe, *Gas Centre Series*, Geneva, Switzerland.

Von der Fehr, N.-H.M. (1996), "Access pricing: A principle analysis," *Norsk Økonomisk Tidsskrift*, 110 årgang, hefte 4, pp 263-290 (in Norwegian), Oslo, Norway.

White Paper (WP) No. 46 (1986–87), "Om petroleumsvirksomheten på mellomlang sikt," *Ministry of Petroleum and Energy*, Oslo, Norway (in
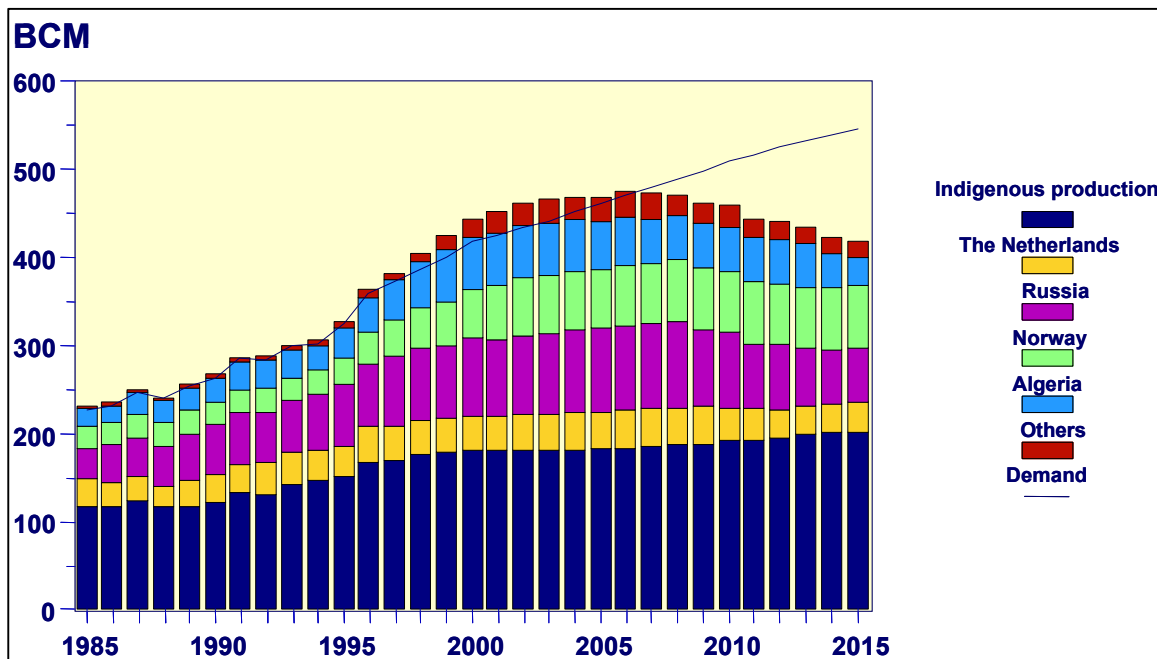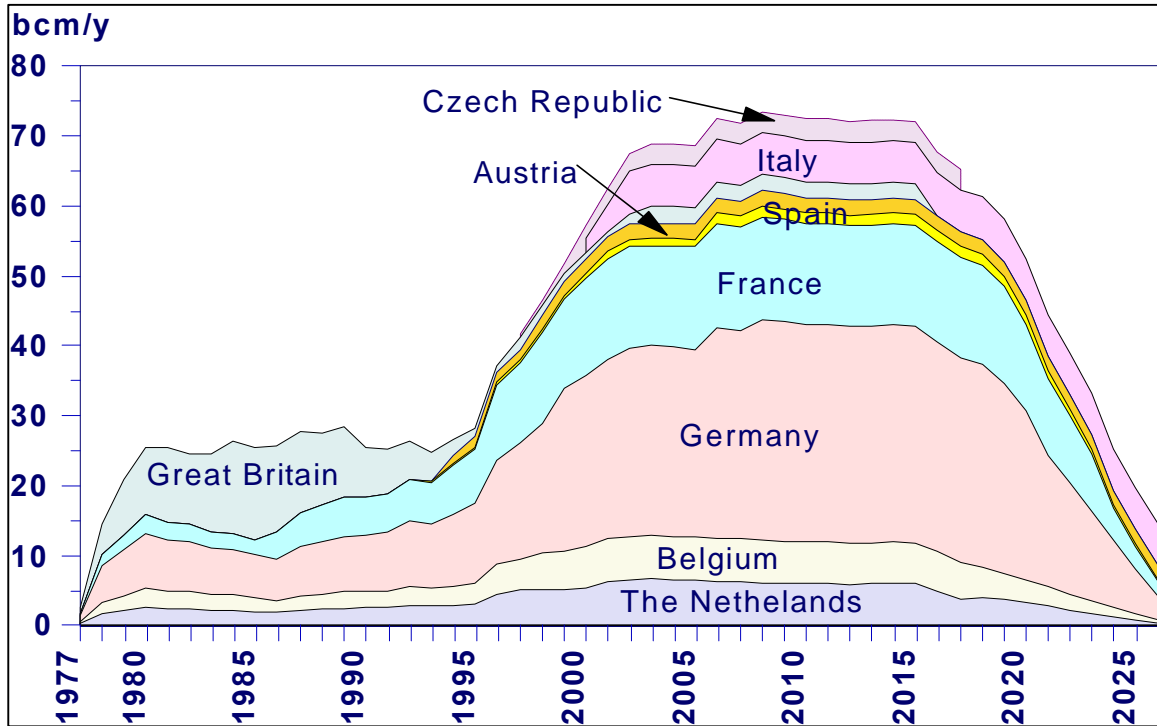
Norwegian). See http//odin.dep.no/nou

White Paper (WP) No. 46 (1997–98), "Olje- og gassvirksomheten," *Ministry of Petroleum and Energy*, Oslo, Norway (in Norwegian). See http//odin.dep.no/nou

