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Decision aiding methodology for developing the Contractual Strategy of complex oil and gas development projects

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Decision aiding methodology for developing the Contractual Strategy of complex oil and gas development projects

Thèse de doctorat de l'Université Paris-Saclay

Préparée à CentraleSupélec

École doctorale n°573 Interfaces :
Approches interdisciplinaires/ fondements applications et innovation

Thèse présentée et soutenue à Gif-sur-Yvette, le 28 novembre 2017, par

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Massinissa MAMMERY

Titre : Méthodologie d'aide à la décision pour l'élaboration et la sélection de la stratégie contractuelle des projets pétroliers complexes.

Mots clés : Gestion de projets, Industrie pétrolière, Contrats, Structuration de problèmes, Aide multicritère à la décision, Découpe de projets.

Résumé :

Cette thèse de doctorat a pour but de proposer une approche d'aide à la décision dans l'élaboration et la sélection de la stratégie contractuelle des projets pétroliers complexes. Elle est supervisée par Franck MARLE et Wassila OUERDANE, et se déroule dans le cadre de la chaire « Maitrise des Risques liés aux Achats dans les Projets Complexes ». La chaire s'appuie sur les compétences du laboratoire Génie Industriel de CentraleSupélec en matière de gestion de projets, management des risques et aide à la décision. La thèse se déroule au sein de TOTAL, plus précisément dans 2 entités : 1) Projets, responsables de l'élaboration de la stratégie contractuelle des projets de développement, et 2) Contrats & Achats, responsable de l'étude de marché et la partie contractuelle des projets.

Un projet de développement d'une nouvelle installation pétrolière est lancé lorsque des études d'exploration et d'appréciation estiment que l'exploitation du gisement d'hydrocarbures découvert sera suffisamment rentable. La taille des projets rencontrés en industrie pétrolière impose de les découper en plusieurs périmètres. Chaque périmètre est attribué à un contracteur avec un type de contrat particulier, formant ainsi la stratégie contractuelle du projet. Les conséquences d'une erreur ou d'une considération insuffisante des risques peuvent être énormes d'un point de vue coût, délai et production.

Durant le processus de sélection de la stratégie contractuelle d'un projet de développement, TOTAL fait face à trois difficultés récurrentes : 1) l'identification d'un nombre raisonnable et pertinent d'alternatives. En raison du grand nombre de contrats possibles et de stratégies contractuelles réalisables, TOTAL court le risque de négliger des alternatives intéressantes ; 2) l'évaluation des alternatives réalisables, qui dépendent de critères d'échelles et de natures différentes, qui les rendent difficile à formaliser et agréger ; 3) le besoin de justifier le choix final de stratégie contractuelle. La résolution de ces difficultés rendra le processus de sélection plus robuste et justifiable.

La problématique de recherche est donc de concevoir une méthodologie d'aide à l'élaboration et la sélection de la stratégie contractuelle des projets de développement. Elle devra être la plus adaptée non seulement en termes de performances coûts, délais, mais devra également tenir compte des risques associés à ces performances. De plus, les interfaces entre contrats devront être considérées, car la performance collective de la stratégie peut être dégradée par rapport aux performances individuelles de chaque contrat.

Ainsi, notre travail de recherche vise à mettre en place des solutions à la fois techniques et pratiques pour d'une part répondre à la question d'identification et de génération d'un ensemble pertinent d'alternatives de contrats et de stratégies contractuelles. D'autre part, construire et mettre en œuvre un système d'estimation et évaluation, permettant d'arriver à une proposition de stratégie contractuelle la plus performante pour le projet de développement.

Pour ce faire, la proposition est un modèle d'aide à la décision à 3 niveaux, qui permet de définir des alternatives au niveau des contrats (appelé niveau élémentaire), au niveau intermédiaire (assemblage de plusieurs contrats), au niveau stratégie contractuelle (le projet de développement). A chaque niveau, les alternatives sont estimées, triées ou classées, par le biais de méthodes d'agrégation multicritères, pour faire face aux difficultés rencontrées durant le processus de sélection de la stratégie contractuelle (SC).

Nous présentons dans le Chapitre 1 le contexte industriel. La première section vise à décrire le groupe TOTAL et plus précisément les départements impliqués dans le processus de sélection de la SC. Les principaux projets de développement traités dans l'industrie pétrolière sont décrits dans la section 2. Nous présentons ensuite le processus de sélection de SC chez TOTAL, en mettant l'accent sur les composantes d'une SC, les facteurs qui interviennent durant le processus de sélection et les différentes étapes du processus. Nous finirons le chapitre par les difficultés rencontrées durant l'élaboration d'une SC.

La Chapitre 2 a pour but d'énoncer la problématique de recherche. En se basant sur la problématique industrielle et une revue littéraire, deux questions de recherche sont posées : 1) Comment générer un ensemble pertinent d'alternatives de stratégies contractuelles ? Pour laquelle la littérature sur la structuration de problèmes, découpage de projets, théorie des Contrats permettent d'apporter des éléments de réponse, 2) Comment construire un système d'évaluation et de comparaison des alternatives de SC ? Pour laquelle la littérature dans le domaine de l'aide multicritère à la décision est appropriée.

Le Chapitre 3 vise à présenter au lecteur les propositions faites au cours de ce travail. La première proposition étant de suivre un processus d'aide à la décision théorique en 4 étapes proposé par (Tsoukiàs, 2008), permettant de (i) représenter la situation du problème, (ii) formuler et (iii) modéliser le problème et arriver à (iv) une recommandation finale. La deuxième proposition est de construire un processus d'aide à la décision à trois niveaux, dont nous décrivons brièvement certaines étapes. Enfin, la troisième proposition est de construire notre propre guide pour nous aider à faire un choix de méthodes d'agrégation multicritères aux problèmes de décision rencontrés.

Notre approche d'aide à la décision en trois niveaux sera présentée dans les Chapitres 4. L'approche a pour but de s'ouvrir à un ensemble pertinent d'alternatives, qui seront estimées, triées, puis classées, afin d'arriver à une proposition justifiable de stratégie contractuelle pour le projet de développement.

Enfin, dans le dernier chapitre, les conclusions et perspectives académiques et industrielles de notre travail sont présentées.

Un exemple d'un projet pétrolier de GNL, qui aura lieu en Papouasie-Nouvelle-Guinée, sera utilisé tout au long de ce rapport pour illustrer les étapes et difficultés du processus de sélection de la SC, mais également notre approche d'aide à la décision.

Title: Decision aiding methodology for developing the contractual strategy of complex oil and gas development projects.

Keywords: Project Management, Oil and Gas Industry, Contracts Management, Problem Structuring, Multicriteria Decision Aiding Analysis, WBS.

Abstract:

This Ph.D. thesis aims at building a decision aiding approach for selecting the contractual strategy of complex oil and gas projects. It is supervised by Franck MARLE and Wassila OUERDANE. It takes place as part of the chair “Managing Procurement Risks in Complex Projects” between TOTAL and CentraleSupélec. The chair relies on the skills of the Industrial Engineering laboratory at “CentraleSupélec” in terms of project management, risk management and decision aiding. The Ph. D. thesis takes place within TOTAL, more precisely within two entities: 1) Project office, responsible of the CS of upstream development projects, and 2) Contract & Procurement, responsible for market intelligence studies and the contractual part of the projects.

A development project of a new oil and gas facility starts when the exploration and the appraisal studies estimate the exploitation of the hydrocarbon deposit is economically viable. The complexity and the size of the projects encountered in the industry impose to split them into several pieces, which represent the scope of future contracts. Each scope is then awarded to a contractor with a specific type of contract and selection mode, forming the contractual strategy to adopt in the project. The consequences of an error or insufficient consideration of risks can be enormous from the point of view of Cost, Schedule, or Production once the project delivered.

