

UNIVERSITY OF OTTAWA

**Combining Balanced Score Card and Data Envelopment Analysis for Analyzing the  
Performance of Small Scale Fisheries**

Master of Science in Systems Science  
Faculty of Graduate and Postdoctoral Studies

**Mona Rezaei**

**Supervisor: Dr. Daniel Lane, Telfer School of Management**

© Mona Rezaei, Ottawa, Canada, 2015

## Abstract

The balanced scorecard (BSC) is an accepted methodology for putting strategy into action. The BSC provides a comprehensive performance measurement for an organization with respect to both financial and non-financial perspectives, including the triple bottom line of planet, people, and profit. Through various implementations to companies, organizations, and sectors, balanced scorecards have been used widely both for strategic purposes, as well as for more tactical focus for auditing current performance. BSC implementation is particularly adequate when integrated with the operational processes of the organization. The integration between the strategic plan and the financial and operational plans proceed via the business process model that covers the operational processes associated with the objectives of the organization in the strategy map. In this way, BSC is a tool for real-time monitoring of performance as well as providing the crucial linkage to the organization's strategy that enables the proper implementation of the organization's strategy. Data envelopment analysis (DEA) has been widely applied for measuring the efficiency of a specific decision-making unit (DMU) against a projected point on an efficiency frontier. DEA is therefore particularly suitable for measuring the organizational efficiency based on the BSC indicators, which are defined as Key Performance Indicators (KPIs). In the commercial fisheries sector, sustainable strategy of fisheries organizations can be gained by running the current operations more effectively, and by integrating processes enabling adaptation to change. The efficiency frontier of the DEA model can be used to calculate the efficiency of fisheries operations. The proposed research is undertaken as part of the Canadian Fisheries Research Network (CFRN) to investigate the application of BSC and DEA for defining commercial fisheries performance evaluation variables with respect to the objectives of environmental sustainability, economic viability, and social and cultural stability in compliance with, and in the absence of, performance monitoring alleged in the Fisheries and Oceans, Canada Integrated Fisheries Management Plans (IFMP). The combination of BSC-DEA methodologies is developed in this research as a required performance monitoring system suitable for IFMPs for analyzing the relative efficiency of commercial fisheries case studies across Canada towards incorporating best sustainable practices in the industry.

**Key words:** Balanced Scorecard (BSC), Key Performance Indicators (KPI), Data Envelopment Analyses (DEA), Integrated Fisheries Management Plans (IFMPs), sustainability, triple bottom line, commercial fisheries industry sector.

## **Acknowledgements**

I would like to thank Professor Dan Lane for encouraging me to pursue this research topic. His contributions to the definition of research objectives, his close supervision and pertinent feedback have helped me to make of my research an enjoyable learning process.

This research would not have been possible without the support of my family and I would like to thank my parents for all their inspiration.

## Table of Contents

<b>Abstract</b> .....	<b>2</b>
<b>Acknowledgements</b> .....	<b>3</b>
<b>1. Introduction</b> .....	<b>11</b>
<b>1.1 Background and Motivation</b> .....	<b>11</b>
<b>1.2 Research Question and Research Objectives</b> .....	<b>13</b>
<b>1.3 Thesis Outline</b> .....	<b>15</b>
<b>2.Literature Review</b> .....	<b>17</b>
<b>2.1 Balanced Scorecard</b> .....	<b>17</b>
2.1.1 Perspectives .....	19
2.1.1.1 Customer Perspective.....	20
2.1.1.2 Internal Process Perspective .....	20
2.1.1.3 Learning and Growth Perspective.....	21
2.1.1.4 Financial Measures .....	22
2.1.2 Interrelationships among four perspectives of BSC.....	23
<b>2.2 Data Envelopment Analysis</b> .....	<b>25</b>
2.2.1 DEA Model Categories .....	27
2.2.2 DEA Model Taxonomy .....	28
<b>2.3 Commercial Fisheries Systems</b> .....	<b>41</b>
2.3.1 Sustainable Fisheries.....	43
2.3.2 Fisheries Management.....	45
2.3.3 Fisheries Application in Performance Measurement.....	48
<b>2.4 Summary</b> .....	<b>49</b>
<b>3. Research Methodology</b> .....	<b>52</b>
<b>3.1 Defining the BSC objectives and the associated KPIs</b> .....	<b>53</b>
<b>3.2 Short listing the KPIs</b> .....	<b>63</b>
<b>3.3 Defining the inputs and outputs for DEA methodology</b> .....	<b>68</b>
<b>3.4 Selecting a DEA model</b> .....	<b>69</b>
3.4.1 The model used in this research .....	70
<b>3.5 An integrated DEA-BSC model</b> .....	<b>71</b>
<b>3.6 Application of the model</b> .....	<b>73</b>
3.6.1 Cause and effect relationship.....	74
3.6.2 Database .....	75
<b>3.7 Summary</b> .....	<b>81</b>
<b>4.Analysis and Results</b> .....	<b>83</b>
<b>4.1 Data</b> .....	<b>84</b>
<b>4.2 Numerical Example - All Inclusive Dataset</b> .....	<b>87</b>
4.2.1 Data statistics .....	87
4.2.2 Efficiency Scores.....	92

4.2.3 Rank.....	93
4.2.4 Efficiency Ranking Graph .....	95
4.2.5 Efficiency plot.....	96
4.2.6 Slacks.....	100
4.2.7 Projection .....	100
4.2.8 Weights.....	101
<b>4.3 Salmon Analysis.....</b>	<b>102</b>
4.3.1 Data statistics .....	102
4.3.2 Efficiency Scores.....	109
4.3.3 Rank.....	110
4.3.4 Graph.....	110
4.3.5 Efficiency plot.....	112
4.3.6 Slacks.....	117
4.3.7 Projection .....	117
4.3.8 Weights.....	117
<b>5.Conclusions and Recommendation.....</b>	<b>120</b>
<b>5.1 Conclusion .....</b>	<b>120</b>
<b>5.2 Recommendations for Future Research.....</b>	<b>122</b>
5.2.1 Reporting Standards.....	122
5.2.2 Integrated BSC-DEA model.....	123
5.2.3 Policy Impact .....	123
<b>5.3 Limitations .....</b>	<b>124</b>
5.3.1 Data Availability .....	124
<b>Bibliography.....</b>	<b>126</b>
<b>Appendix A.....</b>	<b>134</b>
<b>A. Database.....</b>	<b>134</b>
A.1 KPIs and Inputs/Outputs .....	134
A.2 Inputs and Outputs.....	136
<b>Appendix B.....</b>	<b>138</b>
<b>B. All inclusive Results .....</b>	<b>138</b>
B.1 Efficiency Scores.....	138
B.2 Slacks .....	140
B.3 Projection .....	142
B.4 weights .....	147
<b>Appendix C .....</b>	<b>149</b>
<b>C. Salmon Analysis.....</b>	<b>149</b>
C.1 Efficiency Scores.....	149
C.2 Slacks.....	150

<b>C.3 Projections .....</b>	<b>151</b>
<b>C.4 Weights.....</b>	<b>152</b>

## Tables

Table 2.1 Input/ Output .....	31
Table 2.2 DMUs Data .....	31
Table 2.3 CCR Scores & Slacks Results .....	31
Table 2.4 CCR Weights Results .....	32
Table 2.5 BCC (Output-Oriented) Scores & Slacks Results .....	33
Table 2.6 BCC (Output-Oriented) Weights Results .....	34
Table 2.7 ADD Objective Function value .....	35
Table 2.8 ADD Slack variables Results.....	35
Table 2.9 ADD Weights Results .....	36
Table 2.10 SBM VRS Scores & Slacks Result .....	40
Table 2.11 SBM VRS Weights Result .....	41
Table 3.1 A list of business processes of commercial fisheries firm .....	55
Table 3.3 BSC framework for commercial fishery harvesting sectors .....	59
Table 3.5 The weight of factors.....	66
Table 3.4 Key Performance Indicators by Category .....	76
Table 3.5 Short List KPIs and Definitions .....	78
Table 3.6 Database Sectoral Case Studies by Year and Major Group .....	79
Table 3.7 DMUs Description.....	80
Table 4.1 Sectoral Fisheries Harvesting Database Comparisons .....	84
Table 4.2 Consumer Price Index from 1991 to 2009 .....	86
Table 4.3 All Inclusive Model Input/Output Indicators .....	87
Table 4.4 Statistics on Input/Output Data .....	88
Table 4.5 Correlation Matrix.....	88
Table 4.6 Ranking .....	94

Table 4.7 Input/output Data.....	102
Table 4.8 Statistics on Salmon Input/output Data.....	103
Table 4.9 Pairwise Correlation Matrix.....	103
Table 4.10. Ranking.....	110
A.1 KPIs and Inputs/Outputs Data.....	134
A.2 Inputs and Outputs Data.....	136
B.1. Efficiency Scores.....	139
B.2. Slacks.....	140
B.3 Inefficient DMU Projection Results.....	142
B.4 weights.....	147
C.1 Efficiency Scores.....	149
C.2 Slacks.....	150
C.3 Inefficient DMU Projection Results.....	151
C.4 Weights.....	152

## Figures

Figure 3.1 Research methodology steps.....	53
Figure 3.5 Cause and effect relationship among the selected KPIs.....	75
Figure 4.1 All Inclusive Model results: Efficiency Frontier (Input 1, Output 1).....	89
Figure 4.2 All Inclusive Model results: Efficiency Frontier (Input 1, Output 2).....	90
Figure 4.3 Efficiency Frontier (Input 2, Output 1).....	91
Figure 4.4 Efficiency Frontier (Input 2, Output 2).....	92
Figure 4.5 DMUs Efficiency.....	95
Figure 4.6 Efficiency Plot (Input1).....	96
Figure 4.7 Efficiency Plot (Input2).....	97
Figure 4.8 Efficiency Plot (Output1).....	98
Figure 4.9 Efficiency Plot (Output2).....	99
Figure 4.10 Projection percentages for (KPI: 1, 15, 3, 17).....	<b>Error! Bookmark not defined.</b>
Figure 4.11 Data Plot (Output1/Input1).....	104
Figure 4.12 Data Plot (Output2/Input1).....	105
Figure 4.13 Data Plot (Output3/Input1).....	106
Figure 4.14 Data Plot (Output1/Input2).....	107
Figure 4.15 Data Plot (Output2/Input2).....	108
Figure 4.16 Data Plot (Output3/Input2).....	109
Figure 4.17 DMUs Efficiency.....	111
Figure 4.18 Efficiency Plot (Input1).....	112
Figure 4.19 Efficiency Plot (Input2).....	113
Figure 4.20 Efficiency Plot (Output1).....	114
Figure 4.21 Efficiency Plot (Output2).....	115
Figure 4.22 Efficiency Plot (Output3).....	116
Figure 4.23 Projection.....	<b>Error! Bookmark not defined.</b>

# Chapter 1

# Introduction

## 1. Introduction

This document presents the master's thesis of the author in partial fulfillment for the degree of M.Sc. in Systems Science. The research presented in this thesis presents the problem of the monitoring of the multiple perspectives of sectorial performance of alternative commercial fishing operations over time. This research is in support of integrated management of common property commercial fisheries, which are within the mandate in Canada of federal government department of Fisheries and Oceans, Canada.

A common-property resource is the property of no one person, but by definition, of all people in common. The living resources of the ocean are viewed as common property to coastal states. However, when these living resources are harvested, they have market value and are thereafter treated as private property. Commercial fisheries seek ways to increase the productivity in their valued marine subsystems. Thus, productivity assessment and evaluation in commercial fisheries organizations are very important. Productivity performance includes two main factors: 1) efficiency and 2) effectiveness. In order to assess productivity, commercial fisheries seek to control these two parameters toward achieving organizational objectives. In this study these two factors are controlled and measured by BSC (effectiveness) and DEA (efficiency). Thus, these two factors helped us to define the productivity concept and describe the fact that we measure productivity by linking this factor of BSC and for overall performance evaluation DEA.

### 1.1 Background and Motivation

In order to access secure, sustainable future fisheries' performance, efficiency and effectiveness are identified as the two key elements of productivity. Fisheries sustainability covers all sides of productivity including the social and cultural, environmental, and economic aspects of fisheries. Balancing sustainability strategy plays a pivotal role in terms of solidifying the future sustainable state of commercial fisheries productivity and performance. Analyzing the performance gaps by knowing the current status of commercial fisheries regarding, their productivity, and their strategy for the future, would lead to this balance. Thereafter, the comparison of small-scale fisheries sectorial practices before and after the introduction of efficiency regulations in parallel with their current situation would be a starting point toward planning for a balanced and sustainable future. In the case of small boat fisheries, defining fisheries problems by financial measures alone overlooks their non-financial and sustainability-relevant

perspectives. Collectively, these measures are prominent due to their potential to be modified and improved by converting to measurable indicators.

The challenge of managing food supply to match the increasing planetary needs while maintaining the ecological system has become more challenging than at any time in the past. New products and production methods, fragmentation and outsourcing of production processes, and changing value chains are characteristics of today's global fish markets (OECD, 2010). According to The State of World Fisheries and Aquaculture (FAO, 2014), capture fisheries and aquaculture supplied the world with about 145.1 million tonnes of fish products in 2009, as shown in Table 1.1 below.

Table 1.1 World fisheries and aquaculture production and utilization. Source: (FAO, 2014)

	2007	2008	2009	2010	2011	2012
	<i>(Million tonnes)</i>					
<b>PRODUCTION</b>						
<b>Capture</b>						
Inland	10.1	10.3	10.5	11.3	11.1	11.6
Marine	80.7	79.9	79.6	77.8	82.6	79.7
<b>Total capture</b>	<b>90.8</b>	<b>90.1</b>	<b>90.1</b>	<b>89.1</b>	<b>93.7</b>	<b>91.3</b>
<b>Aquaculture</b>						
Inland	29.9	32.4	34.3	36.8	38.7	41.9
Marine	20.0	20.5	21.4	22.3	23.3	24.7
<b>Total aquaculture</b>	<b>49.9</b>	<b>52.9</b>	<b>55.7</b>	<b>59.0</b>	<b>62.0</b>	<b>66.6</b>
<b>TOTAL WORLD FISHERIES</b>	<b>140.7</b>	<b>143.1</b>	<b>145.8</b>	<b>148.1</b>	<b>155.7</b>	<b>158.0</b>
<b>UTILIZATION<sup>1</sup></b>						
Human consumption	117.3	120.9	123.7	128.2	131.2	136.2
Non-food uses	23.4	22.2	22.1	19.9	24.5	21.7
Population ( <i>billions</i> )	6.7	6.8	6.8	6.9	7.0	7.1
Per capita food fish supply ( <i>kg</i> )	17.6	17.9	18.1	18.5	18.7	19.2

*Note:* Excluding aquatic plants. Totals may not match due to rounding.

This impressive development has been driven by a combination of population growth, rising incomes and urbanization, and facilitated by the strong expansion of fish production, more efficient distribution channels and as a whole, more productive processes (FAO, 2014). Therefore, fisheries would aim to maximize their productivity by considering their strategies as a bottom line of their performance as an active sector of a global trend.

The BSC is a strategic managerial tool composed of a collection of measures, arranged in

groups, and denoted as scorecards of the organization's performance. The measures or the key performance indicators are aimed at providing managers or decision makers with a comprehensive view of the major aspects of their organization. BSC combines financial and operational measures, and focuses both on the short- and long-term objectives of the organization (Hosseinzadeh et al., 2010). The key to achieve the current objectives and continuous improvement is dependent on the ability of the organization to measure consistently and constantly the performance of value-added processes within an enterprise (Braam & Nijssen, 2004). Thus, over the last several years, many organizations have adopted a variety of performance measurement systems (PMS) (Fernandes et al., 2006) (Prajogo & Sohal, 2004). One of the PMS methods that have been widely applied is Data Envelopment Analysis (DEA). DEA is an analytical method that can be used to measure the relative efficiency of a set of production systems, or decision-making units (DMUs) on the basis of observed inputs and outputs, which may be expressed with different types of metrics (Najafi et al., 2009)

Fisheries and Oceans Canada (DFO) uses Integrated Fisheries Management Plans (IFMPs) to identify performance outputs for individual fisheries management plans. However, the full integration of Canadian fisheries into the IFMP framework was incomplete and for those IFMPs that had been developed, the content was highly variable between plans. The IFMPs template provides a brief overview of economic conditions and social, as socio-economic dimension and due to the lack of practical performance determinations, there are some examples such as pacific salmon, which is unable to deliver on the template requirements. Aligning all the IFMP processes with strategic goals and measuring the efficiency by focusing on strategic criteria can result in a step forward toward determining the performance of commercial fisheries and a basis for comparison between fisheries case studies, which operate within the commercial fisheries sector.

## 1.2 Research Question and Research Objectives

Limiting fishing effort has been accomplished by limiting harvest efficiency. This approach to fishery management sustains most of the characteristics of a common property resource, but conflicts directly with fishing business management. While the commercial fisheries industry strives for greater efficiency and production, the Canadian public regulator (Fisheries and Ocean, Canada) typically, and in the name of conservation, attempts to reduce the rate of exploitation of fish stocks and harvesting production of the industry by restricting efficiency.

This research project aims at developing a BSC framework to align the performance of commercial fisheries with its associated business strategy in order to enhance the organization's efficiency while focusing on strategy. Furthermore, case studies from the commercial fisheries are examined using publicly available data in an effort to identify the most efficient fisheries sector using the DEA approach. The DEA provides a clear view of efficient performance in comparison with other comparative fisheries case studies.

The following research questions were therefore proposed for this study:

1. How can the Balanced Scorecard (BSC) be designed to apply to the commercial fisheries harvesting sector and what are the corresponding Key Performance Indicators (KPIs) that are appropriate and available (from existing data) for measuring fisheries harvesting sectorial performance?
2. How can DEA be used to determine the multiple perspective efficiencies of fisheries harvesting sectors, and what are the efficiency benchmarks and the relative efficiency of selected commercial fishery case studies?
3. How can the BSC-DEA methods be applied to improve the multiple perspectives of performance measurement of commercial fisheries harvesters as required for the Integrated Fisheries Management Plans?

The objective of this research is to compare the relative efficiency of sectorial fisheries harvesters for different fisheries case studies as a paradigm of the industry to deliberate each other's relative performance using the quantitative techniques of BSC and DEA. The results enable the relative comparison of commercial fishery operations toward the overall goal of sustainable fisheries systems. Several steps are taken to achieve the proposed thesis objectives and to provide the means of answering the research questions.

These steps consist of:

1. Developing an appropriate and a generally applicable BSC model for application to a broad range of commercial fisheries case studies for the east coast and west coast fisheries in Canada. Defining the set of KPI's for each perspective in the BSC model, as well as for the recognition of the triple bottom line of sustainability, i.e., ecological/ ecosystem sustainability, economic viability, and social and cultural stability.
2. Measuring, evaluating, and comparing the suite of fisheries case studies according to their relative efficiency, and determine areas of best practice among case studies under investigation.

3. Preparing suggested performance management reports for a revised IFMP that includes a comparison of harvesting efficiency among the sectors (i.e., gear types) of the fishery.

This study combines the BSC and DEA approaches to identify a comprehensive view to all the financial and non-financial processes taking place in the commercial fisheries industry in Canada.

### 1.3 Thesis Outline

An outline of the key components presented in each chapter of this thesis is as follows:

**Chapter 1 – Introduction:** The current section provides the background information to commercial fisheries global market as well as the motivation for this study.

**Chapter 2 – Literature Review:** A literature review of the concepts examined in this study will be presented in this section. Areas of interest include terminologies, approaches to preparedness, preparedness measures and indicators, and evaluation and preparedness modeling. Chapter 2 also presents applications of the study and a summary of the literature reviewed.

**Chapter 3 – Methodology:** The methodology section of the thesis will examine the tools and potential methods required to develop the framework mentioned as part of the objectives.

**Chapter 4 – Analysis and Results:** An overview of the analysis method and modeling approach will be shown in this section. The sample cases will be used as an example to show the results.

**Chapter 5 – Conclusions and Recommendations:** The outcome as well as recommendations for Balanced Scorecard and Data Envelopment Analyses approaches will be discussed in this chapter.

# Chapter 2

# Literature Review

## 2.Literature Review

This chapter of the, thesis reviews the literature of on the research methodologies of Balanced Scorecard, Data Envelopment Analysis, and the application area on commercial fisheries in Canada, The literature review is divided into four main sections, namely: (2.1) Balanced Scorecard; (2.2) Data Envelopment Analysis; (2.3) commercial fisheries systems; and (2.4) Canadian commercial fisheries case studies. These sections are further subdivided into particular subareas of interest relevant to the thesis research.

### 2.1 Balanced Scorecard

The balanced scorecard is a strategic planning and management system that is used extensively in business and industry, government, and nonprofit organizations worldwide to align business activities to the vision and strategy of the organization, to improve internal and external communications, and to monitor organization performance against strategic goals.

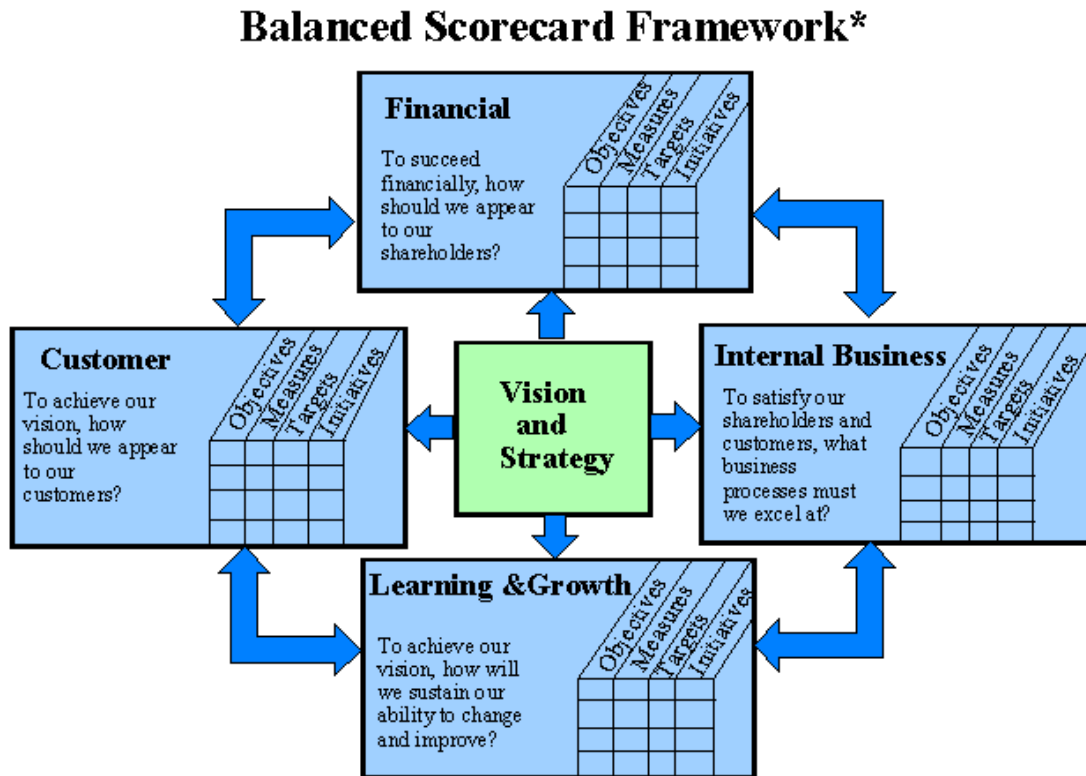
The balanced scorecard (BSC) approach was first introduced by Kaplan and Norton in 1992 as a performance management tool (Kaplan & Norton 1992). Its aim was to present management with a concise summary of the key performance indicators (KPI) of the business, and to support alignment of business operations with the defined strategy of the organization. The authors' intention was to keep a score of a set of Key Performance Indicators (KPIs) that could maintain a balance between objectives and performance perspectives. Kaplan and Norton provided a medium to translate the strategy of the company into a set of related objectives and their performance measurements. Furthermore, these measures effectively communicated a powerful, forward- looking, strategic focus to the entire organization. The fact that companies mainly relied on traditional financial accounting measures was a motivation for Kaplan and Norton to convert a 'narrow and incomplete picture of business performance into a comprehensive one' (Fernandes, Raja, & Whalley, 2006, p. 625)

As a result, they suggested that financial indicators must be put into account with non-financial indicators that reflected customer satisfaction, internal business processes, and the level of learning and growth in the organization. Their BSC was designed to complement the 'financial measures of past performance with measures of the drivers of future performance' (Fernandes, Raja, & Whalley, 2006) (Kaplan & Norton, 1996).

By adopting a ‘holistic’ view of the organization, managers, who were being overwhelmed with data, would spend more time on decision-making according to the results of data analysis. The original balanced scorecard framework included the following four organizational perspectives: (i) the financial perspective; (ii) the customer perspective; (iii) the internal-business-process perspective; and (iv) the learning and growth perspective. These perspectives represent three major stakeholders of any business (shareholders, customers, and employees), thereby ensuring that a holistic view of the organization is used for strategic reflection and implementation. The success of the Balance Scorecard framework depends on the perspectives themselves and the measures chosen to be consistent and flexible with the corporate strategy and changes that might occur in the long term (Fernandes, Raja, & Whalley, 2006) (Kaplan & Norton, 1992) (Kaplan & Norton, 1996).

BSC requires that companies categorize KPIs in four perspectives and develop performance measures within each of these categories as shown in Figure 2.1 below. This figure requires completion of Objectives, measures, targets, and initiatives for each of the four BSC perspectives that arise from the Mission and Vision of the organization. In this way managers can track and measure objectives with feasible activities. Thus, BSC can provide a practical framework not just a strategic framework like a potential idea.

Identification of the ‘strategic objectives’ is based on interviews with managers by internal or external consultants. Then, specific measures can be developed for these objectives through meetings with executives and experts in the industry (Fernandes, Raja, & Whalley, 2006) (Garca Valderrama et al., 2008) (Banker, 2004).



\* Adapted from Kaplan & Norton 1996. *The Balanced Scorecard*. Harvard Business School Press: 9. Original from HBR Jan/Feb 1996, p. 76.

Figure 2.1 Four perspectives for the preparation of a Balanced Scorecard for an organization.

Source: Kaplan and Norton (1996).

Once managers and decision makers define initiatives toward reaching the firm's targets along each perspective, then the organization has a balanced approach to reaching its overall strategic objectives.

### 2.1.1 Perspectives

According to the BSC theory, the original framework has four perspectives that can summarize all feasible and non-feasible aspects of an organization. There are some examples in Kaplan and Norton (2004) that have more than four perspectives in their scorecard, but the majority of them followed the four perspective original framework. In this section, each of the four perspectives of the Balanced Scorecard are examined and described.

### 2.1.1.1 Customer Perspective

Managers need a clear idea of their targeted customer and business segments, and select a set of core outcome measurements for these targeted customers. These outcome measures represent the current situation of the company's processes. Managers must also identify what customers in targeted segments need, and according to these requirements choose the value proposition. They then define objectives and select measures from among three classes of attributes that, if satisfied, will enable the company to develop its business with these targeted customers. The three classes of customer attributes are:

1. Product and service attributes: functionality, quality, and price
2. Customer relationship: quality of purchasing experience and personal relationships
3. Image and reputation

By selecting specific objectives and measures across these three attributes, managers can focus their organization on delivering a superior value proposition to their targeted customer segment (Kaplan & Norton, 1996).

This perspective focuses on identifying the customer and market segments in which the business unit will compete and the measures of the business unit's performance in these marked segments.

### 2.1.1.2 Internal Process Perspective

In the internal-business-process perspective, managers identify the critical processes that are value-added considering the objectives of shareholders and targeted customer segments. In comparison with conventional performance measurement systems, Balanced Scorecard enables - further than monitoring cost, quality, and time-based measures of existing business processes - the demand for internal process performance to be derived from the expectations of specific external constituencies.

The innovation process plays a pivotal role in the internal-business-process perspective. It highlights the importance of first identifying the characteristics and opportunities of market segments that the organization needs to satisfy with designing and developing the products and services for those targeted segments. This approach enables the organization to focus more on research, design, and development processes. The operations process remains important and organizations should identify the cost, quality, time, and

performance characteristics that will enable it to deliver superior products and services to its targeted current customers (Kaplan & Norton, 1996).

The measures focus on the internal processes that will have the greatest impact on customer satisfaction and achieving an organization's financial objectives. In the Internal Process perspective of the Balanced Scorecard, the key processes that have a value adding impact on the whole system are identified in order to continue adding value for customers and, ultimately, shareholders.

### **2.1.1.3 Learning and Growth Perspective**

The ability to meet ambitious targets for financial, customer, and internal-business-process objectives comes from the organizational capabilities for learning and growth. There are three enablers for the learning and growth perspective: (1) employees, (2) systems, and (3) organizational alignment. Strategies for superior performance will generally require significant investments in people, systems, and processes that make the foundation of any organizational improvement. Consequently, objectives and measures for this perspective should be an integral part of any organization's Balanced Scorecard.

A core group of three employee-based measures (satisfaction, productivity, and retention) provide outcome measures from investments in employees, systems, and organizational alignment. The drivers of these outcomes are, to date, somewhat generic and less developed than those of the other three balanced scorecard perspectives. These drivers include summary indices of strategic job coverage, strategic information availability, and a degree of individual, team, and departmental alignment with strategic objectives. The absence of company-specific measures indicates the opportunity for future development of employee, systems, and organizational metrics that can be more closely linked to a business unit's strategy (Kaplan & Norton, 1996).

Human resources are the most valuable organizational resources that can add crucial value to the business processes. This perspective identifies the infrastructure that the organization must build to create long-term growth and improvement. The result of measures in the Learning and Growth perspective of the Balanced Scorecard trace the impact of the human resources on the other aspects of an organization, and eventually managers can modify this foundation to gain its effect on the organizational structure.

#### 2.1.1.4 Financial Measures

Financial Objectives represent the long-term goal of the organization to provide returns based on the capital invested. The Balanced Scorecard makes the financial objectives explicit, and customizes them in different stages of business unit's life cycle. The scorecard enables senior executives of business units to specify not only the metric by which the long-term success of the enterprise will be evaluated, but also the key financial performance to create and to drive the long-term outcome objectives. Indicators of the financial perspectives are customized to the industry, the competitive environment, and the strategy of the business unit (Kaplan & Norton, 1996).

Every indicator selected for each perspective interacts with each other in the whole system as a link of cause-and-effect relationships, ending in financial objectives, that represents a strategic theme for the system under investigation. As a result, the BSC framework is not a group of isolated or even conflicting objectives. The framework tells the story of the strategy, translating to the long-run financial objectives, linking these to the sequence of initiatives that must be taken with financial processes, customers, internal processes, and finally employees to deliver the desire performance (Kaplan & Norton, 1996).

Summarizing the readily measurable economic/financial consequences indicates whether a company's strategy, implementation, and execution are contributing to the profit bottom line improvement. Financial measures are a critical component of the Balanced Scorecard framework, and are considerable especially in the for-profit commercial environment. The measures in this perspective indicate whether strategy execution, which is detailed through key performance indicators chosen in the other perspectives, is leading to improved profit bottom-line results. "The causal paths from non-financial objectives on the scorecard should be linked to financial objectives. This procedure implies that strategy is translated into a set cause and effect relationships, which are crucial because it allows the measurements in nonfinancial areas to be used to predict future financial performance. Thus, the financial measures are about past performance while non-financial measures are the drivers of future performance. The validity of the model relies, however, on the assumption that the cause-and-effect relationship exists between the objectives and their measures in each perspective" (Fernandes et al., 2006, p.626) (Kaplan & Norton, 1996) (Kaplan & Norton, 1992) (Eilat et al., 2006)

### 2.1.2 Interrelationships among four perspectives of BSC

In order to achieve objectives in the financial perspective of BSC framework, all objectives and measures in other perspectives should be linked (Gosselin, 2005); (Laitinen, 2005); (Kim & Davidson, 2004). To achieve a synergetic effect, firms should emphasize the cause and effect relationship among the KPIs in each perspective. Olve, Roy and Wetter (2000) discussed that improved value in human resource and development capital should be the leading indicators of improvement in customer capital and profitability. These authors develop a cause and effect model that indicates that the measures of human resource development would influence the internal business process of the firm directly and from there that customer and financial aspects can be affected (Najafi et al., 2009). These interrelationships are shown in Figure 2.2.

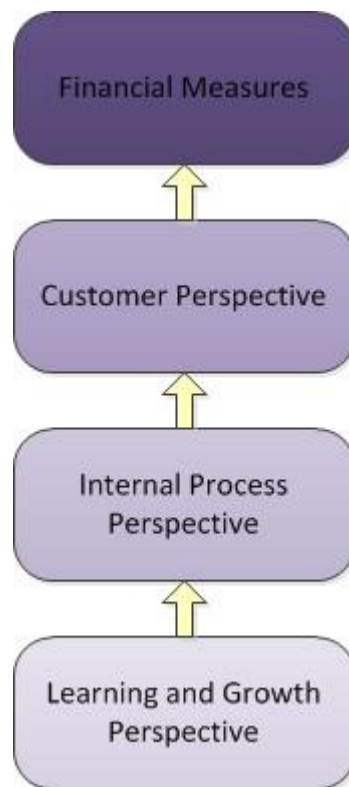


Figure 2.2 Cause and effect relationships among the BSC Perspectives. (Niven, 2001)

Figure 2.2 shows that each perspective would have an impact on each other. As a result, synergetic effects driven from these perspectives could integrate all aspects of an organization. On the other hand, Paul Niven's analogy of the Balanced Scorecard is that of a tree (Figure 2.3).

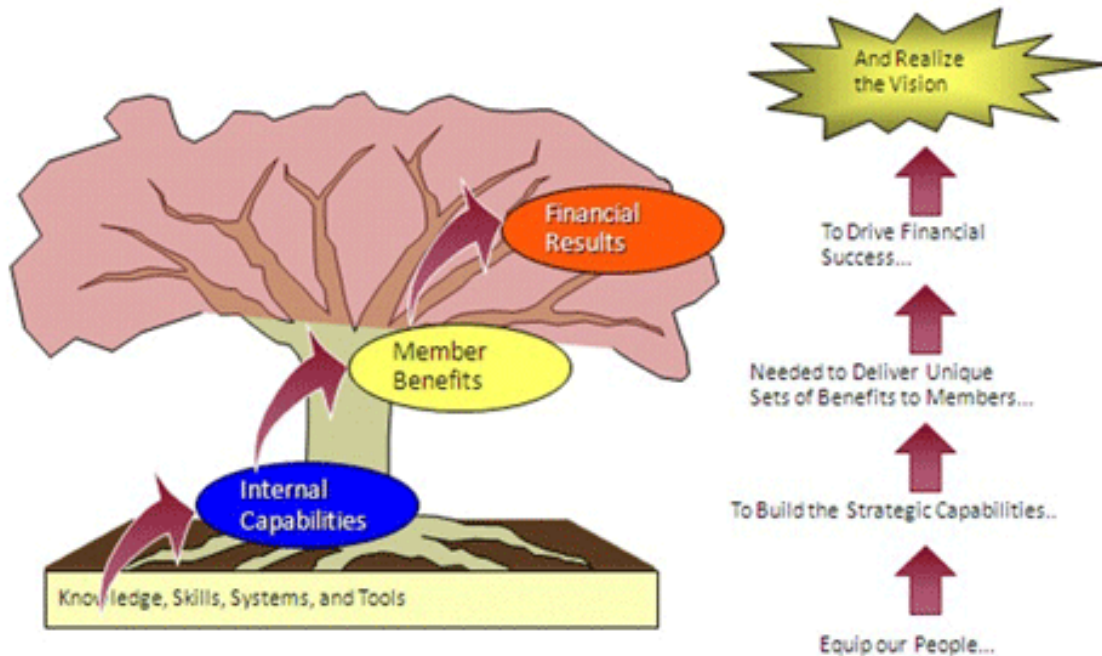


Figure 2.3 Cause and effect. Source: (Niven, 2001)

In Figure 2.3, the Learning and Growth perspective are the roots, the tree trunk is the Internal capabilities of a firm, targeted Customers are the branches, and the leaves represent financial perspective. It is a continuous cycle of renewal and growth in any organization or dynamic system. As in nature, leaves (finances) fall to fertilize the ground and root system, which stimulates knowledge, skills, and growth throughout the organization. In this respect, the Learning and Growth perspective is the foundation on which all other perspectives are built (Niven, 2001).

BSC comprehensive perspectives would make it possible for managers to monitor and ensure that the objectives of the organization's strategy will be implemented and achieved. It also allows to monitoring the evolution of organizational decisions taking into account a set of key indicators. In this respect, each activity in the organization must be belonged to each particular aspect of the strategy to help the organizations to achieve full success. BSC can complete the traditional approach of measuring the financial success of organizations in the way that organizational vision and strategy are converted into goals, strategic indicators, targets and initiatives and that its unfolding occurs through other perspectives beyond the financial, with the focus of maintaining long-term sustainability (Gomes & Romão, 2014) A Balanced Scorecard framework describes the strategy through the objectives and Key Performance Indicators that have been chosen for

measurement. These measures link together in a chain of cause-and-effect relationships from the KPIs in the Learning and Growth perspective to improved financial performance drivers as reflected in the financial perspective.

However, this framework contains a serious failure in its construction, once it focused management strictly on a set of pre-defined indicators and measures and they are not able to respond to simple and fundamental question, such as “what our competitors are doing?” (Kennerley & Neely, 2003). Also, BSC does not monitor competition or technological developments. This implies that does not take into account the uncertainty inherent risks involved in the events that can threaten this strategy. The effect of this control model can lead to serious dysfunctional behavior and loss of control over the implementation of the strategy (Nørreklit, 2003).

In this study, we applied BSC to balance our KPIs with all specific perspectives by strategy map however, another use of this method as a measurement tool is scoring which needs some improvements. In addition to the advantages, BSC needs to be completed by other performance measurement methods in terms of its targets and projections because this method can describe and measure the current situation of the company and understanding future steps would not be possible without making comparisons with the same active sectors in a specific industry. Data Envelopment Analysis as a proper complementary efficiency measurement tool has been described in next section. Also, the Key performance indicators that are defined in each perspective and balanced according to the quantitative and qualitative goals would make a bridge between these two methods.