White Paper (WP) No. 39 (1999–2000), "Olje- og gassvirksomheten," *Ministry of Petroleum and Energy*, Oslo, Norway (in Norwegian). See http//odin.dep.no/nou
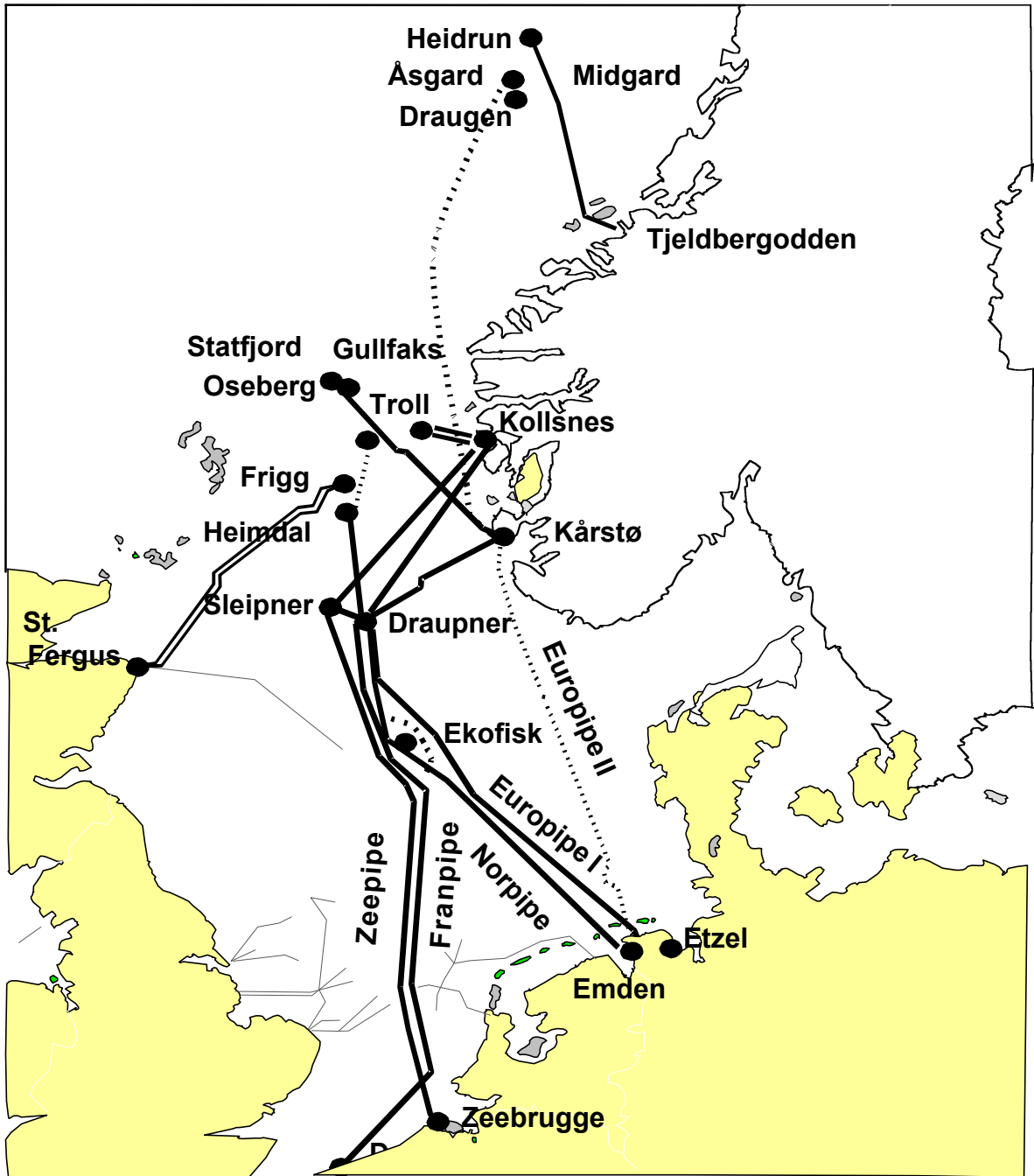
Wilson, P.I. (1997), "Deregulation and natural gas trade relationships: lessons from the Alberta-California experience," *Energy Policy*, Vol. 25, No. 10, pp. 861-869.

11   Appendix

11.1   Gas sales commitments and European demand

11.2 The transportation system

Heidrun

Åsgard

Midgard

Draugen

Tjeldbergodden

Statfjord

Gullfaks

Oseberg

Troll

Kollsnes

Frigg

Kårstø

Heimdal

Sleipner

Draupner

St. Fergus

Europipe II

Ekofisk

Europipe I

Zeepipe

Franpipe

Norpipe

Etzel

Emden

Zeebrugge

D

11.3 Interview schedules
Statoil – Norway

Stakeholder	Position	Date
Transportation Operator (Technical aspects), Shippers Dispatching Representative	Department Manager TCC Control Center	21.05.99 26.05.99
Transportation system operator (Commercial aspects), Transport Owner, Shipper	Lead Negotiator Transportation agreements	25.05.99
Transportation system operator, Shippers Dispatching Representative	Department Manager TCC Engineering Staff	26.05.99
Field Owner, Shipper	Department Manager	28.05.99
Seller	Sales Manager Belgium	28.05.99
Sellers Representative, Sellers Dispatching Representative	Department Manager GSC Control Center	03.06.99 15.06.99
Seller	Department Manager Commercial	03.06.99

Statoil Energy, Alexandria - Virginia

The meeting was conducted Nov. 29 to Dec. 3, 1999 with Senior Vice President for Corporate Development, Senior Vice President for Producer Services and Senior Vice President for Software Solution Center.

Columbia Gas, Fairfax – Virginia

The meeting was conducted Nov. 30, 1999 with Vice President for Strategic Initiatives, Marketing Manager, Account Manager and Employee Strategic Initiatives.

Columbia Gas, Charleston – West Virginia

The meeting was conducted Feb. 16, 2000 with Manager for Commercial Services, Manager Marketing, Manager for Rate and Cost control and some other employees working with topics such as gas control operations, commercial services, facility running, price risk management, volume management and rate design.

TransCanada, Calgary - Canada

The meeting was conducted April 14 and April 17, 2000 with Director for Pipeline Systems Operations, Senior Vice President for Customer Sales and Services, Manager for Sales Strategy, Director for Sales, Vice President for Technology Assessment, Director for Western Market Development.

National Energy Board, Calgary - Canada

The meeting was conducted Apr. 17, 2000 and the author met Chief Economist, Professional Leadership Team and Economist in Applications Business Unit.

Canadian Association of Petroleum Producers, Calgary - Canada

The meeting was conducted Apr. 19, 2000 with Vice President for Regulatory and Transportation Policy and General Counsel.

Tabors Caramanis & Associates, Cambridge

The meeting was conducted Nov. 2, 2000 with a Senior Associate.

11.4 The questionnaires
Statoil Norway - spring 1999

Introduction

The purpose of this activity is to collect empirical descriptive data from Stakeholders. This information will be applied as input data to modelling the "systems engineering optimization model". The questions are organized into two sections. The first section contains questions of a general nature, the second section relates to general questions relevant for each stakeholder including some questions which are tailored the individual stakeholders' specific roles.

The questions, the general section:

1. Please identify the major stakeholders (Norwegian: "aktører") being involved in the Norwegian natural gas transport operations and their major functions.
2. Please describe how these stakeholders interact (main flow only) and/or identify any discrepancies or suggest amendments in:
    3.1) Incose paper figure 3. (Attached)
    3.2) NTNU report 99992 figure 3-1. (Attached).
3. Please identify the major interface documents regulating the Norwegian natural gas transport operations.

The questions, The specific section

4. Please clarify which of the interface documents that are specifically important to you and which articles that are most relevant for you in order to defining:
    a) your major needs (in order to carry out your duties)
    b) your major requirements to the system (so that the system provides you with an "output" that you will expect and require).
    c) your major work tasks or functions
    d) your major responsibilities.