During the contractual strategy selection process of a development project, the oil company encounters three recurring difficulties related to: 1) the identification of a reasonable and relevant set of alternatives. Due to the large number of possible contracts, and feasible contractual strategies, TOTAL runs the risk of neglecting interesting alternatives; 2) the evaluation of potential alternatives, which depends on criteria from different scales and natures difficult to formalize and aggregate; 3) the need to substantiate the chosen contractual strategy solution. Resolving these challenges will make the selection process more justifiable and relevant.

The research problem is to propose a decision aiding methodology for the development and selection of the most appropriate contractual strategy. It has to be the most performing in terms of Cost and Schedule, but should also consider the risks associated with these performances. In addition, the interfaces between the different contracts should also be considered, because the collective performance of the whole strategy may be degraded compared to the performance of each individual contract.

Thereby, our work seeks to implement both technical and practical solutions to answer on the one hand the question of identification and generation of a relevant set of alternatives, at contracts and contractual strategy levels. On the other hand, to build and implement a system of estimation and evaluation of contractual strategies, allowing to come up with the most performing proposal to the upstream development project.

To do so, the proposal is a 3 level decision aiding model, which defines decision alternatives at contract level (called elementary level), intermediary level (assembly of several interrelated contracts) and contractual strategy level (the whole project). At each level, alternatives are estimated, screened out, and possibly ranked with the use of Multicriteria decision aiding methods to deal with the faced challenges during the contractual strategy (CS) selection process.

Chapter 1 presents the industrial context, it starts by describing TOTAL group and more specifically the departments involved in the selection process. The main upstream development projects handled in the oil and gas industry are then described. Afterwards, the CS selection process within TOTAL will be presented, with focus on CS components, drivers that intervene during the selection process, and the steps of the process. We will end the chapter by the difficulties that are inherent to this process.

In Chapter 2, the research problem is specified, based on the industrial issue and a literature review two research questions arise: (i) How to generate a relevant set of contractual strategy options? For which literature on Problem Structuring, Work Breakdown Structure, Matrix based Methodologies, and Contracts Management are relevant, (ii) How to build a system of evaluation and comparison of CS alternatives? For which the literature in Multicriteria Decision Aiding (MCDA) field is appropriate.

Chapter 3 aims to present to the reader the proposals made during this work. The first proposal is to follow a 4- steps global theoretical process proposed by (Tsoukiàs, 2008) to (i) represent the problem situation, (ii) to formulate and (iii) model the problem, and to make (iv) a final recommendation. The second proposal is to build our three level decision aiding process, we describe briefly certain steps. The final proposal is to build our own guideline helping the choice of MCDA aggregation methods to the faced decision problems.

The 3-level decision aiding approach will be presented in Chapters 4. It will seek to open up to a relevant set of alternatives, which will be estimated, screened out, then evaluated, in order to come up with a justified contractual strategy proposal to an upstream development project.

Finally, in the last chapter we will draw both industrial and academic conclusions, as well as perspectives to our work.

An example of an onshore LNG project, which will take place in Papua New Guinea, will be used all along this report to illustrate the steps and faced challenges of the contractual strategy selection process but also the steps of our decision aiding approach.

Summary

Chapter 1: Industrial Context	17
1.1. Description of TOTAL and the departments involved in contractual strategy selection 19	
1.1.1. The Group TOTAL	19
1.1.2. The departments involved in the contractual strategy selection process	20
1.2. Oil and gas upstream development projects.....	21
1.2.1. The design of upstream development projects.....	21
1.2.2. Upstream development projects types within the oil and gas industry.....	23
1.3. The contractual strategy selection process	24
1.3.1. What is a contractual strategy?	24
1.3.2. Drivers influencing the design of a contractual strategy	32
1.3.3. Total's contractual strategy selection process.....	34
1.4. Industrial challenges and difficulties within the CS selection process	41
1.4.1. Decision options generation problem	41
1.4.2. Performances aggregation problem	42
1.4.3. Supporting and justifying the recommendations	42
1.5. Chapter Conclusion	43
Chapter 2: Literature Review and Research Questions.....	45
2.1. A Multi-Criteria Decision Aiding (MCDA) methodology	47
2.1.1. Basic Concepts of MCDA	47
2.1.2. A model of MCDA process	49
2.2. Generating and constructing decision options	51
2.2.1. A general view on the alternatives generation problem.....	51
2.2.2. A focus on the components of contractual strategy options	53
2.3. Evaluating and selecting decision options	57
2.3.1. MCDA aggregation procedures	57
2.3.2. The problem of selecting an aggregation method.....	58
2.4. Research questions	60
2.5. Chapter Conclusion	63
Chapter 3: A Decision Aiding Methodology for the Contractual strategy selection process	65

3.1.	First Proposal: description of the decision aiding methodology based on Tsoukiàs (2008)	67
3.1.1.	The representation of the problem situation	68
3.1.2.	The formulation of the problem	69
3.1.3.	The construction of an evaluation model	70
3.1.4.	The final recommendation	71
3.2.	Second proposal: the 3-level progressive building of the Contractual strategy .	72
3.2.1.	The Elementary level	73
3.2.2.	The contribution: adding an Intermediary level.....	76
3.2.3.	Contractual Strategy level	78
3.3.	Third proposal: selecting aggregation methods involved in the decision process	79
3.3.1.	Characterization of the decision context.....	80
3.3.2.	Definition of the selection criteria	81
3.3.3.	Pre-selection of aggregation methods to compare	83
3.3.4.	Evaluation of the pre-selected methods against the selection criteria	83
3.3.5.	Comparison of the three best methods.....	85
3.3.6.	Discussions & Generalization.....	87
3.4.	Chapter Conclusion	88
	Chapter 4: A 3-level Decision Aiding Process for Contractual strategy selection	89
4.1.	The Elementary level	91
4.1.1.	Identification of Elementary alternatives	91
4.1.2.	Estimation of Elementary alternatives	105
4.2.	The Intermediary level	107
4.2.1.	Identification of Intermediary Alternatives.....	107
4.2.2.	Estimation of Intermediary alternatives	112
4.2.3.	Screening of Intermediary alternatives	114
4.3.	The Contractual strategy level.....	117
4.3.1.	Identification of feasible Contractual strategy alternatives.....	117
4.3.2.	Estimation of Contractual strategy alternatives	119
4.3.3.	Screening of Contractual strategy alternatives	120
4.3.4.	Ranking of Contractual strategy alternatives	122
4.4.	Chapter Conclusion	124
	Chapter 5: Conclusion and Perspective.....	125

Appendix 1 – MCDA aggregation Methods comparison for the faced Sorting decision problem.....	129
Appendix 2 – East African Crude Pipeline (EACOP) project	131
References	141