## 2.2 Data Envelopment Analysis

Data Envelopment Analysis is a managerial tool for measuring efficiency using linear programming techniques (Charnes, 1985). There are many studies in DEA terminology and applications. This review section considers the most important related publications to the method under investigation for the proposed research thesis.

Recent years have seen a great variety of applications of DEA (Data Envelopment Analysis) for use in evaluating the performances of many different kinds of subsystems engaged in any industry. One reason for this is because DEA has opened up possibilities for application in cases that have been resistant to other approaches due to the complex or often unknown nature between multiple inputs and multiple outputs involved in systems often-reported in non-commeasurable units. Determining the efficiency of some applications extend to evaluating the performances of organizations, institutions, cities, regions and countries with many different kinds of inputs and outputs that include for

instance, "social" expenditures as inputs and various "quality-of-life" dimensions as outputs which, in turn, have led to dealing with more important issues at the global level (Cooper et al., 2007).

DEA has also been used to supply new insights into activities (and entities) that have previously been evaluated by other methods. For instance, studies of the best practices with DEA have identified inefficiency in some of the most profitable organizations that served as the benchmarks base on their profitability as the only criterion (Cooper et al., 2007).

A critical concept in DEA approach is efficiency. "DEA considers a decision making unit or DMU is efficient if it complies with the Pareto-Koopmans efficiency, which implies a DMU is efficient if and only if it is not possible to improve any input or output without worsening some other input or output" (Fiallos, 2013).

The basic DEA model computes the virtual efficiency score as the ratio of a weighted sum of outputs to a weighted sum of inputs. These weights used are not determined by human judgment but by solving a linear programming model. Thus, they are derived from the data and not from expert opinion. Alternatively to most scoring schemes where a single structure of weights is used to evaluate each unit's performance, the weights in the DEA virtual efficiency score differ across DMUs. This is because for each individual DMU, a model is run to calculate a set of weights for each input and output. These models can be interpreted as the set of most favorable weights for a specific DMU, in order to maximize its own virtual efficiency score (Cooper et al., 2007).

For each DMU, DEA calculates a measure known as the virtual efficiency score. Depending on the type of DEA model, this score can be interpreted as the required modification (in %) of inputs or outputs to transform an inefficient DMU into an efficient one, or as a value that summarizes all the inefficiencies found in a DMU's inputs, outputs or both (Fiallos, 2013).

Based on the ideas of Farrell (1957), the primary work "Measuring the efficiency of decision making units" by Charnes, Cooper & Rhodes (1978), applied an input/output-oriented model (the CCR model) using linear programming to estimate an empirical production technology frontier (Ebnerasoul, Yavarian, & Azodi, 2009). Later in 1984 Banker, Charnes, and Cooper (1984) introduced the BCC model allowing the breakdown of efficiency into technical and scale efficiencies in DEA. Later, Charnes, Cooper and Rhodes (1989) proposed a quantitative technique that they named Data Envelopment Analysis (DEA) to evaluate the relative efficiency of comparable components of an organization (Cooper et al., 2007).

There have been many studies written on DEA models or applying DEA to various industries at a different stage of the company or DMU level within an organization. There are now several types of applied DEA models with the most basic being the CCR model based on the (Charnes A. , Cooper, Lewin, & Seiford, 1994) methodology. However, there are also DEA models to address returns to scale, either CRS (constant returns to scale) or VRS (variable returns to scale). According to the idea of returns of scale, Charnes et al. (1994) introduced the Additive Model for DEA with Constant Returns to Scale (ADD-CRS) and Lovell and Pastor (1995) developed the primary DEA model as the Additive Model with Variable Returns to Scale (ADD-VRS).

Since the result of the proposed models did not describe the distance between the current situation and the ideal stage of case studies, Tone (2001) introduced a Slack Based Measure with Constant/Variable Returns to Scale methodology. With this model, organizations could measure their slacks to be improved by decreasing inputs in parallel with increasing their outputs. On the whole, DEA has been used widely in performance evaluation through measurements, which can be achieved through various models.

The next subsection presents a discussion around the various DEA models.

### **2.2.1 DEA Model Categories**

All DEA models can be categorized according to: (i) model orientation (input-oriented, output oriented, or non-oriented), (ii) type of efficiency (technical, mix, others), and (iii) a return to scale assumption (constant or variable) (Cooper et al., 2007). In this section we discuss the taxonomy of DEA models.

#### **2.2.1.1 Model Orientation**

Model orientation can define a potential improvement in inputs and outputs, which can be derived from solving the DEA model. These intentions may be to reduce inputs, improve outputs, or both. If the system under investigation has controllable inputs, it may reduce its inputs (such as cost, raw material, etc.). The relative efficiencies can be determined by input-oriented DEA models to transform an inefficient DMU into an efficient one. However, an output-oriented model (ie., applications with controllable outputs like profit, number of products, etc.) determines how much the outputs of an inefficient DMU must be improved in order to achieve efficiency. Finally, A non-oriented DEA model is used for systems that are flexible in determining simultaneous improvement of inputs and outputs to attain full efficiency (Cooper et al., 2007).

### **2.2.1.2 Types of Efficiency**

In the DEA approach there are two most common types of efficiency: technical and mixed efficiency. Under the Pareto-Koopmans definition of efficiency, a DMU is efficient only when technical and mixed inefficiencies are absent (Fiallos, 2013).

A DMU is technically inefficient if it is possible for all its inputs to be reduced proportionally at the same time (Cooper, Seiford, & Tone, 2007). In an input-oriented model, the score that represents the ratio of benchmark performance inputs to actual performance inputs drives technical inefficiency. In an output-oriented model, a similar score is calculated for the outputs as its technical inefficiency. If these scores are equal to 1, the DMU is technically efficient. In some cases, after the technical inefficiency is removed, there are still improvement opportunities. This is due to mixed inefficiency (Fiallos, 2013).

### **2.2.1.3 Return to Scale Assumptions**

Returns to scale refer to the assumed effect of inputs on outputs of a DMU when performing in the efficient frontier. When the proportional change in inputs produces the same proportional change in the outputs, it is assumed to be constant returns to scale (CRS) (Cooper et al., 2007). Some DEA model constraints are used to impose CRS or variable returns to scale (VRS), which allows for constant, increasing and decreasing returns to scale (Fiallos, 2013).

## **2.2.2 DEA Model Taxonomy**

The most commonly used DEA models (Cooper et al., 2007) (Fiallos, 2013) are as follows:

- Charnes, Cooper, Rhodes or CCR input (output)-oriented model (CCR-I (O)) (proposed by Charnes et al., 1978)
- Banker, Charnes, Cooper or BCC input (output)-oriented (BCC-I (O)) (proposed by Banker et al., 1984)
- Additive Model with Constant Returns to Scale (ADD-CRS) (proposed by Charnes et al., 1985)
- Additive Model with Variable Returns to Scale (ADD-VRS) (proposed by Lovell and Pastor, 1995)
- Slack Based Measure with Constant Returns to Scale (SBM-CRS) (proposed by Tone, 2001)

- Slack Based Measure with Variable Returns to Scale (SBM-VRS) (proposed by Tone, 2001)

Below we describe these models in more detail.

### 2.2.2.1 CCR

Given the data on organizations' measurable inputs and/or outputs, the Charnes, Cooper, and Rhodes (1978) model, CCR is the basic DEA model. CCR returns measures for the efficiency of each DMU among  $n$  DMUs. Hence, this model requires  $n$  optimizations, to evaluate the efficiency of each DMU <sub>$j$</sub> ,  $j=1,2,\dots,n$ . Below is the fractional programming problem formulation, that (Cooper, Seiford, & Tone, 2007, p. 23) named it as CCR (FP0), to determine weights for the inputs and outputs as variables.

#### CCR (FP<sub>0</sub>)

Max

$$\theta_0 = \frac{u_1 y_{1o} + u_2 y_{2o} + \dots + u_s y_{so}}{v_1 x_{1o} + v_2 x_{2o} + \dots + v_m x_{mo}} \quad (1.1)$$

Subject to:

$$\frac{u_1 y_{1j} + u_2 y_{2j} + \dots + u_s y_{sj}}{v_1 x_{1j} + v_2 x_{2j} + \dots + v_m x_{mj}} \leq 1 \quad j = 1, 2, 3, \dots, n \quad (1.2)$$

$$v_1, v_2, \dots, v_m \geq 0 \quad (1.3)$$

$$u_1, u_2, \dots, u_s \geq 0 \quad (1.4)$$

As can be seen from the CCR formulation, the objective is to obtain weights for both input and output decision variables that maximize the ratio of DMU<sub>o</sub>, the DMU being evaluated (1.1). The first constraint (1.2) means that the ratio of "virtual output" versus "virtual input" should not exceed 1 for every DMU. The other constraints (1.3)-(1.4) for all outputs and inputs assume nonzero worth. This is reflected in the weights  $u_r$  and  $v_i$  being assigned nonnegative values (Cooper, Seiford, & Tone, 2007, p. 23).

"The above ratio form yields an infinite number of solutions; if  $(u^*, v^*)$  is optimal. However, the transformation developed by Charnes and Cooper (1962) for linear fractional programming selects a representative solution and yields the equivalent linear

programming problem in which the change of variables from  $(u, v)$  to  $(\mu, \nu)$  is a result of the Charnes-Cooper transformation,” (Cooper, Seiford, & Tone, 2007, p. 9)

The following formulation, CCR (LP0) is the equivalent linear program (LP) model:

**CCR (LP<sub>0</sub>)**

Max

$$\theta = \mu_1 y_{1o} + \dots + \mu_s y_{so} \quad (1.5)$$

Subject to:

$$v_1 x_{1o} + \dots + v_m x_{mo} = 1 \quad (1.6)$$

$$\mu_1 y_{1j} + \dots + \mu_s y_{sj} \leq v_1 x_{1j} + \dots + v_m x_{mj} \quad (j = 1, \dots, n) \quad (1.7)$$

$$v_1, v_2, \dots, v_m \geq 0 \quad (1.8)$$

$$\mu_1, \mu_2, \dots, \mu_s \geq 0 \quad (1.9)$$

Each DMU<sub>j</sub> has  $s$  output measures represented by parameters  $y_{rj}$  ( $r=1, 2, \dots, s$  and  $j=1, 2, \dots, n$ ) and  $m$  input measures represented by parameters  $x_{ij}$  ( $i=1, 2, \dots, m$  and  $j=1, 2, \dots, n$ ) (Fiallos, 2013, p. 32).

Let  $S_i^-$  and  $S_r^+$  be slack variables “The performance of a DMU is fully (100%) efficient if and only if both (i)  $\theta^* = 1$  and (ii) all slacks  $= S_i^- = S_r^+ = 0$  and the performance of the DMU is weakly efficient if and only if both (i)  $\theta^* = 1$  and (ii) is  $S_i^- \neq 0$  and/or  $S_r^+ \neq 0$  for some  $i$  and  $r$  in some alternate optima” (Cooper, Seiford, & Tone, 2007, p. 13).

The CCR LP model formulation and solution is illustrated in the following numerical example of four different Pacific salmon fishing sectors (Salmon Seine, Salmon Gillnet, Salmon Troll, and Salmon Mixed Gear) as our defined DMUs, with their 3 inputs and 4 outputs. Table 2.1 illustrates these indexes with their descriptions. This illustrative example is based on the case study presented in Anderson et al., 2012.

Table2.1 Input/ Output  
Source: (Anderson et al., 2012).

Input/ Output	Description
Input 1	Harvesting Cost
Input 2	Administrative expenses
Input 3	Harvest Time
Output 1	Distribution Cost
Output 2	Cost Per Unit of Output
Output 3	Net Operating Profit
Output 4	Maximum Sustainable Yield

Table 2.2 presents index values for each Fishery as our DMUs.

Table2.2 DMUs Data  
Source: (Anderson et al., 2012).

DMU	(Input)(1)	(Input)(2)	(Input)(3)	(Output)(1)	(Output)(2)	(Output)(3)	(Output)(4)
Salmon Seine	285.20	123.8	106.72	48.14	43.1	253	41
Salmon Gillnet	162.30	128.7	64.21	34.62	27.11	148	27
Salmon Troll	275.70	348.5	104.1	36.72	45.98	175	23
Salmon Mixed Gear	210	154.1	104.04	33.16	56.46	160	84

As can be seen in Table 2.3, after applying the CCR model for the data presented in Table 2.2, the efficiency score, slack variables for input ( $S_i^-$ ), and outputs ( $S_r^+$ ) are computed as the result.

Table 2.3 CCR Scores & Slacks Results

No.	DMU	Score	Excess			Shortage			
			S-(1)	S-(2)	S-(3)	S+(1)	S+(2)	S+(3)	S+(4)
1	Salmon Seine	1	0	0	0	0	0	0	0
2	Salmon Gillnet	1	0	0	0	0	0	0	0
3	Salmon Troll	0.899904326	38.27634328	153.7631984	0	2.027558878	0	0	37.03420696
4	Salmon Mixed Gear	1	0	0	0	0	0	0	0

Thus, as the result of our objective function (1.5) we have the efficiency scores that in this case for all of DMUs is equal to 1 except for Salmon Troll that has 0an efficiency

score of 0.8999, which means that this DMU is inefficient relative to the other 3 DMUs in this dataset. Furthermore, as the slack variables,  $S_1^-$  and  $S_2^-$  as excesses of inputs 1 and 2, respectively, and also  $S_3^+$  and  $S_4^+$  as shortfalls for output 3 and 4, respectively, for the inefficient DMU (Salmon Troll). Therefore, as optimum solution we have the inputs and outputs weights as Vs and Us provided in Table 2.4.

Table 2.4 CCR Weights Results

No	DMU	V (1)	V (2)	V (3)	U (1)	U (2)	U (3)	U (4)
1	Salmon Seine	0.002387896	2.58E-03	0	0.020772746	0	0	0
2	Salmon Gillnet	6.16E-03	0	0	2.89E-02	0	0	0
3	Salmon Troll	0	0	0.009606148	0	0.012249651	0.001923802	0
4	Salmon Mixed Gear	0	6.49E-03	0	1.75E-03	1.67E-02	0	0

According to Table 2.4 (v, u) are used as the weights for indexes that refer to  $(\mu, v)$  in (1.5)-(1.9). Variables represented by r and u are the weights to be calculated for each of the m inputs (X) and s outputs (Y). DEA models assign the most favorable weights to inputs and outputs for each DMU in order to maximize its score. Also DEA computed Slack is the amount for improvement. Thus, only the inefficient DMUs have slacks. The original value of inputs or outputs plus slack equals the Target for improving the DMU. Slack contains the Input excesses  $s^-$  and Output shortfalls  $s^+$  for each DMU.

### 2.2.2.2 BCC

BCC is an input (output)-oriented model which means that it can be used for controllable inputs as input oriented model or controllable outputs as output oriented model that are described in section 2.2.1.1 and its fractional programming problem is as follows:

#### BCC (FP<sub>0</sub>)

Max

$$\theta_0 = \frac{uy_0 - u_0}{ux_0} \quad (2.1)$$

Subject to:

$$\frac{uy_i - u_0}{vx_j} \leq 1 \quad (j = 1, \dots, n) \quad (2.2)$$

$$v \geq 0, u \geq 0, u_0 \text{ free.} \quad (2.3)$$

“It is clear that a difference between the CCR and BCC models is present in the free variable  $u_0$ ” (Cooper, Seiford, & Tone, 2007, p. 87).

The output-oriented BCC model evaluates the efficiency of  $DMU_o$  ( $o=1, \dots, n$ ) by solving the following linear program:

### BCC (LP<sub>o</sub>) Output- Oriented

$$\text{Max } \eta_B \quad (2.4)$$

Subject to:

$$\eta_B y_o - Y\lambda \geq 0 \quad (2.5)$$

$$X\lambda \geq x_o \quad (2.6)$$

$$e\lambda = 1 \quad (2.7)$$

$$\lambda \geq 0 \quad (2.8)$$

Where  $\eta_B$  is an optimal expansion (Cooper, Seiford, & Tone, 2007, p. 89). This LP is output oriented because of constrain (2.5) which can explain the concept of weighted output of  $DMU_o$  should be greater and equal to sum of the weighted output of other DMUs. Also, (2.5) and (2.6) seek a virtual unit characterized by inputs  $X\lambda$  and outputs  $Y\lambda$ .

Below, the example above is solved and presented in Table 2.5.

Table 2.5 BCC (Output-Oriented) Scores &Slacks Results

No.	DMU	Score	Excess		Excess		Shortage		Shortage	
			S-(1)	S-(2)	S-(3)	S+(1)	S+(2)	S+(3)	S+(4)	
1	Salmon Seine	1	0	0	0	0	0	0	0	0
2	Salmon Gillnet	1	0	0	0	0	0	0	0	0
3	Salmon Troll	0.92351020	33.886185	208.380152	0	0	0	10.899557	38.669301	8
4	Salmon Mixed Gear	1	0	0	0	0	0	0	0	0

Table 2.5 presents the result of output-oriented BCC model, which, expressed in (2.4)-

(2.8), the optimal expansion rate  $\eta_B$  is displayed in the “Score” column for each DMU.

“The evaluation secured from the CCR and BCC models are also related to each other as follows. An optimal solution for  $BCC_o$  is represented by  $(\eta_B^*, \lambda^*, S^{-*}, S^{+*})$ , where  $S^{-*}$  and  $S^{+*}$  represent the maximal input excesses and output shortfalls, respectively. Notice that  $\eta_B$  (all Scores are equal to 1 except inefficient DMU with 0.9value) is not less than the optimal objective value  $\phi^*$  (all Scores are equal to 1 except inefficient DMU with 0.8value) of the CCR model, since  $BCC_o$  imposes one additional constraints,  $e\lambda = 1$ , so its feasible region is a subset of feasible region for the CCR model” (Cooper, 2007, p.88)

The optimum weights (v and u) are presented in Table 2.6 below.

Table 2.6 BCC (Output-Oriented) Weights Results

No.	DMU	V(0)	V( 1)	V (2)	V (3)	U (1)	U (2)	U (3)	U (4)
1	General	0	0.002387896	2.58E-03	0	0.020772746	0	0	0
2	University	0	6.16E-03	0	0	2.89E-02	0	0	0
3	County	0.208793731	0	0	8.40E-03	1.22E-02	1.20E-02	0	0
4	State	0	0	6.49E-03	0	1.75E-03	1.67E-02	0	0

Similar to CCR, in this method, the indices weights are presented as the optimum results according to BCC formula presented in (2.4)-(2.8).

**2.2.2.3 ADD**

The Basic Additive Model (ADD) is a non-oriented model. A non-oriented DEA model is used for systems that are flexible in determining simultaneous improvement of inputs and outputs to attain full efficiency. The ADD model simultaneously considers technical and mix inefficiencies and is applied under CRS or VRS assumptions. Solving the ADD model does not produce a score that measures the inefficiencies. Instead, it determines the excess of inputs and shortfall of outputs for each DMU relative to its benchmark. Using this model, it is not possible to differentiate between technical and mix inefficiency because it is non-oriented and there is no efficiency score for DMUs (Fiallos, 2013, p. 36).

There are several types of Additive models, from which we select the following:

ADD<sub>o</sub> (LP) VRS

$$\text{Max} \\ z = es^- + es^+ \quad (3.1)$$

Subject to:

$$X\lambda + s^- = x_o \quad (3.2)$$

$$Y\lambda - s^+ = y_o \quad (3.3)$$

$$e\lambda = 1 \quad (3.4)$$

$$\lambda \geq 0, s^- \geq 0, s^+ \geq 0 \quad (3.5)$$

In the above formulation the variables  $s^-$  and  $s^+$  represent the gap between the actual performance and the benchmark. They are called “slack” variables regardless of whether they represent excess input or output shortfall (Cooper et al., 2007, p. 90).

Applying the ADD VRS model to the fishery example results in Table 2.7 that shows the value of objective function presented in model (3.1) above.

Table 2.7 ADD Objective Function value

DMU	Objective
Salmon Seine	0
Salmon Gillnet	0
Salmon Troll	318.1151277
Salmon Mixed Gear	0

As in the previous DEA model outputs, the Salmon Troll is the only inefficient DMU with maximum optimal value 318.115. Table 2.8 illustrates the slack variables for this inefficient DMU.

Table 2.8 ADD Slack variables Results

	(Input)(1)	(Input)(2)	(Input)(3)	(Output)(1)	(Output)(2)	(Output)(3)	(Output)(4)
General	0	0	0	0	0	0	0
University	0	0	0	0	0	0	0
County	62.16091374	207.4470226	9.864736911	0	0	1.615387472	37.027067
State	0	0	0	0	0	0	0

According to (3.1)-(3.5) the optimum results for this model is  $Z^* = 318.115$  (Table 2.7), and  $S^-$  and  $S^+$  (Table 2.8) are the slack variables from Table 2.8. Thus the only slack variables are for Input 1, 2, 3 and Output 3, 4 for the inefficient Salmon Troll DMU. The optimum weights for the ADD model are presented in Table 2.9.

Table 2.9 ADD Weights Results

	(Input)(1)	(Input)(2)	(Input)(3)	(Output)(1)	(Output)(2)	(Output)(3)	(Output)(4)
General	1	1	1	1	1	1.515731225	1
University	1	1	1	1	1	1	1
County	1	1	1	1.227820336	1.557840467	1	1
State	1	1	1	1	1	1	2.601428571

Regarding the ADD formulation that is presented in (3.1)-(3.5), these weights are solved for the  $\lambda$  variable.

Similar to the CCR and the BCC output results, the results of the ADD model shows that Salmon Troll is inefficient however, this model would compute the objective function value presented in (3.1) equation instead of efficiency score. Furthermore, in Table 2.8 slacks are expressed for the inefficient DMU that can interpret as its targeted Inputs and Outputs. In terms of weights like the CCR and BCC models, this model tend to put weights on the indices with better values while, these weights are started from 1 for all indices and because of differences exists in ADD formulae in comparison with the other two basic models. Regarding to the objective function, the basic models would maximize the efficiency score for each DMU ((1.1) and (2.1)) and ADD model considers the maximum combination of excess input or output shortfall for each DMU.

#### 2.2.2.4 SBM

The Slack Base Measure (SBM) DEA model was introduced by (Tone K. , 2001) and has the following properties:

P1: The measure is invariant with respect to the unit of measurement of each input and output item. (Units invariant)

P2: The measure is monotonically decreasing in each input and output slack. (Monotone)

The following is the fractional program formulation for the SBM model under variable returns to scale (VRS) in  $\lambda$ ,  $s^-$  and  $s^+$ .

(SBM, VRS)

$$\min \rho = \frac{1 - \frac{1}{m} \sum_{i=1}^m s_i^- / x_{io}}{1 + \frac{1}{s} \sum_{r=1}^s s_r^+ / y_{ro}} \quad (4.1)$$

Subject to:

$$x_o = X\lambda + s^- \quad (4.2)$$

$$y_o = Y\lambda - s^+ \quad (4.3)$$

$$1^t \lambda = 1 \quad (4.4)$$

$$\lambda \geq 0, s^- \geq 0, s^+ \geq 0 \text{ and } X \geq 0 \quad (4.5)$$

In this model the objective function value  $\rho$  satisfies (P1) because the numerator and dominator are measured in the same units for every item in the objective function (4.1). Also an increase in either  $s^-$  or  $s^+$ , all else held constant, will decrease this objective value and, indeed, do so in a strictly monotonic manner.

Furthermore, we have

$$0 \leq \rho \leq 1 \quad (4.6)$$

and for input we have

$$0 \leq \frac{\sum_{i=1}^m s_i^- / x_{io}}{m} \leq 1 \quad (4.7)$$

This same relation does not hold for outputs since an output shortfall represented by a nonzero slack can exceed the corresponding amount of output produced. In any case, however, we have

$$0 \leq \frac{\sum_{r=1}^s s_r^+ / y_{ro}}{s} \quad (4.8)$$

Thus these represent ratios of average input and output mix inefficiencies with the upper limit,  $\rho = 1$ , reached in (4.1) only if slacks are zero in all inputs and outputs (Cooper et al., 2007)

The first constraint ensures that the input reduction represented by the augmentation of

slack variable  $s^-$  does not go beyond a value represented by a linear combination of DMUs' inputs. The second constraint restricts the increase of evaluated DMU's output, represented by the augmentation of slack variable  $s^+$ , to a value represented by a linear combination of DMUs' outputs. The third constraint adds the convexity condition by ensuring the sum of  $\lambda$  variables is equal to 1. Improved performance of a DMU<sub>o</sub> evaluated under this model is calculated as  $(x_o - s^{-*}, y_o + s^{+*})$  (Fiallos, 2013).

This formula can be transformed to the following SBM linear program in  $t$ ,  $S^-$ ,  $S^+$ , and  $\Lambda$  (Cooper, Seiford, & Tone, 2007):

(SBM LP)

$$\min \tau = t - \frac{1}{m} \sum_{i=1}^m s_i^- / x_{io} \quad (4.9)$$

Subject to:

$$1 = t + \sum_{r=1}^s s_r^+ / y_{ro} \quad (4.10)$$

$$tx_o = X\Lambda + S^- \quad (4.11)$$

$$ty_o = Y\Lambda + S^+ \quad (4.12)$$

$$\Lambda \geq 0, S^- \geq 0, S^+ \geq 0, t > 0 \quad (4.13)$$

Note that  $t > 0$  by virtue of the (4.10) constraint. This means that the transformation is reversible. Thus let an optimal solution of (LP) be

$$(\tau^*, t^*, \Lambda^*, S^-, S^+)$$

Thus the optimum of (SBM VRS) is,

$$\rho^* = \tau^*, \lambda^* = \Lambda^* / t^*, s^{-*} = S^- / t^*, s^{+*} = S^+ / t^*$$

With this optimal solution, we can decide whether a DMU is SBM-efficient as follows:

A DMU  $(x_o, y_o)$  is SBM efficient if and only if  $\rho^* = 1$ .

This means that,  $s^{-*} = 0$  and  $s^{+*} = 0$ , i.e., no input excess and no output shortfall in an optimal solution.

For an SBM-inefficient DMU  $(x_o, y_o)$ , there is an expression as follows:

$$x_o = X\lambda^* + s^{-*}$$

$$y_o = Y\lambda^* - s^{+*}$$

The DMU  $(x_o, y_o)$  can be improved and becomes efficient by deleting the input excesses and augmenting the output shortfalls. This is shown by the following formula (SBM-projection) (Cooper, Seiford, & Tone, 2007):

$$\hat{x}_o \Leftarrow x_o - s^{-*}$$

$$\hat{y}_o \Leftarrow y_o + s^{+*}$$

Based on  $\lambda^*$ , the reference set for  $(x_o, y_o)$  is defined as: “the set of indices corresponding to positive  $\lambda_j^*$ s is called the reference set for  $(x_o, y_o)$ .” (Cooper et al., 2007)

Let  $R_o$  be the reference set designated by

$$R_o = \{j | \lambda_j^* > 0\} (j \in \{1, \dots, n\}).$$

Also  $(x_o, y_o)$  can be expressed by,

$$\hat{x}_o = \sum_{j \in R_o} x_j \lambda_j^*$$

$$\hat{y}_o = \sum_{j \in R_o} y_j \lambda_j^*.$$

This means that a point on the efficient frontier like  $(\hat{x}_o, \hat{y}_o)$  is a positive combination of the member of the reference set,  $R_o$ , each member of which is also efficient (Cooper, Seiford, & Tone, 2007, pp. 96-98).

In this research the SBM VRS model is used because indices are controllable thus, a non-oriented model with variable return to scale could be the most appropriate model to apply.

**(SBM VRS LP)**

$$\min \tau = t - \frac{1}{m} \sum_{i=1}^m s_i^- / x_{io} \quad (4.14)$$

Subject to:

$$1 = t + \sum_{r=1}^s s_r^+ / y_{ro} \quad (4.15)$$

$$tx_o = X\Lambda + S^- \quad (4.16)$$

$$ty_o = Y\Lambda + S^+ \quad (4.17)$$

$$1^t \Lambda = 1^t t \quad (4.18)$$

$$\Lambda \geq 0, S^- \geq 0, S^+ \geq 0, t > 0 \quad (4.19)$$

Regarding the Data presented in Table 2.1 for four different DMUs, Table 2.7 expressed the results of applying the SBM VRS model to the data. The numerator and the denominator of the objective function of model measures the average distance of inputs and outputs, respectively, from the efficiency threshold.

Table 2.10 SBM VRS Scores &amp; Slacks Result

No.	DMU	Score	Excess			Shortage			
			S-(1)	S-(2)	S-(3)	S+(1)	S+(2)	S+(3)	S+(4)
1	Salmon Seine	1	0	0	0	0	0	0	0
2	Salmon Gillnet	1	0	0	0	0	0	0	0
3	Salmon Troll	0.470438945	48.32081716	201.9238059	0	0	6.901391074	6.798361613	50.02113173
4	Salmon Mixed Gear	1	0	0	0	0	0	0	0

According to this table, Salmon Troll is the only inefficient DMU with efficiency score of 0.4704, and also it has slacks in its inputs 1,2 and outputs 2,3, and 4. In comparison with the CCR (0.89) and BCC (0.92) this model computes the lowest efficiency score for Salmon Troll (0.47) by its objective function (4.1). In addition the slacks presented in Table 2.10 for inefficient DMU, are less than the ADD slacks and bigger than CCR and BCC slacks and this can make the targets more feasible to be met.

The next table expresses the solved weights for each input and output by SBM variable return to scale model that its algebraic formula as defined in (4.14)-(4.19).

Table 2.11 SBM VRS Weights Result

No.	DMU	V(1) (1)	V(2) (2)	V(3) (3)	U(1) (1)	U(2) (2)	U(3) (3)	U(4) (4)
1	General	5.00E-03	4.59E-03	3.12E-03	3.28E-02	5.80E-03	9.88E-04	6.10E-03
2	University	2.05E-03	2.59E-03	0.015460215	2.63E-02	9.22E-03	1.69E-03	9.26E-03
3	County	1.21E-03	9.56E-04	6.67E-03	1.81E-02	2.56E-03	6.72E-04	5.11E-03
4	State	1.58E-03	2.36E-03	3.20E-03	7.54E-03	4.43E-03	0.0015625	3.34E-03

In Table 2.11, for each DMUs index set, there are specific optimum weights as the  $\lambda$  presented in SBM VRS formula (4.16)-(4.18). The noted differences in model results are described by Tone (2001) as follows:

“In contrast to the CCR and BCC which are based on proportional reduction (enlargement) of input (output) vectors and which do not take account of slacks, the SBM deals with input excesses and output shortfall. Although the additive model has the weighted sum of slacks as its objective [3.1] can discriminate between efficient and inefficient DMUs. In this framework, the SBM shows a sharp contrast to CCR and BCC... The SBM satisfies such properties as unit invariance and monotone with respect to slacks. Furthermore, it is reference set dependent, i.e. the measure is determined only by its reference set and it is not affected by statistics over the whole data set. Also this model can be modified to cope with input and output orientation as special cases.” (Tone, 2001, p.508)

In conclusion, Managers need to know the efficiency to evaluate the performance of an operation. According to the literature, DEA is a useful tool to measure the efficiency for any type of organization.

In this thesis, the application of DEA is being used to compare efficiency across commercial fisheries harvesting sectors. Commercial fisheries systems are discussed in the next section.

### 2.3 Commercial Fisheries Systems

As the utilization of fishery resources globally has increased dramatically during the last few decades, it has become clear that sustainability is the biggest challenge for this industry. The fact is that fish stocks status are not only debatable, but have the potential to be driven to extinction if exploitation is not controlled. Moreover, the conflicting biological, social, economic and cultural goals inherent in most fisheries are two major

reasons that encourage more efficient ways of managing and operating this industry (Charles, 1994).

A systematic approach toward this industry can describe a fishery system as a set of biophysical, ecological and socio-economic sub-systems that are composed of interconnecting processes, energy and information, as well as a range of stocks and controls that, together, are responsible for the system's overall characteristics and performance, composition, productivity, historical changes, resilience and sustainability (Garcia & Charles, 2008). Figure 2.4 shows a generic view of a fishery system in which, fish interacts with the ecosystem and the biophysical environment whereas fishermen are surrounded by a socioeconomic subsystem (Charles, 2001).

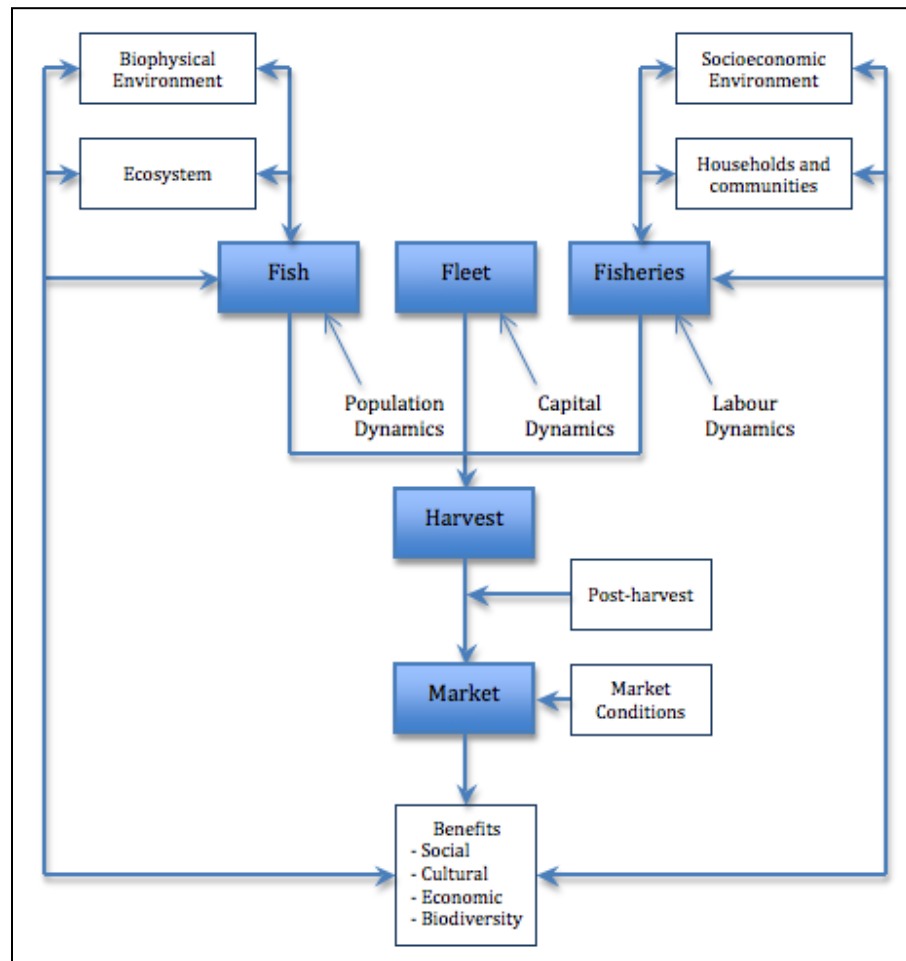


Figure 2.4 Generic View of Fisheries System. Source: Charles (2001)

Charles (2001) divides the fishery system into two main sub-components: a natural system that includes the biotic, abiotic and climate factors, and a human system, which includes the fishing and related economic activities in addition to embedded institutional

and governance components. According to (Garcia & Charles, 2008), the natural components of fishery system may, to some extent, be understood, protected, rehabilitated or enhanced, but the natural sub-system they constitute may not be effectively predicted or controlled. Human activities are more controllable in principle however; social behavior remains a complex source of uncertainty. Throughout the last 50 years, fishery researchers built many simplified representations (models) of the natural and resource use systems. The scope and complexity of the models have increased with time, reflecting complex changes in social demand and the specific questions raised by policy and decision-makers, the types of intervention being contemplated, and the understanding and computational capacity available at the time. Generally, fishery systems are modeled in one of two primary ways, one being visual and diagrammatic (flowcharts, structural charts, etc.), the other mathematical or computer-based (simulation, bio-economic models). While visual modeling is useful for developing a group/consensus understanding of a particular fishery system, the mathematical modeling is efficient for delivering scenario-based analysis. In some cases, the two might be combined together for more comprehensive analysis (Garcia & Charles, 2008).

### 2.3.1 Sustainable Fisheries

In order to address profitability and positive image goals through basic sustainable business practices, first we should define sustainability. In this study sustainability is defined by the triple bottom line. This triple bottom line is known by many names: TBL; 3BL; People, Planet, Profit (the 3 Ps) (figure 2.5); and Ecology, Economy, Equity (the 3Es). All describe the idea of the major forces of our world that must be served to achieve sustainable balance, given our current market models. John Elkington has been attributed with coining the phrase “triple bottom line” in 1994. The main idea was that the triple top line requires that a company’s responsibility be to stakeholders (all people involved in or impacted by a venture) rather than shareholders (only those who profit from the venture) (Jedlicka, 1996).



*Figure 2.5 Triple P: Centre of Sustainable Business Practices. Source: <http://www.unf.edu/coggin/csbp/>*

“People, Planet, Profit” is one of the most common triple bottom line heuristics to describe the complex interactions of sustainability and business demands. To be more exact, People (human capital) refers to equitable and beneficial business practices. Planet (natural capital) refers to a venture’s environmental practices. And finally, Profit (monetary capital) is the global objective shared by all businesses, regardless of their ethics. Within a sustainability framework, the idea of profit needs to be seen as the economic benefit enjoyed by all stakeholders, not just the company’s stockholders (Kambewa, 2007). It doesn’t matter how ecological a business is, if it is not profitable, it cannot sustain its efforts or its positive impacts in that market sector (Jedlicka, 1996). Sustainable development depends on a combined focus of its impact on society (people), the environment (planet), and to its economic value (profit). Increasingly, it is being recognized that these people, profit and planet dimensions are interlinked and an important challenge for public and private policy is to take them jointly into account (Kambewa, 2007, p. 6)(Porter, 2011).

Central to fishery thinking worldwide is the analysis of the balancing act between present-day benefits and future rewards that pre-dates, by a considerable margin, the sustainable development discussion (Beverton & Holt, 1957). Determining sustainable

yields on annual harvests (Total Allowable Catches) can be repeated indefinitely into the future. This determination has been largely the scope of biologists, but in fact there is a range of sustainable yields that will provide biological sustainability therefore, it will depend on other fishery objectives. Furthermore, the well-being of people in fisheries and coastal communities would be the second issue in this area, which can be identified as social, and community concerns. Emphasis is placed on small-scale community-based management, using “appropriate” technology. Within this perspective, the acceptance of sustainable yields is due not to an inherent concern for fish conservation, but rather as a means to preserve the way of life in fishing communities (Charles, 1995).