5. Please clarify the means of interactions taking place between you and:
    a) other stakeholders
    b) how do the identified documents "influence and interact" upon your function? (Is this influence "static and rigid" or is the influence more of an "ever changing and dynamic type")?
    c) the hardware system .

6. Which parts or components of the hardware systems are monitored or controlled by your function?

7. Please identify the major software computer programs acting and their way of contributing.

8. How do you expect the Gas Directive will impact your functions?

9. Please define "prudent" natural gas transport operations.

The questions, The tailored section – transport operator:

10. In the Incose paper a list is specified defining six major operating tasks. These tasks are derived from the transportation agreements.
    a) Are any tasks left out?
    b) Can you priorities the tasks in some ways?
    c) If prioritizing, by which means do you priorities between competing tasks? (Can you provide examples)?

11. In daily operations do you consider to reducing energy consumption in connection with the natural gas transport?

12. Which provision of the Transportation agreements is most likely subject for amendments in order to cope with the Gas Directive?

The questions, The tailored section – shipper representative:

13. In daily operations which activities require most of your time.

14. In your opinion, which interactions are the most difficult to carry out in a "prudent" manner?

15. Please identify your relationship with the field licenses.

16. Do you expect that "new type of shippers" may occur in the North Sea?

The questions, The tailored section – gas seller

17. Do you consider new types of short-term gas sales a likely development as a result of the gas directive?
Companies in Canada – spring 2000
Questionnaire – visit to TransCanda, NEB and CAPP in April 2000

1. *Gas buyer behavior:*
   a) How did gas buyer behavior evolve as de-regulation progressed over the years?
   b) How did this affect the nature of gas sales contracts?
   c) What are the conditions of the different gas sales contracts to day?

2. *Shipper and transport owner behavior:*
   a) How did the gas transportation services evolve?
   b) How did the transportation agreements between transport system owners and shippers develop?
   c) How did shipper requirements reflect the conditions or requirements of the gas sales contracts?
   d) Where there any operational constraints or considerations of importance imposed by transport operations on either sales contracts or transportation contracts?
   e) What are the methods and measures for imbalance control and gas quality, and measurements?

3. *From the regulator's point of view:*
   a) What where the key issues and decisions made, in order to design the rules for cost allocations and tariff regimes, in natural gas transportation?
   b) How are rules for allocation of sunk costs (investment in transportation facilities) covered in tariff regimes (if they are (!))
   c) How is depreciation handled in the tariff regime?
   d) What type of risk sharing exists between transportation system owners and shippers, and between shippers and gas owners, and between gas owners and gas buyers, especially in the context of international gas export, as is the case in the Canadian context, when you sell gas to the US buyer?
   e) What are the rules for allocation of transportation capacity, during periods of transportation restrictions or constraints or during periods of shipper nominations exceeding transportation system capacity?

11.5 Feasibility checks on RDD-100

The criteria are not prioritized.

Criteria	RDD-100	Evaluation
Is the supplier easily accessible within traveling distance for the author?	Offices in Bergen, Norway	Acceptable
Is the program recognized and used by other organizations in Norway?	Applied by the Royal Norwegian Navy on the Frigate project.	Acceptable
Can the program be installed on a PC laptop based on Windows configuration?	Yes (130 MB RAM required)	Acceptable
Is a training course available?	Two days training course offered. Standard course fee paid.	Acceptable
Is a "student's user license" available free of charge?	Yes, the program was installed free of charge.	Acceptable
Does the program support information modelling and requirement traceably?	Yes, this is one of the program's main features and purposes.	Acceptable
Is the program easy to learn?	The program requires a basic understanding of systems engineering processes and a good understanding of the principles of information modelling and the ERA concept.	Manageable with dedicated effort
Does the program easily produce reporting from the PC?	Not strait forward, postscript treatment required.	Not so acceptable. Print out should be paced directly into text processor for editing.
Is program support available in the USA?	Yes. The program is developed in the USA and has a widespread usage.	Support telephone available. Much valuable help obtained.

11.6 Information model printouts

In a separate Volume II of the dissertation all the information model printouts from the RDD program are presented. The contents of this volume is:

The prevailing regime:
Fig 1.1: Requirement traceability: Top view
Fig 1.2: Requirement traceability: Heads of agreement and Transport agreement
Fig 1.3: Requirement traceability: Interface manual
Fig 1.4: Requirement traceability: Operation procedure
Fig 1.5: Requirement traceability: "Opfelx" procedure
Fig 1.6: Requirement traceability: "PAD" permission
Fig 1.7: Requirement traceability: "PUD" permission
Fig 1.8: Requirement traceability: Gas sales agreement, contract fields
Fig 1.9: Requirement traceability: Gas sales agreement, supply fields
Fig 1.10: Requirement traceability: The effectiveness measures
Fig 1.11: Requirement traceability: The effectiveness measures
Fig 1.12: Requirement traceability: The effectiveness measures
Fig 1.13: Requirement traceability: The effectiveness measures

Fig 2.1: System architecture: (Top view)
Fig 2.2: System architecture: Platforms
Fig 2.3: System architecture: Shore terminals
Fig 2.4: System architecture: Treatment terminals
Fig 2.5: System architecture: Productions facilities

Fig 3.1: Behavior model: Dispatching process
Fig 3.1: Behavior model: Optimization process
Fig 3.1: Behavior model: Handling of physical gas process
Fig 3.4: The merged behavior of the dry gas transport operations

Fig 4.1: The context system

11.7 Detailed results – assessment activity B.0
11.7.1 Main classes of information

A seemingly overwhelming amount of raw data was collected during the assessment activity, and the need for classifying the information became apparent. Dahl [281] originally suggested *hardware, software*, and *bioware* as appropriate information classes. These were further disaggregated into the following eight main classes.

- *Source and lower-tier documents*.
  All documents containing requirements.
- *Requirements*
  All specifications of functions, decisions, and components relating to the dry gas transportation system and its operations.
- *Functions*
  All actions allocated to stakeholders.
- *Input/output*
  All discrete or time-related input/output from functions that are "passive" and may cause an effect, e.g., oral or written instructions and criteria defined to enable decision-making.
- *Stakeholders*
  All personnel and other actors who perform one or more functions within the system or who have a right to impose requirements on the system as a whole or on any of its operations.
- *Dry gas transportation system*.[282]
  All "main facilities" of the Statoil-operated dry gas transportation system, as defined in the Transportation Agreements, which themselves are decomposed into "components" such as valves, pipes, and the dry gas itself.
- *Communication and support systems*.
  All systems that support the transfer of technical data and other information (oral, electronic, or written) among stakeholders and components.
- *Context systems*.
  All external systems that affect dry gas transport in any way.

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[281] Dahl (1999-B).