Table of illustrations

Figure 1 - Sectors of the petroleum industry (McFarland, 2015).....	19
Figure 2 - Process of upstream development projects within TOTAL (Source TOTAL internal document).....	21
Figure 3 - Project architecture matrix	24
Figure 4 – An illustration of object assemblies to form contracts perimeters.....	25
Figure 5 - Illustration of contracts perimeters formed by objects assemblies and temporal cuts	26
Figure 6 - Illustration of contract types identification on contracts perimeters	28
Figure 7 - Illustration of a potential contractual strategy	30
Figure 8 - Drivers that influence the design of a contractual strategy	32
Figure 9 - PNG project scope (source TOTAL).....	34
Figure 10 – Steps of the contractual strategy selection process within TOTAL.....	35
Figure 11 - PNG project architecture matrix.....	36
Figure 12 - Contractual strategy alternatives for PNG project.....	37
Figure 13 – A 4-step decision aiding model for complex decision problems (Tsoukiàs, 2008)	49
Figure 14 - Modelling of the dynamic decision problem structuring method, proposed by (Corner and al., 2001)	52
Figure 15 - Selection modes vs. Design uncertainty and Suppliers' competition	55
Figure 16 - Contracts types vs. Risk level.....	55
Figure 17 – Identification of research questions from the encountered issues during CS selection	61
Figure 18 - Research questions and related literature	62
Figure 19 - Decision aiding methodology for contractual strategy selection based on (Tsoukiàs, 2008).....	67
Figure 20 – A 3-level decision aiding process for contractual strategy selection.....	72
Figure 21 - Contracts identification of the project architecture matrix	73
Figure 22 - Identification of potential elementary objects assemblies into row blocks	73
Figure 23 - Cutting the project architecture matrix into Intermediary breakdowns.....	76
Figure 24 - illustration of a feasible contractual strategy combining intermediary alternatives	77
Figure 25 - Approach helping the selection of an aggregation method to our case study	79
Figure 26 - PNG scope of work - Row block assembling.....	92
Figure 27 - Inputs of the row block identification procedure	94
Figure 28 - Identification of contractual configurations per row block	101
Figure 29 - Decision tree for the identification of contractual configurations.....	103
Figure 30 - Contractual configurations identification procedure applied to PNG project	104
Figure 31 - Elementary alternatives estimation on PNG project	105
Figure 32 - Cutting the project scope of PNG project into Intermediary Breakdowns.....	107
Figure 33 - Intermediary Breakdowns identification on PNG project	111
Figure 34 - Intermediary alternatives identification on PNG project.....	111

Figure 35 - Estimation of Elementary alternatives interfaces of IB1	112
Figure 36 - Estimation of Intermediary alternatives of IB1	113
Figure 37 - Dominance based elimination of Intermediary alternatives applied on PNG project	114
Figure 38 - Sorting Intermediary alternatives of IB1 using MR Sort model	116
Figure 39 - Elimination of incompatible Intermediary alternatives couples on PNG project	118
Figure 40 - Identification of Contractual strategy alternatives on PNG project	118
Figure 41 - Estimation of Intermediary alternatives interfaces on PNG project.....	119
Figure 42 - Estimation of Contractual strategy alternatives on PNG project.....	119
Figure 43 - Dominance based elimination on Contractual strategy alternatives of PNG project	120
Figure 44 - Sorting contractual strategy alternatives of PNG project using MR Sort model.	121
Figure 45 - Ranking contractual strategy alternatives of PNG project using MR Sort model	122
Figure 46- Estimation of Elementary alternatives interfaces of EACOP Project	137
Figure 47- Remaining contractual strategies after sorting on EACOP project	139

Table 1 - Advantages and disadvantages of temporal cuts	27
Table 2 - Advantage and disadvantage of each type of contract.....	29
Table 3 - Advantages and disadvantages of selection modes	31
Table 4 – Estimation of the performance of contractual configurations on PNG project.....	39
Table 5 – Estimation of elementary objects criticality on PNG project.....	39
Table 6 - Guidelines helping the choice of a MCDA method to a decision problem	58
Table 7 - Analysis of the evaluation criteria	80
Table 8 - Selection criteria to help the choice of a sorting aggregation method.....	81
Table 9 - Nature, scales and weights of the selection criteria	82
Table 10 - Ranking of aggregation methods on the basis of (Gershon, 1981) function distance	84
Table 11 - Pros & Cons of the selected MCDA Sorting methods.....	86
Table 12 - List of contractors and their capabilities (PNG project)	93
Table 13 - MPk matrix at iteration 1	99
Table 14 - Technical compatibility matrix at iteration 1	99
Table 15 - Pre-project compatibility matrix at iteration 1	99
Table 16 - Suppliers' availability matrix at iteration 2	100
Table 17 - Comparison of MCDA aggregation methods for the faced sorting decision problem	130
Table 18- EACOP List of Elementary Objects	132
Table 19 – Identified Row blocks on EACOP project	133
Table 20 – Identified Contractual Configurations on EACOP Project	134
Table 21 - Elementary alternatives estimation on EACOP Project	135
Table 22- Identification of Contractual Strategy alternatives on EACOP Project.....	136
Table 23 - Estimation of Contractual strategy alternatives on EACOP Project.....	137
Table 24 - Dominance based elimination on Contractual strategies alternatives of EACOP project.....	138

Chapter 1: Industrial Context

Introduction

The complexity and size of projects encountered in the oil and gas industry impose to split them into several, more manageable pieces. Each of them is then awarded to a contractor with a specific selection mode and type of contract, forming the Contractual Strategy (CS) that will be executed throughout the following stages of the project. The design of this CS is an important step in the success of an oil and gas upstream development project, since the execution of million and billion-dollars contracts is based on it.

This initial chapter aims to raise the industrial issues, with a focus on two key elements: (i) the main drivers that intervene during the CS selection process. These drivers may influence the design and the selection of the CS as constraints (limiting the range of possibilities), or as performance indicators (allowing the estimation and evaluation of CS alternatives); (ii) the difficulties encountered during the CS selection process - each of them representing a challenge to establish an efficient CS.

This chapter is organized as follows. The French oil and gas company TOTAL is introduced in Section 1.1, with focus on the departments involved in the CS design. Section 1.2 describes the types of upstream development projects handled by the company, and their different phases, from exploration to first oil (the start of the operation phase). The contractual strategy selection process is presented in Section 1.3 with focus on CS components, drivers that intervene during the process, and the 3 phases of the process. The difficulties encountered during the CS selection process are discussed in Section 1.4. Finally, the industrial issue will be discussed as a conclusion of this chapter, in order to position the ambition of our work.

1.1. Description of TOTAL and the departments involved in contractual strategy selection

1.1.1. The Group TOTAL

TOTAL S.A is a French multinational oil and gas Company, and one of the largest oil companies in the world. Its business covers the entire oil and gas industry, from the exploration and production of crude oil and natural gas to transportation, refining, marketing and international trading. The company is also a chemicals manufacturer. Its activities, as well as other major oil companies, are divided into three sectors: Upstream, Midstream and Downstream (McFarland, 2015), as illustrated in Figure 1.

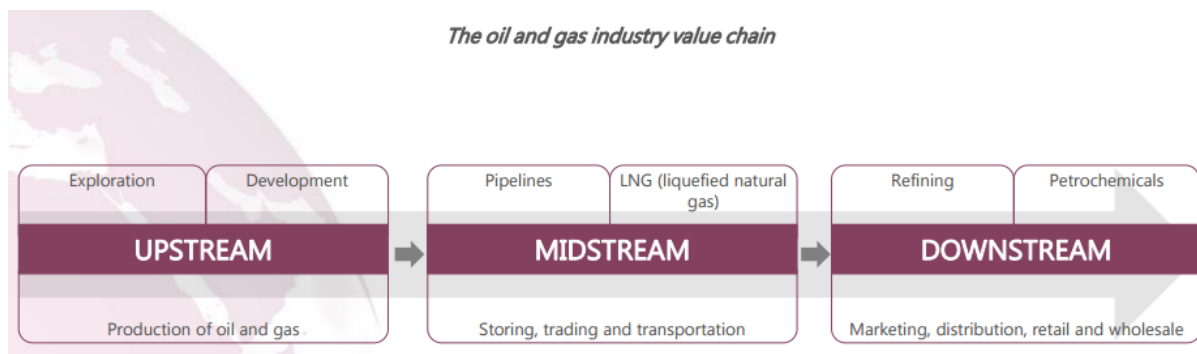


Figure 1 - Sectors of the petroleum industry (McFarland, 2015)

- **Upstream:** The upstream sector includes different activities, like seeking potential hydrocarbons fields, drilling exploratory wells, operating the wells, and bringing the crude oil and/or raw natural gas to the surface.
- **Midstream:** It includes the transportation of the “crude oil” and/or “raw natural gas” through pipelines, tank trucks or oil tankers towards the areas of storage, refining and gas processing plants.
- **Downstream:** It includes the process of refining the “crude oil” and/or processing the “raw natural gas”, as well as the marketing and the distribution of the petroleum products.