### 2.3.2 Fisheries Management

In this section we will introduce both conceptual dimensions of fisheries management and the practical application of determining fishery performance through the initiatives of the federal Department of Fisheries and Ocean (DFO) that is responsible for commercial marine fisheries in Canada.

#### 2.3.2.1 Dimensions of fisheries management

While considerable conflict in fisheries arises due to differences over the desired objectives to be pursued, it is appropriate in examining sustainability to recognize the need for simultaneous achievement of several sustainability components. Charles (1994) proposed a set of four fundamental components of sustainability in fishery context:

1. **Ecological Sustainability:** Implies (a) maintaining the resource base (and related species) at levels that do not foreclose future options; and (b) maintaining or enhancing ecosystem capacity, quality and resilience.
2. **Socio-economic Sustainability:** Focuses on the “macro” level, on maintaining or enhancing overall socio-economic welfare, aggregated across the system under consideration. Since the economic and social involved are inseparably linked in the process of policy formation. This socio-economic welfare is based on a blend of relevant economic and social indicators, such as levels of resource rent (or sustainable net benefits), of distributional equity, and of viability within local and global economies.
3. **Community Sustainability:** emphasizes the “micro” level, focusing on the need to sustain communities as valuable human systems in their own right (being more than simply collections of individuals). This involves maintaining or enhancing

- the community's economic and socio-cultural well-being, its overall cohesiveness, and the long-term health of the relevant human systems.
4. **Institutional Sustainability:** Involves the maintenance of suitable financing, administrative and organizational capability over the long term, as a prerequisite for the above three components of sustainability. Institutional sustainability implies that there be no decay over time in the quality of institutional arrangements, appoint related in particular to the manageability and enforceability of resource use regulations.

The first three of these sustainability components can be viewed as the fundamental points of the Sustainability Triangle and the Triple Bottom Line. The fourth, institutional sustainability interacts amongst these, potentially affected (positively or negatively) by any policy focused on ecological, socio-economic and/or community sustainability. Overall sustainability requires reasonable levels of all four components. This provides a general guideline for policy development, focused on developing a practical framework for assessing sustainability in fisheries.

“Evaluating the nature and extent of sustainability involves two related tasks: (1) assessing the current state of the system, and (2) predicting the future state of the system. The first of these might be seen as a status report, while the second concerns the impact of proposed human activities, building on analogous methods in environmental impact assessment. A process of sustainability assessment for accomplishing such evaluations, both qualitatively and quantitatively, involve three steps: (1) a concrete set of criteria (a checklist) that must be met in order to achieve each component of sustainability; (2) a corresponding set of quantifiable sustainability indicators, reflecting the status of each of the criteria; and (3) where appropriate, aggregations of indicators into indices of sustainability”(Charles,1995,p.202).

#### ***2.3.2.1 Integrated Fisheries Management Plans (IFMPs)***

Fisheries and Oceans Canada (DFO) uses Integrated Fisheries Management Plans (IFMPs) to guide the conservation and sustainable use of marine resources. The IFMP is both a process and a document. Its primary goal is to provide a planning framework for the conservation and sustainable use of fisheries resources and the process by which a given fishery will be managed for a period of time. An IFMP is developed to manage the fishery of a particular species in a given region. IFMPs combine the best available science on a species with industry data on capacity and methods for harvesting that species.

IFMPs were first introduced by DFO in the mid-1990s, with the concept and general content confirmed in July 1995 through a memorandum from the Assistant Deputy

Minister (ADM) of Fisheries Management. IFMPs were seen as a means to improve program delivery, ensure greater integration of functional and technical expertise within DFO, increase linkages within DFO, and identify performance outputs for individual fisheries management plans. The expectation was to have fully integrated IFMPs completed for all major Canadian fisheries by 1996/1997. Unfortunately, during the following decade, the full integration of Canadian fisheries into the IFMP framework was incomplete, with many major and minor fisheries either having outdated plans or none at all. For those IFMPs that had been developed, the content is highly variable between plans. (Department of Fisheries and Ocean, 2014)

“In recent years there has been growing pressure to renew IFMPs and ensure their application in all major fisheries, largely as a result of marketplace demands for demonstrated sustainable fishing practices and the need for a departmental vehicle for implementing sustainable fisheries policies. Through an IFMP renewal process initiated in 2007/08, departmental representatives from all regions and relevant sectors modified the existing IFMP template based on lessons learned since the mid-1990’s and emerging issues. In 2011-12, the IFMP template and guidance document were once again updated to consider new emerging issues including safety at sea, climate change, aquatic invasive species, marine protected areas and marine protected area networks, and the further refinement of the Sustainable Fisheries Framework” (Department of Fisheries and Ocean, 2014).

As a matter of fact, the IFMPs template (that presented in their website) only provides a brief overview of economic conditions and social, as socio-economic dimension. Furthermore, the ecological aspect is a brief overview outlining the main biological characteristics of the species with emphasis on the stock science and status aspects, which impact on management of the species. In terms of objectives, IFMPs clearly state long-term objectives for sustainable fisheries under the following potential headings: Stock Conservation, Ecosystem, Stewardship, Social, Cultural, and Economic (i.e., commercial, recreational, Aboriginal), and Compliance. For each long-term objective, there must be short-term objectives specific for the duration of the plan. In order to measure performance, for single-year plans, the template provides stock conservation and ecosystem management measures to meet objectives. Finally, in the performance review of the Management Objectives Evaluation Criteria Section number (3.10): there must be Outlined indicators that will be used to determine if the plan objectives are met. These may include indicators specifically developed for this plan, as well as other existing tools (i.e. fishery checklist) (Department of Fisheries and Ocean, 2014)

Examples of fisheries management plans are found at the DFO IFMPs website which are

categorized by the DFO regions: Central and Arctic Region, Gulf Region, Maritimes Region, Newfoundland and Labrador Region, Pacific Region and Quebec Region. By looking at each regional application of IFMPs, it can be noticed that there is a gap between the academic (as introduced by Charles (1995)) and the practical applied IFMP framework. For instance, Canadian Atlantic Herring in 2013 shows that objectives did not have an established framework according to IFMPs template or any other sustainable dimensions. Therefore, there are some strategies and objectives followed by their relevant tactics that are introduced without any standard framework. As a result there cannot be any established benchmark for all different fleets to be compared by their productivity or performance and the IFMP template would not help it because it is not defined by practical terms such as measurable indicators in each dimensions. Also, lack of data can cause a serious problem in examining the application of any strategic framework or validation of indicators that are defined in this industry because there is no integration between strategies, template or framework, and indicators.

Management of fisheries has generally been discussed within the framework of common property resources because they are often not privately owned. (Kambewa, 2007, p. 20).

### 2.3.3 Fisheries Application in Performance Measurement

There are some performance measurement studies such as Australian Department of Fisheries which has defined Key performance indicators in order to measure fisheries management; compliance and education; research and monitoring; marine safety. These categories are broad and in this research BSC framework would make them more specific, understandable and practical. Beside this, other studies such as (Tingley, Pascoe, & Caylan, 2005), (Shen, Shen, & Xu, 2013), (Pascoe & Mardle, Efficiency analysis in EU fisheries: Stochastic Production Frontiers and Data Envelopment Analysis, 2003), (Pascoe, Tingley, & Mardle, Multi-output measures of technical efficiency in EU fisheries, 2003) have used technical efficiency of DEA method while in this research we consider technical and mixed efficiency as well as providing efficiency scores and benchmark of selected commercial fisheries.

Furthermore, Pascoe et al. in 2003 provided guidance for measurement and assessment of fishing capacity by a DEA output oriented model with assistance VRS and CRS comparisons however, there is a lack of a specific ranking of DMUs based on efficiency scores and a valid benchmark for the current time. In this study we use all the benefits from the application of BSC-DEA model such as BSC perspectives, Triple bottom and IFMPs objectives to address the KPIs as well as technical and mixed efficiencies, ranking list of efficiency scores, projections for inefficient DMUs, and benchmark.

## 2.4 Summary

Based on the above literature review, the Balanced Scorecard is a powerful strategic tool, which can translate the strategies of an organization into actions. There are various experiments and examples applying this scorecard to enhance the interactions between their components through integration of their functions. Also, the interrelationships among the four perspectives of BSC have drawn significant attention. However, scholars seem not to have reached a consistent agreement on the interrelationships among the four perspectives of the BSC.

The problem of performance evaluation has a variety of methods, which seek to develop quantitative measures to assess the performance of organizations. The methods range from simple screening procedures to sophisticated and complicated mathematical ones. There has been limited study about the combination between BSC and DEA. In 2002 Rouse, Putterill and Ryan described the tools for analyzing the performance and frameworks used to support change management in the aircraft servicing and maintenance division by BSC-DEA methodology. Also Eilat, Golany and Shtub (2006) proposed and demonstrated the BSC-DEA methodology for the construction and analysis of efficient, effective and balanced portfolios of R&D projects. This integrated method has the advantages of both BSC and DEA methods and the application measures the strategy and compares the case studies in terms of their efficiency and effectiveness. Since the cases to be studied in this research are from the Canadian commercial fisheries, this part of the literature review refers the reader to some information about the current situation of this industry and the opportunities that the study can make accordingly.

Given the importance of marine fisheries as a source of food and livelihood, as well as their socio-cultural significance, it is clear that a prerequisite for sustainable use of the oceans is the active pursuit of sustainability in fishery systems. However, the inherent complexity of these systems, combined with the history of ecological, social and economical background in fisheries industry, would make reaching to this goal incredibly challenging. This chapter has attempted to provide a comprehensive framework of reviewing the available literature, including grey literature attributed to government policy, for evaluating progress toward sustainability.

Referring to the gap between the conceptual dimensions and the practical application of performance measurement, a tentative framework is provided by BSC for assessing all financial and non-financial aspects as well as sustainability dimensions such as triple bottom line and the ecological, socio-economic, community and institutional

components. Furthermore, in terms of performance measurement the propose linkage of BSC and DEA uses the key performance indicators to evaluate the process of sustainable development. This framework is speculative in nature, and a clear need exists for practical testing to demonstrate the validity of the proposed indicators and the feasibility of measuring each indicator under varying circumstances.

The next chapter presents a discussion of the proposed methodology for applying the combined BSC and DEA methodologies to commercial fisheries case studies.

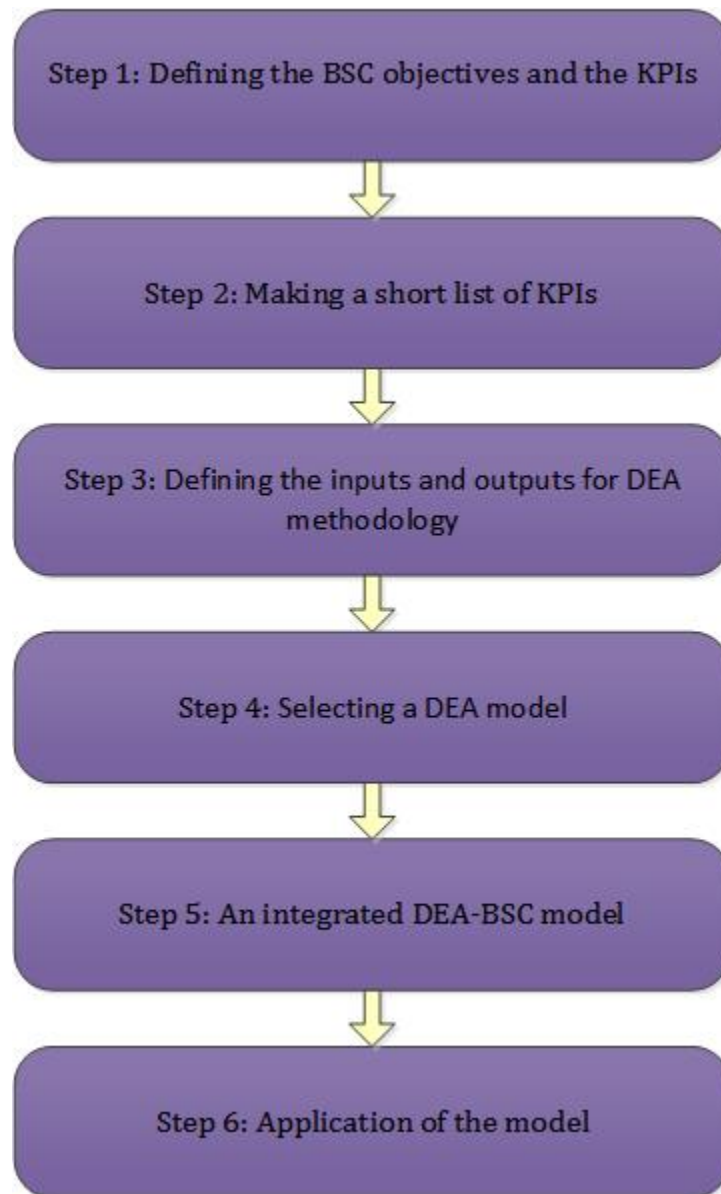
# Chapter 3

# Methodology

### 3. Research Methodology

This thesis aims at measuring sectorial performance in Canada's commercial marine fisheries and understanding what it means for commercial fisheries in Canada to be efficient and effective operations. Answering this question requires identifying how a commercial fisheries case study process aligns with its strategies, and how operations could be considered efficient. The methodology presented in this chapter aims to answer this question by balancing the company's goals with its processes, and evaluating its efficiency based on the input and output indicators that are defined to measure the objectives. Several pre-existing tools and the literature findings of Chapter 2 are integrated toward developing a framework to evaluate the efficiency of alternate sectors of the commercial fish harvesting operations.

The research methodology of this thesis is composed of five sequenced steps as presented in Figure 3.1:



*Figure 3.1 Research methodology steps*

The following subsections discuss these steps of the proposed research methodology as presented in Figure 3.1.

### **3.1 Defining the BSC objectives and the associated KPIs**

Companies adopt the Balanced Scorecard framework to clarify and gain consensus on strategy, to focus organizational change initiatives, to develop leadership capabilities at strategic business units, and to gain coordination and economies across multiple business

units. In this thesis, our aim is to develop a BSC framework (based on achieving operational excellence) for commercial fisheries sectors to align their goals with their strategies. Commercial fisheries sectors define alternative fisheries harvesting methods for capture of the same-targeted commercial fish species. For example, different harvesting sectors in the Atlantic Canada commercial groundfish fishery (cod, haddock, halibut) include the mobile fishing gear sectors (e.g., net fisheries of bottom trawl, midwater trawl, longline), and the nonmobile fishing gear sectors (gillnet, hook and line, traps). The current status of the fish harvesting sector is defined by standard Key Performance Indicators to measure the business processes held in the sector based on its identified objectives.

By identifying objectives on which the fish harvesting sector should focus its attention and resources, the scorecard provides a framework for a strategic management system that organizes issues, information, and a variety of vital management processes. Objectives for customers, internal business processes, and employees and systems are linked to achieve long-run financial performance. The Balanced Scorecard does not eliminate a role for financial measurement in a management system, but it embeds financial measurement in a more balanced management system that links short-term operational performance with long-term strategic objectives (Kaplan & Norton, 1996).

The commercial fish harvesting sectors of interest in this research fall in the class of small or medium sized enterprises. While they, in general, share the same set of business processes, there are sectoral differences depending on targeted species, work locations, sold products, and targeted markets. The following list of common business processes are extracted from (Explorations Unlimited, 2006) a benchmarked competitiveness study of BC's Sea Urchin fisheries. The study divided business processes into four main parts: (i) governmental policies, (ii) operations, (iii) marketing and (iv) administration. Governmental policies and administration processes are merged together for simplicity purposes. Table 3.1 contains a list of business processes of the general commercial fisheries harvesting sector.

Table 3.1 A list of business processes of commercial fisheries firm

<b>Operations</b>	<b>Marketing</b>	<b>Govt/Administration</b>
Harvesting	Market Research	Resource Sustainability
Processing	Product Development	Financial Management
Quality Control	Pricing	Human Resources
Supply Chain Management	Promotion/Advertising	Information System
Purchases	Market Development	
	Selling	
	Packaging	
	Customer Service	

In order to ensure that BSC implementation is helping commercial fisheries sectors to achieve their goals in a sustainable manner, the three main components of sustainability are taken into consideration. Table 3.2 shows an evaluation template to be used with all case studies as the main objectives of fisheries sustainability. Furthermore, the main objectives are defined by the triple bottom line: (1) social equity, (2) economic viability, and (3) environmental sustainability factors. "People, planet and profit" succinctly describes the triple bottom line and the goal of sustainability (Porter & Kramer, Creating Shared Value, 2011).

Table 3.2 Performance/Objectives Evaluation Table

Objectives Processes	People	Profits	Planet
<b>Fisheries Operations</b>			
Harvesting	-Satisfied fishermen	-Lower harvesting costs -Better Fishing Tech.	- No overfishing
Processing	-Professional processing workers	-Lower processing Facilities Costs	
Quality Control	- Quality expert workers	- Maintained quality standards.	
Supply Chain Management		-Continuous Supply -Minimum time to market - IS Integration with partners	- More efficient inventory and transportation systems.
Purchases		- Lower cost of supply - More integration with suppliers.	- High quality equipment.
<b>Marketing</b>			
Market Research			
Product Development	-Training and R&D		
Pricing		- Efficient and innovative pricing system	
Promotion/ Advertising	- Loyalty to a product	- Clear Promotion Strategy.	- Better environmental awareness
Market Development	- Coordination with local retailers	- Clear Market Segmentation	
Selling	- Better Product	-	
Packaging	- Support local firms	-Lower packaging costs -Better packaging quality	- Sustainable packaging standards
Customer Service	- Satisfied Customers	- Long-term contracts	- Customers support eco-sustainability
<b>Government Policies/Administration</b>			
Resource Sustainability	- Educated Workers	- Sustainable Income	Sustainable Ecology
Financial Management			
Human Resources	- Job opportunities for local community - Satisfied and capable workers	- Lower HR financial costs.	
Information System	- Easy to use IS. - More efficient Workers.	- Integrated Processes. - Efficient Information flow.	- Measurable eco-Metrics.

Table 3.2 is used to align a firm's processes and objectives with its strategic goals. The commercial fisheries processes are listed on the left side of the table, and the general measuring dimensions of the firm's strategic goals related to the triple bottom line: People, Profit and Planet, are presented in the three separate columns of the table. By linking processes and objectives to the strategic goals, the BSC indicators can be obtained. The BSC indicators are determined as the aligned Key Performance Indicators (KPIs).

In terms of KPIs, BSC requires that KPIs be classified into its perspectives. Kaplan and Norton required that companies recognize its KPIs in BSC perspectives and develop performance measures within each of these perspectives or categories (Fernandes, Raja, & Whalley, 2006).

Definitions of KPIs have a consistent thread and focus on quantifiable, measurable progress towards achieving goals and objectives. In other words:

“Key Performance Indicators (KPIs) are quantitative and qualitative measures used to review an organization's progress against its goals. These are broken down and set as targets for achievement by departments and individuals. The achievement of these targets is reviewed at regular intervals”. (FinPa, 2009)

Each KPI has characteristics (some, but not necessarily all) such that KPIs should be:

- ❖ Relevant to and consistent with the specific fishery sector's vision, strategy and objectives;
- ❖ Focused on fisheries wide strategic value rather than non-critical local business outcomes – selection of the wrong KPI can result in counterproductive behavior and sub optimized outcomes;
- ❖ Representative – appropriate to the fishery together with its performance;
- ❖ Realistic – fits into the fishery's constraints and cost effective;
- ❖ Specific – clear and focused to avoid misinterpretation or ambiguity;
- ❖ Attainable – requires targets to be set that are observable, achievable, reasonable and credible under expected conditions as well as independently validated;
- ❖ Measurable – can be quantified/measured and may be either quantitative or qualitative;
- ❖ Used to identify trends – changes are infrequent, may be compared to other data over a reasonably long time and trends can be identified;
- ❖ Timely – achievable within the given timeframe;
- ❖ Understood – individuals and groups know how their behaviors and activities contribute to overall agency goals;

- ❖ Agreed – all contributors agree and share responsibility within the agency;
- ❖ Reported – regular reports are made available to all stakeholders and contributors;
- ❖ Governed – accountability and responsibility is defined and understood;
- ❖ Resourced – the program is cost effective and adequately resourced throughout its lifetime; and
- ❖ Assessed – regular assessment to ensure that they remain relevant.

There are a number of approaches and some suggestions. Organizations are encouraged to identify approaches to develop KPIs that are most relevant to their unique business outcomes and activities. In this regard, it is appropriate to focus selection of KPIs on statutory and regulatory requirements and obligations (Auditor, 2010).

Since our focus is on operation management processes, all goals are recommended based on the reports and active people in fisheries industry. Furthermore, some of the goals measurements are from Kaplan & Norton study held in 2004 and the objectives are based on the goals that are important for achieving to the operation quality. As the result, Table 3.3 presents the proposed BSC framework, which is the foundation of this research.

Table 3.3 BSC framework for commercial fishery harvesting sectors

Perspectives	Goals	Objectives (Key Perspective)	Indicators/Measures/KPIs
Financial	-Become the industry cost leader. (Profit)	-Lower harvesting cost. (Profit)	-Total annual Cost for the whole fishery/ average per vessel for the fleet -% Of annual reduction in cost per catch.
		-Lower general, selling & administrative expenses.	-General, selling, and administrative expenses per vessel of output or per location.
	-Improve use of existing assets. (Profit)	-Sustainable income. (Profit)	-Sales/assets ratio. -Profit ratio (profit margin per unit output).
		-Higher net operating profit. (Profit)	-Net operating profit (Gross income- Operating cost).
		-Full utilization of the existing capacity. (Profit)	-Catch *effort (actual days fished)/ Total vessel capacity* No. Days in a season
		-Lower level of debt. (Profit)	AVG level Debt per vessel.
Customer	-Lower the customer's cost; increase the customer's profit. (People)	-Efficient and innovation pricing system. (People).	-Average Price.
		-Increase the processors profit. (People) -Loyalty to product. (People) -Satisfied processors. (People)	-Processors profitability from own fishery's catches and services ( the difference between price they sell and buy).
	-Deliver high quality products to processors. (People)	-Deliver products that meet processors specification. (People) -Long-term contracts. (Profit)	-AVG price/Max price.
Internal business processes	1-Develop and sustain supplier relationship. -Lower the cost of ownership. (Profit)	-Low cost suppliers. (Profit)	-The ratio of harvesting processors arrangements.
		-Use new ideas from suppliers. (People)	-Advance product development from suppliers. (People)
	-Achieve supplier partnership. (People)	-Continuous supply. (Profits) -Enhance the value proposition offered to customer. (People)	-Percentage of fleet for which suppliers provide services
		2-Produce products and services. -Lower the cost of producing products/services. (Profit)	-Lower cost of key operating processes. (Profit)
			-Lower cost of marketing, selling, distribution, and administrative processes. (Profit)
-Continuously improve processes. (Profit)	-Substantial improvements in processes. (Profit)	-CPUV (Catch/effort) -Cost of inspection and testing. -Cost of fuel/Total Cost	

	-Improve process responsiveness. (Profit)	-Integrated processes. (Profit)	-Transit time+ harvesting time(from start of production until product completed). -Harvest time (time the product is actually being processed). -Process efficiency (Ratio of process time to cycle time).
	-Improve fixed asset utilization. (Profit)	-Improve capacity utilization. (Profit)	-% Of capacity utilization.
		-Reliable equipment. (Profit)	-Equipment reliability (percent of time available for production).
		-Lower the breakdowns. (Profit)	-Number and percent of breakdowns.
	3-Distribute product and services to customers. -Enhance quality. (People)	-Maintained quality standards. (Profits) -Better product. (People)	- AVG price/Max price.
	4-Risk management. -Manage financial risk/maintain high credit quality. (Profit)	-Reduce the cost associated with financial distress. (Profit)	-Debt to equity ratio. -Interest coverage ratio
-Manage technological risk. (Profit)	-High quality equipment. (Planet) -Better fishing tech. (Profit) -Efficient information flow. (Profit)	-Technology ranking of equipment	
<b>Environmental and social</b>	-Social impacts management systems. (Planet) -To comply with the highest quality, health and safety standards. (Planet) -Minimal environmental impact through Eco-efficiency concepts. (Planet)	-Customer support eco-sustainability. (Planet) -Better environmental awareness. (Planet) -Measurable eco-metrics. (Planet) -Sustainable ecology. (Planet) -No overfishing. (Planet)	-Time for response to environmental changes. -Number of fishers/public aware of decision outcome. -Maximum sustainable yield. -Abundance of target Stock.
<b>Learning and growth</b>	-Develop in skills in quality management and process improvement. (Planet)	-Professional harvesters workers. (People) -Quality expert workers. (People)	-% Of employees trained in state of the art harvesting techniques. -Crew share/ Gross income
		-Training and R&D. (People) -Educated workers. (People) -Job opportunities for local community. (People)	-% Of employees with knowledge and training
	-Culture for continues improvement. (People)	-Improve knowledge management system. (People) -More efficient workers. (People)	-Number of new process improvement ideas generated. -% Of employee process improvement suggestions adopted. -Number of ideas for quality and process improvement shared across multiple organizational units. -Performance improvement from employee suggestions and actions (cost saving, defect reduction, yield enhancement, process time reductions).

The BSC framework noted above in Table 3.3 includes all four perspectives (Financial, Customer, Internal business processes, and Learning and Growth). As managing the operations of an organization is the most critical component of the fisheries sector's strategy, the goals are defined toward operational quality. Accordingly, the objectives and KPIs are taken from this strategy and goals.

The goals and objective relative to each perspective should enhance the influence of each other to make a synergetic impact on the whole organization. The strategic map realizing these impacts are shown in Figure 3.2. The figure illustrates these kinds of interactive impacts among all the components of the proposed BSC framework.

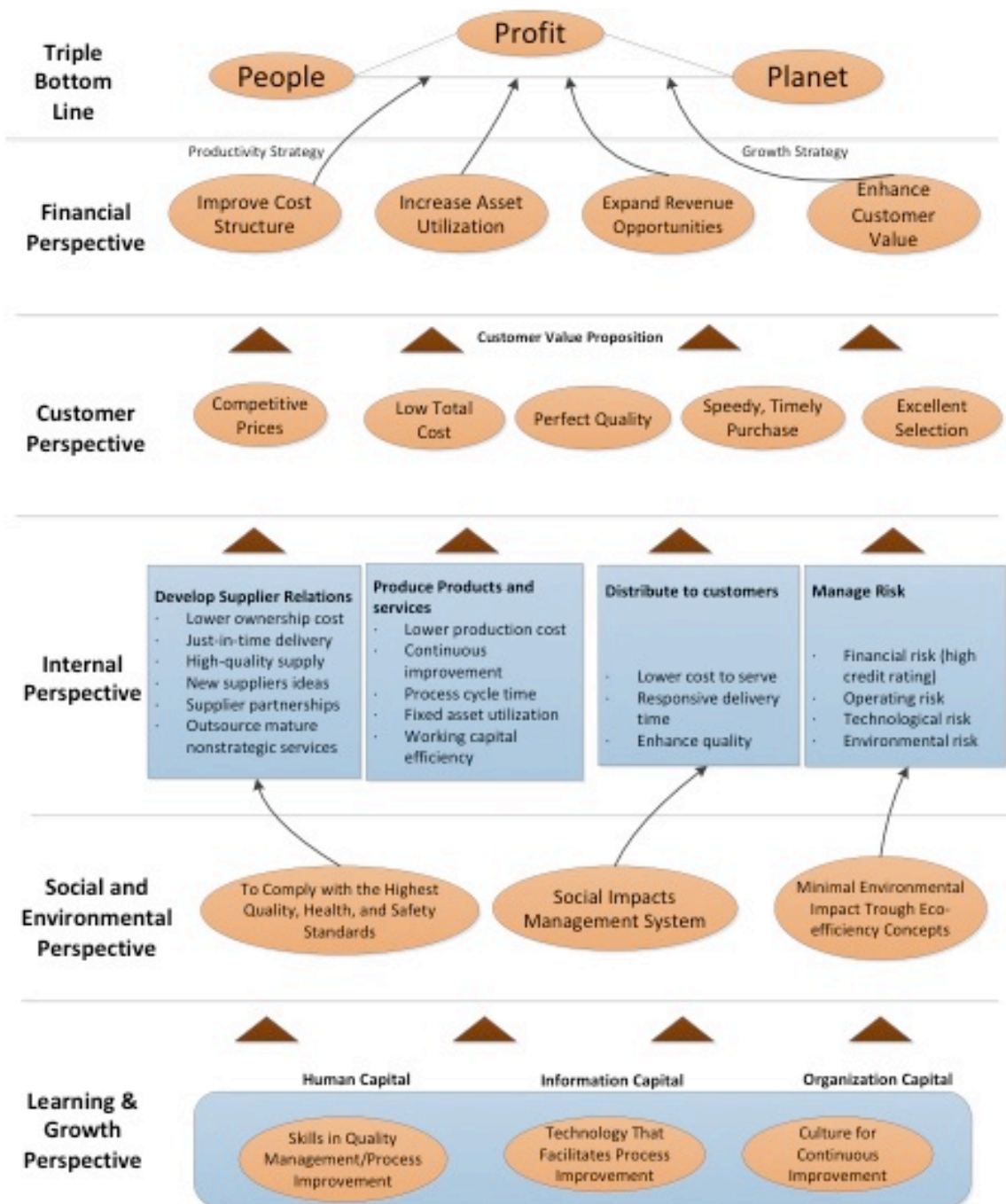


Figure 3.2 Strategy map template. Based on Kaplan (2004)

Operations management can encompass up to four important internal processes (see Figure 3.2) (Kaplan & Norton, 2004):

1. Develop and sustain supplier relationships
2. Produce products and services
3. Distribute and deliver products and services to customers
4. Manage risk

According to the vision and strategy of commercial fisheries harvesting sectors, the goals clearly fit in each perspective based on the sector's operational excellence. This research considered the relevant objectives according to the goals expressed for the sector, and used standard KPIs to measure them respectively.

### 3.2 Short listing the KPIs

In the late of 1960s Deng had studied the prediction and control of economical and fuzzy systems and encountered systems with high uncertainty (Fazli & Rezaei, 2012). Indices of these systems were hardly justified by Fuzzy Mathematics or Probability and Statistics. In Fuzzy Mathematics, we deal with uncertain issues, which are justifiable by experts through discrete/continuous membership functions. In problem solving, with the help of Probability and Statistics, the distribution functions are recognized by enormous volumes of data to achieve the proper reliability (Fazli & Rezaei, 2012).

If there are few experts and little level of experience, if is a lack of the ability to extract the membership function, or few numbers of samples, what can be done? To solve, in 1982, Deng introduced Grey Systems Theories (Liu & Lin, 2006). These theories can be categorized in 5 areas: (i) assessment, (ii) modeling, (iii) prediction, (iv) decision-making and (v) control. One of the proposed approaches of this theory is in the area of decision-making. In recent years, Grey system theory has been an effective methodology that deals with uncertain and indeterminate problems (Fu, Zhu, & Sarkis, 2010).

The Grey number refers to a number with undetermined value with an interval, which encompasses its value. Grey numbers can be only with lower bound  $\otimes \in [a, \infty]$  or higher bound  $\otimes \in (-\infty, \bar{a})$ , or with lower bound  $\underline{a}$  and higher bound  $\bar{a}$  simultaneously. In this condition the Grey number is called interval and is shown:  $\otimes \in [\underline{a}, \bar{a}]$

If two Grey numbers are given as:  $\otimes_1 \in [a, b], a < b; \otimes_2 \in [c, d], c < d;$

And \*is used as the symbol of an operation between  $\otimes_1$  and  $\otimes_2$  then:

$$1) \otimes_3 = \otimes_1 * \otimes_2$$

which  $\otimes_3$  is an interval Grey number. So we must have:  $\otimes_3 \in [e, f]$ ,  $e < f$ ; And for each  $\otimes_1$  and  $\otimes_2$  we have:  $\otimes_1 \sim * \otimes_2 \sim \in [e, f]$ . In the case of addition, subtraction, multiplication and division of two Grey numbers  $\otimes_1 \otimes_2$ , symmetric and inverse of any Grey number are defined as below (Liu, Guo,, & Dang, 1999).

The addition of two Grey numbers:

$$1) \otimes_1 + \otimes_2 \in [a + c, b + d];$$

The diverse of a Grey number:

$$2) - \otimes = [-b, -a]$$

The subtraction of two Grey numbers:

$$3) \otimes_1 - \otimes_2 = \otimes_1 + (- \otimes_2) \in [a - d, b - c]$$

The diverse of one Grey number:

$$4) a b \succ 0, \otimes^{-1} \in [1/b, 1/a]$$

The multiplication of two Grey numbers:

$$5) \otimes_1 \cdot \otimes_2 \in [\min \{ac, ad, bc, bd\}, \max \{ac, ad, bc, bd\}]$$

The division of two Grey numbers:

$$6) \otimes_1 / \otimes_2 = \otimes_1 \cdot \otimes_2^{-1} \quad cd > 0, \otimes_1 / \otimes_2 \in [\min \{a/c, a/d, b/c, b/d\}, \max \{a/c, a/d, b/c, b/d\}]$$

$$7) K \in \mathfrak{R}^+, K \cdot \otimes \in [Ka, Kb]$$

The other regulations for addition and division for real numbers can be expanded to interval Grey sets (Moore, 1966), (Fazli & Rezaei, 2012).

In this study, in order to make a short list of KPIs, One of the proposed approaches of this theory, which is in the area of decision-making, has been applied. According to qualitative extracted criteria and uncertain judges by experts in determination of the rate of importance, we used one of the decision-making approaches in uncertain situation in this study. Since there are several numbers of KPIs, using pair comparison to determine weights was not efficient. Therefore through interviews and use of grey numbers (Table 3.4) and collected ideas of experts (Dabbaghi, Malek, & Aulizadeh, Evaluating the

quality of corporate mission statements, 2010) and factors' weight  $\otimes w = \{\otimes w_1, \otimes w_2, \dots, \otimes w_k\}$  have calculated as below:

If decision makers group (experts) is consisted of "K" people, to evaluate the weight of factor "Q<sub>j</sub>" the relationship below can be used:

$$1) \otimes w_j = 1/K [\otimes w_{j1} + \otimes w_{j2} + \dots + \otimes w_{jk}]$$

Which  $\otimes w_{jk}$  ( $j= 1,2,\dots,n$ ) is the "ith" criterion value from the perspective of "Kth" decision maker which is shown by grey number  $\otimes w_{jk} = [\overline{w_{jk}}, \underline{w_{jk}}]$ .

Table 3.4 Evaluation scale to determine the weights (Dabbaghi et al., 2010)

Scale	Very High	High	Medium High	Medium	Medium Low	Low	Very Low
$\otimes W$	[0.9,1.0]	[0.7,0.9]	[0.6,0.7]	[0.4,0.6]	[0.3,0.4]	[0.1,0.3]	[0.0,0.1]

If we consider  $K=8$  and let  $\{Q_1, \dots, Q_8\}$  be the 8 experts, then we can summarize the analysis of experts' ideas by computing the average of weights into table 3.5:

Table 3.5 The weight of factors

KPI	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	W	Perspective
<b>1-Total annual Cost for the whole fishery/ average per vessel for the fleet</b>	L	M	VH	MH	H	VH	H	MH	(0.6125,0.7625)	<b>Financial</b>
2-% Of annual reduction in cost per catch.	M	L	M	L	MH	VL	MH	VL	(0.275,0.425)	
3-General, selling, and administrative expenses per vessel of output or per location.	MH	H	MH	M	MH	L	MH	M	(0.498,0.65)	
4-Sales/assets ratio.	H	MH	VH	H	VH	VH	MH	H	(0.75,0.8875)	
5-Profit ratio (profit margin per unit output).	H	M	M	M	H	M	M	M	(0.475,0.7125)	
<b>6-Net operating profit (Gross income- Operating cost).</b>	MH	H	VH	M	H	MH	MH	MH	(0.6375,0.775)	
<b>7-Catch *effort (actual days fished)/ Total vessel capacity* No. Days in a season</b>	H	H	VH	MH	VH	M	M	MH	(0.65,0.8)	
<b>8-AVG level Debt per vessel.</b>	H	VH	H	VH	H	H	MH	MH	(0.725,0.875)	
<b>17-Average Price.</b>	H	VH	MH	H	VH	H	MH	H	(0.725,0.9375)	<b>Customer</b>
18-Processors profitability from own fishery's catches and services (the difference between price they sell and buy).	MH	H	M	MH	MH	M	MH	L	(0.498,0.65)	
<b>19-AVG-price/Max price.</b>	MH	MH	H	H	H	VH	H	MH	(0.6875,0.8375)	
20-The ratio of harvesting processors arrangements.	ML	VH	MH	L	M	VL	VL	H	(0.375,0.5375)	<b>Internal business processes</b>
21-Percentage of fleet that take advantage of innovations from suppliers.	MH	M	ML	M	ML	M	ML	L	(0.35,0.5)	
22-Percentage of fleet for which suppliers provide services	MH	L	H	MH	ML	MH	M	MH	(0.4875,0.625)	
<b>23-Cost per unit of output (for organizations producing homogenous outputs) Total cost/total catch.</b>	VH	H	MH	H	H	VH	H	M	(0.7,0.8625)	
<b>24-Marketing, selling, distribution, and administrative expenses as percent of total costs.</b>	H	H	MH	H	H	VH	H	MH	(0.7,0.8625)	
	H	ML	H	MH	H	H	MH	MH	(0.6125,0.7625)	
<b>25-CPUV (Catch/effort)</b>	VH	VH	MH	MH	MH	VH	H	L	(0.6625,0.7875)	
<b>26-Cost of inspection and testing.</b>	MH	VH	L	H	MH	VH	MH	H	(0.6375,0.775)	
<b>27-Cost of fuel/Total Cost</b>	ML	MH	M	M	MH	ML	MH	ML	(0.4375,0.5625)	
28-Transit time+ harvesting time(from start of production until product completed).	H	H	VH	H	H	H	H	ML	(0.675,0.85)	
29-Harvest time (time the product is actually being processed).	VL	H	L	VL	M	M	H	ML	(0.325,0.4875)	
<b>30-Process efficiency (Ratio of process time</b>										

to cycle time).										
31-% Of capacity utilization.										
<b>32-Equipment reliability (percent of time available for production).</b>	H	VH	ML	MH	MH	H	H	H	(0.65,0.8)	
33-Number and percent of breakdowns.	H	ML	ML	MH	MH	ML	MH	MH	(0.499,0.6125)	
34-AVG price/Max price.	M	H	M	M	M	H	M	M	(0.475,0.7125)	
<b>35-Debt to equity ratio.</b>	VH	VH	MH	M	VH	VH	VH	H	(0.775,0.9)	
36-Interest coverage ratio	MH	ML	M	ML	M	M	ML	L	(0.35,0.5)	
37-Technology ranking of equipment	MH	H	M	MH	M	MH	MH	L	(0.498,0.65)	
38-Time for response to environmental changes.	M	L	M	VL	MH	VL	MH	L	(0.275,0.425)	<b>Environmental and Social</b>
39-Number of fishers/public aware of decision outcome.	MH	MH	M	MH	MH	M	H	L	(0.498,0.65)	
40-Maximum sustainable yield.	ML	VH	M	L	MH	VL	VL	H	(0.375,0.5375)	
<b>41-Abundance of by catch.</b>	VH	VH	MH	ML	MH	MH	H	MH	(0.65,0.7625)	
42-% Of employees trained in state of the art harvesting techniques.	H	ML	MH	ML	MH	ML	MH	MH	(0.499,0.6125)	<b>Learning and growth</b>
<b>43-Crew share/ Gross income</b>	H	VH	M	M	H	VH	MH	MH	(0.65,0.8)	
44-% Of employees with knowledge and training	MH	L	H	MH	ML	MH	M	MH	(0.4875,0.625)	
45-Number of new process improvement ideas generated.	H	VH	H	M	M	MH	VH	MH	(0.65,0.8)	
46-% Of employee process improvement suggestions adopted.	M	MH	ML	ML	M	M	ML	L	(0.35,0.5)	
47-Number of ideas for quality and process improvement shared across multiple organizational units.	H	M	M	M	H	M	M	M	(0.475,0.7125)	
48-Performance improvement from employee suggestions and actions (cost saving, defect reduction, yield enhancement, process time reductions).	M	VH	MH	VL	ML	L	VL	H	(0.375,0.5375)	
49-% Of employees trained in state of the art harvesting techniques.	M	MH	ML	ML	MH	M	MH	ML	(0.4375,0.5625)	
50-Crew share/ Gross income	M	H	MH	MH	MH	M	MH	L	(0.498,0.65)	

To identify the important KPIs, we omitted the unimportant ones with little importance rate from experts' perspectives. Unimportant KPIs were those with the value smaller than 0.5 (Dabbaghi, Moazemi, & Kimiagari, Planning for reaching goals and vision SWOT by gap analysis, Focus group interview and evaluating the implementation in oil industry,

2008). Therefore in table 3.5 33 KPIs are omitted. After omitting, 17 main KPIs become the short list of KPIs that are main factors for evaluation and presented in section 3.6.2 in this chapter.