[282] For simplicity the "dry gas system" is modeled. Much of the conclusions and discussions are still quite relevant for the entire natural gas system, i.e. the inclusion of the upstream "rich" gas system.

In order to facilitate the creation of information models at a desired level of accuracy the classes above were divided into sub-classes, through an iterative process (the B.4 activity) to better organize the information.

Source documents

The source documents are classified into three sub-classes to reflect different tiers in a hierarchical structure of documents. The three sub-classes are:

- *Public documents*.
  These are documents readily available in the public domain such as acts, white papers or related textbooks, journal papers and different symposium proceedings.
- *Licensee's documents*.
  These documents relate to a specific license such as for example a given production or transportation license. MPE approves such documents and these documents are normally not available in public. In this work the sales contracts are categorized into this group.
- *Operator's documents*.
  These documents regulate the operator's responsibilities and work tasks. These documents are normally developed, maintained and implemented by the companies themselves. These documents are not subject for an MPE approval nor are they available in public.

Requirements

Requirements are classified into *two* groups, [283] and the classification takes place at the "*leaf-level*". Higher-level requirements are not classified. The two classes are:

- *Behavioral requirements*.
  The behavioral requirements specify the functions of the system and the operations. Behavioral requirements usually do not state how the system is built or how to perform operations. They only communicate *what* the system and the operations shall do. As was discussed in Section 3.2.5.2, the leaf-level requirements specify *functions,* and in the behavior information model, see Section 3.2.5.4, all *input/output items* to and from the functions are identified.

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[283] The definitions of classes of requirements as suggested here are based on Asbjørnsen (1992). See also Dahl (1999) and Oliver et al. (1997) and the "RDD-100" user manual.

The behavioral requirements are classified into three sub-classes: *pre-operational, operational and post-operational,* of which the operational behavioral requirements are prime focus in this work.

- *Non-behavioral requirements.*
  These requirements specify all physical components and they specify economic requirements and conditions. The non-behavioral requirements also specify the stakeholders, see foot note [44].

Functions
Functions are classified into *two* groups:

- *Discrete functions.* A discrete function is the lowest level of observable behavior being modelled. [284]
- *Time functions.* A time function is an aggregated function consisting of one or more discrete functions and time functions.

Input and output
The input and output of functions are classified into *two* groups:
- *Discrete items.* Discrete items are the lowest level of observable inputs or outputs from functions.
- *Time items.* A time item is an aggregate of items.

Stakeholders
There are many stakeholders identified and the list of stakeholders is long. The stakeholders may be grouped into seven major groups. There are likely different ways of classifying this information and the suggested list of groups is only one possible option. The groups applied here are *authorities and advisory committees, licensees*, *shippers*, *sellers*, *representatives, operators* and *gas buyers.*

Authorities and advisory committees
- The Ministry on Petroleum and Energy (MPE)
- The FU
- The GFU

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[284] RDD-100 User manual, page 179

Licensees
- The production field owners. Each partner is a separate owner in the license and there are many licensees on the NCS.
- The transport system owners. Each partner is a separate owner in each license. There are several transport system licenses on the NCS.
- The gas storage owners.

Sellers
- The seller group. Each partner is a separate seller in each seller group. The seller groups are listed into two categories to reflect their different responsibilities in relation to the gas sales agreements. Some sellers have the contractual responsibility for the contracts, while others have the supply responsibility (or a combination of both responsibilities):
  - the contractual gas seller group
  - the supply gas seller group

Operators
- The production field operator. There are many production field operators on NCS.
- The transportation system operator. There are several transportation system operators on the NCS. In this work only one operator is considered, namely Statoil.[285]
- The treatment terminal operator
- The riser platform operator
- The shore terminal operator
- The gas storage operator

Shippers
- The shippers. There are many shipper groups and each partner is a separate shipper in the shipper group.

Representatives
- The shippers' representative. There is normally only one shippers' representative appointed for each license; specified in the transportation agreements. There are many shippers' representatives on the NCS. Statoil conducts this function on behalf of a number of shipper groups.

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[285] As previously noted, Statoil operates approximately 90 % of the dry gas transportation network on the NCS.

- The shippers' dispatching representative. The dispatching representative performs the dispatching tasks on behalf of the shippers' representative. In this work, there is only one shippers' dispatching representative considered, namely Statoil. Statoil conducts this function centralized (at the Bygnes control center) on behalf of a number of shipper groups.
- The sellers' representative. There are a number of sellers' representatives on the NCS. Statoil conducts this function on behalf of a number of seller groups.
- The sellers' dispatching representative. There is only one appointed sellers' dispatching representative for all licenses operated by Statoil. Statoil conducts this function centralized (at the Forus gas sales center) on behalf of a number of seller groups.
- The gas storage dispatching representative. Statoil conducts this function on behalf of the gas storage owner group.

Gas buyers
- The gas buyers

Technical system facilities

In every systems engineering process it is imperative to accurately define the systems boundaries. In this work the systems boundary is drawn around the "Norwegian dry gas transportation system". As explained earlier, this is done due to simplicity and due to the assumption that much of the "rich gas" system may fall outside the jurisdiction of the Gas Directive. The following facilities are included in the work and thus comprise the dry gas system:

- Pipelines:
  Zeepipe, Europipe, Europipe II, FranPipe, Statpipe/Norpipe, Zeepipe from Sleipner to Sleipner riser platform (Slr), Zeepipe from Draupner to Slr, Statpipe from Kårstø to Draupner, Statpipe from Heimdal to Draupner, Zeepipe 2B from Kollsnes to Draupner and Zeepipe 2A from Kollsnes to Slr.
- Shore terminals:
  Dunkerque, Emden ERF, Emden ED, Zeebrygge.
- Platforms:
  Sleipner Riser Platform (Slr) and Draupner Riser Platform (Dr).
- Treatment terminals: Kårstø and Kollsnes.

Communication system

In order to facilitate communication of oral, written and technical data between the stakeholders, and the context system and the system facilities, a communication and support system is developed. In this work, no further classification is performed and the system is referred to as one entity only. [286]

Context system

Given the definition of the systems boundaries, the facilities of the context system are implicitly given. These facilities are defined to be *the five locations were gas is delivered* into the system and the systems downstream the *five exit locations* of the system. The gas storage is treated as a context system.