Within TOTAL, upstream development projects are handled by the Exploration & Production branch (EP), supported by TOTAL Global Services branch (TGS). The EP branch explores and develops oil and gas fields to meet energy demand worldwide.

1.1.2. The departments involved in the contractual strategy selection process

Since our work aims to propose a decision aiding methodology for the contractual strategy (CS) selection process, the thesis takes place within two entities, from EP and TGS branches: 1) Project office, the accountable and decision-maker for the CS selection and implementation of upstream development projects, and 2) Contracts & Procurement, the responsible of the contractual part of the projects and market intelligence studies.

Moreover, the design of a contractual strategy depends on the data and the knowledge of other entities/ sub-entities, from the EP branch, via its Development and Support to Operations entity (EP/DSO), supported by TGS branch, via TOTAL Global Procurement (TGS/TGP) entity, which provide data on:

- *Cost and Schedule Estimates*: these estimates affect the choice of a contractual strategy over another, as the performance of CS depends highly on the two indicators;
- *Local industrial Strategy*: an industrial survey of each country in which the development project takes place is performed, in order to undertake local content actions;
- *The scope of work*: the list of equipment, and methods of design, construction and Installation of facilities;
- The Environment, Health and Safety policy to prevent incidents and reduce adverse effects;
- Risk assessment studies;
- Feedback on potential Contractors;
- Well Drilling Strategy, Geotechnical and Oceanic data, etc.

1.2. Oil and gas upstream development projects

1.2.1. The design of upstream development projects

The term “Development project” is used to refer to all the phases of the development of a hydrocarbon discovery from the beginning of its basic engineering to the end of its commissioning (see Figure 2).

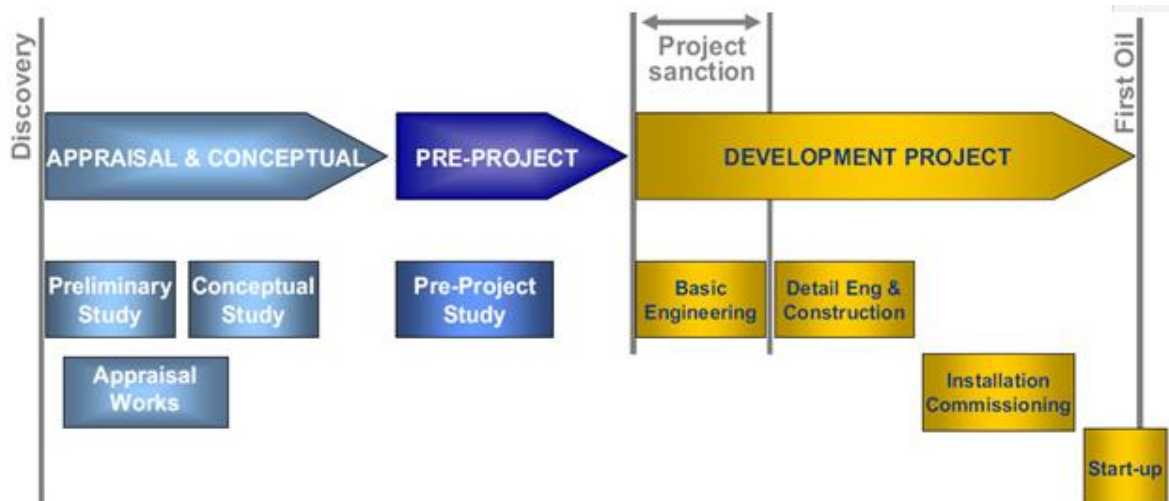


Figure 2 - Process of upstream development projects within TOTAL (Source TOTAL internal document)

An upstream project starts when the exploration and the appraisal studies estimate the exploitation of a hydrocarbon deposit economically viable. The preliminary phase is then launched, during which a preliminary study is developed (the potential of hydrocarbons assessment, costs and schedule estimates, weather conditions, etc.), it is followed by a conceptual study, allowing to decide what will be the architecture of the development project, i.e. the equipment, services and materials. Then comes the pre-project study, which consists in splitting the project into several scopes; each scope is then awarded to one or several contractors with a specific type of contract and selection mode (described on what follows), forming the *contractual strategy* which will be carried out during the project execution.

Chapter 1: Industrial Context

Once the contractual strategy is validated by an internal committee, then agreed by partners and local authorities, the project development is sanctioned. Generally, it goes through the following life cycle:

- **Basic Engineering:** it aims to provide technical details, such as improving the reliability of cost and schedule estimates, the dimensions of the equipment and materials, preparing the bidding phase, detecting critical items, etc. It can be assigned, depending on the project, to one or several contractors after an initial bidding phase.
- **Detailed Engineering:** its aim is to deliver a more detailed technical file on the execution of the following phases (from procurement to commissioning).
- **Procurement:** during this phase, bulk and raw materials, services and equipment are bought, and supplied to construction yards. A specific phase called ‘Supply’ may be added in the Procurement process, for the transportation from manufacturing to construction yards.
- **Construction:** the construction of the facilities as well as the assembly of equipment and materials are usually performed during this phase, either it is on land, or on construction yards.
- **Transport and Installation:** once the equipment are designed, they are transported to the site, before being installed. It is generally performed by the construction contractor.
- **Commissioning:** this is the last stage before first oil, during which the construction system’s performance and reliability are tested.

Once the phases of the development project executed, the operation of the deposit can start. Oil and gas extraction can last several years, up to several decades in some projects depending on the size of the deposit.

1.2.2. Upstream development projects types within the oil and gas industry

There are three main types of upstream development projects in the oil and gas industry, all handled by TOTAL:

1. **Deep Offshore.** It consists of building a fixed or floating offshore construction (platform, floating vessel), pipelines, a drilling system, and subsea equipment to operate an oil reservoir. The platforms/ vessels are made to support the devices necessary for the drilling and oil extraction. Some platforms/ vessels are used to transform the oil, to facilitate the transport and export (such as FPSOs).
2. **Heavy crude oil and oil sands.** Most of the time, heavy crude oil & oil sands are extracted onshore, on land. The technologies are often sophisticated and expensive, even if relatively cheaper than deep offshore projects.
 - **Heavy crude oil:** more dense and viscous than light oils, they are classified according to their ability to flow in reservoirs. Their extraction requires specific and innovative production methods.
 - **Oil sands:** they are so viscous that they are frozen in their reservoirs. Recovery methods depend upon the depth of the deposits: up to 100 meters deep, they are produced in open cast mines; beyond this depth, they are extracted by reducing the viscosity of the sand inside the reservoir.
3. **Natural Gas.** Within TOTAL, liquefied natural gas is distinguished from unconventional gases:
 - **Liquefied natural gas (LNG):** after extraction of gas in hydrocarbon deposits on land or at sea, the gas is transported by pipelines to an onshore gas processing plant. The gas is purified before moving into giant refrigerators then liquefaction trains, where it is cooled to very low temperatures. Once this operation is carried out, it becomes LNG, with a much smaller volume than its initial state. It becomes thus less expensive and easier to transport via “LNG carriers” to countries consumers.
 - **Unconventional gases:** the term covers mainly three types of resources. They are distinguished from "conventional gas" by the geological characteristics of the rock containing them: *Tight gas*: which is trapped within reservoir rocks of very low permeability, *Shale gas*: which is trapped within shale formations, and *Coal gas*: meanwhile is trapped in coal deposits which can contains up to 3 times more gas per unit volume.