### 3.3 Defining the inputs and outputs for DEA methodology

This step in the research methodology focuses on the presentation of the inputs and outputs, which are vital to build a proper requirement for DEA methodology. To extract these prerequisites from our BSC framework, this section describes the method for classifying the KPIs as a tangible tool in a systematic order for use in DEA.

Business processes can generally be described as activities that produce a specific output of value to the customer (Bask, Tinnila, & Rajahonka, 2010) Laguna and Marklund (2004). This is provided a more detailed and precise definition of business process as

“A network of activities and buffers with well-defined boundaries and precedence relationships, which utilize resources to transform inputs into outputs for the purpose of satisfying customer requirements”. (Laguna & Marklund, 2004, p. 23)

Examples of business processes are purchasing, manufacturing, sales, recruitment, technical support, etc. (Evangelos L. Psomas, 2011). Figure 3.3 illustrates the concept of business processes.

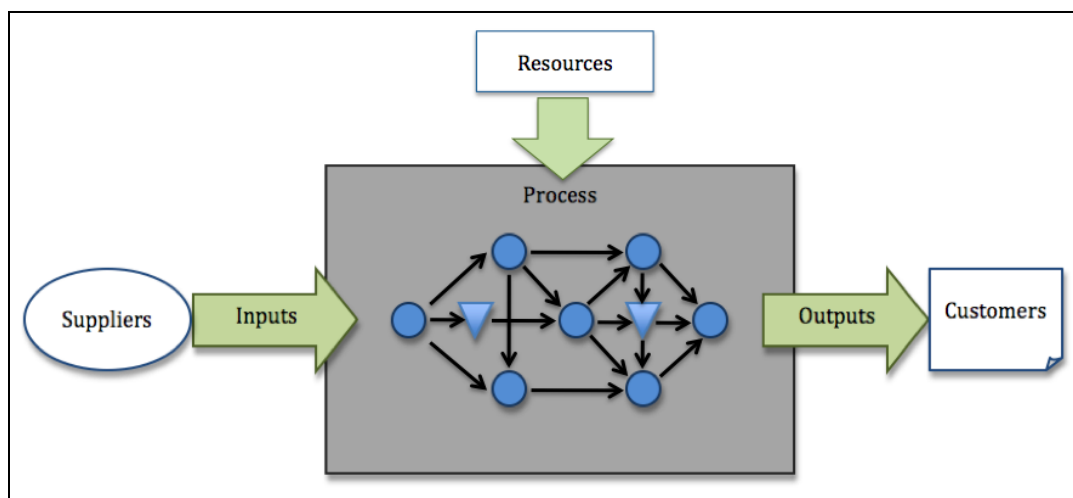


Figure 3.3 Presentation of business process concept. Source: (Laguna & Marklund, 2004)

Laguna and Marklund (2004) explained the main components of process structure as the following:

1. Inputs and Outputs – establish the interaction between the process and its environment. They can be tangible such as raw materials and cash, or intangible such as information, energy and time.
2. Flow Units – defined as a “transient entity that proceeds through various activities and finally exits the process as finished output”. An example of a flow unit can be the frame in a bicycle-assembly process.
3. The Network of Activities and Buffers – where as activities can be looked at as micro processes consisting of a collection of tasks, while Buffers are the waiting time or space in which flow units are held if they are not under any processing.
4. Resources – refer to the tangible assets that are necessary to perform activities within a process.
5. Information Structure – describes how the process works and how performance is realized.

The processes that an organization depends on for success, more than others are often referred to as “core processes,” or “key processes”. (Bask, 2010)

In order to apply DEA, it is essential to extract the inputs and outputs from the selected and established KPIs. Thus, this thesis focuses on the system identification to clarify the KPIs in case of inputs and outputs. In order to improve outputs would need to increase while, inputs indices would need to decrease.

### 3.4 Selecting a DEA model

Data Envelopment Analysis uses a linear programming model to evaluate and compare DMUs (Decision Making Units) in terms of their performance. It applies a benchmarking approach where each DMU’s performance is compared to the most efficient one under DEA terminology. It assumes that performance is a combination of inputs and outputs of a system under investigation.

There are two ways to define the efficiency score depending on the selected DEA model:

1. Constructing a composite unit by selecting the highest outputs and lowest inputs among all units and then comparing its efficiency with other DMU’s performance; and
2. Picking a real existing unit with an optimum combination of inputs and outputs as the benchmark for comparisons.

As a result, efficient DMUs define the efficient frontier that forms a reference of best performance. Inefficient DMUs are projected onto the efficient frontier to enable their comparison relative to the efficient DMUs with similar profiles in terms of input-output mix.

Considering that this research is concerned with five perspectives (Financial, Customer, Internal Business Processes, Environmental & Social, and Learning & Growth – Table 3.3) for the evaluation of small-scale fisheries' harvesters sectoral performance, DEA is selected as an evaluation method because of the ability to:

1. Consider multiple evaluation measures.
2. Assess performance without the need of human judgment in determining the relative importance of each measure.
3. Establish benchmark performance.
4. Identify improvement opportunities and determine practice modifications required to attain benchmark performance.
5. Adequately discriminate between the performances of DMUs.
6. Identify and penalize compensatory behavior (high performance in one or few measures compensating for low performance on the others).

Although meeting item 5 is not guaranteed by DEA, the method has the ability to satisfy it if the number of DMUs is large enough compared to the number of selected inputs and outputs. In regard to item 6, there are DEA models that apply restrictions to the eligible values for weights thereby restricting compensatory behavior (Fiallos, 2013). In this research this behavior would be affected by the cause and effect relationships among inputs and outputs, which are driven from BSC framework.

#### **3.4.1 The model used in this research**

Depending on the selected inputs and outputs, which are either controllable or uncontrollable, the related model in terms of characteristics such as orientation and return to scale must be selected. According to the short list of indicators that are selected as inputs and outputs for DEA, and the basis of performance measurements, if small-scale fisheries can control all inputs, then the input-oriented DEA models should be selected. The same rule is applicable for output-oriented models. However, if the fisheries case studies can control and modify both inputs and outputs, non-oriented models such as ADD and SBM would be selected as a measurement tool for evaluating the sectoral performance.

According to the short list of KPIs, which are defined as the inputs and outputs for the DEA model, it is reasonable to assume that small-scale fisheries' performance should influence their own results under each of the KPIs by which they are being evaluated. Thus, a non-oriented DEA model is preferable. Only non-oriented models such as ADD and SBM are capable of identifying improvement opportunities in each input and output. However, the ADD model does not provide a performance or efficiency score that can be used to identify how near or far a DMU is from benchmark. To be more exact, solving the SBM model produces a score that captures all input and output inefficiencies of a fishery's performance and provides information to determine the level of compliance with the benchmark. Thus, for the application to the sectoral commercial fisheries problem, the SBM is deemed to be the most appropriate DEA model and it is applied in this application.

#### **3.4.2 Slack Base Measure (SBM)**

The SBM model as presented in chapter 2 section 2.2.2.4, addresses the limitation of the ADD model in that it allows for the calculation of a score. This model produces a score  $\rho$  with a value between 0 and 1 that is interpreted as "the ratio of mean input and output mix inefficiencies" (Cooper, Seiford, & Tone, 2007). A score of  $\rho = 1$  indicates an efficient DMU.

After selecting the most proper model according to indexes, the next step is to define the inputs and outputs for our SBM VRS LP model. In the following section this step is presented.

### **3.5 An integrated DEA-BSC model**

This section deals with an integrated DEA-BSC model, which is an approach to clarify the efficiency of the sector based on the strategy. This subsection focuses on measuring the efficiency according to the level of inputs or outputs obtained from the BSC by integrating strategy, goals, objectives, and KPIs with the efficiency score,.

Research shows that BSC is a useful technique to drive and calculate performance measures. Ziegenfuss (2000) demonstrated the use of the "Balanced Scorecard" methodology in selecting performance indicators for internal auditing departments. Data Envelopment Analysis (DEA) analyzes the performance of a set of comparable decision-making units (DMUs). Each DMU is evaluated in terms of a set of outputs that represent its successes, and a set of inputs that represent the resources. Therefore, DEA can be a useful tool in setting benchmarks and evaluating BSC results. The aim of this study is to

measure the performance according to the strategy. As such, an objective, structural equation model is applied to test the interrelationships of all the variables in the entire model. The proposed structural equation model is shown in Figure 3.4.

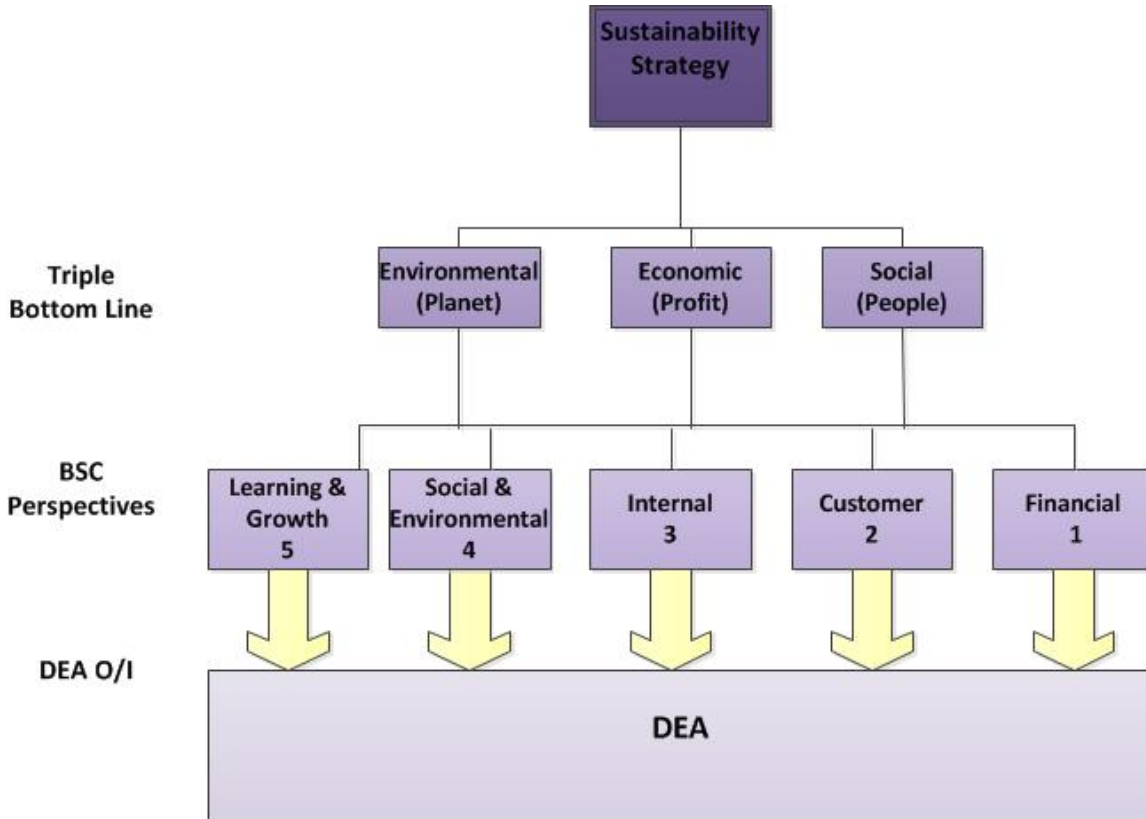


Figure 3.4 Combined BSC and DEA model. Base on Source: (Ebnerasoul, Yavarian, & Azodi, 2009)

The Integrated DEA-BSC conceptual model relies on the BSC methodology, which provides a systemization concept where strategic objectives are formulated in terms of five perspectives (Kaplan & Norton, 1992). In this systematic model, strategy, as the highest hierarchy level includes a single statement, denoted by the sector. Furthermore, it checks whether all the important organizational aspects are measured. For each objective in each perspective, one or more KPIs are formulated. While some objectives are formulated into quantitative measures, other can be measured using only qualitative measures. Using the BSC methodology, a perspective is defined to be a group of Key Performance Indicators.

Efficiency and effectiveness as the main factors of productivity should be improved together, so that it can enhance productivity. If an organization has high efficiency but doesn't gain effectiveness then the efforts of the organization are not aligned with its

strategy.

On the other hand if the organization's effort is efficient but not to be effective, it moves slowly to achieve the defined strategy. Since the effectiveness and goal achievement measured by BSC and DEA would measure efficiency of an organization, both factors of productivity (effectiveness and efficiency) can be measured by combining two models simultaneously. As a result, the organization's perspectives can be defined and promoted by BSC technique, and then with regard to these perspectives, the performance evaluation will be determined by DEA (Ebnerasoul, Yavarian, & Azodi, 2009). Then the outputs and inputs will be extracted from KPIs in each perspective. Furthermore, organizations compare themselves to the ideal organization in terms of efficiency in each perspective and Triple P dimensions. While their efficiency is less than 100%, they will try to approach the ideal organization's specification by process changes, procedure revision, and using the other approaches in order to raise output (Ebnerasoul, Yavarian, & Azodi, 2009).

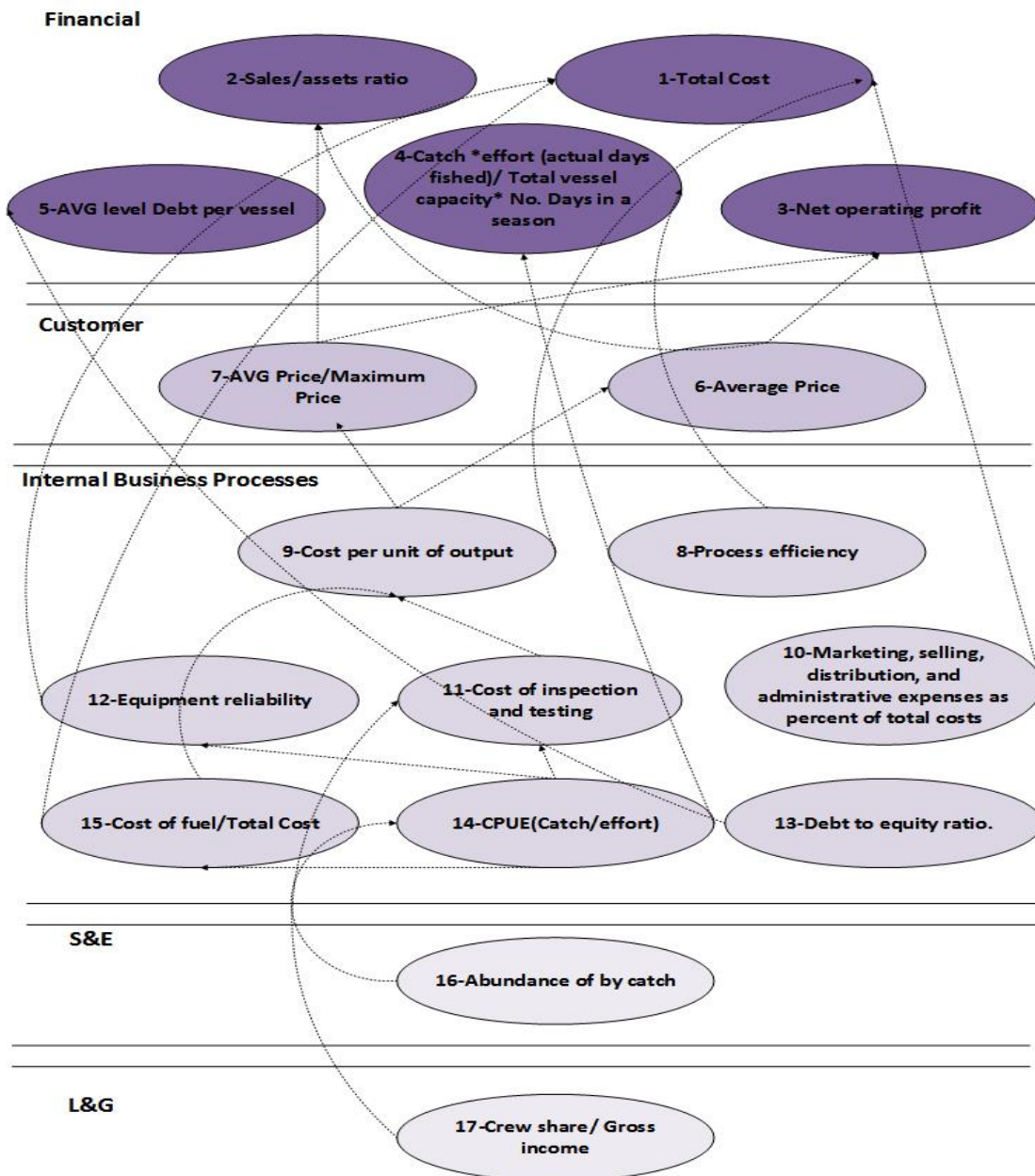
### 3.6 Application of the model

In order to apply the DEA model, there are some DMUs which would represent the highest performance in one input, or output and some may have the lowest performance in one index. In this case, DEA would weight the better index more to improve the DMU according to the efficiency frontier. Also, weighting the evaluation criteria produces rankings that are sensitive to changes in these weights' values. To overcome this shortcoming, Cherchye and Vermeulen (2006), as well as Van Ours and Vermeulen, (2006) have proposed a ranking method that does not require expressing the relative importance of each criterion in terms of weights. Their method, defined as an ordinal approach, requires determining if a criterion is more important than another but does not require expressing these differences numerically (Fiallos, 2013).

Although, the selected method avoids the assignment of weights it still introduces subjectivity when establishing the importance of one criterion relative to another. Moreover, none of these methods provide information that helps establish the necessary performance revisions for an individual DMU that would lead to benchmark practice. In contrast, using KPIs as inputs and outputs decrease the affect of compensatory behavior due to the cause and effect relationship among indexes. Thus, if the performance were high in one index it would be high in its effected index as well. Thereafter, careful examination of DEA characteristics allows us to confirm that this methodology has the desired features for our evaluation problem.

### 3.6.1 Cause and effect relationship

One of the characteristics of BSC framework is the existence of cause and effect relationships among the goals and accordingly the KPIs in each perspective therefore; there is a high level of dependency between each KPIs in terms of their formulas. In this section the cause and effect relationship among the selected KPIs is illustrated in Figure 3.5:



*Figure 3.5 Cause and effect relationship among the selected KPIs*

As can be seen in the Figure 3.5 each indicator in each perspective has at least one cause or effect relationship on the others in next perspective or the same one. These 17 KPIs are translated into inputs and outputs for DEA method and as a result the entire indexes in DEA would be balanced in terms of their weights of importance. Furthermore, the compensation behavior would be satisfied for all DMUs as they can perform a balanced combination of inputs and outputs.

### **3.6.2 Database**

The database of sectoral Canadian fish harvesting groups includes a short list of Key performance Indicators (KPIs) that are selected through one of the decision-making methodologies from BSC framework (Table 3.4). Each of these KPIs measures one or more objectives in each five BSC perspectives (Financial, Customer, Internal Business Processes, Social & Environmental, Learning & Growth) and KPI goal, as well as membership in different categories, e.g., Fishery Sustainability (triple bottom line), DEA Input or Output status, and related IFMP Objective.

Table 3.4 Key Performance Indicators by Category

Key Performance Indicators (KPIs)	BSC Perspective	Sustainability Triple Bottom Line	DEA I/O	IFMP Objective	KPI Objective	KPI Goal
1.Total Cost, benchmarked against competitors	Financial	Profit	Input	Economical	Lower harvesting cost	Become the industry cost leader
2.Sales/assets ratio	Financial	Profit	Output	Economical	Sustainable income	Maximize use of existing assets
3.Net operating profit (G. income-Operating cost)	Financial	Profit	Output	Economical	Higher net operating profit	Maximize use of existing assets
4.Catch *effort (actual days fished)/ Total vessel capacity* No. Days in a season	Financial	Profit	Output	Economical	Full utilization of the existing capacity	Maximize use of existing assets
5.AVG level Debt per vessel	Financial	Profit	Input	Economical	Lower level of debt	Maximize use of existing assets
6.Average Price	Customer	People	Input	Social	Efficient and innovation pricing system	Lower the customer's cost; increase the customer's profit
7.AVG Price/Maximum Price	Customer	People	Input	Social	Deliver products that meet processors specification	Deliver high quality products to processors
8.Process efficiency (Ratio of harvest time to cycle time)	Internal	Profit	Output	Economical	Integrated processes	Improve process responsiveness
9.Cost per unit of output (for organizations producing homogenous outputs)	Internal	Profit	Input	Economical	Lower cost of key operating processes	Lower the cost of producing products/services
10.Marketing, selling, distribution, and administrative expenses as percent of total costs	Internal	Profit	Input	Economical	Lower cost of marketing, selling, distribution, and administrative processes	Lower the cost of producing products/services
11.Cost of inspection and testing. (Monitoring DMP)	Internal	Profit	Input	Economical	Substantial improvements in processes	Continuously improve processes
12.Equipment reliability (percent of time available for production)	Internal	Profit	Output	Economical	Reliable equipment	Improve fixed asset utilization
13.Debt to equity ratio.	Internal	Profit	Input	Economical	Reduce the cost associated with financial distress	Manage financial risk/maintain high credit quality
14.CPUV (Catch/effort)	Internal	Profit	Output	Stock conservation	Substantial improvements in processes	Continuously improve processes
15.Cost of fuel/Total Cost	Internal	Profit	Input	Economical	Substantial improvements in processes	Continuously improve processes
16.Abandance of Target Stock	S&E	Planet	Input	Ecosystem	No overfishing	Minimal environmental impact through Eco-efficiency concepts
17.Crew share/ Gross income	L&G	People	Output	Economical	Quality expert workers	Develop in skills in quality management and process improvement

As can be seen in Table 3.4 the shaded rows illustrate the specific KPI row as DEA model inputs whereas the unshaded rows show DEA outputs. Also, there are four categories assigned to each KPI, as follows:

- 1) BSC – the perspective of the method (Kaplan & Norton, *Translating Strategy into Action*, 1996);
- 2) Sustainability – associated with the triple bottom line and designated by People, Planet, and Profit;
- 3) DEA – designation for the KPI as an input or an output performance measure;,,
- 4) IFMP designator objectives (Stock Conservation, Ecosystem, Stewardship, Social, Cultural, and Economic Compliance
- 5) KPI Objectives – stated strategic objective of the sector; and
- 6) KPI Goals – stated goal of the sector.

For instance, the first KPI, “Total Cost, benchmarked against competitors” would measure the goal of “Become the industry cost leader” at a high level, and “Lower harvesting cost” as an objective associated with this goal. Furthermore, the KPI is in the BSC financial perspective, and in Economical category in terms of the IFMP. Since costs are a determinant of profit, then this KPI is recognized in the sustainability concept as “Profit”. Similarly, the other 16 KPIs of Table 3.4 would be defined in each column as the basis of our performance evaluation.

Thus, it is considered that each sectoral case for the commercial fishery would be evaluated by these 17 KPIs, and thereafter their results can be interpreted in terms of these 6 categories (from the list above).

#### **3.6.2.1 KPIs formulae**

In this study, the formula for each KPI is defined to be measurable in a practical way. Table 3.5 illustrates the short list of KPIs from Table 3.4 with their respective formulae.

Table3.5 Short List KPIs and Definitions

No	KPI	KPI Formula
1	Total Cost, benchmarked against competitors	Variable Cost +Fix Cost (Capital Cost included)
2	Sales/assets ratio	Gross Income/assets (Net Fixed Assets+ License Purchase Cost)
3	Net operating profit	Gross Income-Operating cost (V. cost)
4	Catch *effort (actual days fished)/ Total vessel capacity* No. Days in a season	Catch *effort (actual days fished)/ Total vessel capacity* No. Days in a season
5	AVG level Debt per vessel	Debt/Number of vessels
6	Average Price	AVG Price=Gross Income/Total Catch
7	AVG Price/Maximum Price	AVG Price/Maximum Price
8	Process efficiency (Ratio of harvest time to cycle time)	Harvest time/Transit time+ Harvest time
9	Cost per unit of output (for organizations producing homogenous outputs)	Total Cost/Total Catch
10	Marketing, selling, distribution, and administrative expenses as percent of total costs	Admin fee/Total Cost
11	Cost of inspection and testing.(Monitoring DMP)	
12	Equipment reliability (percent of time available for production)	
13	Debt to equity ratio.	Debt/Equity
14	CPUV	Catch/effort (actual days fished)
15	Cost of fuel/Total Cost	Cost of fuel/Total Cost
16	Abundance of Target Stock	
17	Crew share/ Gross income	Crew Share/Gross Income

We are able to measure the performance of selected fisheries by the defined KPI indicators, and thereafter, the measures could be identified as an input or output for the DEA model to be evaluated. Due to a limitation of data availability for each case study, we find and measure different KPIs from different reports. Thus, for the next step, which is using these measures for defining inputs and outputs in DEA model, we have to consider those values that are shared between all case studies in terms of enhancing data availability.

### 3.6.2.2 Sectoral Case studies

Table 3.6 presents the selected sectoral case studies that are under investigation for applying the DEA model and evaluating the performance of each sector as a result.

Table 3.6 Database Sectoral Case Studies by Year and Major Group

Case studies	BC 1991	BC 1994	Gulf Lobster 2004	Pacific Fleet 2007	BC 2009	NL/35- 64/2004	NL/35- 64/2006
Salmon	Salmon Seine	Salmon Seine		Salmon Seine	Salmon Seine		
	Salmon Gillnet	Salmon Gillnet		Salmon Gillnet	Salmon Gillnet		
	Salmon Gillnet- Troll	Salmon Gillnet- Troll					
	Salmon Troll	Salmon Troll		Salmon Troll	Salmon Troll		
	Total Salmon	Total Salmon			Total Salmon		
Herring	Herring Seine	Herring Seine		Herring Seine			
	Herring Gillnet	Herring Gillnet					
	Total Herring	Total Herring	Herring				
Halibut	Halibut	Halibut		Halibut			
Sablefish	Sablefish	Sablefish		Sablefish			
Ground fish Trawl	Ground fish Trawl	Ground fish Trawl		Ground fish Trawl			
Geoduck	Geoduck	Geoduck		Geoduck			
Prawn Trap	Prawn Trap	Prawn Trap		Prawn Trap			
Shrimp Trawl	Shrimp Trawl	Shrimp Trawl		Shrimp		Shrimp	Shrimp
Crab Trap	Crab Trap	Crab Trap	R. Crab	Crab		Crab	Crab
Tuna			B. Tuna	A. Tuna			
Red Sea Urchin				Red Sea Urchin			
Sea Cucumber				Sea Cucumber			
Lobster			Lobster				

As noted in Table 3.6 above, there are 27 small-scale fisheries that are selected (shaded cells) according to their relative importance in terms of comparisons and data availability. This thesis compares the shaded sectoral case studies based on data from: 1991, 1994, 2004, 2007 and 2009, and their associated annual reports that show data that varies for each fishery in each year.

Furthermore, these sectoral case studies are defined as DMUs in DEA methodology. Therefore, we confirm that 28 DMUs are under investigation in this thesis. These DMUs are defined specifically in Table 3.7 below:

Table 3.7 DMUs Description

<b>DMU</b>	<b>Product</b>	<b>Gear</b>	<b>Year</b>	<b>Region</b>
<b>SS 91</b>	Salmon	Seine	1991	Pacific (British Colombia)
<b>SS 94</b>	Salmon	Seine	1994	Pacific (British Colombia)
<b>SS 2007</b>	Salmon	Seine	2007	Pacific (British Colombia)
<b>SS 2009</b>	Salmon	Seine	2009	Pacific (British Colombia)
<b>SG 91</b>	Salmon	Gillnet	1991	Pacific (British Colombia)
<b>SG 94</b>	Salmon	Gillnet	1994	Pacific (British Colombia)
<b>SG 2007</b>	Salmon	Gillnet	2007	Pacific (British Colombia)
<b>SG 2009</b>	Salmon	Gillnet	2009	Pacific (British Colombia)
<b>ST 91</b>	Salmon	Troll	1991	Pacific (British Colombia)
<b>ST 94</b>	Salmon	Troll	1994	Pacific (British Colombia)
<b>ST 2007</b>	Salmon	Troll	2007	Pacific (British Colombia)
<b>ST 2009</b>	Salmon	Troll	2009	Pacific (British Colombia)
<b>HS 91</b>	Herring	Seine	1991	Pacific (British Colombia)
<b>HS 94</b>	Herring	Seine	1994	Pacific (British Colombia)
<b>HS 2007</b>	Herring	Seine	2007	Pacific (British Colombia)
<b>HS GL 2004</b>	Herring	Seine	2004	Atlantic (Gulf)
<b>GT 91</b>	Ground fish	Trawl	1991	Pacific (British Colombia)
<b>GT 94</b>	Ground fish	Trawl	1994	Pacific (British Colombia)
<b>GT 2007</b>	Ground fish	Trawl	2007	Pacific (British Colombia)
<b>CT 91</b>	Crab	Trap	1991	Pacific (British Colombia)
<b>CT 94</b>	Crab	Trap	1994	Pacific (British Colombia)
<b>CT 2007</b>	Crab	Trap	2007	Pacific (British Colombia)
<b>CT GL 2004</b>	Crab	Trap	2004	Atlantic (Gulf)
<b>CT NL/35-64/2004</b>	Crab	Trap	2004	Atlantic (Newfoundland)
<b>CT NL/35-64/2006</b>	Crab	Trap	2006	Atlantic (Newfoundland)
<b>SH NL/35-64/2004</b>	Shrimp	Dragger	2004	Atlantic (Newfoundland)
<b>SH NL/35-64/2006</b>	Shrimp	Dragger	2006	Atlantic (Newfoundland)

In this thesis, the BSC and DEA methods have been approved as powerful tools to analyze and evaluate the performance among comparable units in management. By combining these two models and applying the concept to the real situation, decision makers will be aware from the deviation between the real performance of commercial fisheries firms and the determined strategic plan. In conclusion, this integrated model has capabilities of both BSC and DEA methods.

All the data used for the illustrative database presented in appendix A.1 and A.2 are extracted from (Gislason, The BC Fishing Fleet: Financial Returns, 1997) (Gislason, The British Columbia Salmon Fleet financial Profile, 2009) (Results of the Costs and Earnings Survey for the Lobster Fishing Enterprises, 2006) (Nelson, 2007) (Costs and Earning Survey , 2006) (Gardner Pinfold Consulting Economists Ltd, 2006).

### 3.7 Summary

In this chapter the methodology is described in six steps:

- (1) Defining the BSC objectives and the KPIs,
- (2) Short listing the KPIs,
- (3) Selecting a DEA model,
- (4) Defining the inputs and outputs for DEA methodology,
- (5) An integrated DEA-BSC model, and
- (6) Application of the model.

Therefore, first and foremost step is to develop the BSC framework with its goals and KPIs for small-scale fisheries. In this analysis, seventeen KPIs are identified for further evaluation according to Grey decision making method. By identifying the inputs and outputs from our shortlist, a DEA model is selected, as the most relevant model according to the controllability of the list of inputs and outputs. In the next chapter, the application of the integrated BSC-DEA model is introduced by an illustrative database. In next chapter, the BSC-DEA model will be applied, based on the data from the database.

# Chapter 4

## Analysis and Results

## 4. Analysis and Results

In this chapter, the results and analysis for the thesis are discussed for 2 DEA applied models on the small-scale commercial fisheries data. The objective is to develop an integrated DEA-BSC model for measuring the performance of small-scale commercial fisheries sector in Canada that is compatible with the presentation of the proposed but unfulfilled intentions of the Integrated Fisheries Management Plans (IFMPs). These results are presented here in the form of three common goals for the sectors (Ebnerasoul, Yavarian, & Azodi, 2009):

1. Achieving strategic objectives (effectiveness goal).
2. Optimizing the usage of resources in generating desired outputs (efficiency goal)
3. Obtaining balance

To contribute successfully to the achievement of an organization's mission, the performance scorecard must effectively interpret strategy into operational terms. Strategy is thus 'operationalized' through the assumed relationships between actions and their impacts. By measuring these impacts on the expected outputs, the company can improve them toward generating the desired strategic outputs. In terms of getting the balance right, an appropriate balance that encompasses a scorecard should be driven by the value proposition on which the strategy is based. Therefore, the BSC model is applicable for evaluating organizations considering their strategic concerns, which can cover all the financial and non-financial aspects of an organization.

Managers need to know efficiency to evaluate the performance of an operation. According to the literature, DEA is a useful tool to measure the efficiency for any type of organization. In this thesis, the application of DEA is used to compare efficiency across commercial fisheries sectors. This chapter has two major parts. In the first part, an illustrative fisheries sector database is presented based on the short list KPIs defined by the BSC framework as discussed in Chapter 3. In the second part, the result of the applied DEA SBM model to the database is analyzed.

## 4.1 Data

According to the illustrative database structure presented in Chapter 3, fisheries data were gathered for all available data for the short list of KPIs (Tables 3.4-3.6). Thereafter, the BSC-DEA model is applied to the database characteristics as presented in Table 4.1.

Table 4.1 Sectoral Fisheries Harvesting Database Comparisons

Model Number	Model Name	Number of DMUs	Number of DEA Indices	Number of Inputs	Number of Outputs
<b>1</b>	All Inclusive	27	4	2	2
<b>Fleet-Gear</b>					
<b>2</b>	Salmon All	12	5	2	3
<b>3</b>	Salmon- Seine	4	5	2	3
<b>4</b>	Salmon- Gillnet	4	5	2	3
<b>5</b>	Salmon- Troll	4	5	2	3
<b>6</b>	Herring- Seine	4	4	2	2
<b>7</b>	Ground fish- Trawl	3	7	4	3
<b>8</b>	Crab- Trap	6	4	2	2
<b>9</b>	Shrimp	2	9	4	5
<b>Year</b>					
<b>10</b>	1991	6	7	4	3
<b>11</b>	1994	6	7	4	3
<b>12</b>	2007	6	7	5	2
<b>13</b>	2009	3	9	5	4
<b>14</b>	Gulf 2004	3	4	2	2
<b>15</b>	Newfoundland 2004	2	9	5	4
<b>16</b>	Newfoundland 2006	2	9	5	4
<b>Region</b>					
<b>17</b>	Pacific	21	3	2	1
<b>18</b>	Atlantic	7	4	2	2

As can be seen in Table 4.1, there are 18 different models that can be analyzed by the integrated BSC-DEA model method. Additional models may be evaluated by adjusting (increasing or decreasing) the number of DEA indices for input and output variables. The all-inclusive model developed for this analysis is an illustrative model that takes into account all fleets reports from 1991 to 2007, in both the Atlantic and Pacific regions as the complete set of commercial fisheries DMUs. Thus, in this case, there are 27 DMUs, which may be compared to each other in terms of efficiency based on at least one input and output variable. Furthermore, additional DEA models can be categorized by species, by gear, and by region in the event that it is important to have a benchmark fleet based on a given species, year, or region in the fishery.

DEA model Requirement 5, section 3.4 states: “adequately discriminate between the performances of DMUs”. This would not be guaranteed unless the number of DMUs is large enough compared to the number of selected inputs and outputs (the formula  $m \leq \#DMUs$ ). The first two highlighted models in Table 4.1, (i) All Inclusive and (ii) Salmon All, are the selected models for further evaluation in this thesis. The All Inclusive set, with 2 inputs and outputs, is presented as the numerical example of the BSC-DEA model. The Salmon All set is selected because of its identical species that can make its benchmark more appropriate to this fishery case.