- The dry gas productions system:
  Sleipner field Platform, Heimdal Platform, Supply fields upstream Kårstø including the "rich gas" pipelines, Supply fields upstream Kollsnes including the "rich gas" pipelines, and the Ekofisk production facilities. [287]
- The gas buyers' dry gas distribution and consumption systems:
  Downstream Zeepipe Terminal, downstream Dunkerque Terminal, downstream Emden ED Terminal and downstream Emden ERF Terminal
- The gas storage:
  Etzel gas storage

11.7.2 Assessment of main documents

Participants Agreements

This agreement defines whom the parties are that constitutes the transportation licensees. The documents specify two stakeholders:

- Transport system owners
- Shippers

Upstream Agreements

The author chooses to discuss these documents here as incorporated documents of the transportation license. One may argue that these documents

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[286] For a detailed outline of the system see Dahl (1998-B)

[287] Rich gas is natural gas containing natural gas liquids (NGL) in dense phase inside a pipeline.

could have been ordered into the documentation hierarchy elsewhere, as the documents are relevant for the production field license as well. These documents play an important role in order to achieve the resource management effectiveness measure. The Upstream Agreements are summarized into five types of agreements: [288]

- Substitution Agreements
- Modulation Agreements
- Regularity Support Agreements
- Storage Agreements
- Supply Agreements

These five agreements are all negotiated and agreed upon between owners of gas, whether these owners are field licensees or shippers. The five documents are treated jointly in the model as they conceptually are much the same. Each Upstream Agreement has been modelled to incorporate one leaf-level requirement and one function. The five functions calculate the daily right amount of gas to be shipped according to the given agreement. When all these five calculations are done, a trade-off has to be done, as there are many provisions of the agreements that simultaneously have to be considered. Trade-offs and iterations are done so that the right aggregated delivery instruction to the production field is found. All these tasks are allocated to the shipper's dispatching representative.

Interface Manuals [289]

The Interface Manuals incorporate requirements regarding rules for dispatching of gas. The requirements specify discrete functions and time functions for a number of tasks:

- dispatching of availability instructions from gas production fields, riser platforms, shore terminals, and treatment terminals, and pipelines systems
- dispatching of gas delivery instructions and requests (nominations)
- rules for trade-off calculations in order to arrive at the right delivery instructions
- rules for shortfall handling

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[288] In connection with the discussion of the behavior model in Section 5.5.4, the core features of each of the five agreements above are elaborated.
[289] See for example procedure H728-3 vol. 1 and vol. 2, sect. 1.2 (Statoil proprietary)

A total number of 10 leaf-level requirements were identified. As pointed out earlier, each of the leaf-level requirements specifies a function, which subsequently has been allocated to a stakeholder. The only stakeholder allocated here was the Transportation System Operator.

Measurement Manual

The Measurement Manual specifies rules for how to verify the exact energy contents of the gas being delivered to customers. This has to be done in order to calculate correct toll and conduct imbalance control. A number of three leaf-level requirements and functions were identified. All activities are "after the fact" activities which means that the stakeholder performs these tasks on the day following the actual gas delivery. The only stakeholder allocated to these tasks was the Transportation System Operator.

Operations Philosophy Manual

The Operations Philosophy Manual incorporates requirements on two important aspects of natural gas transport operations, namely:

- rules for handling of physical gas in the pipelines
- rules for gas quality monitoring and control

This manual specifies the actions to be done in order to maintain the integrity of the facilities. It also specifies the rules for how to blend different gas streams correctly so that the gas deliveries meet the sales specifications. The manual specifies how the Transportation System Operator shall set the right pressure and flow at the systems' control valves. The leaf level requirements specify the following functions:

- read information on flow, pressure and gas quality at all locations
- perform trade-offs in order to calculate the right "set-point" at all input and output valves.
- adjust the flow and pressure at all remotely controlled input and output valves.
- instruct production field-, treatment terminal-, riser platform-, and shore terminal- operators to adjust gas flows and outlet pressures if required.

Nine functions are identified and all functions are allocated to the Transportation System Operator.

Tariff Procedure

The Tariff Procedure incorporates rules for tariff (toll) calculations. The Transportation system operator shall perform three main functions:

- allocate the correct gas volume shipped for each shipper
- calculate the energy contents of the shippers' gas
- calculate the shippers' tariff (toll)
- issue tariff (toll) to the shippers

Procedure for linepack arrangement between transportation systems and operational flexibility arrangement between fields.[290]

This is an important and quite specific procedure. The Transportation system operator and the Shipper Dispatching Representative have developed the document. The document incorporates rules for how to utilize the transportation system and the production fields as compensating means in order to optimize gas deliveries and daily resource management on the NCS.

The document gives no specific information on what type of superior requirements it aims to fulfill. It is thus not strait forward to allocate the procedure into the document hierarchy. The author has incorporated the procedure to the Transportation Agreement as one possible solution. The procedure gives rules for several specific topics, either directly or indirectly:

- rules for minimization of flaring
- rules for minimization of transients
- rules for optimization of oil production
- rules for optimization of NGL production
- rules for dispatching of operational flexibility

The transport operations must be optimized based on several conditions. Such conditions consist of securing the pipelines integrity, minimizing gas flaring, and optimizing oil and NGL production. In order for the Transportation System Operator to do so, two specific methods can be applied, termed Operational Flexibility (Opflex) and Line packing (Linepack).

The Procedure specifies a total number of ten functions. The Transportation System Operator performs the functions (partly on behalf of the Shippers' Dispatching Representative). Nine of the functions consist of calculating the gas volumes to be treated as "opflex" and "linepack" volumes.

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[290] Dated 27.06.94, Procedure no.: H727-19

The last function is the dispatching of these volumes.

Shippers dispatching representative appointment procedure
This document authorizes a specific organization unit in Statoil [291] to perform the shippers' dispatching representative functions on behalf of several shippers. Two types of requirements are identified and each requirement specifies a function as follows:

- dispatch field imbalances
- dispatch the Upstream Agreements

Modelling of production field licensees' documents
The production fields belong to the context; they are outside of the systems boundary as defined in this work. The purpose for identifying requirements incorporated in the production field licensees' documents is to understand the requirements exposed on the system by its surroundings. Three relevant requirements were identified. First, the production field facilities are specified as such in these documents. Secondly, these documents specify the Field Participants and finally, the documents incorporate requirements related to production field gas dispatching. The latter requirements are stated in the Interface Manuals, developed jointly between the Transportation System Operator and the Production Field Operators. As a summary of these documents only two important requirements are relevant here:

- Rules for how the Production Field Operator shall issue field availability
- Rules for how the Production Field Operator shall receive his delivery instructions

Modelling of gas sales agreements
The gas sales agreements are briefly modelled, and the main purpose is to identify the dispatching rules and specific gas delivery terms. Several types of gas sales agreements exist. The first type identified here is termed *Gas Sales Agreements - GFU*. This term refers to the "intermediate" stage in the agreement's life cycle, following the signing, but prior to the final assignment. Secondly, the term *Gas Sales agreement - Contractual Field* is used to identify the assigned agreements. Thirdly, the term *Gas Sales Agreement – Supply Field* applies for those agreements that are assigned or allocated to the

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[291] Bygnes Control Center at Karmøy

supply fields (including the old depletion contracts).

Gas Sales Agreements - GFU

The PUD and PAD processes and the GFU and FU processes are all ingredients in the comprehensive approval processes resulting in final licenses and assignments of gas sales contacts. These approval processes are all conducted in the context systems. Therefore, in the RDD-100 printouts only modest attention is given to these processes. The main interests here are the assigned contracts because the execution of these contracts has a direct influence on transport operations and dispatching processes.