1.3. The contractual strategy selection process

1.3.1. What is a contractual strategy?

In the literature the term “contracting strategy” is often used to refer to the process used for selecting a particular type of contract to a project, especially in the construction industry, (Perry, 1985; Vesay, 1991; Smith, 2002; Powell, 2016). However, it is quite different compared to the contractual strategy of a development project. The complexity and the size of the projects encountered in the oil and gas industry make that we deal with many contracts, which make the faced problem more complex: not only the best contract type and selection mode of each contract must be selected, but also the perimeters of each one, more especially, as the interfaces between the contracts can significantly degrade the performance of the whole project compared to the performance of each individual contract, it is important to be careful when it comes to split the project into several contracts.

The contractual strategy (CS) is a set of coordinated actions and decisions for the success of an upstream development project. It allows to define the split of project scope into objects - containing elementary objects - and phases (the life cycle of each elementary object), forming cells (see Figure 3), whose assembly into pieces will form the perimeters of future contracts. Each of these “multi-cells” pieces is then assigned to a contractor with particular type of contract and selection mode. From TOTAL’s point of view, a CS aims to support the project in terms of business (Company’s overall strategy and interests, return on investment, local development, etc.), risk sharing and allocation (between TOTAL and its contractors), cost and schedule.

Contractual Strategy		Basic Engineering (BE)	Detailed Engineering (DE)	Procurement (P)	Construction (C)	Transport & Installation (T&I)	Commissioning (Com)
Object 1	Elementary Object 1,1						
	Elementary Object 1,2						
	Elementary Object 1,3						
	Elementary Object 1,4						
Object 2	Elementary Object 2,1						
	Elementary Object 2,2						
...	...						
Object k	Elementary Object k,1						
	Elementary Object k,2						
	Elementary Object k,3						
	Elementary Object k,4						

Figure 3 - Project architecture matrix

Thereby, a contractual strategy is characterized by three components: 1) the scope of contracts, 2) the types of contracts associated to each scope, and 3) the selection mode of contractors. They are discussed in what follows:

1.3.1.1. The scope of contracts

The identification of contracts perimeters depends on two dimensions: (i) the assembly of one or more elementary objects into object assemblies, and (ii) the split of the life cycle of object assemblies into temporal cuts.

Assembly of elementary objects. Contracts are often composed of several elementary objects (sometimes from two different objects). Indeed, to avoid the management of a large number of contracts and interfaces, it is more interesting to assemble elementary objects if possible. The identification of object assemblies may depend on several drivers, such as: the market situation, the nature of the objects; the compatibility of pre-project studies between objects. Figure 4 illustrates an example of objects gatherings. For instance, Object assembly 2 gathers the elementary objects 1.2, 1.3, and 1.4.

Project Scope of Work		Basic Engineering (BE)	Detailed Engineering (DE)	Procurement (P)	Construction (C)	Transport & Installation (T&I)	Commissioning (Com)
Object 1	Elementary Object 1.1	Object assembly 1					
	Elementary Object 1.2						
	Elementary Object 1.3	Object assembly 2					
	Elementary Object 1.4						
Object 2	Elementary Object 2.1	Object assembly 3					
	Elementary Object 2.2						
...					
Object k	Elementary Object k.1	Object assembly N					
	Elementary Object k.2						
	Elementary Object k.3						
	Elementary Object k.4						

Figure 4 – An illustration of object assemblies to form contracts perimeters

Splitting the life cycle of object assemblies into temporal cuts. Once objects assemblies are known, the question of the split of their life cycle arises. Here again, it is preferred to not separate the phases of an object assembly. The identification of the temporal cuts depends on several drivers, such as: the market situation, the size of the scope, scope uncertainty. The main temporal cuts scenarios are described in what follows.

- **Basic Engineering Phase (BE).** Ideally, oil companies have a great benefit in gathering the whole Basic Engineering phase in one contract, as it allows to have an overall view on the project. However, it happens that some elementary objects/ objects assemblies may have constraints such as, schedule criticality, Engineering uncertainty, lack of competition, technical compatibility with other objects. On that case, the BE is split (see Object 1 on Figure 5).
- **Detailed Engineering, Procurement, and Construction Phases.** For these three phases, TOTAL considers five main temporal cuts:
 - **Engineering, Procurement, and Construction Phases (EPC):** it is a particular form of contracting arrangement where the EPC Contractor is made responsible for all the activities of the object assembly, from the design, procurement, and construction phases, to the commissioning and handover (see the orange perimeter on Figure 5);

- **EPC with C not fixed:** it consists in assigning, once the Basic Engineering is performed, an entire object assembly to a contractor. It is appropriate when having doubts on the construction scope (see the purple perimeter on Figure 5);
 - **EP+C:** it consists in assigning the Engineering and Procurement phases to a first contractor, and the realization of the Construction phase to a second contractor (see the gray perimeters on Figure 5);
 - **EPCm:** it consists in assigning, once the BE is performed, the Detailed Engineering, the Procurement, and the management of the Construction to a first contractor, and the realization of the Construction phase to a second contractor (see the red perimeter on Figure 5);
 - **E+P+C:** this alternative consists in assigning the Engineering phases to a first contractor, the Procurement to a 2nd contractor, and the Construction to a 3rd one (see the blue perimeters on Figure 5).
- **Transport, Installation, and Commissioning.** Transport, Installation and Commissioning phases of an object assembly are usually handled by the Construction contractor. However in certain projects, notably in deep offshore projects, for economic reasons, it happens that the three phases of the subsea equipment are handled by the Construction contractor of the Pipelines (see the green perimeter on Figure 5).

Figure 5 illustrates an example of contracts perimeters formed by objects assemblies and temporal cuts.

Project Scope of Work		Basic Engineering (BE)	Detailed Engineering (DE)	Procurement (P)	Construction (C)	Transport & Installation (T&I)	Commissioning (Com)
Object 1	Elementary Object 1.1	BE	EP		C		
	Elementary Object 1.2		EPC T&I Com				
	Elementary Object 1.3						
	Elementary Object 1.4						
Object 2	Elementary Object 2.1	EPC with C not fixed				EPC + T&I Com EO 2.1	
	Elementary Object 2.2						
...	...						
Object k	Elementary Object k.1	E	P	C			
	Elementary Object k.2	EPCm					
	Elementary Object k.3						
	Elementary Object k.4						

Figure 5 - Illustration of contracts perimeters formed by objects assemblies and temporal cuts

Advantages and disadvantages:

Based on our analysis, TOTAL employees, and internal company documents, the main advantages and disadvantages of each temporal cut, have been summarized in Table 1. We will make use of the table in our proposal (see Section 4.1.1) to build relevant contracts perimeters.