In addition, some KPIs are in dollar values (KPIs: 1, 3 and 5 in our short list – refer to the table here), which means that they should be translated by a proper index. In order to make a current comparison for benchmark, this study (1,3,5) uses monthly consumer price index (CPI) data from 1991 to 2009 (that is the last year of investigation) to show changes in the cost of a fixed "basket" of consumer purchases. These include food, shelter, furniture, clothing, transportation, and recreation. An increase in this cost is due to inflation and the effect is to bring data in different years to a common end point in time. The calculator's results are based on the most recent month for which the CPI data are available. This will normally be about two months prior to the current month (Table 4.2).

Table 4.2 Consumer Price Index from 1991 to 2009

Data Source: Statistics Canada, CONSUMER PRICE INDEXES FOR CANADA, MONTHLY (V41690973 series.) (<http://www.bankofcanada.ca/rates/related/inflation-calculator/>)

Years	2009				
	Per cent change	Number of years	AVG Annual Rate of Inflation (%)/ Decline in the Value of Money	CPI for first year	CPI for second year
1991	37.86	18	1.80	(Jul 1991) 83.2	(Jul 2009) 114.7
1994	33.84	15	1.96	(Jul 1994) 85.7	(Jul 2009) 114.7
2004	9.24	5	1.78	(Jul 2004) 105.0	(Jul 2009) 114.7
2007	2.41	2	1.20	(Jul 2007) 112.0	(Jul 2009) 114.7
2009	0.00	0	NA	(Jul 2009) 114.7	(Jul 2009) 114.7

In this study two DEA software packages have been used to evaluate selected models. These are:

#### 1) DEA solver

This software is an Excel add-in that is provided in a package as part of the text by (Cooper, Seiford, & Tone, 2007).

#### 2) Data Envelopment Analysis Online Software,

DEAOS.com is a user-friendly web-based application that allows users to evaluate data with DEA models (Behin-Cara, 2014).

In the following subsection, the results of the DEA models and analysis are presented including the format of the result reports in detail. Appendix A.1 contains available data for the selected fleet and their KPIs as indices of DEA. Therefore, depending on the DEA model reported, the data are varied in terms of the number of KPIs for each fleet. Also Appendix A.2 presents the data shown in A.1 with all kind of fleet's inputs and outputs that are used in the DEA models for evaluation as extracted from the Atlantic and Pacific commercial fishing fleet performance reports for 1991, 1994, 2004, 2006, and 2009. In this Appendix the unshaded cells are the missing data thus; their associated indexes cannot be used for evaluation in DEA approach.

## 4.2 Numerical Example - All Inclusive Dataset

In this section a numerical example is used for illustration of the BSC-DEA method for all 27 DMUs in the dataset (Table 3.4, and Appendix A.1 and A.2). The following report provides the result from running the SBM model (DEA-Solver LV3.0/ SBM Non-Oriented (SBM-V) with Variable Returns to Scale (Sum of Lambda = 1)) for the first illustrative model as noted in Table 4.1 (all-inclusive model with 2 inputs and 2 outputs and including all 27 DMUs). In the following subsection, the format of the DEA output report resulting from solving the “SBM VRS LP” model is presented in detail.

### 4.2.1 Data statistics

In this section there are tables and graphs are used to illustrate the statistical information of the selected All-inclusive model. In Table 4.3 below, there are 2 inputs and 2 outputs that can be selected according to the data availability for all dataset components (see Appendix A.1 and A.2) these indices belong to different dimensional categories in the proposed framework (Table 4.3 and Table 3.4).

Table 4.3 All Inclusive Model Input/Output Indicators

I/O	Key Performance Indicators (KPIs)	BSC	Sustainability	IFMP	Objectives	Goals
Input 1	1.Total Cost, benchmarked against competitors	Financial	Profit	Economical	Lower harvesting cost	Become the industry cost leader
Input 2	15.Cost of fuel/Total Cost	Internal	Profit	Economical	Substantial improvements in processes	Continuously improve processes
Output 1	3.Net operating profit (G. income- Operating cost)	Financial	Profit	Economical	Higher net operating profit	Maximize use of existing assets
Output 2	17.Crew share/ Gross income	L&G	People	Economical	Quality expert workers	Develop in skills in quality management and process improvement

According to Table 4.3, the selected inputs and outputs are the KPIs from financial, internal business processes and learning and growth perspectives of the Balanced Score Card (Table 3.4). Also these indices measure profit and people as sustainability terms, and finally, they belong to the economical dimension of the IFMPs.

Table 4.4 records the minimum, maximum, mean and standard deviation for each of the 2 inputs and 2 outputs in terms of the raw data (Appendix A.1 and A.2). Table 4.5 provides the pairwise correlation values between each index in the All Inclusive model.

Table 4.4 Statistics on Input/Output Data

	Input 1 (KPI: 1)	Input 2 (KPI: 15)	Output 1 (KPI: 3)	Output 1 (KPI: 17)
<b>Max</b>	644006.7	0.3272	23620583.72	0.757829493
<b>Min</b>	8139	0.0347	0.1	0.0898
<b>Average</b>	104706.433	0.162324186	2803517.552	0.320970378
<b>SD</b>	129823.9906	0.069759017	6164805.119	0.150141937

Table 4.5 below provides the correlation matrix and the pairwise correlation between each index. Correlation is the mutual relation of two or more things. Correlation refers to any statistical relationships involving dependence. Thus the full relationship would be 1, which is between the same inputs or outputs in Table 4.5, i.e., the diagonal elements of the correlation matrix. In Table 4.5 indices with positive correlation have the same direction impact on each other however, the negative ones present the opposite direction effect. Also, in cases that the correlation is 1, there is not any relationship between the related inputs and outputs.

Table 4.5 Correlation Matrix

	Input 1 (KPI: 1)	Input 2 (KPI: 15)	Output 1 (KPI: 3)	Output 1 (KPI: 17)
<b>Input 1 (KPI: 1)</b>	1	0.319248949	0.522683395	0.352080801
<b>Input 2 (KPI: 15)</b>	0.319248949	1	0.40847578	-0.080376759
<b>Output 1 (KPI: 3)</b>	0.522683395	0.40847578	1	-0.038407716
<b>Output 1 (KPI: 17)</b>	0.352080801	-0.080376759	-0.038407716	1

Graphical results are based on selected input and output pairings that represent efficient DMUs located on the efficient frontier noted in the graphs. For example, in Figure 4.1, the graphic shows that 5 efficient DMUs (Salmon Gillnet 2009 – SG2007, Salmon Troll 2009 – ST2009, Salmon Gillnet 2007 – SG2007, Crab Trap 2007 – CT2007, and Ground fish Trawl 2007 – GT2007). These are denoted as being on the efficiency frontier based on Input 1 (KPI: 1) versus Output 1 (KPI: 3).

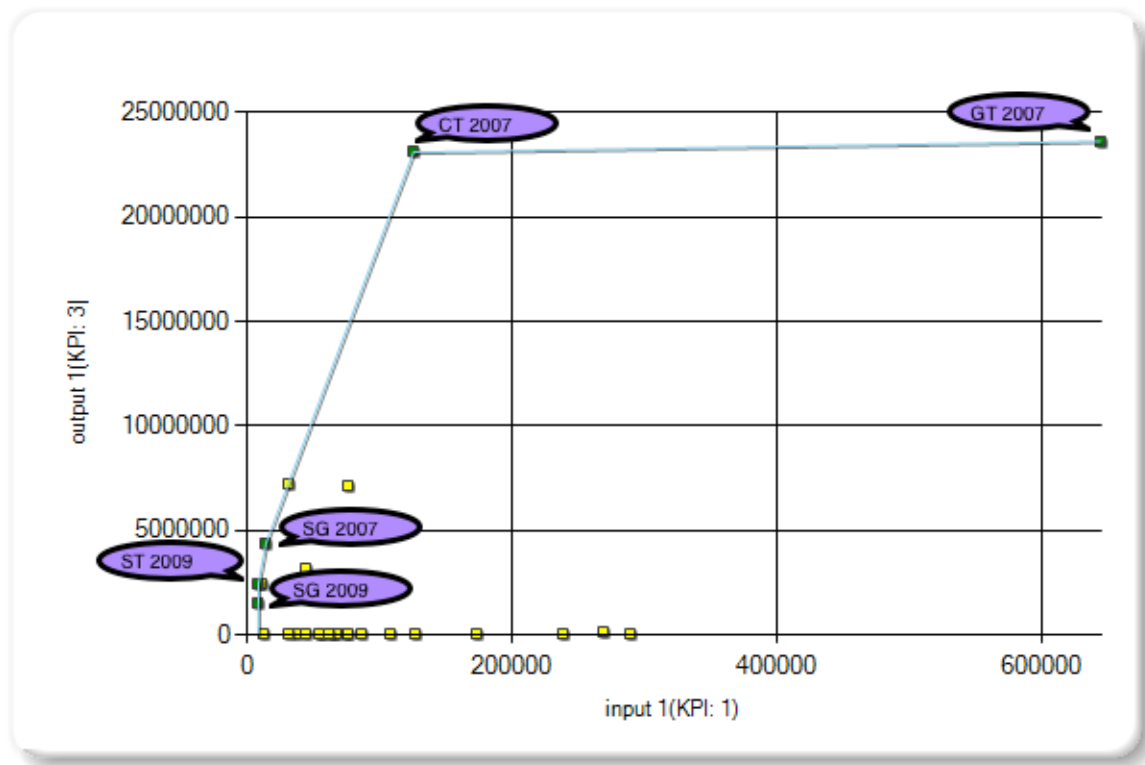


Figure 4.1 All Inclusive Model results: Efficiency Frontier (Input 1, Output 1)

According to Input 1 (KPI: 1) as Total Cost, benchmarked against competitors, and Output 1 (KPI: 3), Net operating profit (Annual Gross Income less Operating Cost), these 5 DMUs act efficiently while others should improve their performance to the nearest efficient unit based on these input and output scales.

Figure 4.2 shows that 5 efficient DMUs (Salmon Gillnet 2009 –SG2009, Salmon Troll 2009 – ST2009, Salmon Seine – SS2009, Crab Trap 2004 –CT NL/35-64/2004, Crab Trap 2006 –CT NL/35-64/2006). These are on efficiency frontier based on Input 1 (KPI: 1) and Output 2 (KPI: 17).

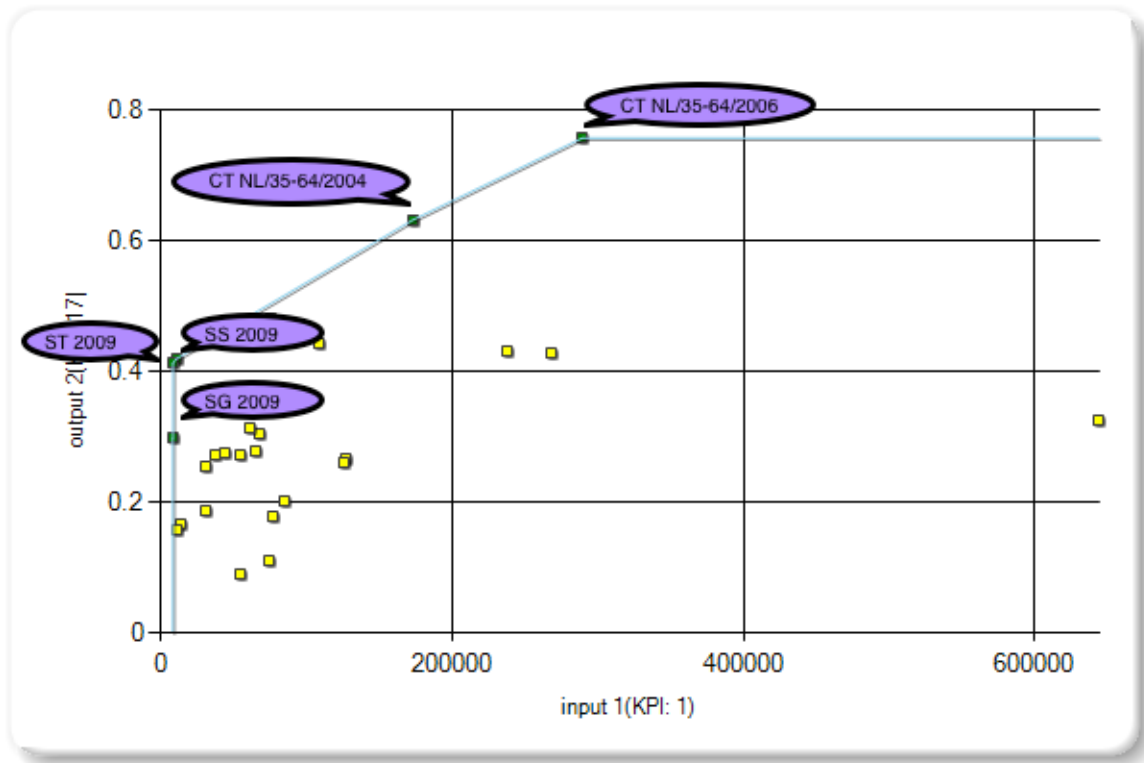


Figure 4.2 All Inclusive Model results: Efficiency Frontier (Input 1, Output 2)

Thus 20 DMUs are not efficient with regard to the indicator pairs for Input 1 and Output2.

Figure 4.3 shows the efficient frontier based on Input 2 (KPI: 15) as Total Cost, and Output 1 (KPI: 3), Net operating profit (Gross Income-Operating Cost).

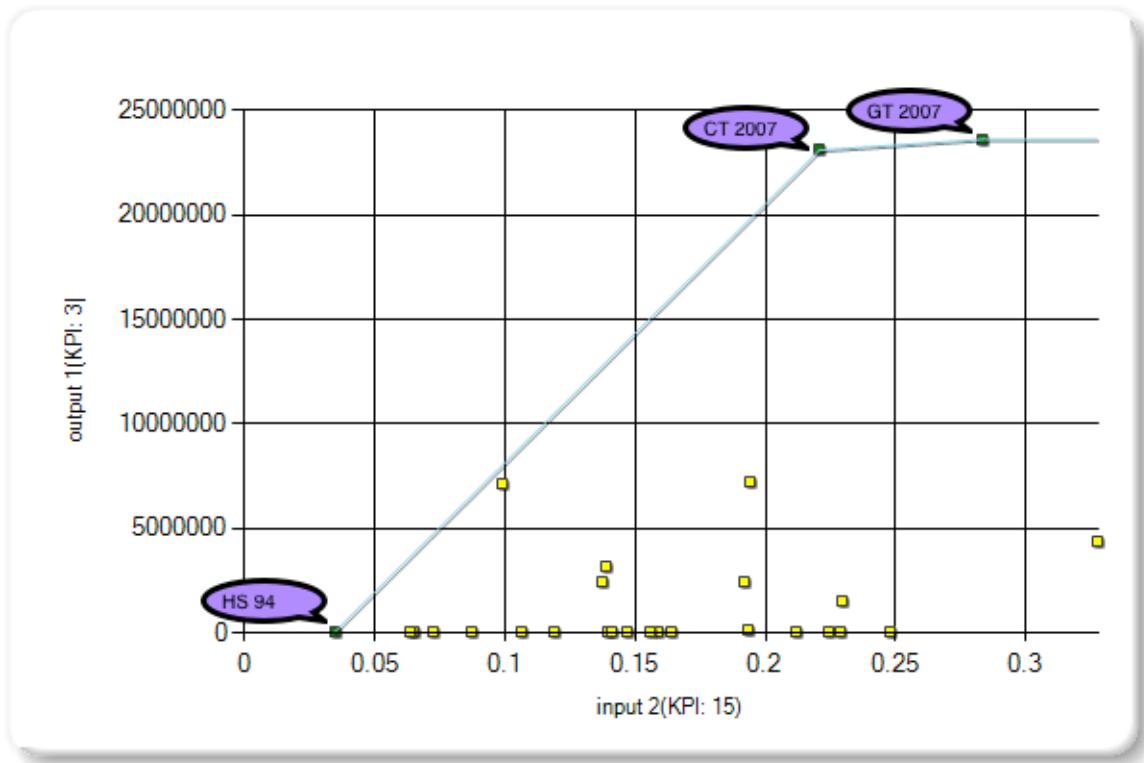


Figure 4.3 Efficiency Frontier (Input 2, Output 1)

According to Figure 4.3, only 3 DMUs (Herring Seine 94 – HS94, Crab Trap 2007 – CT2007, and Groundfish Trawl 2007 – GT2007) are on the efficiency frontier. Therefore with respect to these indicators, there are 24 DMUS that could improve their performance, i.e., increase Output 1, and decrease Input 2, all things the same.

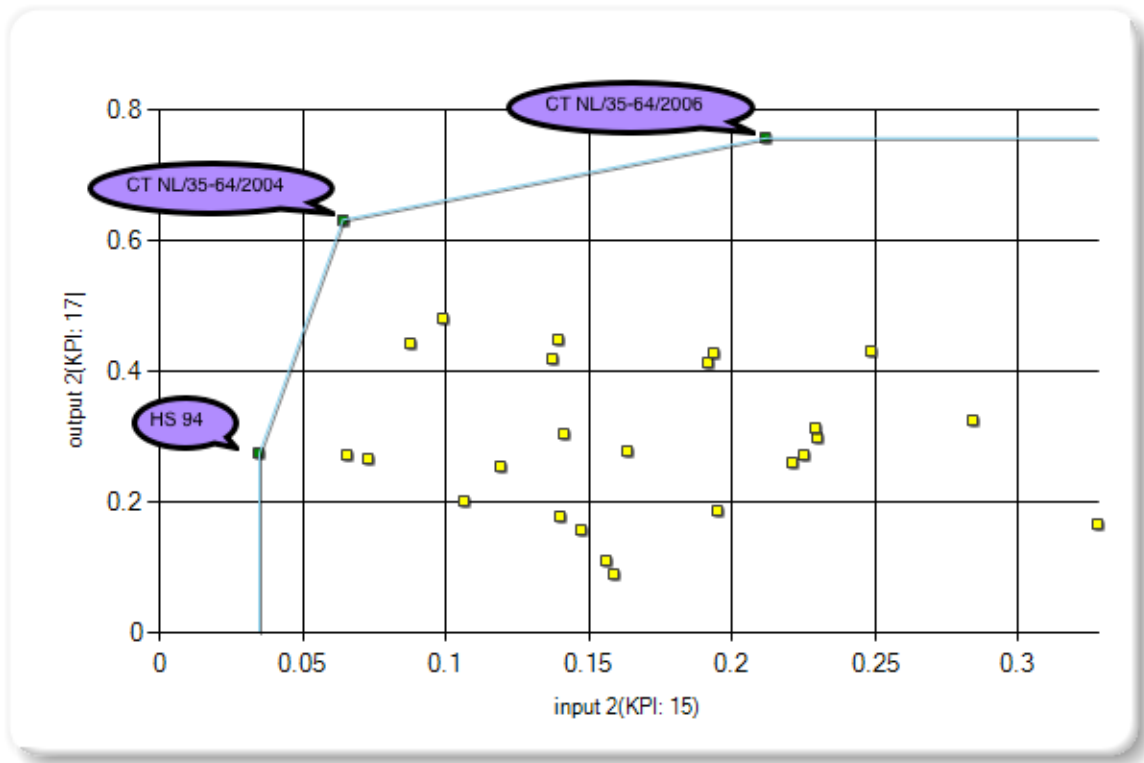


Figure 4.4 Efficiency Frontier (Input 2, Output 2)

Finally, based on the pairwise combination of Input2 (KPI: 15), Cost of fuel/Total Cost, and Output2 (KPI: 17), Crew share/Gross Income, there are 3 DMUs (Herring Seine 94 – HS94, Crab Trap 2004 –CT NL/35-64/2004, Crab Trap 2006 –CT NL/35-64/2006), which are efficient.

#### 4.2.2 Efficiency Scores

DEA calculates an efficiency score for each DMU according to all their weighted outputs and inputs. In this thesis, the SBM model is applied with variable returns of scale because the relationship between inputs and outputs was not constant. Variable returns to scale covers constant return to scale as well because it includes all kind of returns constant and variable both together. According to the Slack Base Model formula presented in section 3.3.2.1, the results of the objective function are shown in Table 4.6, as well as references and lambdas that are described further below.

Reference DMUs serve as “benchmarks” for each evaluated DMU. Improvement information for each input and output and scores, under each group, provide a reference to define priorities of performance improvement. In addition to the performance score, DEA also identifies benchmark DMUs that serve as reference for each underperforming DMU, determining the practice modifications required for achieving benchmark performance. Efficient DMUs define the efficient frontier that forms a reference of best performance. Inefficient DMUs are projected onto the efficient frontier to enable their comparison relative to efficient DMUs with similar performance in terms of the Input-Output mix.

Furthermore, each  $\lambda$  (Lambdas) is associated with a DMU and optimal values greater than zero indicate that a given DMU is efficient.

$$\Lambda = t\lambda$$

A limit defined by a linear combination of DMUs’ inputs and outputs (sections 3.3.2.1 and 2.2.2.4)

$$\begin{aligned} \vartheta x_o &\geq X\lambda \\ y_o &\leq Y\lambda \end{aligned}$$

Appendix B.1 illustrates DMUs with their efficiency scores, ranks, their reference set, and also the lambda value. As can be seen in Appendix B.1, DMUs that have an Efficiency Score of 1 are efficient. Thereafter, their lambda values are 1 and they are their own reference as well. However, DMUs with lower efficiency scores are defined as inefficient DMUs and their reference DMU would be the nearest efficient DMU on the efficiency frontier. For example, Salmon Seine (SS 91) as our first DMU is inefficient because its efficiency score is lower than 1 (8.04E-03) and its reference set has three different reference DMUs (SS 2007 with 0.816877556 lambda, HS 94 with 0.182170938 lambda, and CT 2007 with 9.42E-04 lambda) that are all efficient and are a set that this DMU should improve its performance with the reference of their locations on the efficiency frontier.

#### 4.2.3 Rank

Table 4.7 presents the ranking list for all 27 DMUs according to their efficiency scores as computed by the SBM model.

Table 4.6 Ranking

Rank	DMU	Score
1	CT NL/35-64/2006	1
1	CT NL/35-64/2004	1
1	CT 2007	1
1	SS 2007	1
1	SS 2009	1
1	GT 2007	1
1	HS 94	1
1	SG 2007	1
1	ST 2009	1
1	ST 2007	1
11	SG 2009	0.999687832
12	HS 2007	0.722927908
13	HS 91	3.42E-02
14	SS 94	2.42E-02
15	ST 94	1.03E-02
16	SH NL/35-64/2004	9.64E-03
17	SS 91	8.04E-03
18	CT GL 2004	6.67E-03
19	SG 94	6.61E-03
20	CT 94	6.50E-03
21	HS GL 2004	0.006420792
22	ST 91	5.87E-03
23	SH NL/35-64/2006	5.28E-03
24	GT 94	4.71E-03
25	SG 91	4.56E-03
26	GT 91	4.20E-03
27	CT 91	2.96E-03

According to this Table there are 10 efficient DMUs among 27 DMUs in this model, and others are inefficient because of their lower efficiency score.

4.2.4 Efficiency Ranking Graph

In order to illustrate efficient DMUs more clearly, Figure 4.5 is a comprehensive diagram with the rankings on the vertical axis and the efficiency score on its horizontal. Thus, with this combination all DMUs can be evaluated.

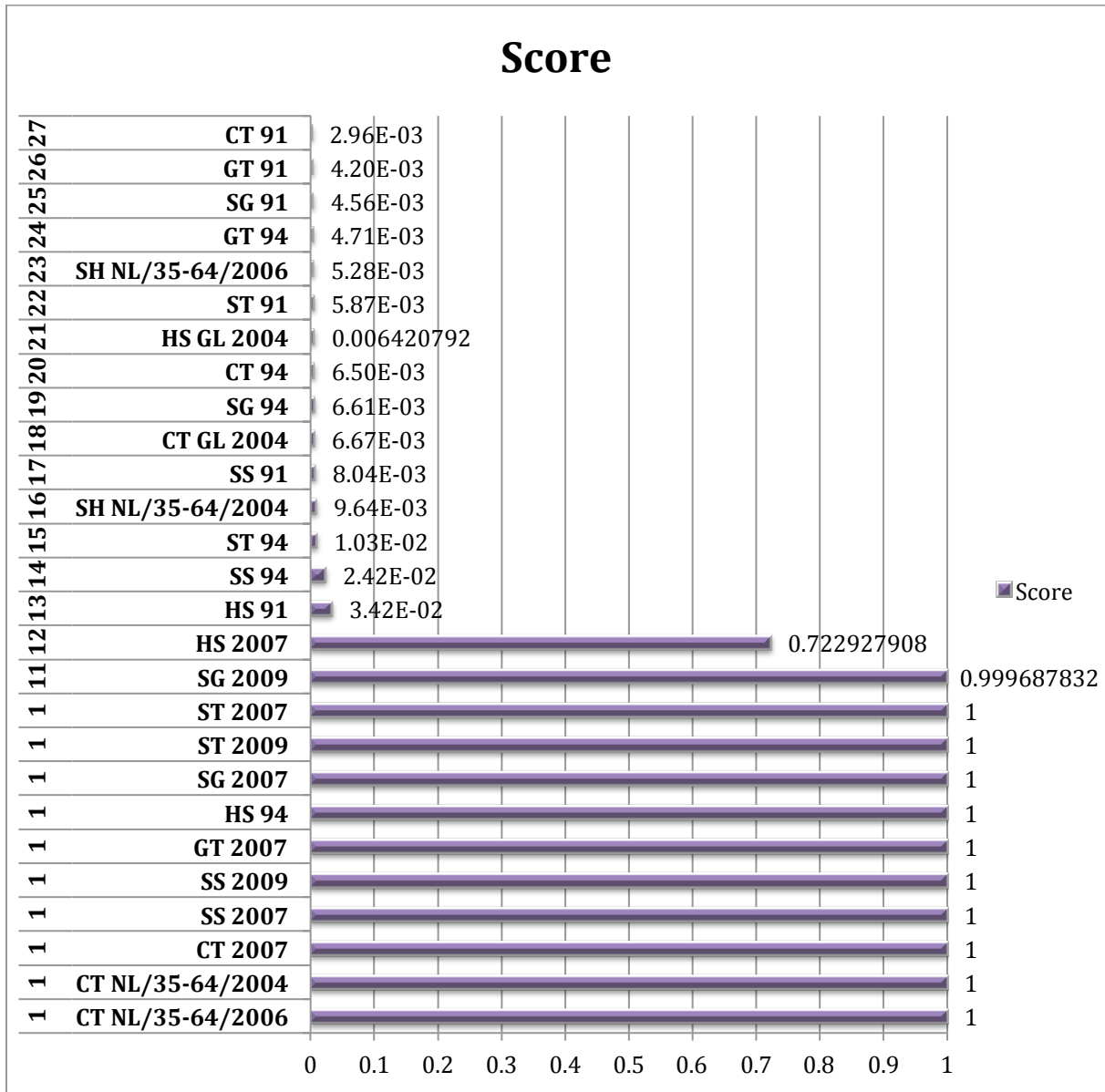


Figure 4.5 DMUs Efficiency

Simply, it can be determined that Crab Trap in 2004 (CT2004), 2006 (CT2006), 2007 (CT2007) and Salmon Seine and Troll in 2007 (SS2007, ST2007) and 2009 (SS2009, ST2009) plus Herring Seine in 94 (HS94) and Groundfish Trawl in 2007 (GT2007) are efficient among all 27 DMUs in this All Inclusive model.

#### 4.2.5 Efficiency plot

In this section all DMUs can be compared by their efficiency according to the selected indices.

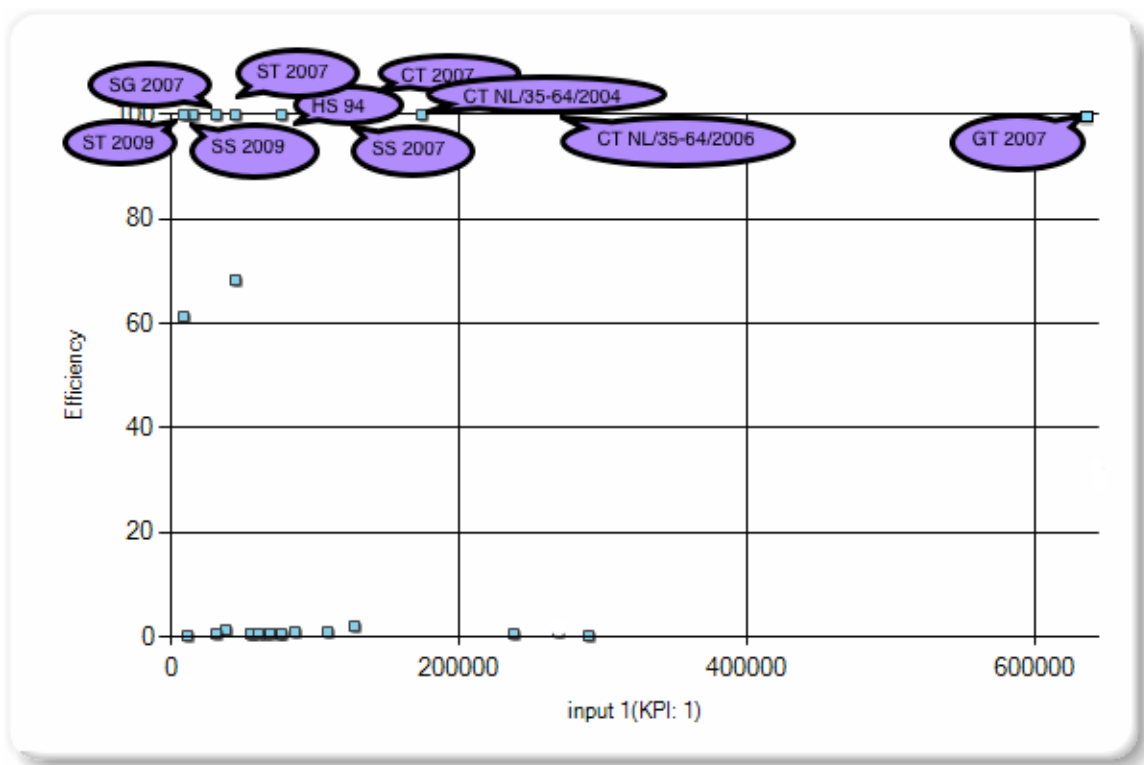


Figure 4.6 Efficiency Plot (Input1)

In Figure 4.6, all DMUs are illustrated based on their efficiency percentage and their input 1 (Total cost) value. In this study efficient units are the main focus therefore all the efficient DMUs are assigned in the figure with callout labels. In this way, fisheries DMUs can be compared based on each input and output.

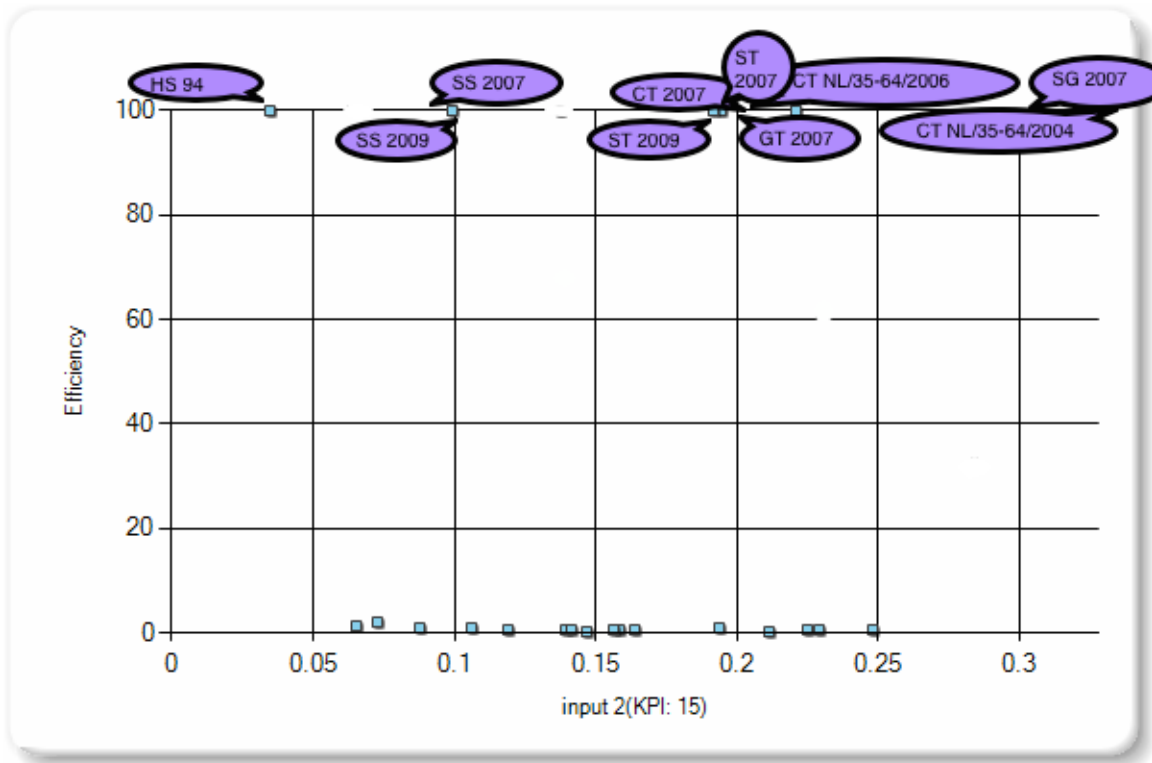


Figure 4.7 Efficiency Plot (Input2)

Figure 4.7 shows the overall evaluation of efficiency scores based on Input 2, which is Cost of fuel/ Total cost. According to this key Performance Indicator, most of the efficient DMUs (7 out of 10) have values greater than mean (0.15).

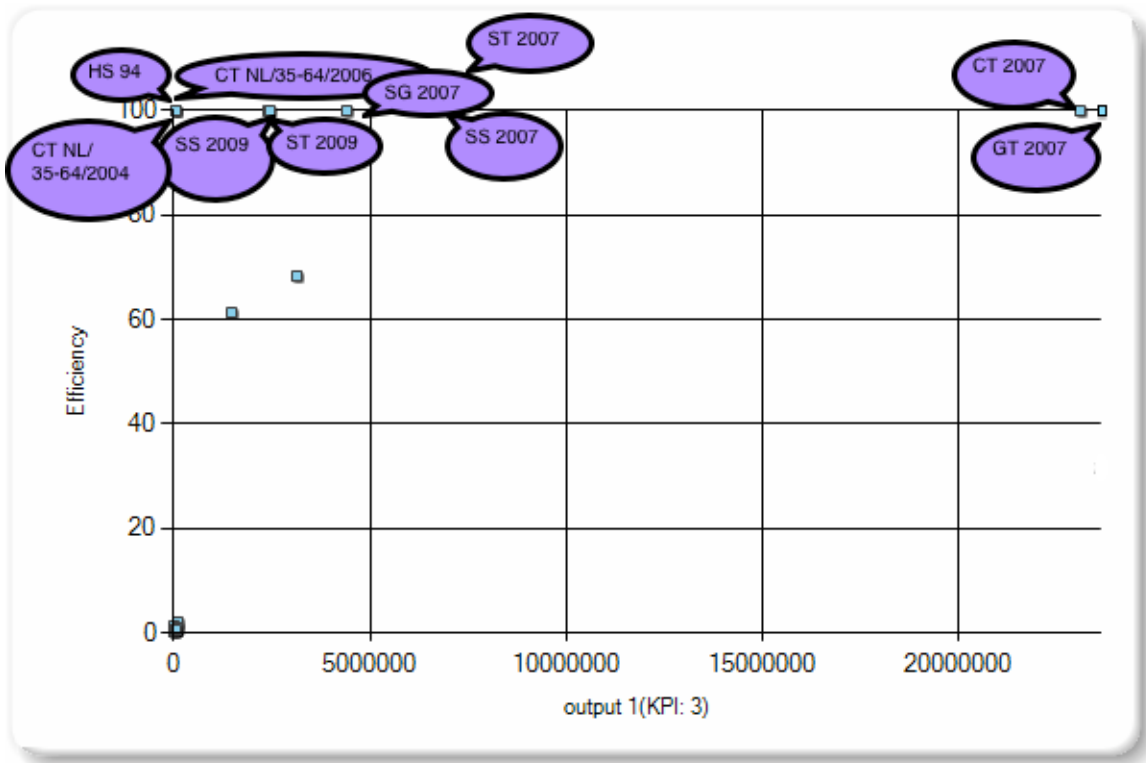


Figure 4.8 Efficiency Plot (Output1)

From Figure 4.8, data for Output 1 has a wide range, and case studies mostly act the same in terms of their Net Operating Profit. Considering Figure 4.8, all 27 DMUs except CT and GT 2007 have lower than \$10 million annual Net Operating Profit. However, it is noted that two efficient DMUs make more than \$20 million in Net Operating Profit.