Gas Sales Agreements - Contractual Fields, - Supply Fields

In the modelling work these two types of contracts are treated jointly. They both belong to the context system, and the main issue of importance here is to identify all interactions between these contracts and the transportation system and its operations. Five documents are identified:

- Gas Sales Agreements' Appendixes
- Identification Procedure
- Operating Agreements
- Invoicing Manual
- Seller and Shipper Administration Procedures

The Gas Sales Agreements contain references to Appendixes. These Appendixes specify important parameters related to the gas quality requirements and other essential delivery terms. The Gas Sellers' Representative and Shippers' Representative have developed several Identification Procedures [292] based on the requirements specified in the Gas Sales Agreements. The Identification Procedures specify rules for shortfall handling and rules for how to prioritize gas deliveries between production fields.

The Gas Seller Representative has developed several Operating Agreements [293] based on the requirements specified in the Gas Sales Agreements. These documents specify requirements for dispatching and reporting. The Gas Sellers Representative and the Shipper Representatives have developed several Seller and Shipper Administration Procedures [292] in order to document the seller's and shipper's representative functions on behalf

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[292] See Statoil document "Orientering om Statoils Gass-Salgsadministrsasjon, 5.3.96"
[293] See Statoil GSC archive, called "driftsavtaler" in Norwegian.

of the other sellers and shippers.

11.7.3 Assessment of the upstream agreements

Upstream Agreements – Substitution

From time to time gas sales commitments are done between production field licensees and gas buyers where no physical pipeline exists between them. Or in other words, it is impossible for the seller to supply the customer with his own physical gas. The Substitution Agreements are designed to correct this situation and they typically take the form of a swap arrangement.

A typical situation is shown in the Figure 34 below. In this case, field A has a contractual obligation with buyer 2, but his physical gas is delivered into pipeline A and not into pipeline B. A Substitution Agreement ("swap") features a solution, as illustrated in the drawing. Field B delivers the gas on behalf of field A. Substitution Agreements may last for many years and they usually have extensive contractual provisions.
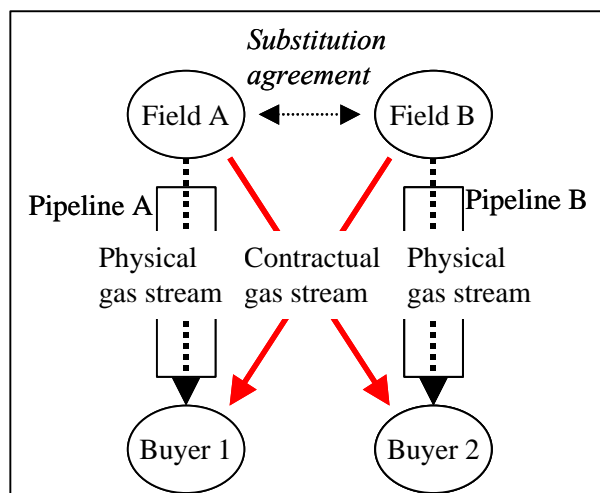
Figure 34.   Substitution Agreements

Upstream Agreements – Modulation

The Modulation Agreements are designed to allow a given field to produce gas according to an optimized field reservoir production schedule. Modulation Agreements are thus important tools to enhance resource management. In connection with hydrocarbon production from a subsea production field, many constraints must be considered. Issues like reservoir depletions plans, gas or water injection plans, well maintenance and threshold values in production facilities are considered by the operator when he optimizes the fields' production plans. Further, very often the production plans at one field must be harmonized with production plans at a neighboring field.

The core issue here is that such optimized production plans seldom match the gas sales commitments. If the gas sales commitments – and the buyers' random requests – should set the daily production plan at the production fields, the field reservoir may be deteriorated over time.

Modulation Agreements are therefore designed to let some production fields deliver gas according to an optimized plan and let other fields fluctuate on the former field's behalf. In Figure 35 below two curves are shown – one represents the optimized physical production curve and the other represents the contractual obligation delivery curve. These two curves do not fit. In the early years of the sales contract, the given field is in a need for borrowing gas. Later, the field has a surplus of gas and finally the field provides too little gas to meet the sales obligations. In the periods of too little gas, (marked with: "-" in Figure 35) a Modulation Agreement can be entered into, allowing another field to supply the gas. The opposite takes place when too much gas is produced. These types of contracts may last for many years and they usually have extensive contractual provisions.
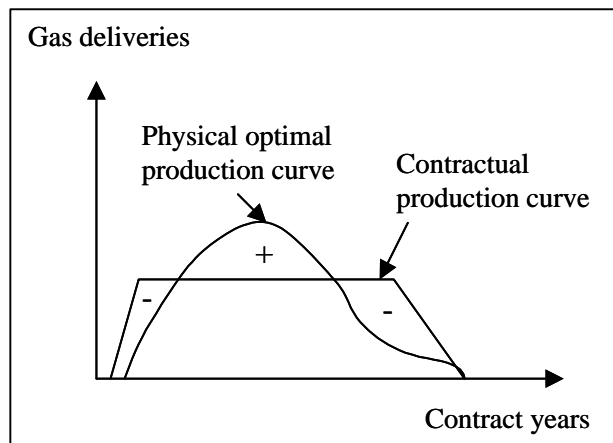

Figure 35.   Modulation Agreements

Upstream Agreements – Regularity Support

The nature of this agreement is much the same as the modulation agreements, except that this agreement usually has a much narrower time frame or duration. Typically, such agreements are designed to enhance regularity on a daily basis. The way this agreement works is illustrated in Figure 36 below. If there is a surplus production from a given field, a defined assisting field holds back his own production and thereby balances out the commingled stream to match the buyer's request for gas delivery.
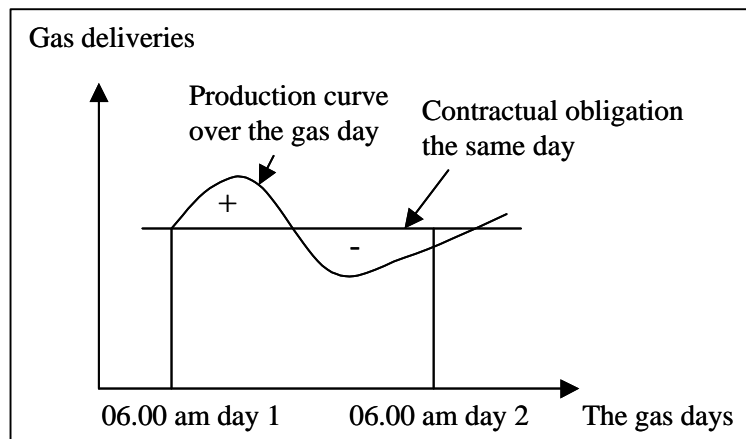
Figure 36. Regularity Support Agreements

Upstream Agreements – Storage

The storage agreement is a specific variant of the modulation agreement. If for instance, enhanced oil production creates associated gas that for different reasons are not sold, an alternative gas allocation is needed. One alternative is a storage agreement that allows the field to store its gas in another field.