Temporal cuts	Pros	Cons
Engineering, Procurement and Construction (EPC)	<ul style="list-style-type: none"> - Strong experience within the CPY (TOTAL); - Minimal CPY personal required and light follow-up; - Minimal interfaces to manage for the CPY; - Single point of responsibility; - High cost certainty and schedule. 	<ul style="list-style-type: none"> - Need robust BE and contract preparation to secure costs/planning and minimize changes; - A working environment under Contractor's (CTR) control; - High claim potential in case of change orders; - High risk bonus for the CTR; - Limited competition due to the size and risk uncertainty; - More lengthy decision process.
EPC with C not fixed	<ul style="list-style-type: none"> - Same as EPC but: - Less risk uncertainty on construction; - More competition for construction compared to EPC; - Flexibility to make change orders during the detailed engineering; - Lower prices due to a larger list of construction CTRs. 	<ul style="list-style-type: none"> - Same as EPC but: - Less commitment from CTR for construction efficiency in terms of cost and planning: need to have an incentive/ penalty mechanism; - The need to supervise the construction phase closely from the CPY (+ organization/ resource); - Potential overtaking cost and schedule.
EP + C	<ul style="list-style-type: none"> - Better definition of scope before the bidding phase; - Control of engineering; - Larger list of construction CTR; - Possibility of getting lower price; - Lower risk bonus compared to EPC contracts. 	<ul style="list-style-type: none"> - CPY need to be organized as an EPC; CTR (competency, resources, tools/software); - Direct management of the construction CTR by the CPY; - Need to set incentive/ penalty mechanism; - Increased interfaces to be manager; - The split of responsibilities is difficult to manage.
EPCm	<ul style="list-style-type: none"> - Same as EP+C but: - Less CPY resources required; - Better scope definition, therefore lower claim risk from the construction CTR; - Construction packages will lead to more competition; - More visibility on cost/ schedule structure. 	<ul style="list-style-type: none"> - Same as EP+C but: - Increased interface with many CTRs on site - Potential cost and schedule creep - Need highly experienced CPY involvement to check EPCm CTR deliverables; - No strong experience within TOTAL.
E + P + C	<ul style="list-style-type: none"> - Same as EP+C but: - Direct control from CPY on the procurement. 	<ul style="list-style-type: none"> - Same as EP+C but: - Highest risk on CPY; - Highest needs in CPY's organization; - No strong experience within TOTAL.

Table 1 - Advantages and disadvantages of temporal cuts

1.3.1.2. The types of contracts

In the oil and gas industry and more particularly within TOTAL, there are 3 main types of contracts (remunerations), varying from a fixed price Lump sum contract to a totally non-risk cost Reimbursable contract. After making inquiries of TOTAL employees, and internal documents, we came to realize that the main types of contracts encountered in the oil & gas industry are the following:

- **Lump Sum (LS).** It consists on an agreement of a fixed price for the execution of a scope; it is the type of remuneration with less visibility for the company. Once the contract signed, the company has no knowledge on cost and schedule baselines. It is the most widely used contract by TOTAL with its contractors; according to their general opinion: "*It allows transferring risk responsibilities to contractors*".
- **Unit Rates (UR).** It consists on a measurable payment as the project progresses, in which the contractor is paid a fixed amount of money per unit of work.
- **Reimbursable (R).** It consists on paying back the expenses covered by the contractor, either at the end of the deliverables, or on different milestones defined in the contract, to which is added a fixed sum or a percentage (of the order of 6 to 8%), corresponding to the contractor's profits for his work. Used in high-risk projects for which neither the CPY nor the contractor do have the skills and expertise needed to conduct the scope.

Figure 6 illustrates the selection of a contract type for each contract perimeter:

Project Scope of Work		Basic Engineering (BE)	Detailed Engineering (DE)	Procurement (P)	Construction (C)	Transport & Installation (T&I)	Commissioning (Com)
Object 1	Elementary Object 1.1	Lump Sum	Lump Sum		Reimbursable		
	Elementary Object 1.2		Unit Rate				
	Elementary Object 1.3						
	Elementary Object 1.4						
Object 2	Elementary Object 2.1	Reimbursable			Lump Sum		
	Elementary Object 2.2						
...	...						
Object k	Elementary Object k.1	Reimbursable	Reimbursable	Reimbursable			
	Elementary Object k.2	EPCm Lump Sum +C Reimbursable					
	Elementary Object k.3						
	Elementary Object k.4						

Figure 6 - Illustration of contract types identification on contracts perimeters

Advantages and disadvantages:

Table 2 below summarizes the main advantages and disadvantages of each type of contract:

Contract types	Pros	Cons
Lump Sum (LS)	<ul style="list-style-type: none"> - The contractor has full responsibility for risks; - The level of involvement of TOTAL is limited to supervision; - The costs are fixed. 	<ul style="list-style-type: none"> - The level of risk included in the price fixed by the contractor is unknown; - The project is not compatible to large scope changes; - High profit margins asked by the contractor.
Unit Rates (UR)	<ul style="list-style-type: none"> - Costs structure and risks are visible; - More flexible to change orders. 	<ul style="list-style-type: none"> - Mobilization and high-level involvement of the CPY; - Waste of time in negotiations.
Reimbursable (R)	<ul style="list-style-type: none"> - More flexible to change orders; - The risks are not included in the contract. 	<ul style="list-style-type: none"> - All project risks are under the responsibility of the CPY; - High-level involvement of the CPY. - Low incentive of contractors in terms of costs and Planning.

Table 2 - Advantage and disadvantage of each type of contract

1.3.1.3. The selection modes of contractors

The selection mode of contractor(s), aims to determine what will be the tendering process associated to each contract. After making inquiries of TOTAL employees and internal documents, we came to realize that the main selection modes of contractors encountered in the oil and gas industry are the following:

- **Single Source (SS):** contract is established with one contractor on the basis of its expertise in the field, without any tendering process. It happens most of the time, when the regulation of the host country imposes a local contractor.
- **Call for Tender (CFT):** the company makes a tender between potential contractors, only one is awarded for the development of the contract scope. It is the most widely selection mode used by TOTAL.
- **Design Competition (DC):** the basic engineering phase of an object assembly is assigned to several contractors; the one who present the most advantageous design is awarded to pursue the other phases of the object assembly.
- **Open Book Tendering (OBT):** the contractor and the company negotiate the cost and schedule of deliverables on various milestones with complete transparency on their structure until generally, 60% of the detailed engineering. The contract is then converted to a particular type of contract for the other phases.

Figure 7 illustrates a complete contractual strategy with its three components:

Project Scope of Work		Basic Engineering (BE)	Detailed Engineering (DE)	Procurement (P)	Construction (C)	Transport & Installation (T&I)	Commissioning (Com)
Object 1	Elementary Object 1.1	(CFT) BE LS	(CFT) EP LS		(CFT) C T&I Com R		
	Elementary Object 1.2		(CFT) EPC T&I Com UR				
	Elementary Object 1.3						
	Elementary Object 1.4						
Object 2	Elementary Object 2.1	(OBT) EPC with C not fixed R				(DC) EPC LS+ T&I Com EO 2.1 LS	
Elementary Object 2.2							
...	...						
Object k	Elementary Object k.1	(CFT) E R		(CFT) P R	(CFT) C T&I Com R		
	Elementary Object k.2	(CFT) EPCm LS +C R					
	Elementary Object k.3						
	Elementary Object k.4						

Figure 7 - Illustration of a potential contractual strategy

Advantages and disadvantages:

Table 3 summarizes the main advantages and disadvantages of each selection mode:

Selection modes	Pros	Cons
Single Source (SS)	<ul style="list-style-type: none"> - Quick start of the project by avoiding the bidding phase; - No required negotiation, the costs are fixed. 	<ul style="list-style-type: none"> - Limited use of certain types of contracts: reimbursable, unit rates. - No competition, bargaining power in favor of the contractor.
Call For Tender (CFT)	<ul style="list-style-type: none"> - Bargaining power in favor of the CPY; - Cost / Price and Deadlines are known at the end of the process, - Incites the contractors to optimize the costs and to meet the schedule; - Shared risks. 	<ul style="list-style-type: none"> - Slow start of the project because of the bidding phase; - Waste of time in negotiations; - High costs due to the preliminary studies and the tendering process.
Design Competition (DC)	<ul style="list-style-type: none"> - Incites the contractors to optimize the costs, to meet the schedule and to share risks; - Cost / Price and deadlines are known at the end of the basic engineering; - Allows competition for the design; - Creative design and better scope clarity. 	<ul style="list-style-type: none"> - Supervision process required; - Oblige contractors to align themselves with certain decisions; - Waste of time in negotiations; - High costs, due to the preliminary studies and the tendering process.
Open Book Tendering (OBT)	<ul style="list-style-type: none"> - Total transparency of estimates; - The risks are not included in the contract; - Good cost estimates, risks and uncertainties; - No waste of time in the bidding phase. 	<ul style="list-style-type: none"> - Greater involvement of the CPY; - Risks are managed by the CPY; - The Cost of the project is variable or uncertain in the early stages; - Complex conversion process into a Lump sum.