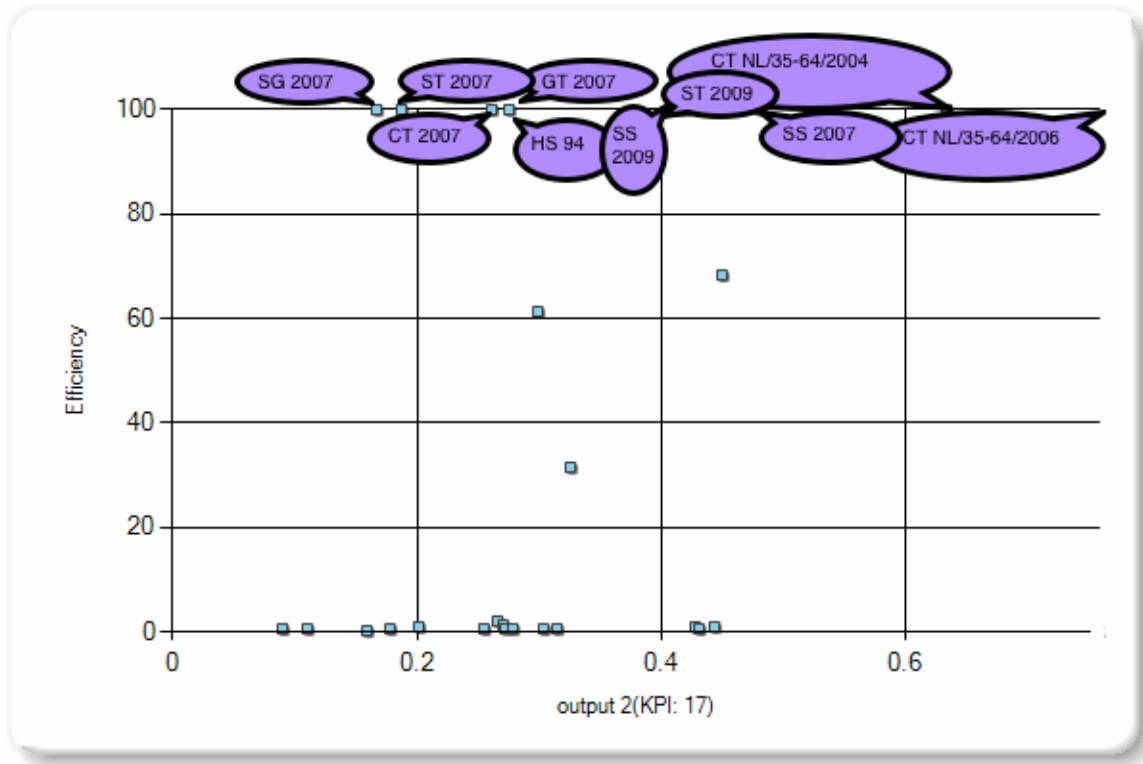


Figure 4.9 Efficiency Plot (Output2)

Lastly, the Efficiency Plot of Figure 4.9 shows on the horizontal axis, the Crew share/ Gross Income ratio. Most inefficient DMUs have lower than 0.4 value in terms of this output. While, efficient DMUs spread normally between 0.2 to 0.8.

#### 4.2.6 Slacks

DEA computed Slack is the amount for improvement. Thus, only the inefficient DMUs have slacks. The original value of inputs or outputs plus slack equals the Target for improving the DMU. Slack contains the Input excesses  $s^-$  and Output shortfalls  $s^+$  for each DMU. In the SBM (Slacks-based measure),  $s^-$  and  $s^+$  are defined via 2.2.2.2.4 section, and they indicate the total slacks of the concerned DMU.

Appendix B.2 presents all DMUs with their scores as well as their excesses of inputs and shortage of their outputs. As an example, the first DMU (SS 91) with 8.04E-03 score is inefficient and its first input excess is 38029.46325 which means that it must decrease its Input 1 by this amount and also increase its Output 1 by 5843073.031. However, we note that Input 2 and Output 2 have zero slack as  $s^-$  and  $s^+$ .

#### 4.2.7 Projection

The DMU  $(x_o, y_o)$  can be improved and become efficient by deleting the input excesses and augmenting the output shortfalls. Appendix B.3 contains a projection Table regarding to each index. As can be seen in the first column, the DMU number,. The second column is the name of DMU, and also its Inputs and Outputs with their identities. Furthermore, there are efficiency scores for DMUs and real values for each Index as well as projections or improvements for each index, the differences between the improvements and real values and the percentage of projections of the inefficient DMUs are useful to understand the amount of required increase or decrease for each Input and Output to realize efficiency.

This part contains projections of each DMU onto the efficient frontier by the chosen model therefore; Figure 4.11 based on Appendix B.3 is a bar chart for all DMUs that require projections or improvements in their inputs and outputs.

5 DMUs (SS 91, SS 94, ST 94, SH NL/35-64/2004, and SH NL/35-64/2006) need to decrease their Input 1 (KPI: 1), which is total cost (by -35.15%, -52.39%, -12.32%, -67.19%, -63.34%) that is shown on the bar chart. Thus these percentages are targets for these DMUs in terms of their financial perspective.

Also 6 DMUs (SG 2009, HS 2007, HS GL 2004, CT GL 2004, SH NL/35-64/2004, and SH NL/35-64/2006) need to decrease their second input (KPI: 15), which is cost of fuel/total cost, by (-0.01%, -15.05%, -24.75%, -24.18%, -33.50%, -49.01%) that are

shown on the bar chart. These percentages are targets for inefficient DMUs to be reached in terms of their Internal Business Processes perspective.

SS 91, SS 94, SG 91, SG 94, ST 91, ST 94, HS 91, HS GL 2004, GT 91, GT 94, CT 91, CT 94, CT GL 2004, SH NL/35-64/2004, and SH NL/35-64/2006 should increase their Output 1 (KPI: 3) that is Net Operating Profit (NOP) also SG 2009, and HS 2007 should increase it by 0.03%, 55.84% in terms of their financial perspective.

Finally, the enhancement for Output 2 (KPI: 17) that expresses the Crew share/ Gross income is for 13 inefficient DMUs (SS 94, SG 91, SG 94, ST 91, ST 94, HS 91, HS GL 2004, GT 91, GT 94, CT 91, CT 94, CT GL 2004) by (2.33%, 289.27%, 180.92%, 0.02%, 65.20%, 33.52%, 14.65%, 32.31%, 19.87%, 2.55%, 156.12%, 43.13%, 11.27%) illustrated percentages in Figure 4.11. Thus these are the improvements required for inefficient DMUs in their Learning and Growth perspective (see Table 3.4).

According to (Frei & Harker, 1998) “Unless there is an explicit restriction to hold outputs or inputs constant, the ability to adjust both simultaneously is superior in terms of determining what a branch would look like if efficient”, the projections presented in this section are the targets for each indices that are the KPIs identified in BSC framework (Table 3.3) that should be satisfied simultaneously. Thus for each inefficient DMU there is a target that can clarify the weaknesses exist in each perspectives and dimensions that are defined for each KPI (Table 3.4).

#### 4.2.8 Weights

Variables represented by  $r$  and  $u$  are the weights to be calculated for each of the  $m$  inputs ( $X$ ) and  $s$  outputs ( $Y$ ). Given the nature of DEA models, which assign the most favorable weights to inputs and outputs for each DMU in order to maximize its score, some DMUs will attain a high score a very good performance in a single input or output. These weights, derived from the data are the optimal set of weights each DMU can have in order to generate the best possible performance score.

Optimal weights  $v(i)$  and  $u(i)$  for Inputs and Outputs are exhibited in Appendix B.4 where  $v(0)$  Corresponds to the constraints (4.16) and (4.17) in Chapter 2, which means the sum of the weighted inputs must be greater and equal to the selected DMU weighted input and the sum of the weighted outputs must be less and equal to the selected DMU weighted output.

### 4.3 Salmon Analysis

In this section 12 salmon DMUs are evaluated by SBM model to provide a benchmark for salmon fleet in east and west coast according to the reports in 1991, 1994, 2007, and 2009.

#### 4.3.1 Data statistics

This subsection shows statistics on data and a summary report of results obtained for the case of the DEA applied to a subset of the DMUs that refer to Pacific Salmon. Table 4.11 shows indices used for evaluating the Pacific salmon fleets performance. In this case, the data supports 2 input indicators and 3 output indicators of performance.

Table 4.7 Input/output Data

I/O	Key Performance Indicators (KPIs)	BSC	Sustainability	IFMP	Objectives	Goals
<b>Input 1</b>	<b>1.Total Cost, benchmarked against competitors</b>	Financial	Profit	Economical	Lower harvesting cost	Become the industry cost leader
<b>Input 2</b>	<b>15.Cost of fuel/Total Cost</b>	Internal	Profit	Economical	Substantial improvements in processes	Continuously improve processes
<b>Output 1</b>	<b>2.Sales/assets ratio</b>	Financial	Profit	Economical	Sustainable income	Maximize use of existing assets
<b>Output 2</b>	<b>3.Net operating profit (G. income- Operating cost)</b>	Financial	Profit	Economical	Higher net operating profit	Maximize use of existing assets
<b>Output 3</b>	<b>17.Crew share/ Gross income</b>	L&G	People	Economical	Quality expert workers	Develop in skills in quality management and process improvement

As can be inferred from the input/output table, Table 4.7, each index belongs to one specific category of our proposed framework.

Table 4.8 Statistics on Salmon Input/output Data

	Input1 (KPI: 1)	Input2 (KPI: 15)	Output1 (KPI: 2)	Output2 (KPI: 3)	Output3 (KPI: 17)
<b>Max</b>	126625.05	0.3272	0.7299	7245569.3	0.48087
<b>Min</b>	8139	0.0727	0.0138	22292.06	0.0898
<b>Average</b>	56195.08583	0.158241667	0.393965323	2102894.905	0.271083939
<b>SD</b>	39535.9173	0.067953703	0.222422673	2634186.309	0.131385258

Table 4.8 shows Max, Min, Average, and Standard Deviation values of each Inputs and Outputs used in SBM model. Also the following Table 4.9 illustrates the relation between indices.

Table 4.9 Pairwise Correlation Matrix

	Input1 (KPI: 1)	Input2 (KPI: 15)	Output1 (KPI: 2)	Output2 (KPI: 3)	Output3 (KPI: 17)
<b>Input1 (KPI: 1)</b>	1	-0.772582679	0.837562305	-0.40589926	-0.036930595
<b>Input2 (KPI: 15)</b>	-0.772582679	1	-0.538302844	0.327220408	-0.3334344
<b>Output1 (KPI: 2)</b>	0.837562305	-0.538302844	1	-0.233248269	-0.376742872
<b>Output2 (KPI: 3)</b>	-0.40589926	0.327220408	-0.233248269	1	0.275404261
<b>Output3 (KPI: 17)</b>	-0.036930595	-0.3334344	-0.376742872	0.275404261	1

This relationship is defined by the correlation for each combination between inputs and outputs that would change in one direction with any motivation in one or both of them. For example, by each unit decrease in Input1 (Total cost), Input 2 (Cost of fuel/Total Cost) would increase by -0.772582679 and Output1 (Sales/assets) would decrease by 0.837562305.

Data plots that are presented for each index below provide further statistical information about this model dataset.

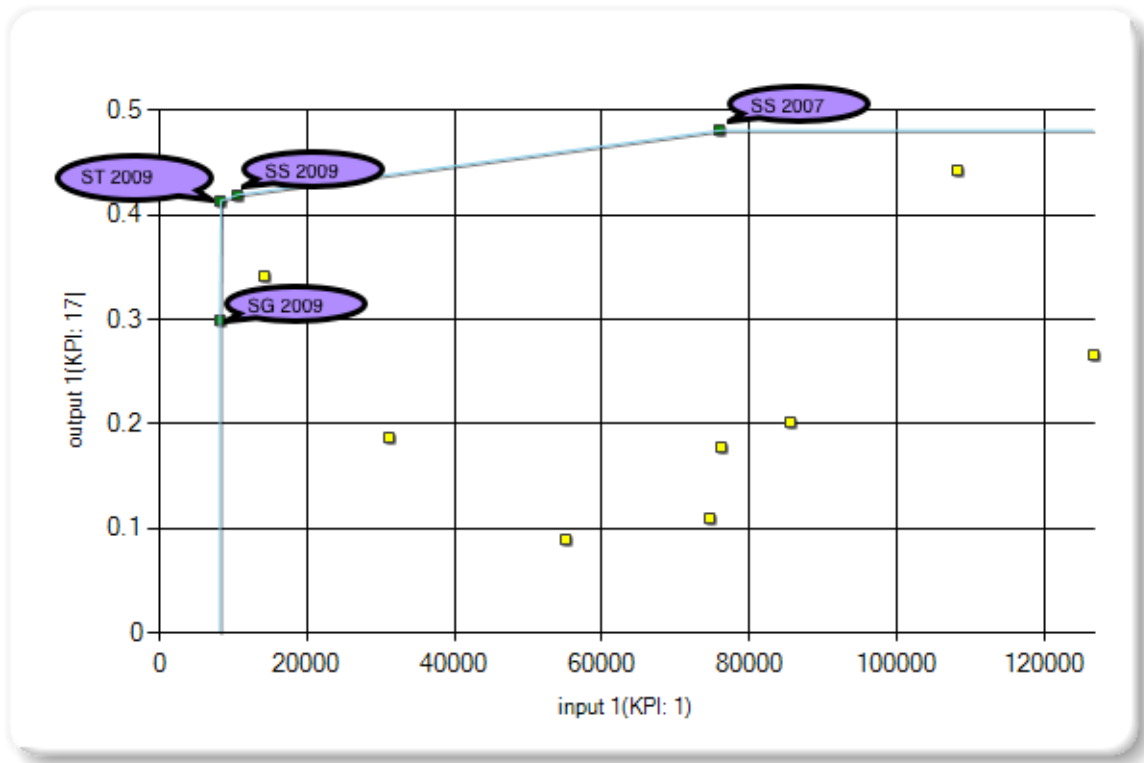


Figure 4.10 Data Plot (Output1/Input1)

In Figure 4.11, four DMUs SG 2009, ST 2009, SS 2009 and SS 2007, each with input 1 and output 1, are depicted. The efficient frontier, which is continuous, consists of three line segments. A feasible replacement of inefficient DMUs with  $S^-$  and  $S^+$  in both vertical and horizontal direction. Thus, it is clear that this model considers the input excesses and the output shortfall simultaneously in arriving at a point on the efficient frontier, which is most distant from any inefficient DMUs. Figure 4.12 below shows this frontier according to Input1 and Output2.

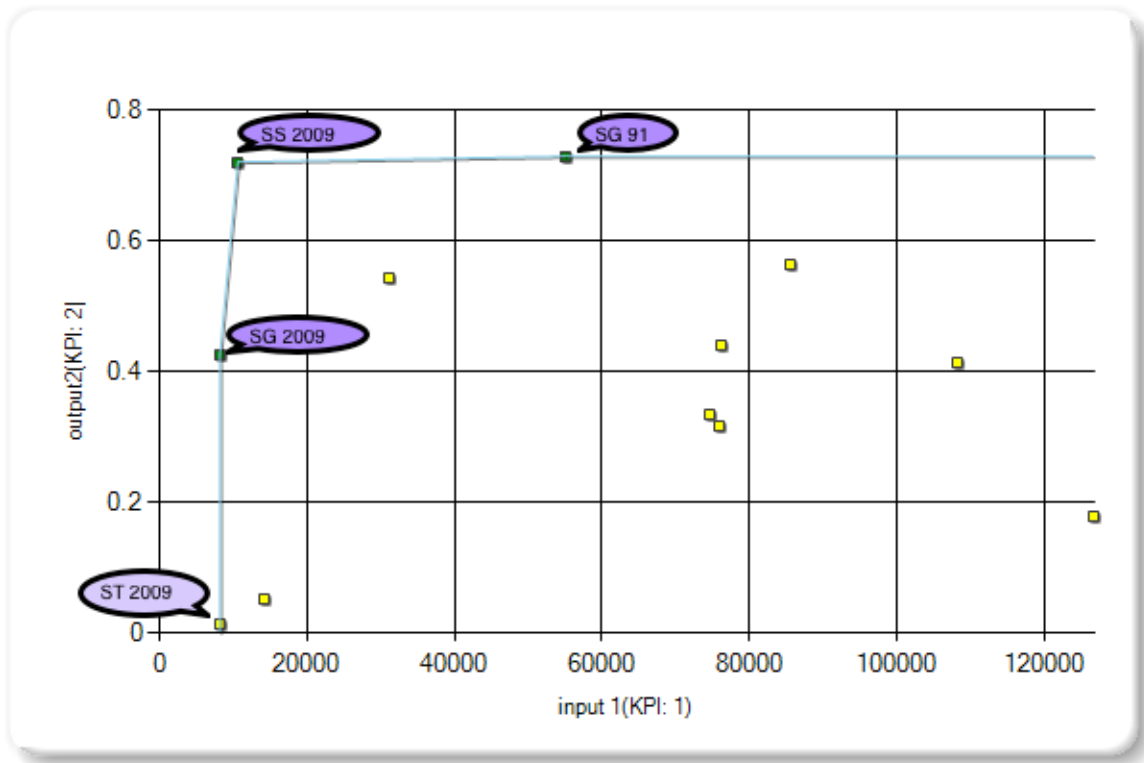


Figure 4.11 Data Plot (Output2/Input1)

Three efficient DMUs SG 2009, SS 2009, and SG 91 are on the frontier in Figure 4.12. ST 2009 is on the frontier but the distance between this DMU and frontier is short therefore the improvements on its indices would be small to replace it on the frontier. Figure 4.13 illustrates another frontier base on Input 1 and Output3.

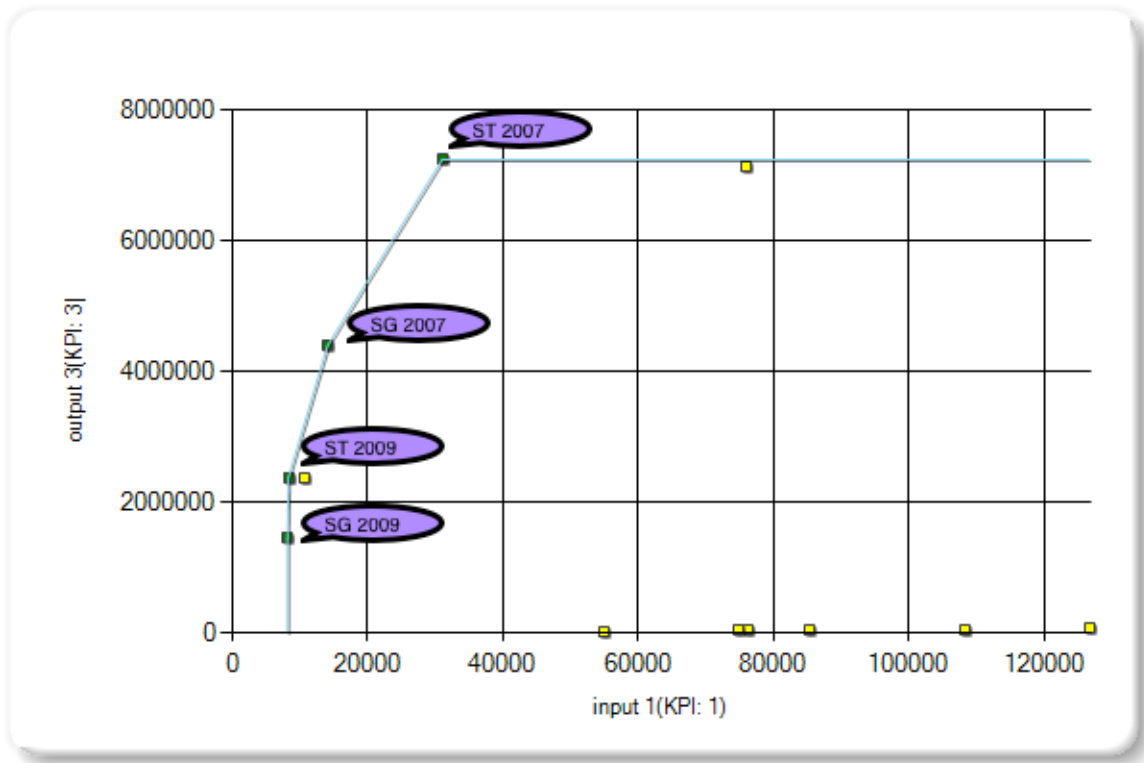


Figure 4.12 Data Plot (Output3/Input1)

Considering this combination of input1 (Sales/ Assets ratio) and output 3 (Crew share/ Gross income ration) four DMUs SG 2009, ST 2009, SG 2007, and ST 2007 are on the frontier.

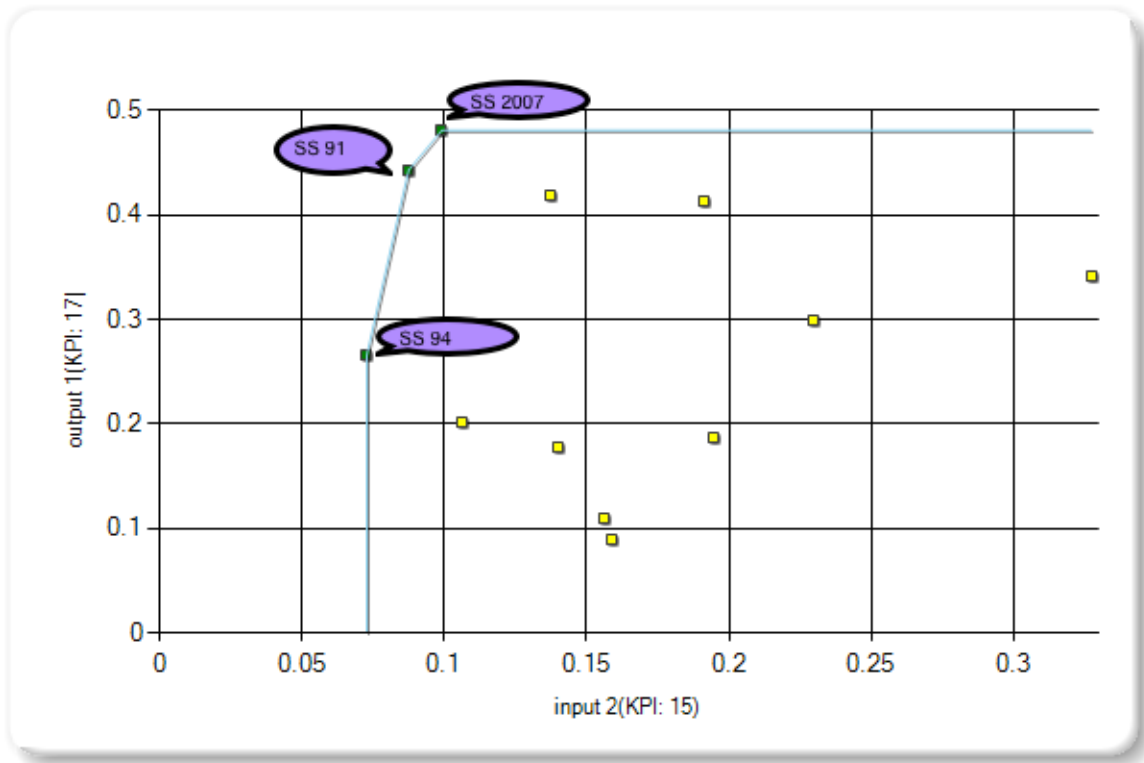


Figure 4.13 Data Plot (Output1/Input2)

For pairwise of input2 (Cost of fuel/ Total Cost ratio) and output 1 (Sales/ Assets ratio) three DMUs SS 94, SS 91, and SS 2007 are on the frontier.

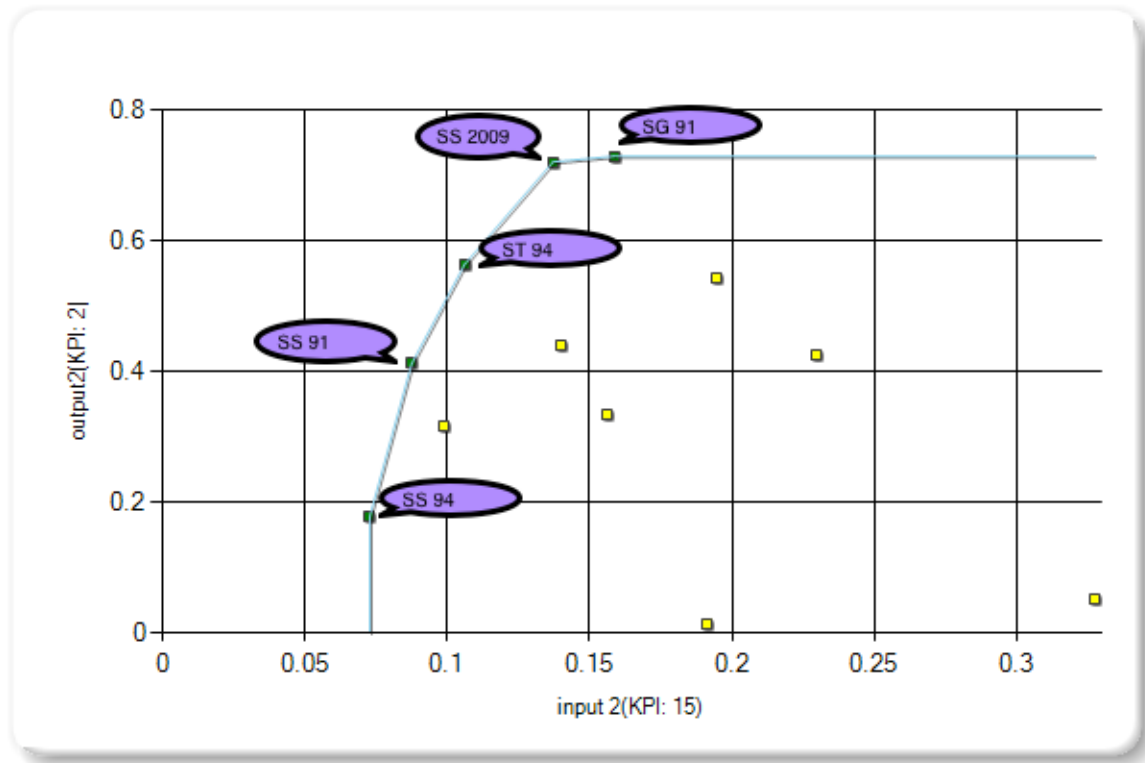


Figure 4.14 Data Plot (Output2/Input2)

Five DMUs (SS 94, SS 91, ST 94, SS 2009, and SG 91) are on the frontier of input2 (Cost of fuel/Total Cost ratio) and output 2 (Crew share/ Gross income ratio) pairwise.

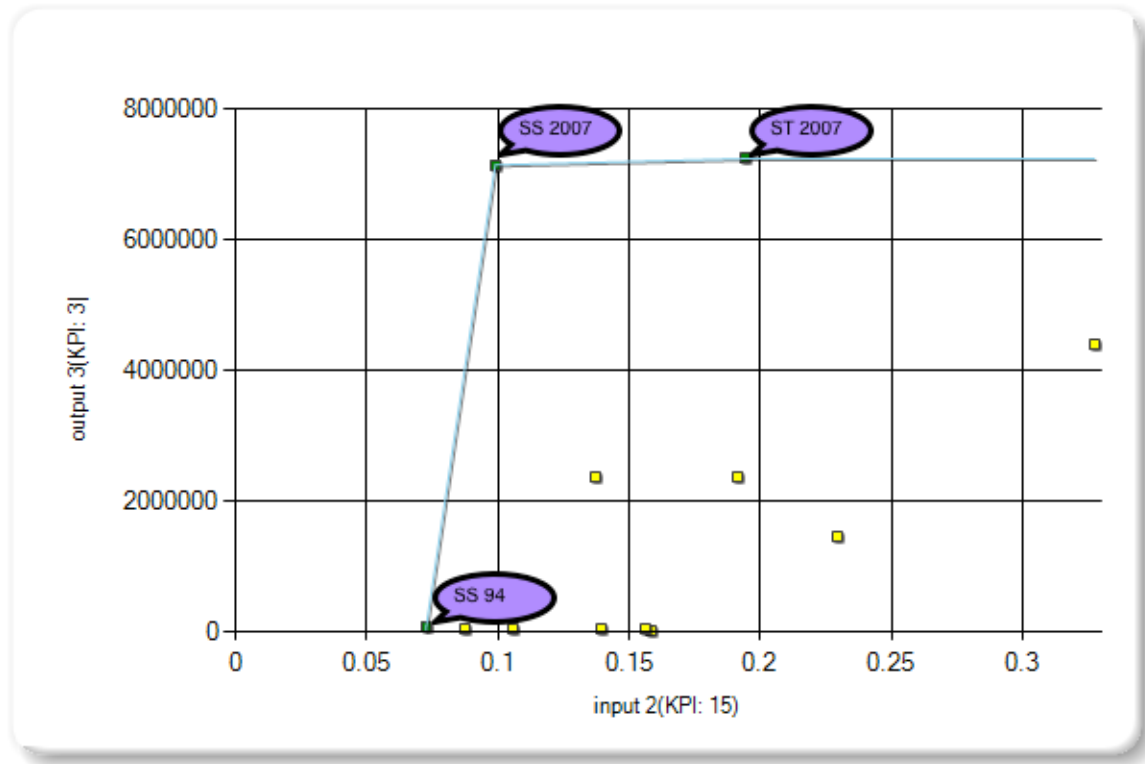


Figure 4.15 Data Plot (Output3/Input2)

Considering the combination of input2 and output 2 five DMUs SS 94, SS 91, ST 94, SS 2009, and SG 91 are on the frontier. Taking these considerations into account we can obtain a definition of efficiency as follows for the SBM model.

#### 4.3.2 Efficiency Scores

Appendix C.1 contains the DEA-score, reference set, Lambda value for each DMU in the reference set and ranking in input and in the descending order of efficiency scores. In this Table is shown that DMUs SS91, SS94, SS 2007, SS 2009, SG 2007, SG 2009, ST 94, ST 2007, and ST 2009 are efficient (Score=1) and DMUs SG 91 (Score=8.56E-03), SG 94 (Score=2.54E-02), and ST 91 (Score= 0.019045471) are inefficient. Also the reference set for sample inefficient DMU like SG 91 compose of SS 2007 ( $\lambda_{SS\ 2007} = 0.376289895$ ) and ST 2007 ( $\lambda_{ST\ 2007} = 0.623700105$ ).

### 4.3.3 Rank

Table 4.10 contains the ranking of Salmon fisheries in the descending order of efficiency scores. As can be seen 9 over 12 DMUs are efficient.

Table 4.10. Ranking

Rank	DMU	Score
1	ST 2009	1
1	SS 91	1
1	SS 94	1
1	SS 2007	1
1	SS 2009	1
1	ST 2007	1
1	ST 94	1
1	SG 2007	1
1	SG 2009	1
10	SG 94	2.54E-02
11	ST 91	0.019045471
12	SG 91	8.56E-03

### 4.3.4 Graph

The bar chart of the DEA scores in the ascending order is exhibited in Figure 4.17.

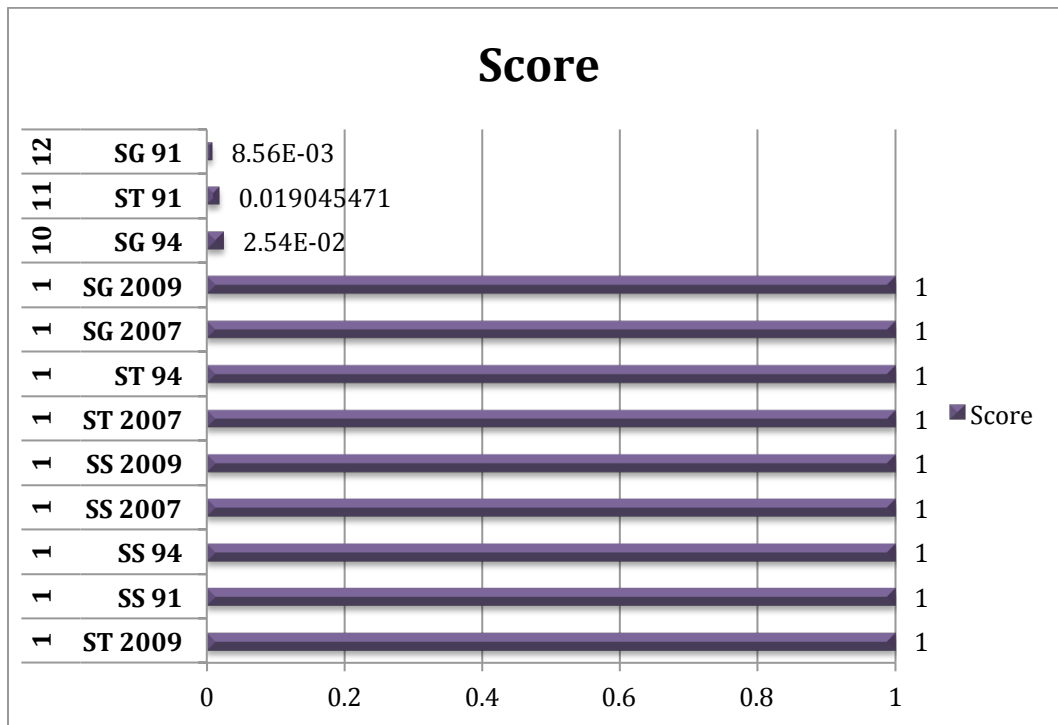


Figure 4.16 DMUs Efficiency

From Figure 4.17 it can be shown that Salmon Troll in 94, 2007, 2009, Seine in 91, 94, 2007, 2009, and Gillnet in 2007 and 2009 are efficient among all other 27 DMUs. Thus, they can make an efficiency frontier due to their efficiency score, which is equal to 1. Whereas, Troll in 91 and Gillnet in 91 and 94 are inefficient with far distance.

4.3.5 Efficiency plot

In this part, efficiency plots are presented for each input and output. In Figure 4.18, the 9 efficient DMUs (that are expressed in Table 4.10) are shown based on their Input 1 (Total cost) value.

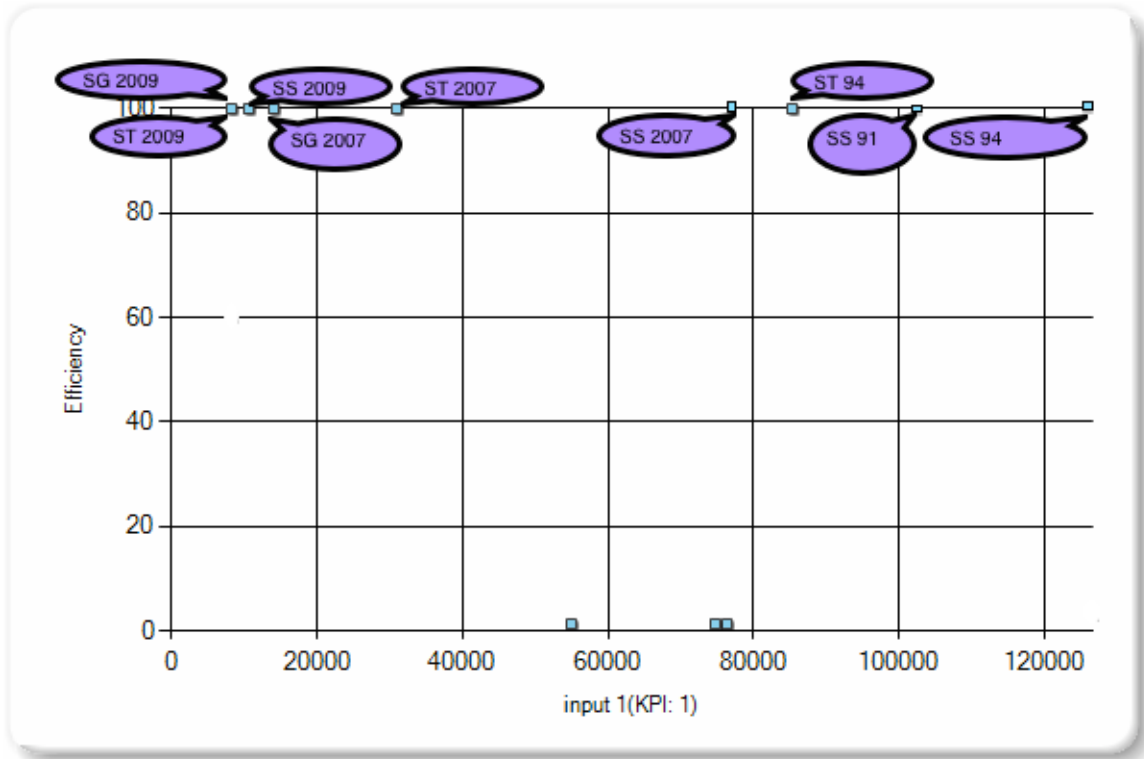


Figure 4.17 Efficiency Plot (Input1)

Next figure shows Input 2 (Cost of fuel/ Total Cost) values for all DMUs and the efficient ones are illustrated via text balloons.

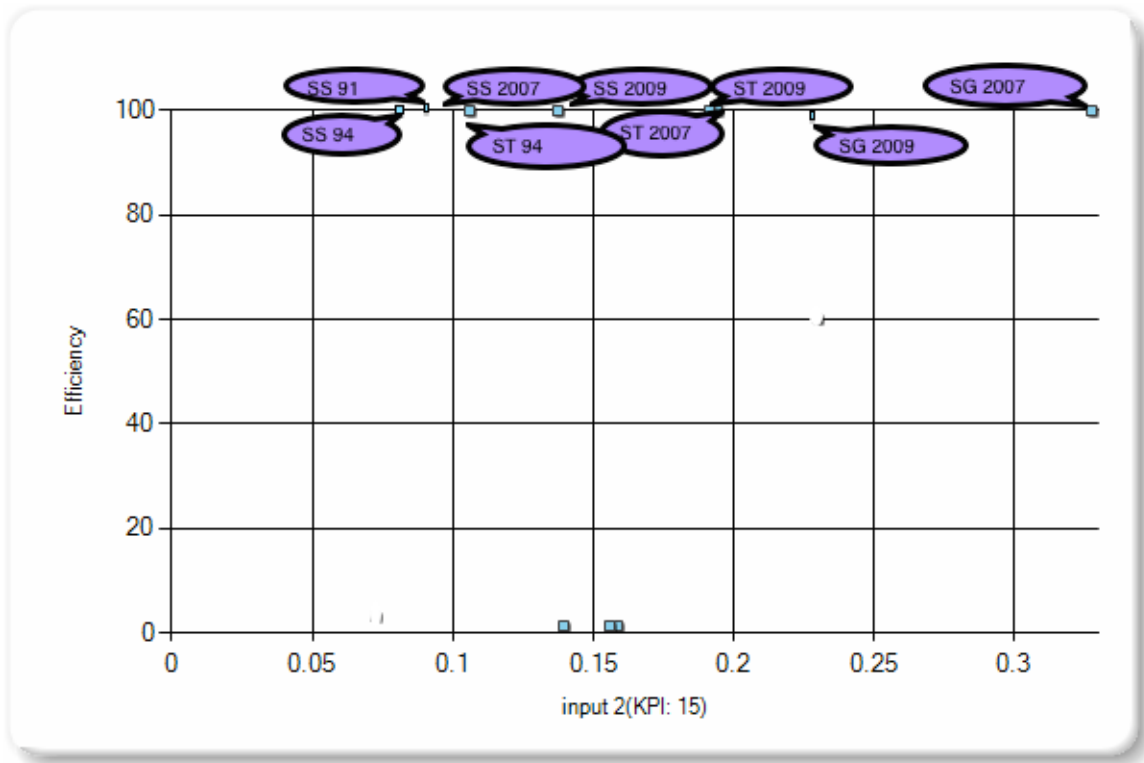


Figure 4.18 Efficiency Plot (Input2)

According to this Figure, SG 2007 has the highest value in terms of input2, which means that it has the most quotation giving the cost of fuel among other efficient DMUs.