These agreements typically cause some characteristic operational modes, worthy of note. The main principle for gas storage is illustrated in Figure 37 below. Field A and field B have entered into a storage agreement, allowing field B to store a gas volume *c* in field A. The dotted arrow illustrates this agreement. Further, if we now assume that each field has entered into an individual gas sales contract they will be commitment to deliver gas volumes *a* and *b,* respectively. These arrangements will eventually cause the Transportation System Operator to instruct a physical gas production (and delivery) from the two fields equal to the gas volumes: *(a-c)* and *(b+c),* respectively.

This fact causes some technical and commercial complications. First, if the gas quality in the two fields are substantially different and the blending is too unproportional, the gas quality of the commingled stream (downstream point 2) may be off-specification according to requirements laid down in the gas sales contracts. In other words, if the gas sales contracts have to narrow quality terms, this effectively may hamper the possibilities for storing of gas between fields.
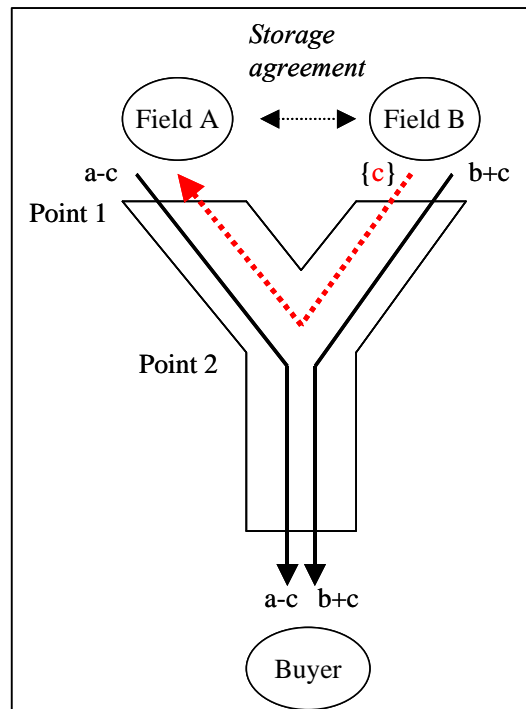
Figure 37.   Storage Agreement

A second characteristic condition is that such agreements typically raise difficult questions related to tolling, a condition sometimes referred to as "backhaul" or "displacement of gas".[294] This situation can easily be illustrated by referring to Figure 37 and by asking the following question: what shall be the correct gas volume subject for toll in the pipeline section located between *point 1* and *point 2*?

Two possible answers exist. First, the toll can be based on the contractual gas stream, which in this case would be *a*. The second option is to base the toll on the physical gas stream which in this case yields *a-c*. In the special case of *a=c*, no physical gas stream is flowing in this pipeline section.

The IEA study report makes one interesting observation when it points to this fact. It states that in a "bundled", or vertically integrated regulatory regime, these types of considerations have not fully been studied, but in a liberalized regime, these issues will be increasingly important.[295]

Upstream Agreements – Supply
The last type of agreement to be mentioned here is the supply

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[294] See IEA (1994) page 132 and Madden (Financial Times) (1997) page 53.
[295] These types of considerations have been carefully discussed among shippers on the NCS.

agreements. These agreements allow some fields to supply gas under a specific gas sale contract held by another licensee group. These agreements are crucial features that support the resource management effectiveness measure. The nature of the agreement is shown in Figure 38.
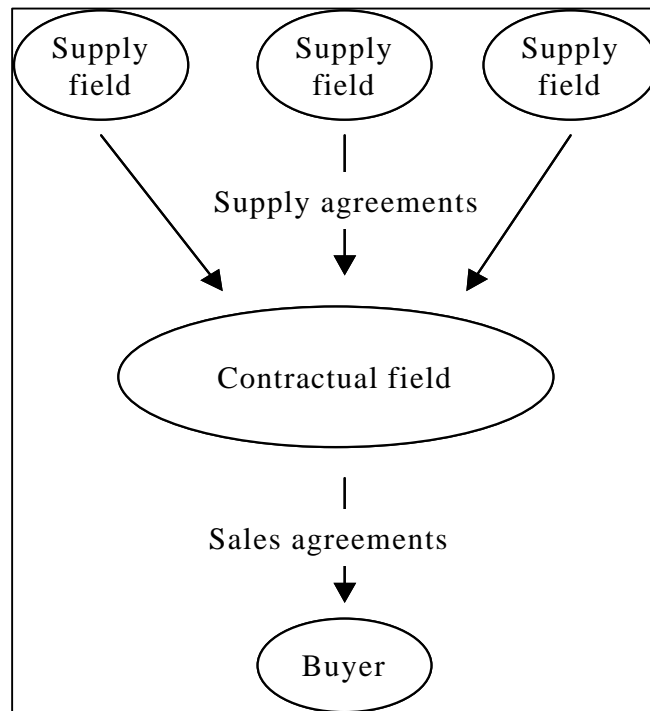

Figure 38.   Supply Agreement

Two important expressions are worthy of note in this context, namely the terms *sellers' share* (SES) and *suppliers' share* (SUS). These terms are applied to distinguish between a gas seller's different obligations under different contracts. Based on the MPE's *assignment*, a particular field will be *contractually responsible* according to the *contractual gas sales* agreements for a given percentage-share of the total gas sales. However, at the same time, based on the MPE's allocation, the same field may be responsible for the *physical supply* of a given, albeit different percentage-share of the total sale. So in other words, a specific field may be *contractually* responsible for X percentage of the total sale, but on a given day is asked to *supply* Y percentage of the sale. During a normal day the fields are asked to deliver according to the SUS while shortfall situations requires delivery instructions based on the SES calculations. The sellers- and shippers- dispatching representative performs these calculations and issues delivery instructions accordingly. Normally, there exists only *one* contractual field linked to one gas sales agreement.

11.7.4 The Operational Flexibility concept

Operational Flexibility (opflex) is a phrase used by the Transportation System Operator and the Shippers' Dispatching Representative and it refers to a specific means for optimizing gas transportation and gas sales. In day-to-day operations gas may be borrowed from a neighboring field or injected into a neighboring field to solve urgent needs. Such needs may occur due to production facility interruptions and shut-downs. In 1998 approximately 630 events [296] occurred. The clue here is that the Transportation System Operator or the Shippers' Dispatching Representative has been authorized to instruct such operations on their own discretion, if there is a need to do so. Such operations are done daily whenever there is a shortage or a surplus of gas somewhere in the system.

Normally, no specific commercial conditions are specified for the conduct of the Opflex, other than some specified maximum limits and timeframes to balance unsettled accounts as soon as the situation causing the problem has been resolved. This is in contrast to the Upstream Agreements that all have commercial terms specified for the service offered.