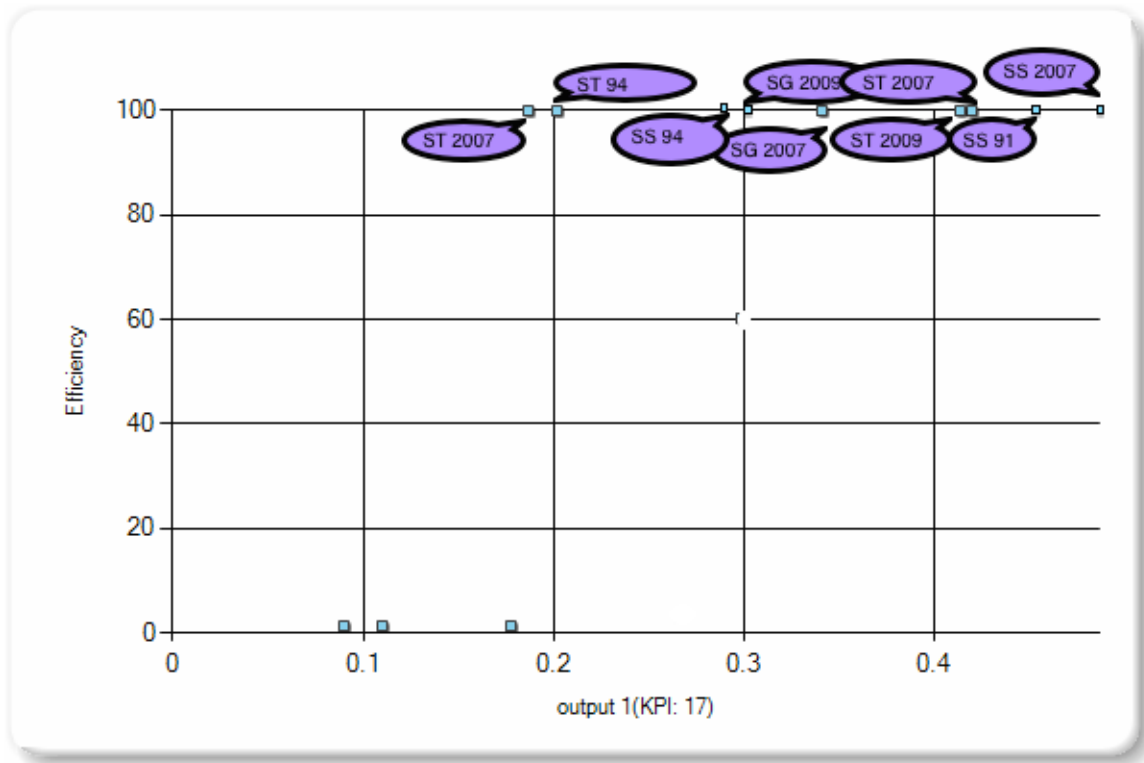


Figure 4.19 Efficiency Plot (Output1)

In this efficiency plot most of the efficient DMUs have more than 0.3 as the ratio of Sales/assets which seems to be pretty good compare to other DMUs.

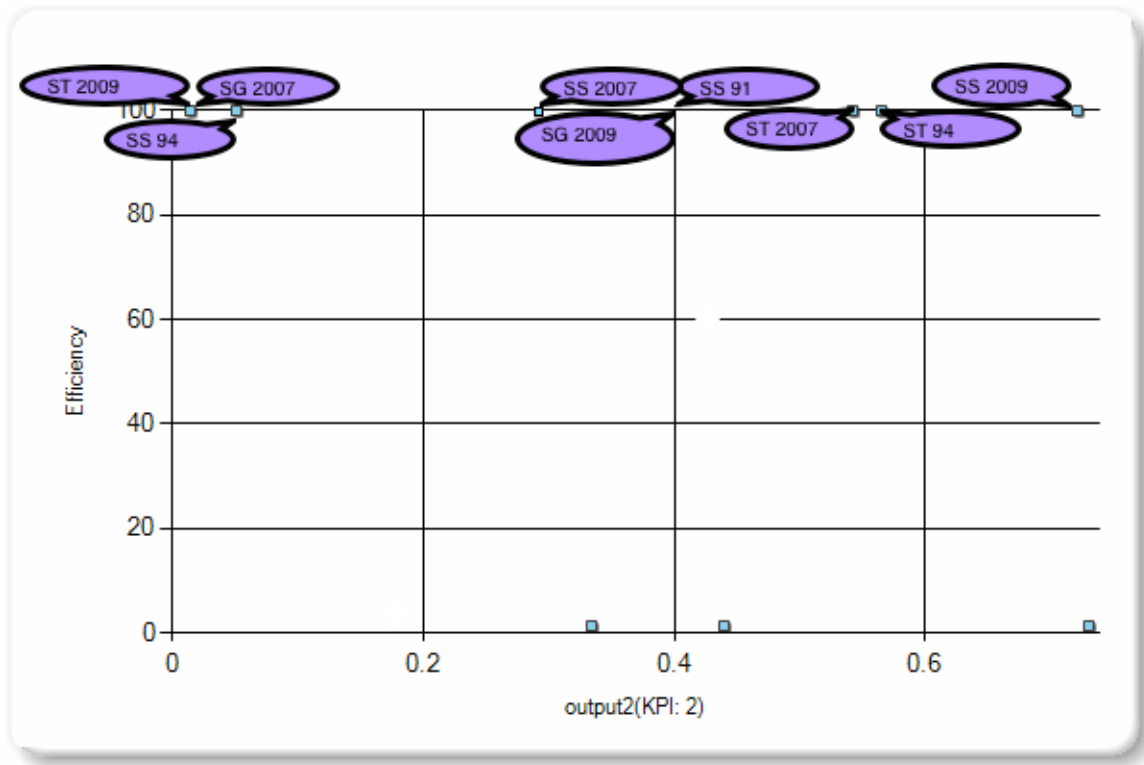


Figure 4.20 Efficiency Plot (Output2)

Considering Output2 Net Operating Profit (NOP ) as basis of comparison, SS2009 has the highest profit among others.

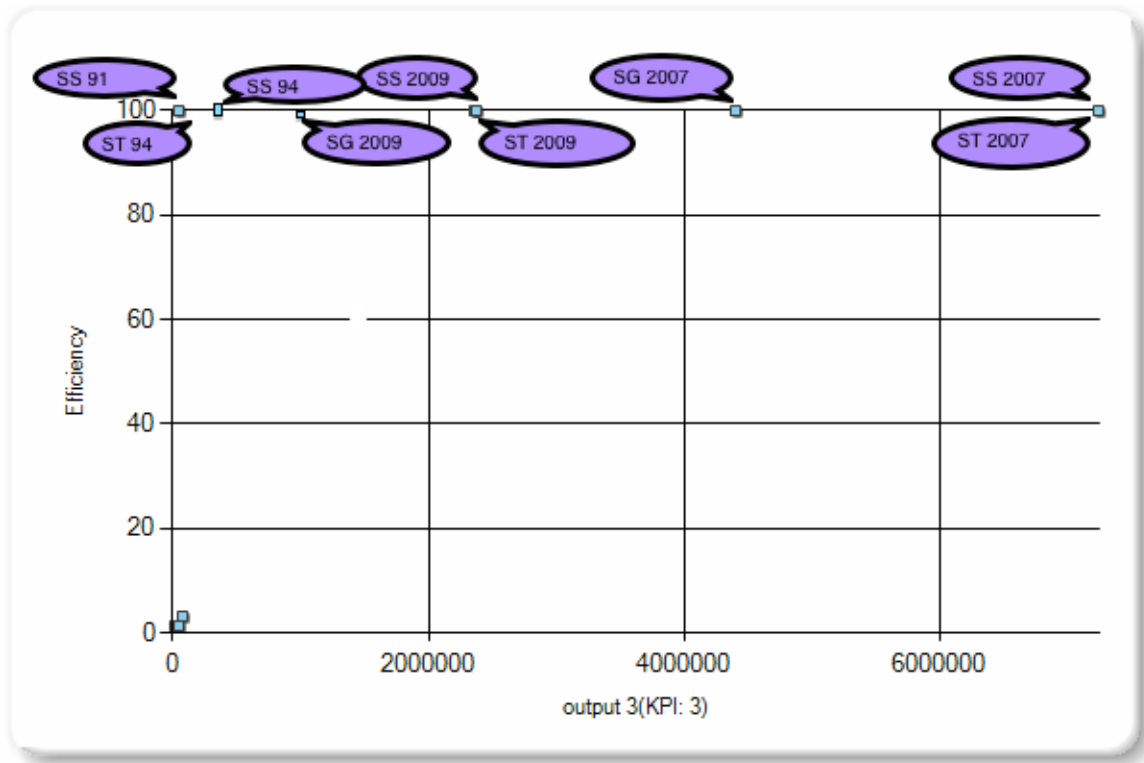


Figure 4.21 Efficiency Plot (Output3)

Considering Output3 (crew share/Gross income) SS and ST in 2007 have the highest ratio among others.

#### 4.3.6 Slacks

DEA computed Slack is the amount for improvement of this variable index in order to render the DMU efficient in comparison with the other DMUs in the model. Thus, only the inefficient DMUs have slacks. The original value of inputs or outputs plus slack equals the Target for improving the DMU. Slack contains the Input excesses  $s^-$  and Output shortfalls  $s^+$  for each DMU. In the SBM (Slacks-based measure),  $s^-$  and  $s^+$  are defined via 2.2.2.2.4 section, and they indicate the total slacks of the concerned DMU.

Appendix C.2 presents all DMUs with their scores as well as their excesses of inputs and shortage of their outputs. As an example, the fifth DMU (SG 91) with 8.56E-03 score is inefficient and its first input excess is 7006.723994 which means that it must decrease its Input 1 by this amount and also increase its Output 1, 2, and 3 by 9.74E-02, 7187473.327, 0.207840812 as defined slack however, Input 2 and Output 2 have zero slack as  $s^-$  and  $s^+$

#### 4.3.7 Projection

The DMU  $(x_o, y_o)$  can be improved and becomes efficient by deleting the input excesses and augmenting the output shortfalls. Appendix C.3 presents a projection Table regarding to each index. As can be seen the first column is number of DMUs, the second is the name of DMU and also its Inputs and Outputs with their identities. Furthermore, there are efficiency scores for DMUs and real values for each Index as well as projections or improvements for each index, the differences between the improvements and real values and the percentage of projections which can be useful to understand the amount of required increase or decrease for each Input and Output.

The negative values in difference and percentage columns reflect the necessary decreases for inputs of a DMU to become efficient. Also the positive values would mean in the same way for outputs.

#### 4.3.8 Weights

Variables represented by  $r$  and  $u$  are the weights to be calculated for each of the  $(m)$  inputs  $(X)$  and outputs  $(Y)$ . Given the nature of DEA models, which assign the most favorable weights to inputs and outputs for each DMU in order to maximize its score, some DMUs will attain a high score a very good performance in a single input or output. These weights, derived from the data are the optimal set of weights each DMU can have in order to generate the best possible performance score.

Optimal weights  $v(i)$  and  $u(i)$  for Inputs and Outputs are exhibited in Appendix C.4,  $v(0)$  corresponds to the constraints (4.16) and (4.17) Therefore, the indexes that need improvement would not get weight because they are not strong on those indexes and DEA will not put any weights on them to make the DMUs efficient.

# Chapter 5

## Conclusion and recommendations

## 5. Conclusions and Recommendation

In this final chapter of the thesis, the conclusions and recommendations of this research are presented. The conclusions are linked to the responses of the thesis work to the original research questions (section 1.2). The recommendations report on future research opportunities related to this problem, as well as the limitations of the current work.

In general terms, the outcomes of applying the proposed BSC-DEA model presented here are listed below as extracted and adapted from (Ebnerasoul, Yavarian, & Azodi, 2009)):

- a) Develop the well-defined strategic framework for the small scale commercial fisheries sector: BSC as a strategic management tool categorizes the important aspects of the fisheries sector and provides a measurement tool in the form of the Key Performance Indicators (KPIs).
- b) Define the ideal unit within the fisheries sector including the inputs and outputs variables of the ideal unit obtained through the optimum input and output selection of real organizations.
- c) Show the ideal unit specifications (input/output) that have occurred.
- d) Rank the units based on the ideal or efficient organization.
- e) Motivate other units/organizations to perform more efficiently.

This chapter is comprised of three main sections: 5.1 Conclusions; 5.2 Recommendations; and 5.3 Limitations of this research.

### 5.1 Conclusion

In this section, a summary of the response to each of the research questions is presented.

1. How can the Balanced Scorecard (BSC) be designed to apply to the commercial fisheries harvesting sector and what are the corresponding Key Performance Indicators (KPIs) that are appropriate and available (from existing data) for measuring fisheries harvesting sectorial performance?

In order to measure the performance of small-scale fisheries in terms of their productivity, a combined BSC-DEA model to measure the productivity according to its components, effectiveness (doing the right things) and efficiency (doing things right) has been developed. To measure the effectiveness, each organization measures its well-defined strategy. In Chapter 3, we introduced the proposed BSC framework with its 5 perspectives (Financial, Customer, Internal Business Processes, Social & Environmental, and Learning & Growth) that covers all financial and non-financial aspects of a company,

and its goals (as long term targets) and objectives (as short term targets) in each perspective.

In order to measure these objectives in each perspective, we identified the relative Key Performance Indicators (KPIs). Due to the lack of data availability for commercial fisheries organizations, a short list of KPIs is presented and selected by expert decision-making methods. The KPIs selected represented all perspectives of BSC, as well as the elements of fisheries sustainability corresponding to the dimensions of Fisheries and Oceans, Canada IFMPs.

2. How can DEA be used to determine the multiple perspective efficiencies of fisheries harvesting sectors, and what are the efficiency benchmarks and the relative efficiency of selected commercial fishery case studies?

The appropriate DEA method was selected based on the short list of KPIs and the understanding of alternative DEA model designs. According to the controllable indices of the input and output variables, the non-oriented SBM (Slack Base Model) was judged to be the most appropriate DEA model to evaluate the commercial fisheries performance in terms of their efficiency scores. The SBM (VRS) model was applied to the All inclusive fisheries data model with 27 DMUs and to the Salmon All model with 12 DMUs. In the All inclusive model, 10 sectors were evaluated as efficient DMUs for the efficiency benchmark in the 2-inputs and 2-outputs system.. For the Salmon All model, 9 of the 12 DMUs were evaluated as efficient for the 2-inputs and 3-outputs model.

The ranked list of fisheries according to their efficiency and effectiveness, clarifies the benchmark in this industry as well as targets that are a motivation for those fisheries sectors that are evaluated as being inefficient.

3. How can the BSC-DEA methods be applied to improve the multiple perspectives of performance measurement of commercial fisheries harvesters as required for the Integrated Fisheries Management Plans?

Demands for sustainable management that considers the strategies and their applications, and strengthens the engagement of fishermen in defining and applying processes, are putting pressure on governments and fishery interests alike. In many fisheries, the disorganized reported data and inconsistent monitoring of fisheries performance cause serious problems in gauging performance improvement. Without comparisons based on strategies, there is no ideal performance as a target for operating enhancement.

This thesis sets out a strategic framework to guide fishery performance monitoring and reporting into the future. This framework is founded by a powerful performance measurement tool in the form of an integrated BSC-DEA model. As such, the purpose of this tool is to provide a common understanding of the importance and need for the multiple perspectives of performance measurement of commercial fisheries harvesters as required for the Integrated Fisheries Management Plans for evaluating their performance regardless of their different market. The BSC-DEA model provides a consistent approach to the development and application of a standard reporting template in all fisheries would be necessary for their performance improvement. This approach identifies a concise set of fisheries data required to be collected to measure performance across a spectrum of economic, social, and environmental dimensions. As such, the approach fills the void in the stated but unfulfilled objectives of the IFMPs.

## 5.2 Recommendations for Future Research

In this section, recommendations around the reporting standards in the fishery industry are discussed, with specific direction toward applying the proposed BSC-DEA model for benchmarking fisheries sector performance, and its policy impact on continuous fisheries improvement.

### 5.2.1 Reporting Standards

Demands for sustainable management in commercial fisheries are considerable. It is important that the strategies, operations, and applications of the fisheries are monitored and that the engagement of fishermen are strengthened in order to define and apply effective processes for improving fisheries sustainability in all dimensions including economic (profit), social (people), and environmental (planet). In many fisheries, however, the required data and inconsistent monitoring of fisheries performance cause a serious problem for understanding performance and improving it over time.

This thesis sets out a framework based on strategic management to guide fishery performance monitoring and reporting into the future. As such, the purpose of this tool is to provide a common understanding of the importance and need for fisheries monitoring and reporting standards for evaluating performance regardless of the fishery markets, species, or harvesting methods. Since, different fisheries do not operate on the same basis, a consistent approach to the development and application of reporting standards in all fisheries is necessary for performance improvement. While this strategic framework addresses the goals for all fisheries, it also recognizes the unique basis for fisheries. Thus

by standard reporting according to this template, fishermen can benefit from aligning to the updated strategies. Similarly, researchers and DFO Management can benefit from the current benchmark of fisheries in its decision making processes especially in terms of policy making.

### 5.2.2 Integrated BSC-DEA model

Application of the BSC-DEA framework for balancing the goals and indicators in practice, would benefit from experts opinion in the fishing industry by engaging them to participate in defining the goals and the significant KPIs for further analysis. It is recommended that a strategy team be composed of people with different backgrounds related to the BSC perspectives (e.g., Financial, Customer, Business Processes, Social and Environmental, and Human Resource professionals). The acceptance of any strategic framework depends on the level of acceptance among fishermen that are responsible for its implementation. As well, development of a simple software package that would assist fishermen as users to track fisheries performance according to the proposed BSC-DEA model would make it easy to collect the needed data and to compare current and future situations for a specific fishery.

### 5.2.3 Policy Impact

Fishery monitoring and catch reporting requirements are required to support this integrated BSC-DEA model to ensure identified selective fishing standards and objectives are being achieved. For example, the regulatory policy of marine protected areas as areas closed to the fisheries (“closed areas”) impact on fisheries efficiency. Thus, before implementing such policies, fisheries managers can measure the anticipated impacts on the efficiency score of specific fisheries through the change of its corresponding KPIs (such as profit, total cost, by-catch, etc.,) and compare all cost and benefits in terms of the financial and non-financial aspects of our proposed BSC. Thereafter, informed decisions and compensation can be determined accordingly.

As noted above, the proposed integrated BSC-DEA model for fisheries provides information to the IFMP process that is currently not being delivered. In this way, fishery managers in collaboration with harvesters and other interests would be able to address strategic and sustainability aspects and monitor progress in meeting associated performance goals. Furthermore, our suggested KPIs can be used to direct the collection of data and input into transparent performance reporting. Consequently, a systematic approach must be applied for determining fishery information requirements

and how best to meet them.

### 5.3 Limitations

This research faces limitations that need to be recognized. These limitations are in terms of data gathering and the interpretation of the BSC methodology. In the discussion below, these limitations are discussed.

#### 5.3.1 Data Availability

Reliable, timely and accessible fisheries information is the foundation of sustainable management. The worldwide trend towards sustainable fisheries and supporting management practices is calling for significant improvements in monitoring and reporting. In this environment, it is vital that our fisheries have a consistent approach to determining information requirements in a practical and accepted way by all executives, one that inspires confidence and cooperation among harvesters, global consumers and the Canadian public.

Deficiencies remain in information gathering, in terms of coverage of the fisheries, missing or unreliable data. In this thesis, 50 KPIs were examined for which appropriate data could not be found. However, indicators were able to be extracted mostly from DFO, CFRN Project 1.1, and the standard KPIs for BSC perspectives results. This means, among other things, that in this industry, defined goals and their corresponding indicators are not necessarily explicitly reported. The consequences are that the required data at the firm level does not appear to exist, or, is otherwise proprietary and not available.

BSC has demonstrated some inadequacy in certain circumstances like its application. As a framework it separates the goals, objectives and their measurements in different perspectives however these goal settings are top to bottom which means that the executives might not see these goals and KPIs mutual to their real job or understand them properly, and it makes financial and non-financial aspects difficult to be balanced by sector. Also, the cause-and-effect relationship presented in Figure 3.5 in the strategic map is based on assumptions because of our data limitation, which might feed the control system with incorrect information that will cause the anticipation of the results of the performance indicators.

In terms of DEA methodology, Lack of Data causes a big problem in making a reasonable benchmark specially for salmon fleet. As presented in chapter 4 most of the

DMUs became efficient because of the small number of DMUs. In this thesis we tend to compare more perspective specially in social and environmental perspective while, increasing the number of indices with the same number of DMUs could make the results unreal.

## Bibliography

(n.d.).

(n.d.). Retrieved from <http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/ifmp-gmp/index-eng.htm>.

Anand, M., Sahay, B., & Saha, S. (2005). *Balanced Scorecard in Indian Companies* (Vol. 30). Vikalpa.

Anderson, D. R., Sweeney, D. J., Williams, T. A., Camm, J. D., & Kipp, M. (2012). *An Introduction to Management Science: Quantitative Approaches to Decision Making* (Revised Thirteenth Edition ed.). Mason, USA: South-Western Cengage Learning.

Anderson, D., Sweeney, D., Williams, T., Camm, J., & Martin, K. (2012). *An Introduction to Management Science*. (thirteenth, Ed.) Mason, USA: SOUTH-WESTERN.

Auditor, V. (2010). *Key Performance Indicators*. Public Record Office victoria. Melbourne: State Government of Victoria.

Banker, R. D. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science* (30(9)), 1078-1078 .

Banker, R. D., Change, H., Janakiraman, S. N., & Konstans, C. (2004). A balanced scorecard analysis of performance metrics. *European Journal of Operational Research* , 154, 423-436.

Bask, A. H., Tinnila, M., & Rajahonka, M. (2010). Matching service strategies, business models and modular business processes. *Business Process Management Journal* , 16 (1), 153-180.

Behin-Cara. (2014). *Data Envelopment Analysis Online Software*. Retrieved 09 2014, from DEAOS: <https://www.deaos.com>

Bergendahl, G. &. (2008). Evaluating the performance of Swedish banks according to service efficiency. *European Journal of Operational Research* (185), 1663–1673.

Beverton, R., & Holt, S. (1957). *On the Dynamics of Exploited Fish Populations* (Vol. 2). London, UK: Ministry of Agriculture, Fisheries & Food, Fisheries Invest.

Braam, G., & Nijssen, E. (2004). Performance Effects of Using the Balanced Scorecard. *Long Range Planning* (37(4)), 335-349.

Charles, A. (1991). Small-scale fisheries in North America: Research perspectives. In J.-R. Durand, J. Lemoalle, & J. Weber, *La Recherche Face a la Peche Artisanale* (pp. 157-84). Paris: Editionns de l'ORSTOM.

Charles, A. (2001). *Sustainable Fishery Systems*. Oxford UK.

Charles, A. T. (1995). *Peace in the Oceans Ocean Governance and the Agenda for Peace*. Costa Rica: The Proceedings of Pacem in Maibus XXIII.

Charles, A. T. (1994). Towards sustainability: The fishery experience. *Ecological Economics* (11(3)), 201-211.

Charnes, A. C. (1985). Foundations of data envelopment analysis for pareto-koopmans efficient empirical production functions. *Journal of Econometrics* (30(1-2)), 91-107.

Charnes, A., Cooper, W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European journal of operational Research*, .

Charnes, A., Cooper, W., Lewin, A., & Seiford, L. (1994). *Data envelopment analysis: theory, methodology and applications*. Massachusetts, 1. Kluwer Aca: demic Publishers.

Charnes, A., Cooper, W., Wei, Q., & Huang, Z. (1989). Cone-ratio data envelopment analysis and multi-objective programming. *International Journal of Systems Science* , 1099-118.

Chen, T. C. (2007). DEA performance evaluation based on BSC indicators incorporated (The case of semiconductor industry). *International Journal if productivity and performance management* , 56 (4), 335-357.

Cherchye, L., & Vermeulen, F. (2006)). Robust Rankings of Multidimensional Performances An Application to Tour de France Racing Cyclists. *Journal of Sports Economics* , 7( (4), 359-373.

Clark, C. (1973). *The economics of overexploitation*. Science 181.

Cooper, W. W., Seiford, L. M., & Tone, K. (2007). *Data Envelopment Analysis* (2nd ed.). New York, NY, USA: Springer Science+Business Media, LLC.

(2006). *Costs and Earning Survey* . Fisheries and Oceans Canada Newfoundland and Labrador Region.

Dabbaghi, A., Malek, A., & Aulizadeh, A. (2010). Evaluating the quality of corporate mission statements. Russia: the 6th international strategic management conference.

Dabbaghi, A., Moazemi, M., & Kimiagari, S. (2008). Planning for reaching goals and vision SWOT by gap analysis, Focus group interview and evaluating the implementation in oil industry. *the7th international strategic management conference*. Tehran.

- De Haas, M., & Kleingeld, A. (1999). Multilevel Design of Performance Measurement Systems: Enhancing Strategic Dialogue Throughout the Organization. *Management Accounting Research*, 10 (1).
- Deng, J. (1982). Grey Control System. *Journal of Huazhong University of Science and Technology* (3), 9-18.
- Deng, J. (1990). *Theory of Grey System*. Wuhan: Huazhong University of Science and Technology Press.
- Department of Fisheries and Ocean. (2014). *Prepering an Integrated Fisheries Management Plans*. Retrieved from Fisheries and Ocean Canada: <http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/ifmp-gmp/guidance-guide/preparing-ifmp-pgip-elaboration-eng.htm#a1>
- Ebnerasoul, S. A., Yavarian, H., & Azodi, M. A. (2009). Performance Evaluation of Organizations: An Integrated Data Envelopment Analysis and Balanced Scorecard Approach. *International Journal of Business and Management*, 4 (4), 42-48.
- Eilat, H. G. (2006). Constructing and evaluating balanced portfolios of R&D projects with interactions: A DEA based methodology. *European Journal of Operational Research* (172), 1018–1039.
- Eilat, H. G. (2008). R&D project evaluation: an integrated DEA and balanced scorecard approach. *OMEGA international journal of management science* (36), 895 – 912.
- Eilat, H., Golany, B., & Shtub, A. (2006). Constructing and evaluating balanced portfolios of R&D projects with interactions: A DEA based methodology. *European Journal of Operational Research*, 172, 1018-1039.
- Evangelos L. Psomas, C. V. (2011). Core process management practices, quality tools and quality improvement in ISO 9001 certified manufacturing companies. *Business Process Management Journal*, 17 (3), 437 - 460.
- Explorations Unlimited, I. (2006). *Benchmarked Competitiveness Study of BC's Sea Urchin Fisheries*. Ottawa: Agriculture and Agri-food Canada.
- FAO. (2014). *The State of World Fisheries and Aquaculture*. Retrieved from <http://www.fao.org/docrep/013/i1820e/i1820e.pdf>
- Farrel, M. J. (1957). The Measurment of Productive Efficiency. *Journal of Royal Statistical Society*, 120 (3), 253-290.
- Fazli, S., & Rezaei, M. (2012). Identifying Significant Factors Affecting Decision Maker's Risk Attitudes in Multinational Construction Projects in Iran. *ournal of Basic and Applied Scientific Research (JBASR)*, II (12).

- Fernandes, K. J., Raja, V., & Whalley, A. (2006). Lessons from implementing the balanced scorecard in a small and medium size manufacturing organization. *Technovation*, 26 (5-6), 623-634.
- Fiallos, J. (2013). A Model for Performance Evaluation of Emergency Department Physician. Ottawa, ON, Canada.
- FinPa, N. M. (2009). *Key Performance Indicators*. Melbourn.
- Frei, F., & Harker, P. (1998). Projections Onto Efficient Frontiers: Theoretical and Computational Extensions to D.E.A. *THE WHARTON FINANCIAL INSTITUTIONS CENTER*, 18-21.
- Fu, X., Zhu, Q., & Sarkis, J. (2010). A Grey-DEMATEL Methodology for Green Supplier Development Program Evaluation. *GPMI Working Papers* (2010-15), 4.
- Garca Valderrama, T., Mulero Mendigorri, E., & Revuelta Bordoy, D. (2008). Relating the perspectives of the balanced scorecard for R&D by means of DEA. *European Journal of Operational Research*.
- Garcia, S., & Charles, A. (2008). Fishery Systems and Linkages: Implications for Science and Governance. *Ocean and Coastal Management* (51:), 505-527.
- Gardner Pinfold Consulting Economists Ltd. (2006). *Profile of the Atlantic Shrimp Industry*.
- Giokas, D. (2008). Assessing the efficiency in operations of a large Greek bank branch network adopting different economic behaviors. *Economic Modeling* (25), 559-574.
- Gislason, G. (1997). *The BC Fishing Fleet: Financial Returns*. Canada Fisheries and Ocean.
- Gislason, G. (2009). *The British Columbia Salmon Fleet financial Profile*. Canada Fisheries and Ocean.
- Gomes, J., & Romão, M. (2014). Advantages and limitations of performance measurement tool: The Balanced Scorecard. *PROCEEDINGS OF THE 7th IADIS INTERNATIONAL CONFERENCE INFORMATION SYSTEMS 2014 ISBN: 978-989-8704-04-7* (p. 5). Madrid, Spain: IADIS Press.
- Gomes, J., & Romão, M. (n.d.). *Advantages and Limitation of Performance Management Tools: Balanced Scorecard*. Retrieved 08 25, 2014, from academia.edu: [http://www.academia.edu/6284921/Advantages\\_and\\_Limitations\\_of\\_Performance\\_Measurement\\_Tools\\_the\\_Balanced\\_Scorecard](http://www.academia.edu/6284921/Advantages_and_Limitations_of_Performance_Measurement_Tools_the_Balanced_Scorecard)
- Gosselin, M. (2005). An empirical study of performance measurement in manufacturing firms. *International Journal of Productivity and Performance Management*, 54 (5/6), 419-437.

- Gulland, J. (1977). *Fish Population Dynamics*. New York: Wiley interscience.
- Hosseinzadeh, L., Sadjadi, S., Khaki, A., & Najafi, E. (2010). A combined Interval Net DEA and BSC for Evaluating Organizational Efficiency. *Applied Mathematical Sciences*, 4 (40), 1975-1999.
- <http://www.bankofcanada.ca/rates/related/inflation-calculator/>. (n.d.).
- Jedlicka, W. (1996). *Sustainable Graphic Design: Tools, Systems and strategies for Innovative Print Design*. United State of America.
- Kambewa, E. V. (2007). *Contracting for Sustainability An Analysis of the lake victoria-EU Nile perch Chain*. Netherlands: wageningen Academic Publisher.
- Kanji, G. &. (2001). Measuring Leadership Excellence. *Total Quality Management*, 12 (6), 709.
- Kaplan, R. S., & Norton, D. P. (2004). *Strategy Maps*. p. 66.
- Kaplan, R. S., & Norton, D. P. (1996). *Translating Strategy into Action*. Boston, MA: Harvard Business School Press.
- Kaplan, R., & Norton, D. (1996). *Using the balanced scorecard as a strategic management system*. Boston: Harvard Business Review.
- Kaplan, R., & Norton, D. P. (1992). The balanced Scorecard: measures that drive performance. *Harvard Business Review*, 71-90.
- Kennerley, M., & Neely, A. (2003). Measuring performance in a changing business environment. *International Journal of Operations & Production Management*, 23 (2), 213-229.
- Kim, C. S., & Davidson, L. F. (2004). The effects of IT expenditures on banks' business performance: Using a Balanced Scorecard approach. *Managerial Finance*, 30 (6), 28- 45.
- Knox Lovell, C. A., & Pastor, J. T. (1995). Units invariant and translation invariant DEA models. *Operations Research Letters* (18(3)), 147-151.
- Laguna, M., & Marklund, J. (2004). *Business Process Modeling, Simulation and Design*. Upper Saddle River: Prentice Hall.
- Laguna, M., & Marklund, J. (2004). *Business Process Modeling, Simulation And Design*. Prentice Hall.
- Laitinen, E. K. (2005). Microeconomic analysis of the balanced scorecard: a case of Nokia Corporation. *International Journal of Productivity and Performance Management* (54), 325-340.

Liu, S., & Lin, Y. (2006). *Grey Information Theory and Practical Applications*. London Limited: Springer-Verlag.

Liu, S., G. B., & Dang, Y. (1999). *Grey system Theory and applications*. Scientific Press.

Malina, M. a. (2001). Communicating and controlling strategy: An empirical study of the effectiveness of the balanced scorecard. *Journal of Management Accounting Research* (13), 48 - 90.

Ming, M. &. (2008). Efficiency and effectiveness in railway performance using multi-activity network DEA model. *International journal of management science Omega*, (36), 1005 – 1017.

Moore, R. (1966). *Interval Analysis*. Englewood Cliffs, NJ: Prentice-Hall.

Nørreklit, H. (2003). The Balanced Scorecard: What is the Score? A Rhetorical Analysis of the Balanced Scorecard. *Accounting, Organizations and Society*, 28 (6), 591-619.

Najafi, E., Aryanegad, M. B., Hosseinzadeh Lotfi, F., & Ebnerasoul, A. (2009). Efficiency and Effectiveness Rating of Organization with Combined DEA and BSC. *Applied Mathematical Science*, 3 (26), 1249-1264.

Nelson, S. (2007). *Pacific Commercial Fishing Fleet*.

Niven, P. R. (2001). *Balanced scorecard step by step maximizing performance and maintaining result*.

OECD. (2010). *Globalization in Fisheries and Aquaculture: Opportunities and Challenges*. Retrieved 08 12, 2014, from [http://www.oecd-ilibrary.org/agriculture-and-food/globalisation-in-fisheries-and-aquaculture\\_9789264074927-en](http://www.oecd-ilibrary.org/agriculture-and-food/globalisation-in-fisheries-and-aquaculture_9789264074927-en)

Olve N.G. Roy, J. W. (2000). *Performance Drivers: A Practical Guide to Using the Balanced Scorecard*. West Sussex.

Othman, R. (2009). *How Balanced Scorecard can fail: some caves*. Borneo Bulletin.

Othman, R., Ahmad Domil, A., Cheenik, Z., Abdullah, N., & Hamzah, N. (2006). A case study of balanced scorecard implementation in a Malaysian company. *Journal of Asia-Pacific Business*, 7 (2), 55-72.

Pascoe, S., & Mardle, S. (2003). *Efficiency analysis in EU fisheries: Stochastic Production Frontiers and Data Envelopment Analysis*. UK: University of Portsmouth Centre for the Economics and Management of Aquatic Resources (CEMARE).

Pascoe, S., Kirkley, J., Greboral, D., & Morrison, C. (2003). *Measuring and assessing capacity in fisheries*. Rom, Italy: FAO Fisheries Technical Paper.

Pascoe, S., Tingley, D., & Mardle, S. (2003). *Multi-output measures of technical efficiency in EU fisheries*. UK: University of Portsmouth Centre for the Economics and Management of Aquatic Resources (CEMARE).

Porter, M. e., & Kramer, M. (2011). Creating Shared Value. *Harward Business Review* .

Porter, M. e., & Kramer, M. (2011). Creating Shared Value. *Harward Business Review* .

Prajogo, D. I., & Sohal, A. S. (2004). "The Multidimensionality of TQM Practices in Determining Quality and Innovation Performance - An Empirical Examination. *Technovation* , 24 (6), 443-453.

(2006). *Results of the Costs and Earnings Survey for the Lobster Fishing Enterprises*. Fisheries and Ocean Canada Gulf Region.

Ricker, W. (1987). *Computation and Interpretation of Biological Statistics of Fish Populations*. Supply and Service Canada. Ottawa: Bulletin 191.

Rouse P, M. P. (2002). Integrated Performance Measurement Design: Insights from an Application in Aircraft Maintenance. *Management Accounting Research* , 13 (2), 229-248.

Schaefer, M. (1954). *Some Aspects of the Dynamics of Populations Important to the Management of the Commercial Marine Fisheries*. Bulletin of the Inter-American Tropical Tuna Commission.

Shen, S., Shen, Z., & Xu, B. (2013). Analysis of Fishery Production Efficiency based on the Three-Stage DEA. *JOURNAL OF NETWORKS* , 8 (2).

Tingley, D., Pascoe, S., & Caylan, L. (2005). Factors affecting technical efficiency in fisheries: stochastic production frontier versus data envelopment analysis approaches. *Fisheries Research* .

Tone, K. (2001). A slacks-based measure of efficiency in data envelopment analysis. *European Journal of Operational Research* , 508.

Tone, K. (2001). Slacks-based measure of efficiency in data envelopment analysis. *European Journal of Operational Research* (130(3)), 498-509.

Van Ours, J. C., & Vermeulen, F. (2007). Ranking Dutch economists. *De Economist* , 155 (4), 469-487.

William W. Cooper, L. M. (2007). *Data Envelopment Analysis* (2nd ed.). New York, NY, USA: Springer Science+Business Media, LLC .

World Commission on Environment and Development. (1987). *Our Common Future*. Oxford: Oxford University Press.

Ziegenfuss, D. E. (2000). Developing an internal auditing department balanced scorecard. *Managerial Auditing Journal*, 15 (1/2), 12-19.

## Appendix A

### A. Database

This part of our illustrative database contains available data for the selected fleet and their KPIs as indexes of DEA. All the data used for the illustrative database presented in appendix A.1 and A.2 are extracted from (Gislason, The BC Fishing Fleet: Financial Returns, 1997) (Gislason, The British Columbia Salmon Fleet financial Profile, 2009) (Results of the Costs and Earnings Survey for the Lobster Fishing Enterprises, 2006) (Nelson, 2007) (Costs and Earning Survey , 2006) (Gardner Pinfold Consulting Economists Ltd, 2006).

#### A.1 KPIs and Inputs/Outputs

This table expresses the number of KPIs with their categories as inputs and outputs. The table presents the data in terms of the DMUs ( left hand side), by region (Atlantic and Pacific), and year of study.