11.7.5 The Linepack concept

The last operational optimization measure to be mentioned here is the Linepack concept. Line packing (Linepack) means to store gas in a specific pipeline, by increasing the pressure in the pipe and thus obtaining a larger pipeline inventory of gas. In the Figure 39 below, the concept is illustrated. The Transportation System Operator seeks to maintain the Linepack at a "good average working pressure". [297] The pipeline's capability to store gas, shall serve contradicting goals. If a production field, for example, experiences problems with its gas injection facilities it must export excessive volumes of gas. The goal is that the pipeline shall be able to receive these volumes. A similar situation occurs if a buyer decreases his nominations faster than what is a feasible production shut down rate.

The pipeline inventory capacity will also serve in an opposite situation, namely as a "supplier" of gas. The Transportation System Operator seeks to store some gas in the pipeline. This gas can be withdrawn from the pipeline, if for example, the gas buyers increase their nominations faster than production capabilities. Another aspect is the fact that the Norwegian pipelines are long in distance and the delayed response at the outlet, to an increased production at

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[296] Source: Statoil
[297] Soruce: Statoil

the inlet, is significant. [298] The use of Linepack is at the Transportation System Operators' discretion and several detailed rules for its usage are specified in a procedure.[299]
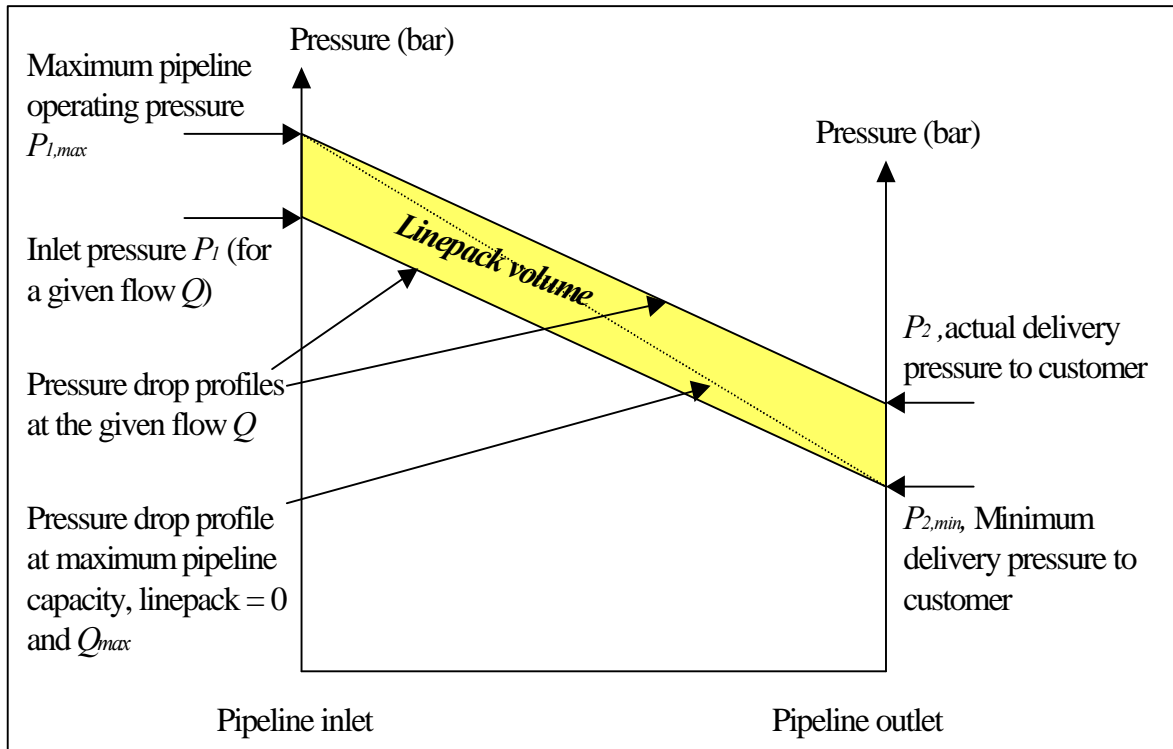

Figure 39.   The Linepack concept

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[298] Dahl (1998-A)

[299] "The Procedure for linepack arrangement between transportation systems and operational flexibility arrangement between fields"

11.8 Gantt chart of work

Below is a Gantt chart of the work, updated by October 2000.

ID	Task Name	Duration	% Com
1	**Administration**	4 wks	100%
2	Mentor co-ordination	1 wk	100%
3	Preparation for USA and visiting tr	3 wks	100%
4	**A: Strategy development**	13 wks	100%
7	A.2: Identification academic fields	3 wks	100%
8	A.3: Conceptual framework	3 wks	100%
5	A.1: Strategy breakdown	2 wks	100%
6	INCOSE 1999 Paper writing	1 wk	100%
9	**B: System re-engingeering process**	28 wks	100%
11	B.1: Assess information current re	5 wks	100%
10	B.2: Define effectiveness measure	3 wks	100%
12	Literature search and reading	4 wks	100%
13	B.3: Creat information models/RD	8 wks	100%
14	B.4: Testing of model	2 wks	100%
15	B.5: Document and write dissertat	4 wks	100%
16	INCOSE 2000 paper writing	2 wks	100%
17	**C: Systems engineering process**	55 wks	74%
18	C.1: Assess information new regin	6 wks	100%
19	Literature search and reading	6 wks	100%
20	C.2: Redefine effectiveness meas	4 wks	90%
21	IAEE paper writing	4 wks	100%
22	C.3: Specify scenario	3 wks	100%
23	C.4: Develop new toll rules	10 wk	60%
24	C.5: GassOpt testing and analyze	3 wks	80%
25	C.6: Modify information models	2 wks	0%
26	C.7: Test new modifications	2 wks	0%
27	C.8: Document and dissertation w	15 wk	65%
28	**Paper milestones**	93,2 wk	0%
29	Paper #1 (INCOSE 1999)	0 wks	100%
30	Paper #2 (INCOSE 2000)	0 wks	100%
31	Paper #3 (IAEE)	0 wks	100%
32	Paper #4 (draft)	0 wks	30%

12   Enclosure of papers

12.1   INCOSE 1999 Paper

"Systems engineering and Statoil natural gas transport operations", *Proceedings of the Ninth Annual International Symposium of the International Council on Systems Engineering (INCOSE),* (Brighton, UK, June 1999) vol. II, pp 791-798.

12.2   INCOSE 2000 Paper

"Information modelling and systems re-engineering – an efficient approach to assessing complex current Norwegian natural gas transport operations", *Proceedings of the Tenth Annual International Symposium of the International Council on Systems Engineering (INCOSE),* (Minneapolis, USA, July 2000) pp 49-56.

12.3   IAEE 2000 Paper

"A European Natural Gas Market in Transition: Is a New Tariff Regime in Norwegian Dry Gas Transportation Needed? Overview of a Complex Issue", *Annual European Energy Conference 2000 (IAEE*), (Bergen, Norway, August 31- September 1, 2000)