A.1 KPIs and Inputs/Outputs Data

	BC 1991				BC 1994				Pacific Fleet 2007				BC 2009			
	KPI	Input	KPI	Output	KPI	Input	KPI	Output	KPI	Input	KPI	Output	KPI	Input	KPI	Output
Salmon Seine	1	78,480	2	0.4122	1	94,610	2	0.7299	1	74,237	3	6982289	1	10,562	2	0.1781
	5	44.21252372	3	20880	5	130.7086614	3	59340	6	0.3114	12	15,000	6	0.651202749	3	1628
	13	0.1787	17	0.4431	13	0.8795	17	0.2657	9	0.3307	17	0.48087	9	0.7272	14	414.9714286
	15	0.0874			15	0.0727			11	5,776			11	18	17	0.42
									15	0.099			15	0.1371		
Salmon Gillnet	BC 1991				BC 1994				Pacific Fleet 2007				BC 2009			
	KPI	Input	KPI	Output	KPI	Input	KPI	Output	KPI	Input	KPI	Output	KPI	Input	KPI	Output
	1	39,860	2	0.3338	1	55,830	2	0.5643	1	13,747	3	4299979	1	8,139	2	0.049987908
	5	21.53752288	3	16170	5	14.65940054	3	30260	6	0.8321	12	5,000	6	0.760485651	3	-482
	13	0.5873	17	0.0898	13	0.3685	17	0.11	9	0.8956			9	4.1272	14	58
15	0.1585			15	0.156			11	999			15	0.2295	17	0.298258345	
								15	0.3272							
Salmon Troll	BC 1991				BC 1994				Pacific Fleet 2007				BC 2009			
	KPI	Input	KPI	Output	KPI	Input	KPI	Output	KPI	Input	KPI	Output	KPI	Input	KPI	Output
	1	55,350	2	0.5422	1	63,840	2	0.7214	1	30,273	3	7075011	1	8,292	2	0.0138
	5	15.28089888	3	24140	5	18.80492091	3	36660	6	2.6838	12	7,500	6	0.3006	3	2165
	13	0.2853	17	0.1774	13	0.2675	17	0.2018	9	2.1764	17	0.1871	9	4.869	14	23.65277778
15	0.1396			15	0.106			11	903			11	72	17	0.41354	
								15	0.1944			15	0.1915			

	BC 1991				BC 1994				Pacific Fleet 2007				Gulf Lobster 2004				
	KPI	Input	KPI	Output	KPI	Input	KPI	Output	KPI	Input	KPI	Output	KPI	Input	KPI	Output	
Herring Seine	1	27,050	2	0.3497	1	32,570	2	0.4582	1	43,136	3	3066506	1	49,761	3	34752	
	5	40.99378882	3	15400	5	129.4117647	3	36660	6	0.4625	17	0.45	15	0.2246	17	0.2713	
	13	0.0906	17	0.2711	13	0.3464	17	0.2747	9	0.3443							
	15	0.0651			15	0.0347			11	8,560							
									15	0.139							
Groundfish Trawl	1	46,980	2	1.7311	1	50,590	2	1.1142	1	628,847	3	23064563					
	5	151.8518519	3	17280	5	130.0884956	3	18080	6	0.48	12	108,333					
	6	0.69	17	0.2789	6	0.69	17	0.3033	9	0.4086	17	0.3252					
	9	0.581298952			9	0.591004673			11	52,220							
	13	1.6565			13	0.8963			15	0.2836							
	15	0.1635			15	0.1411											
Crab Trap	1	8,240	2	0.8591	1	23,020	2	1.2335	1	122,364	3	22552870	1	55,577	3	39946	
	5	9.433962264	3	2880	5	30.37383178	3	9470	6	2.4497	17	0.261	15	0.229	17	0.3147	
	13	0.2941	17	0.1587	13	0.5039	17	0.2553	9	1.8528							
	15	0.1468			15	0.1186			11	3,624							
									15	0.2207							
		NL/35-64/2004				NL/35-64/2J3KI/2006											
		KPI	Input	KPI	Output	KPI	Input	KPI	Output								
		1	158578	3	39590	1	276342	3	-40015								
		6	5.37	12	3036	6	2.29	12	22380								
		9	4.87722212	14	637.5294118	9	4.314987895	14	1392.225176								
		10	0.001759387	17	0.632816394	10	0.010298833	17	0.757829493								
		15	0.063911766			15	0.211553076										
Shrimp		NL/35-64/2004				NL/35-64/4R/2006											
		KPI	Input	KPI	Output	KPI	Input	KPI	Output								
		1	245706	3	99043	1	227232	3	62289								
		6	1	12	10446	6	0.81	12	8756								
		9	0.853424382	14	5141.178571	9	0.847263922	14	5706.277915								
		10	0.002763465	17	0.427202417	10	0.004761653	17	0.431144643								
	15	0.193532107			15	0.24815607											

## A.2 Inputs and Outputs

This table presents the data shown in A.1 with fleet's inputs and outputs that are used in DEA models for evaluation as extracted from the Atlantic and Pacific commercial fishing fleets reports in 1991, 1994, 2004, 2006, and 2009. As can be seen in the table, the white cells are the missing data. Associated indices cannot be used for evaluation in the DEA models.

### A.2 Inputs and Outputs Data

1991	Input 1(1)	Input 2(5)	Input 3(13)	Input 4(15)	Output 1(2)	Output 2(3)	Output 3(17)
SS	78,480	44.21252372	0.1787	0.0874	0.4122	20880	0.4431
SG	39,860	21.53752288	0.5873	0.1585	0.3338	16170	0.0898
ST	55,350	15.28089888	0.2853	0.1396	0.5422	24140	0.1774
HS	27,050	40.99378882	0.0906	0.0651	0.3497	15400	0.2711
GT	46,980	151.8518519	1.6565	0.1635	1.7311	17280	0.2789
CT	8,240	9.433962264	0.2941	0.1468	0.8591	2880	0.1587

1994	Input 1(1)	Input 2(5)	Input 3(13)	Input 4(15)	Output 1(2)	Output 2(3)	Output 3(17)
SS	94,610	130.7086614	0.8795	0.0727	0.7299	59340	0.2657
SG	55,830	14.65940054	0.3685	0.156	0.5643	30260	0.11
ST	63,840	18.80492091	0.2675	0.106	0.7214	36660	0.2018
HS	32,570	129.4117647	0.3464	0.0347	0.4582	36660	0.2747
GT	50,590	130.0884956	0.8963	0.1411	1.1142	18080	0.3033
CT	23,020	30.37383178	0.5039	0.1186	1.2335	9470	0.2553

2007	Input 1(1)	Input 2(6)	Input 3(9)	Input 4(11)	Input 5(15)	Output 1(3)	Output 2(12)	Output 3(17)
SS	74,237	0.3114	0.3307	5,776	0.099	6982289	15,000	0.48087
SG	13,747	0.8321	0.8956	999	0.3272	4299979	5,000	
ST	30,273	2.6838	2.1764	903	0.1944	7075011	7,500	0.1871
HS	43,136	0.4625	0.3443	8,560	0.139	3066506	-	0.45
GT	628,847	0.48	0.4086	52,220	0.2836	23064563	108,333	0.3252
CT	122,364	2.4497	1.8528	3,624	0.2207	22552870	-	0.261

2009	Input 1(1)	Input 2(6)	Input 3(9)	Input 4(11)	Input 5(15)	Output 1(2)	Output 2(13)	Output 3(14)	Output 4(17)
SS	10,562	0.651202749	0.7272	18	0.1371	0.1781	1628	414.9714286	0.42
SG	8,139	0.760485651	4.1272	45	0.2295	0.049987908	-482	58	0.298258345
ST	8,292	0.3006	4.869	72	0.1915	0.0138	2165	23.65277778	0.41354

GL 2004	Input 1(1)	Input 2(5)	Input 3(9)	Input 4(15)	Output 2(3)	Output 3(17)
HS	49,761	-	-	0.2246	34752	0.2713
CT	55,577	-	-	0.229	39946	0.3147
L	43,706	5.55	2.670536478	0.1934	222811	0.291

NL/35-64/2004	Input 1(1)	Input 2(6)	Input 3(9)	Input 4(10)	Input 5(15)	Output 1(3)	Output 2(12)	Output 3(14)	Output 4(17)
CT	158578	5.37	4.87722212	0.001759387	0.063911766	39590	3036	637.5294118	0.632816394
S	245706	1	0.853424382	0.002763465	0.193532107	99043	10446	5141.178571	0.427202417

NL/35-64/2006	Input 1(1)	Input 2(6)	Input 3(9)	Input 4(10)	Input 5(15)	Output 1(3)	Output 2(12)	Output 3(14)	Output 4(17)
CT(2J3KI)	276342	2.29	4.314987895	0.010298833	0.211553076	-40015	22380	1392.225176	0.757829493
S(4R)	227232	0.81	0.847263922	0.004761653	0.24815607	62289	8756	5706.277915	0.431144643

## Appendix B

### B. All inclusive Results

This appendix contains the numerical example results that presented in chapter 4 section 4.2.

#### B.1 Efficiency Scores

DEA would calculate an efficiency score for each DMU according to their weighted outputs and inputs. In this study we applied SBM model with variable return of scale because the relationship between inputs and outputs were not constant and variable return to scale would cover constant return to scale as well. According to the Slack Base Model formula presented in section 3.3.2.1, the results of objective function are shown in Appendix B.1, as well as references and lambdas that are described further below.

Reference DMUs will serve as benchmarks for each evaluated DMU. Improvement information for each input and output and scores under each group provide a reference to define priorities of performance improvement. In addition to the performance score, DEA also identifies benchmark DMUs that serve as reference for each underperforming DMU, determining the practice modifications required for achieving benchmark performance. Efficient DMUs define the efficient frontier that forms a reference of best performance. Inefficient DMUs are projected onto the efficient frontier to enable their comparison relative to efficient ones with similar profits in terms of Input-Output mix.

Appendix B.1 illustrates DMUs with their efficiency scores, ranks, their reference set, and also the lambda value. As can be seen in this table, DMUs that have score 1 are efficient thereafter, their lambdas are 1 and they are their own reference as well. However, DMUs with lower efficiency scores are defined as inefficient DMUs and their reference DMU would be the nearest efficient DMU on the efficiency frontier. For example, Salmon Seine (SS 91) as our first DMU is inefficient because its efficiency score is lower than 1 ( $7.42E-03$ ) and its reference set has three different reference DMUs (ST 2009 with  $2.52E-02$  lambda, HS 94 with  $0.712704199$  lambda, and CT 2007 with  $0.262121009$  lambda) that are all efficient and are a set that this DMU should improve its performance with the reference of their locations on the efficiency frontier.

## B.1. Efficiency Scores

No.	DMU	Score	Rank	Reference set ( $\lambda$ )					
1	SS 91	8.04E-03	17	SS 2007	0.816877556	HS 94	0.182170938	CT 2007	9.42E-04
2	SS 94	2.42E-02	14	HS 94	0.795687059	CT 2007	0.204302941		
3	SS 2007	1	1	SS 2007	1				
4	SS 2009	1	1	SS 2009	1				
5	SG 91	4.56E-03	25	SS 2009	0.551567092	HS 94	8.65E-02	CT 2007	0.361934821
6	SG 94	6.61E-03	19	SS 2009	0.284080375	HS 94	0.220154159	CT 2007	0.495755466
7	SG 2007	1	1	SG 2007	1				
8	SG 2009	0.999687832	11	SG 2009	0.999458039	ST 2009	5.32E-04		
9	ST 91	5.87E-03	22	SS 2009	0.171428552	HS 94	0.358958957	CT 2007	0.469602491
10	ST 94	1.03E-02	15	HS 94	0.616654801	CT 2007	0.383335199		
11	ST 2007	1	1	ST 2007	1				
12	ST 2009	1	1	ST 2009	1				
13	HS 91	3.42E-02	13	SS 2009	0.251940599	HS 94	0.723309457	CT 2007	2.47E-02
14	HS 94	1	1	HS 94	1				
15	HS 2007	0.722927908	12	SS 2007	0.507062511	SS 2009	0.489284169	CT 2007	3.65E-03
16	HS GL 2004	0.006420792	21	SS 2009	0.618331006	CT 2007	0.381658994		
17	GT 91	4.20E-03	26	SS 2009	0.45391567	HS 94	0.103497005	CT 2007	0.442577325
18	GT 94	4.71E-03	24	SS 2009	0.290060491	HS 94	0.297573849	CT 2007	0.41235566
19	GT 2007	1	1	GT 2007	1				
20	CT 91	2.96E-03	27	SS 2009	0.824463942	ST 2007	0.052673608	ST 2009	0.12285245
21	CT 94	6.50E-03	20	SS 2009	0.636297284	HS 94	0.262921183	CT 2007	0.100771533
22	CT 2007	1	1	CT 2007	1				
23	CT GL 2004	6.67E-03	18	SS 2009	0.562965537	CT 2007	0.437024463		
24	CT NL/35-64/2004	1	1	CT NL/35-64/2004	1				
25	CT NL/35-64/2006	1	1	CT NL/35-64/2006	1				
26	SH NL/35-64/2004	9.64E-03	16	SS 2007	0.755912207	CT 2007	0.244087793		
27	SH NL/35-64/2006	5.28E-03	23	SS 2007	0.773842012	CT 2007	0.226157988		

## B.2 Slacks

DEA computed Slack is the amount for improvement. Thus, only the inefficient DMUs have slacks. The original value of inputs or outputs plus slack equals the Target for improving the DMU. Slack contains the Input excesses  $s^-$  and Output shortfalls  $s^+$  for each DMU. In the SBM (Slacks-based measure),  $s^-$  and  $s^+$  are defined via 2.2.2.2.4 section, and they indicate the total slacks of the concerned DMU.

Appendix B.2 presents all DMUs with their scores as well as their excesses of inputs and shortage of their outputs. As an example, the first DMU (SS 91) with 8.04E-03 score is inefficient and its first input excess is 38029.46325 which means that it must decrease its Input 1 by this amount and also increase its Output 1 by 5843073.031 as defined slack however, Input 2 and Output 2 have zero slack as  $s^-$  and  $s^+$ .

B.2. Slacks

No.	DMU	Score	Excess	Excess	Shortage	Shortage
			I1 (KPI: 1)	I2 (KPI: 15)	O1 (KPI: 3)	O2 (KPI: 17)
			S-(1)	S-(2)	S+(1)	S+(2)
1	SS 91	8.04E-03	38029.46325	0	5843073.031	0
2	SS 94	2.42E-02	66337.98883	0	4678314.793	6.20E-03
3	SS 2007	1	0	0	0	0
4	SS 2009	1	0	0	0	0
5	SG 91	4.56E-03	0	0	9675974.044	0.259761274
6	SG 94	6.61E-03	0	0	12107908.3	0.19901738
7	SG 2007	1	0	0	0	0
8	SG 2009	0.999687832	0	2.25E-05	492.5108583	5.83E-05
9	ST 91	5.87E-03	0	0	11245322.31	0.115672757
10	ST 94	1.03E-02	10524.77512	0	8834913.631	6.76E-02
11	ST 2007	1	0	0	0	0
12	ST 2009	1	0	0	0	0
13	HS 91	3.42E-02	0	0	1195263.346	3.97E-02
14	HS 94	1	0	0	0	0
15	HS 2007	0.722927908	0	2.09E-02	1753630.515	0
16	HS GL 2004	0.006420792	0	5.56E-02	10273162.91	8.77E-02

<b>17</b>	GT 91	4.20E-03	0	0	11301564.43	5.54E-02
<b>18</b>	GT 94	4.71E-03	0	0	10216229.81	7.73E-03
<b>19</b>	GT 2007	1	0	0	0	0
<b>20</b>	CT 91	2.96E-03	0	0	2672641.697	0.247755909
<b>21</b>	CT 94	6.50E-03	0	0	3867289.65	0.110101324
<b>22</b>	CT 2007	1	0	0	0	0
<b>23</b>	CT GL 2004	6.67E-03	0	5.54E-02	11412278.08	3.55E-02
<b>24</b>	CT NL/35-64/2004	1	0	0	0	0
<b>25</b>	CT NL/35-64/2006	1	0	0	0	0
<b>26</b>	SH NL/35-64/2004	9.64E-03	180347.5037	0.064826623	10934629.44	0
<b>27</b>	SH NL/35-64/2006	5.28E-03	150632.4138	0.121632642	10691726.99	0

### B.3 Projection

The DMU  $(x_o, y_o)$  can be improved and becomes efficient by deleting the input excesses and augmenting the output shortfalls. Appendix B.3 presents a projection Table regarding to each index. As can be seen the first column is number of DMUs, the second is the name of DMU and also its Inputs and Outputs with their identities. Furthermore, there are efficiency scores for DMUs and real values for each Index as well as projections or improvements for each index, the differences between the improvements and real values and the percentage of projections which can be useful to understand the amount of required increase or decrease for each Input and Output.

In this table for each input and output if the data and projection column had the same amount, the difference column would be zero as well as its percentage, which means that there is no need to improve that specific index. However, the negative values in difference and percentage columns reflect the necessary decreases for inputs of a DMU to become efficient. Also the positive values would mean in the same way for outputs.

B.3 Inefficient DMU Projection Results

No	DMU	Score	Projection	Difference	%
1	I/O	Data			
	SS 91	8.04E-03			
	I1 (KPI: 1)	108192.98	70163.5167 5	- 38029.46325	-35.15%
	I2 (KPI: 15)	0.0874	0.0874	0	0.00%
	O1 (KPI: 3)	28785.29	5871858.32 1	5843073.031	999.90 %
	O2 (KPI: 17)	0.4431	0.4431	0	0.00%
2	SS 94	2.42E-02			
	I1 (KPI: 1)	126625.05	60287.0611 7	- 66337.98883	-52.39%
	I2 (KPI: 15)	0.0727	0.0727	0	0.00%
	O1 (KPI: 3)	79420.05	4757734.84 3	4678314.793	999.90 %
	O2 (KPI: 17)	0.2657	0.27189830 3	6.20E-03	2.33%
3	SS 2007	1			
	I1 (KPI: 1)	76026.64	76026.64	0	0.00%

	I2 (KPI: 15)	0.099	0.099	0	0.00%
	O1 (KPI: 3)	7150612.04	7150612.04	0	0.00%
	O2 (KPI: 17)	0.48087	0.48087	0	0.00%
<b>4</b>	SS 2009	1			
	I1 (KPI: 1)	10562	10562	0	0.00%
	I2 (KPI: 15)	0.1371	0.1371	0	0.00%
	O1 (KPI: 3)	2419605.79 3	2419605.79 3	0	0.00%
	O2 (KPI: 17)	0.41941952 5	0.41941952 5	0	0.00%
<b>5</b>	SG 91	4.56E-03			
	I1 (KPI: 1)	54951.23	54951.23	0	0.00%
	I2 (KPI: 15)	0.1585	0.1585	0	0.00%
	O1 (KPI: 3)	22292.06	9698266.10 4	9675974.044	999.90 %
	O2 (KPI: 17)	0.0898	0.34956127 4	0.259761274	289.27 %
<b>6</b>	SG 94	6.61E-03			
	I1 (KPI: 1)	74722.3	74722.3	0	0.00%
	I2 (KPI: 15)	0.156	0.156	0	0.00%
	O1 (KPI: 3)	40499.67	12148407.9 7	12107908.3	999.90 %
	O2 (KPI: 17)	0.11	0.30901738	0.19901738	180.92 %
<b>7</b>	SG 2007	1			
	I1 (KPI: 1)	14078.4	14078.4	0	0.00%
	I2 (KPI: 15)	0.3272	0.3272	0	0.00%
	O1 (KPI: 3)	4403639.21	4403639.21	0	0.00%
	O2 (KPI: 17)	0.1660194	0.1660194	0	0.00%
<b>8</b>	SG 2009	0.99968783 2			
	I1 (KPI: 1)	8139	8139	0	0.00%
	I2 (KPI: 15)	0.2295	0.22947749	-2.25E-05	-0.01%
	O1 (KPI: 3)	1488810.31 3	1489302.82 4	492.5108583	0.03%
	O2 (KPI: 17)	0.29825834 5	0.29831668 8	5.83E-05	0.02%
<b>9</b>	ST 91	5.87E-03			
	I1 (KPI: 1)	76305.83	76305.83	0	0.00%
	I2 (KPI: 15)	0.1396	0.1396	0	0.00%
	O1 (KPI: 3)	33279.54	11278601.8 5	11245322.31	999.90 %
	O2 (KPI: 17)	0.1774	0.29307275 7	0.115672757	65.20%
<b>10</b>	ST 94	1.03E-02			

	I1 (KPI: 1)	85442.8	74918.0248 8	- 10524.77512	-12.32%
	I2 (KPI: 15)	0.106	0.106	0	0.00%
	O1 (KPI: 3)	49065.37	8883979.00 1	8834913.631	999.90 %
	O2 (KPI: 17)	0.2018	0.26944556 1	6.76E-02	33.52%
<b>11</b>	ST 2007	1			
	I1 (KPI: 1)	31002.8	31002.8	0	0.00%
	I2 (KPI: 15)	0.1944	0.1944	0	0.00%
	O1 (KPI: 3)	7245569.3	7245569.3	0	0.00%
	O2 (KPI: 17)	0.1871	0.1871	0	0.00%
<b>12</b>	ST 2009	1			
	I1 (KPI: 1)	8292	8292	0	0.00%
	I2 (KPI: 15)	0.1915	0.1915	0	0.00%
	O1 (KPI: 3)	2442638.07	2442638.07	0	0.00%
	O2 (KPI: 17)	0.41354	0.41354	0	0.00%
<b>13</b>	HS 91	3.42E-02			
	I1 (KPI: 1)	37291.29	37291.29	0	0.00%
	I2 (KPI: 15)	0.0651	6.51E-02	0	0.00%
	O1 (KPI: 3)	21230.53	1216493.87 6	1195263.346	999.90 %
	O2 (KPI: 17)	0.2711	0.31081904	3.97E-02	14.65%
<b>14</b>	HS 94	1			
	I1 (KPI: 1)	43591.35	43591.35	0	0.00%
	I2 (KPI: 15)	0.0347	0.0347	0	0.00%
	O1 (KPI: 3)	49065.37	49065.37	0	0.00%
	O2 (KPI: 17)	0.2747	0.2747	0	0.00%
<b>15</b>	HS 2007	0.72292790 8			
	I1 (KPI: 1)	44175.89	44175.89	0	0.00%
	I2 (KPI: 15)	0.139	0.11808633 6	-2.09E-02	-15.05%
	O1 (KPI: 3)	3140430.7	4894061.21 5	1753630.515	55.84%
	O2 (KPI: 17)	0.45	0.45	0	0.00%
<b>16</b>	HS GL 2004	0.00642079 2			
	I1 (KPI: 1)	54357.97	54357.97	0	0.00%
	I2 (KPI: 15)	0.2246	0.16900532 1	-5.56E-02	-24.75%
	O1 (KPI: 3)	37962.42	10311125.3 3	10273162.91	999.90 %
	O2 (KPI: 17)	0.2713	0.35895309 4	8.77E-02	32.31%

<b>17</b>	GT 91	4.20E-03			
	I1 (KPI: 1)	64766.9	64766.9	0	0.00%
	I2 (KPI: 15)	0.1635	0.1635	0	0.00%
	O1 (KPI: 3)	23822.31	11325386.7 4	11301564.43	999.90 %
	O2 (KPI: 17)	0.2789	0.33432440 4	5.54E-02	19.87%
<b>18</b>	GT 94	4.71E-03			
	I1 (KPI: 1)	67709.14	67709.14	0	0.00%
	I2 (KPI: 15)	0.1411	0.1411	0	0.00%
	O1 (KPI: 3)	24198.09	10240427.9	10216229.81	999.90 %
	O2 (KPI: 17)	0.3033	0.31102539 7	7.73E-03	2.55%
<b>19</b>	GT 2007	1			
	I1 (KPI: 1)	644006.7	644006.7	0	0.00%
	I2 (KPI: 15)	0.2836	0.2836	0	0.00%
	O1 (KPI: 3)	23620583.7 2	23620583.7 2	0	0.00%
	O2 (KPI: 17)	0.3252	0.3252	0	0.00%
<b>20</b>	CT 91	2.96E-03			
	I1 (KPI: 1)	11359.71	11359.71	0	0.00%
	I2 (KPI: 15)	0.1468	0.1468	0	0.00%
	O1 (KPI: 3)	3970.38	2676612.07 7	2672641.697	999.90 %
	O2 (KPI: 17)	0.1587	0.40645590 9	0.247755909	156.12 %
<b>21</b>	CT 94	6.50E-03			
	I1 (KPI: 1)	30809.73	30809.73	0	0.00%
	I2 (KPI: 15)	0.1186	0.1186	0	0.00%
	O1 (KPI: 3)	12674.55	3879964.2	3867289.65	999.90 %
	O2 (KPI: 17)	0.2553	0.36540132 4	0.110101324	43.13%
<b>22</b>	CT 2007	1			
	I1 (KPI: 1)	125313.85	125313.85	0	0.00%
	I2 (KPI: 15)	0.2207	0.2207	0	0.00%
	O1 (KPI: 3)	23096555.2 6	23096555.2 6	0	0.00%
	O2 (KPI: 17)	0.261	0.261	0	0.00%
<b>23</b>	CT GL 2004	6.67E-03			
	I1 (KPI: 1)	60711.26	60711.26	0	0.00%
	I2 (KPI: 15)	0.229	0.17363387 4	-5.54E-02	-24.18%
	O1 (KPI: 3)	43636.25	11455914.3 3	11412278.08	999.90 %

	O2 (KPI: 17)	0.3147	0.35018212 3	3.55E-02	11.27%
<b>24</b>	CT NL/35-64/2004	1			
	I1 (KPI: 1)	173227.59	173227.59	0	0.00%
	I2 (KPI: 15)	6.39E-02	6.39E-02	0	0.00%
	O1 (KPI: 3)	43247.36	43247.36	0	0.00%
	O2 (KPI: 17)	0.63281639 4	0.63281639 4	0	0.00%
<b>25</b>	CT NL/35-64/2006	1			
	I1 (KPI: 1)	289200.98	289200.98	0	0.00%
	I2 (KPI: 15)	0.21155307 6	0.21155307 6	0	0.00%
	O1 (KPI: 3)	0.1	0.1	0	0.00%
	O2 (KPI: 17)	0.75782949 3	0.75782949 3	0	0.00%
<b>26</b>	SH NL/35-64/2004	9.64E-03			
	I1 (KPI: 1)	268404.55	88057.0463 3	- 180347.5037	-67.19%
	I2 (KPI: 15)	0.19353210 7	0.12870548 4	- 0.064826623	-33.50%
	O1 (KPI: 3)	108192.69	11042822.1 3	10934629.44	999.90 %
	O2 (KPI: 17)	0.42720241 7	0.42720241 7	0	0.00%
<b>27</b>	SH NL/35-64/2006	5.28E-03			
	I1 (KPI: 1)	237805.75	87173.3362 4	- 150632.4138	-63.34%
	I2 (KPI: 15)	0.24815607	0.12652342 7	- 0.121632642	-49.01%
	O1 (KPI: 3)	65187.48	10756914.4 7	10691726.99	999.90 %
	O2 (KPI: 17)	0.43114464 3	0.43114464 3	0	0.00%

## B.4 weights

Variables represented by  $v$  and  $u$  are the weights to be calculated for each of the ( $m$ ) inputs ( $X$ ) and outputs ( $Y$ ). Given the nature of DEA models, which assign the most favorable weights to inputs and outputs for each DMU in order to maximize its score, some DMUs will attain a high score a very good performance in a single input or output. These weights, derived from the data are the optimal set of weights each DMU can have in order to generate the best possible performance score.

Optimal weights  $v(i)$  and  $u(i)$  for Inputs and Outputs are exhibited in Appendix B.4,  $v(0)$  Corresponds to the constraints  $\sum_j^n \lambda_j \geq l$  and  $u(0)$  to  $\sum_j^n \lambda_j \leq u$ . Therefore, the indexes that need improvement would not get weight because they are not strong on those indexes and DEA will not put any weights on them to make the DMUs efficient.

B.4 weights

No.	DMU	Score	V (1) (KPI: 1)	V (2) (KPI: 15)	U (1) (KPI: 3)	U (2) (KPI: 17)
1	SS 91	8.04E-03	0	15.22948529	0	0.665215622
2	SS 94	2.42E-02	0	17.16087046	0	4.56E-02
3	SS 2007	1	0	5.050505051	0	13.40745537
4	SS 2009	1	4.73E-05	3.646973012	0	1.192123805
5	SG 91	4.56E-03	1.35E-05	6.745073899	0	2.54E-02
6	SG 94	6.61E-03	1.07E-05	5.390136816	0	3.00E-02
7	SG 2007	1	1.97E-03	1.528117359	0	3.011696223
8	SG 2009	0.999687832	3.90E-03	2.178649237	0	1.675875709
9	ST 91	5.87E-03	1.16E-05	5.819281214	0	1.66E-02
10	ST 94	1.03E-02	0	10.41986825	0	2.55E-02
11	ST 2007	1	1.11E-04	2.572016461	0	2.672367718
12	ST 2009	1	6.28E-05	2.610966057	0	1.533175557
13	HS 91	3.42E-02	1.06E-04	53.08330542	0	6.31E-02
14	HS 94	1	4.05E-04	1884.817779	1.02E-05	300.5519967
15	HS 2007	0.722927908	1.35E-05	3.597122302	0	3.323324164
16	HS GL 2004	0.006420792	1.36E-05	2.226179875	0	1.18E-02
17	GT 91	4.20E-03	1.16E-05	5.801791005	0	7.52E-03
18	GT 94	4.71E-03	1.29E-05	6.416681722	0	7.77E-03
19	GT 2007	1	0	1.763046544	0	1.537515375
20	CT 91	2.96E-03	7.82E-05	3.41897906	0	9.31E-03

<b>21</b>	CT 94	6.50E-03	3.39E-05	16.89158527	0	1.27E-02
<b>22</b>	CT 2007	1	0	6.101868061	0	10.98056724
<b>23</b>	CT GL 2004	6.67E-03	1.22E-05	2.183406114	0	1.06E-02
<b>24</b>	CT NL/35-64/2004	1	0	1634.836728	1.16E-05	165.1115602
<b>25</b>	CT NL/35-64/2006	1	2.82E-04	4704.797412	1.26E-04	5861.807927
<b>26</b>	SH NL/35-64/2004	9.64E-03	0	2.583550639	0	1.381907962
<b>27</b>	SH NL/35-64/2006	5.28E-03	0	2.014861054	0	1.350131465

## Appendix C

### C. Salmon Analysis

This appendix shows the results of Salmon analysis presented in chapter 4, section 4.3.

#### C.1 Efficiency Scores

Appendix C.1 contains the DEA-score, reference set, Lambda value for each DMU in the reference set and ranking in input and in the descending order of efficiency scores. In this Table is shown that DMUs SS91, SS94, SS 2007, SS 2009, SG 2007, SG 2009, ST 94, ST 2007, and ST 2009 are efficient (Score=1) and DMUs SG 91 (Score=8.56E-03), SG 94 (Score=2.54E-02), and ST 91 (Score= 0.019045471) are inefficient. Also the reference set for sample inefficient DMU like SG 91 compose of SS 2007 ( $\lambda_{SS\ 2007} = 0.376289895$ ) and ST 2007 ( $\lambda_{ST\ 2007} = 0.623700105$ ).

C.1 Efficiency Scores

No.	DMU	Score	Rank	Reference set (lambda)					
1	SS 91	1	1	SS 91	1				
2	SS 94	1	1	SS 94	1				
3	SS 2007	1	1	SS 2007	1				
4	SS 2009	1	1	SS 2009	1				
5	SG 91	8.56E-03	12	SS 2007	0.376289895	ST 2007	0.623700105		
6	SG 94	2.54E-02	10	SS 2007	0.429571133	ST 94	0.447805989	ST 2007	0.122622878
7	SG 2007	1	1	SG 2007	1				
8	SG 2009	1	1	SG 2009	0.999875933				
9	ST 91	0.019045471	11	SS 2007	0.562923046	ST 94	0.366606775	ST 2007	7.05E-02
10	ST 94	1	1	ST 94	1				
11	ST 2007	1	1	ST 2007	1				
12	ST 2009	1	1	ST 2009	1				

## C.2 Slacks

DEA computed Slack is the amount for improvement. Thus, only the inefficient DMUs have slacks. The original value of inputs or outputs plus slack equals the Target for improving the DMU. Slack contains the Input excesses  $s^-$  and Output shortfalls  $s^+$  for each DMU. In the SBM (Slacks-based measure),  $s^-$  and  $s^+$  are defined via 2.2.2.2.4 section, and they indicate the total slacks of the concerned DMU.

Appendix C.2 presents all DMUs with their scores as well as their excesses of inputs and shortage of their outputs. As an example, the fifth DMU (SG 91) with 8.56E-03 score is inefficient and its first input excess is 7006.723994 which means that it must decrease its Input 1 by this amount and also increase its Output 1, 2, and 3 by 9.74E-02, 7187473.327, 0.207840812 as defined slack however, Input 2 and Output 2 have zero slack as  $s^-$  and  $s^+$ .

C.2 Slacks

No.	DMU	Score	Excess	Excess	Shortage	Shortage	Shortage
			Input1 (KPI: 1)	Input2 (KPI: 15)	Output1 (KPI: 2)	Output2 (KPI: 3)	Output3 (KPI: 17)
			S-(1)	S-(2)	S+(1)	S+(2)	S+(3)
1	SS 91	1	0	0	0	0	0
2	SS 94	1	0	0	0	0	0
3	SS 2007	1	0	0	0	0	0
4	SS 2009	1	0	0	0	0	0
5	SG 91	8.56E-03	7006.723994	0	9.74E-02	7187473.327	0.207840812
6	SG 94	2.54E-02	0	4.22E-02	0	3941641.171	0.20987786
7	SG 2007	1	0	0	0	0	0
8	SG 2009	1	0	0	0	90.88363693	1.03E-05
9	ST 91	0.019045471	0	0.031310898	0	4520549.034	0.180459023
10	ST 94	1	0	0	0	0	0
11	ST 2007	1	0	0	0	0	0
12	ST 2009	1	0	0	0	0	0

### C.3 Projections

The DMU  $(x_o, y_o)$  can be improved and becomes efficient by deleting the input excesses and augmenting the output shortfalls. Appendix B.3 presents a projection Table regarding to each index. As can be seen the first column is number of DMUs, the second is the name of DMU and also its Inputs and Outputs with their identities. Furthermore, there are efficiency scores for DMUs and real values for each Index as well as projections or improvements for each index, the differences between the improvements and real values and the percentage of projections which can be useful to understand the amount of required increase or decrease for each Input and Output.

To simplify this table we omitted efficient DMUs with zero percentage. The negative values in difference and percentage columns reflect the necessary decreases for inputs of a DMU to become efficient. Also the positive values would mean in the same way for outputs.

C.3 Inefficient DMU Projection Results

No.	DMU	Score			
	I/O	Data	Projection	Difference	%
<b>5</b>	SG 91	8.56E-03			
	Input1 (KPI: 1)	54951.23	47944.50601	-7006.723994	-12.75%
	Input2 (KPI: 15)	0.1585	0.1585	0	0.00%
	Output1 (KPI: 2)	0.3338	0.431164146	9.74E-02	29.17%
	Output2 (KPI: 3)	22292.06	7209765.387	7187473.327	999.90%
	Output3 (KPI: 17)	0.0898	0.297640812	0.207840812	231.45%
<b>6</b>	SG 94	2.54E-02			
	Input1 (KPI: 1)	74722.3	74722.3	0	0.00%
	Input2 (KPI: 15)	0.156	0.113832864	-4.22E-02	-27.03%
	Output1 (KPI: 2)	0.5643	0.5643	0	0.00%
	Output2 (KPI: 3)	40499.67	3982140.841	3941641.171	999.90%
	Output3 (KPI: 17)	0.11	0.31987786	0.20987786	190.80%
<b>9</b>	ST 91	0.019045471			
	Input1 (KPI: 1)	76305.83	76305.83	0	0.00%
	Input2 (KPI: 15)	0.1396	0.108289102	-0.031310898	-22.43%
	Output1 (KPI: 2)	0.5422	0.5422	0	0.00%
	Output2 (KPI: 3)	33279.54	4553828.574	4520549.034	999.90%
	Output3 (KPI: 17)	0.1774	0.357859023	0.180459023	101.72%

## C.4 Weights

Variables represented by  $r$  and  $u$  are the weights to be calculated for each of the ( $m$ ) inputs ( $X$ ) and outputs ( $Y$ ). Given the nature of DEA models, which assign the most favorable weights to inputs and outputs for each DMU in order to maximize its score, some DMUs will attain a high score a very good performance in a single input or output. These weights, derived from the data are the optimal set of weights each DMU can have in order to generate the best possible performance score.

Optimal weights  $v(i)$  and  $u(i)$  for Inputs and Outputs are exhibited in Appendix C.4,  $v(0)$  Corresponds to the constraints (4.16) and (4.17) Therefore, the indexes that need improvement would not get weight because they are not strong on those indexes and DEA will not put any weights on them to make the DMUs efficient.

C.4 Weights

No.	DMU	Score	V(1) (1)	V(2) (15)	U(1) (2)	U(2) (3)	U(3) (17)
1	SS 91	1	0	18547.61519	778.7510547	1.16E-05	2934.387384
2	SS 94	1	2.61E-03	6.877579092	11077.80222	4.35E-04	1.254547736
3	SS 2007	1	0	5.050505051	0.757460985	0	0.693188041
4	SS 2009	1	1.41E-04	3.927993477	1.871607711	0	0.794749203
5	SG 91	8.56E-03	0	4.322533578	8.55E-03	0	3.18E-02
6	SG 94	2.54E-02	0	3.205128213	5.718679977	0	7.69E-02
7	SG 2007	1	6.72E-04	1.528117359	1.054754522	0	2.007797482
8	SG 2009	1	6.92E-04	2.178649237	8.833373983	0	1.117543205
9	ST 91	0.019045471	0	3.581661891	5.243902056	0	3.58E-02
10	ST 94	1	4.75E-05	4.716981132	174.8333601	0	1.651800461
11	ST 2007	1	3.74E-05	11.40368499	5.597077418	0	1.781578479
12	ST 2009	1	1.81E-03	2.610966057	24.15458937	0	15.66830661