Table 3 - Advantages and disadvantages of selection modes

1.3.2. Drivers influencing the design of a contractual strategy

As mentioned in Section 1.1.2, the CS selection process is handled by the Project entity. However, its design depends on several data provided by other departments. Figure 8 shows their temporality during upstream development projects, according to the different information gathered during our analysis of the CS selection process. These data are crucial to the design of the right strategy, and therefore the success of the project, they are described hereunder.

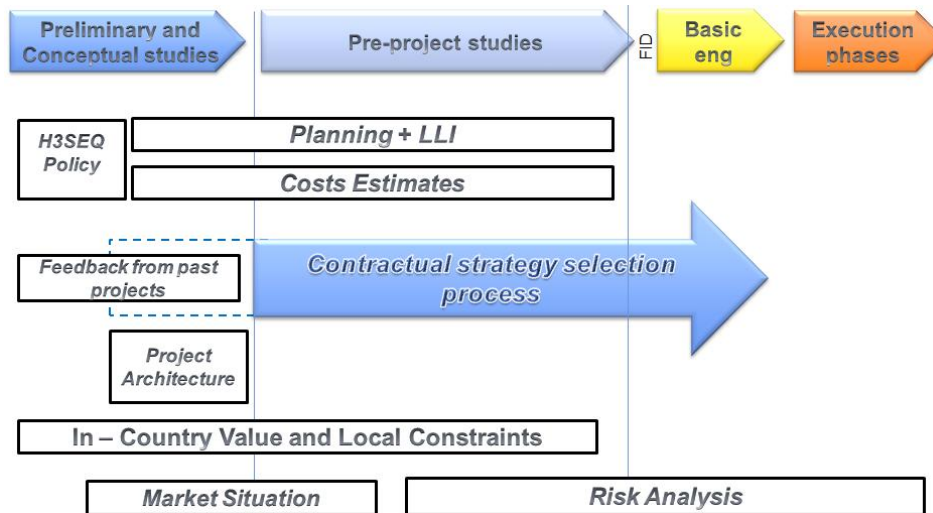


Figure 8 - Drivers that influence the design of a contractual strategy

1. **“In-country” value and local constraints.** Prior the development of an oil field, it is important to consider the expectations of the host country. These expectations can affect directly the contractual strategy to be adopted, especially when local contractors are imposed to the company. In addition, to improve the image of the company, it is very important to participate in the economic and sustainable development of communities and territories where the company operates. To achieve this goal, TOTAL develops actions such as: support plans for local development and implementation of local development projects.
2. **H3SEQ Policy.** At early stage of preliminary studies, TOTAL establishes the H₃SEQ policy to undertake during the operation of the project. It consists on designing laws, rules, guidance and processes to help protect employees, and the environment from harm. However, the compliance with H₃SEQ policy standards is important for oil and gas companies, this may play a major role on the contractual strategy selection (contracts terms and perimeters, selection of a type of contract, selection of a contractor).
3. **Project Architecture.** Defining project architecture aims to provide the needs in terms of facilities, equipment, materials and services to set up for the operation of the hydrocarbon deposit. The knowledge of the architecture is essential to the design of the contractual strategy. Indeed, the architecture has a direct influence on the market situation and provides information on scope uncertainty, which are both key decision drivers to the selection of a contractual strategy.

- 4. Market situation and contractors capabilities.** Throughout the bidding process, TOTAL will meet first with a number of potential suppliers to discuss their availability, and then negotiate the clauses of the contracts with the chosen ones. It is important to know early enough, what are the market situation and the capabilities of potential suppliers, which will respond to an eventual bidding. Indeed, the split of the project into contracts' perimeters and the selection modes of contractors are highly influenced by the number of suppliers and their skills.
- 5. Planning and Long Lead Items.** TOTAL makes schedule estimates for the development time of each equipment, elementary-object and object, from its basic engineering to its commissioning. These estimates can detect critical items called Long Lead Items (LLI), the equipment for which the periods of design and manufacturing are the longest; they will be conceived in advance by private individuals to avoid schedule delays. The completion time of an upstream development project depends strongly on project split, the selection mode of CTRs, and the types of contracts, decided during the design of the contractual strategy. Schedule estimate is therefore a key performance index to the evaluation of a contractual strategy.
- 6. Costs estimation.** Similarly to the schedule, TOTAL makes cost estimates for equipment, objects but also EPC (engineering, procurement, construction) contracts. Once the project architecture defined, it is completed by the cost base of each elementary object, for which an estimation of its EPC cost is made. The estimated elements are as follow:

 - The procurement and transportation of bulk and raw materials;
 - The construction works on yard, installations, and indirect costs of construction;
 - The costs of studies, engineering, and sites supervision;
 - The costs of project management.

These elements determine the EPC cost, to which is added the company cost of capital and the contingencies. Costs estimation is also a key performance index to the evaluation of a contractual.
- 7. Risk analysis.** During contractual strategy identification, TOTAL identify risks and assesses their level of criticality, that is to say their potential impact on the performance of the project in terms of cost and schedule, either positive or negative. The risks can be of different natures: they can appear inside the perimeters of a contract, on the interfaces between two contracts, interfaces between two contractors, a contractor and the Oil Company, etc. However, TOTAL focuses on execution risks and does not give enough importance to the risks encountered while defining the contractual strategy. We believe that the impacts of the risks on project's performance in terms of cost and schedule vulnerability are also key performance indexes.
- 8. Feedback from past projects.** Feedbacks allow to learn from mistakes made on past projects and to do not reproduce them; they also help to provide more accurate assessments of the different pieces of a contractual strategy and their interfaces.

1.3.3. Total's contractual strategy selection process

1.3.3.1. The PNG project: an illustrative example

In order to illustrate and clarify the concepts and steps regarding the contractual strategy selection process, we will make use of the PNG development project as an example. The PNG ELK Antelope project is an onshore LNG development project that took place in Papua New Guinea. The scope of this project is briefly introduced on Figure 9:

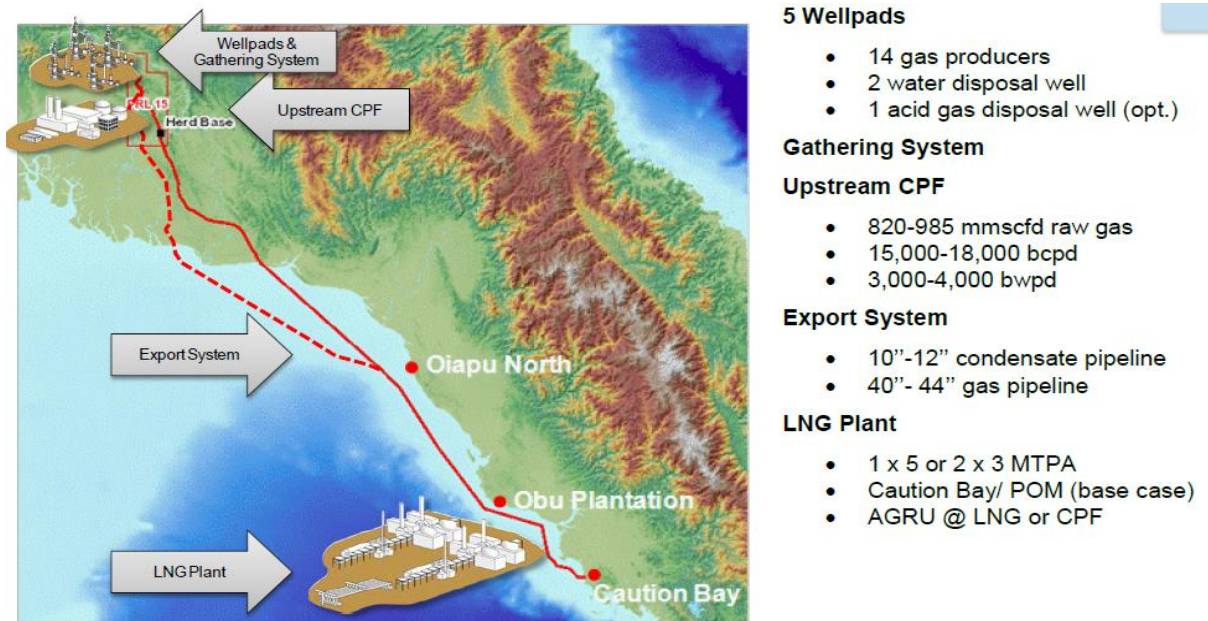


Figure 9 - PNG project scope (source TOTAL)

The project is constituted of the following objects:

- **Upstream Centralized Processing Facility (CPF):** it provides crude oil and gas separation, intermediary storage of oil, gas and water, as well as export support;
- **Wellpads:** they represent land areas that have been cleared for the installation of drilling rigs. The Wellpads contain gas producers, water disposal wells, and an acid gas disposal;
- **Gathering System:** also known as Flowlines, they are large diameter pipes for connecting the Wellpads to the CPF;
- **Export System:** the system contains onshore and offshore gas export pipelines; used to export natural gas from the CPF to the LNG plant.
- **Liquefied Natural Gas Plant (LNG):** it is a facility used for gas purification and liquefaction. The PNG plant contains:
 - *LNG process:* an onshore gas processing plant;
 - *LNG tanks:* used for the storage of liquefied gas;
 - *Power plant:* an industrial facility for the generation of electric power through generators to control the LNG process;
 - *Jetty:* a land structure built to bear LNG facilities.

1.3.3.2. The steps of the CS selection process

Starting from the architecture of the project (materials, equipment and services), the contractual strategy (CS) selection process represents all the steps leading to the selection of a relevant CS. As shown in Figure 10, it goes through 3 phases: (1) the identification phase: in which a number of workable alternatives are identified; (2) the evaluation phase: in which the identified alternatives are evaluated, according to a set of criteria; (3) the selection phase: in which a proposal of a contractual strategy is made. During each phase a number of drivers are taken into consideration, some are used for the identification phase (Local constraints, H3SEQ policy, Project architecture, Market situation, Feedback from past projects), others are used to estimate and evaluate CS alternatives during the evaluation and selection phases (Cost estimates, Schedule estimates, Risk uncertainty from different kinds and natures).

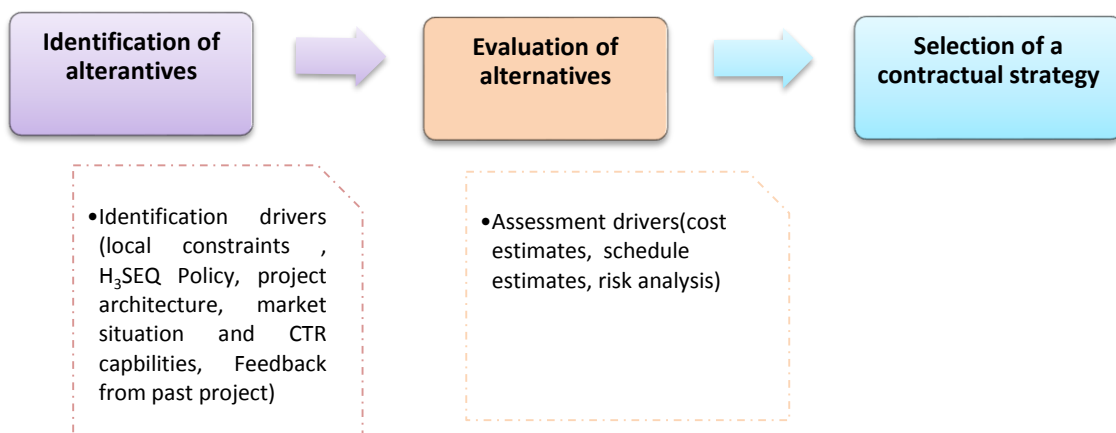


Figure 10 – Steps of the contractual strategy selection process within TOTAL

In what follows, we describe each step by relying on the PNG project. The different elements and results were given by an internal document from the company.

Step 1: Identification of the contractual strategy options

Once the project architecture is defined, the identification phase starts by designing the project architecture matrix (see Figure 3). It consists in defining: (1) the elementary objects, which can be a combination of equipment, services, materials or installations; (2) the objects, which is a gathering of several elementary objects; 3) the phases, which represent the life cycle of each object (Basic Engineering, Detailed Engineering, Procurement, Construction, Transport and Installation, and Commissioning). The architecture matrix of PNG project is depicted in Figure 11.

Project Management		Basic Engineering (BE)	Detailed Engineering (DE)	Procurement (P)	Construction (C)	Transport & Installation (T&I)	Pre-Commissioning (PCom)	Commissioning (Com)
upstream facilities (UF)	CPF Wellpads (WP) Infield Flowlines (FL)							
Pipeline (PL)	Onshore Gas Export Pipe (OnP) Offshore Gas Export Pipe (OffP)							
LNG facilities (LNG)	LNG process (Prc) LNG tanks (Tks) Power plant (PP) Jetty							

Figure 11 - PNG project architecture matrix

- The Centralized Processing Facility (CPF), Wellpads, and Flowlines were gathered in one object, named “Upstream Facilities”;
- The export System containing the elementary objects Offshore gas export pipe and Onshore gas export pipe was named as the “Pipeline” object;
- The LNG plant containing the elementary objects LNG process, LNG tanks, Power Plant and Jetty was named as the “LNG facilities” object.

Each of these elementary objects/ objects has the same life cycle.

1. Identification of contractual configurations

Once the matrix designed, the first step is to identify a relevant number of CS alternatives. To do that, on PNG project, the company identified first what is called feasible contractual configurations (CC). A CC is a combination of a temporal cut, a selection mode and a type of contract. For this project, six contractual configurations were considered, they are as follow:

- **EPC LS:** once the basic engineering performed, an entire object assembly is awarded to one contractor, with a Lump sum type of contract;
- **EPC with C not fixed:** once the basic engineering performed, an entire object assembly is awarded to one contractor, with a Lump sum contract for the phases detailed engineering, and procurement, and a Reimbursable contract for the construction phase;
- **EPC with Open Book Tender:** once the basic engineering performed, an entire object assembly is awarded to one contractor, with complete transparency on cost and schedule basis. The contract is at some point converted to a Lump sum for the other phases;

Step 2: Estimation and Evaluation of the contractual strategy options

Once the alternatives identified, the next step consists in their evaluation. For the PNG project, the evaluation was performed according to different steps from the selection of the adequate criteria to the evaluation of elementary objects.

Selection of the set of criteria. The criticality of the elementary objects, and the performance of the contractual configurations identified in the previous step have been estimated according to the following criteria. The evaluation scales varying: (i) from “1-poorly performing”, to “3-very performing” for the contractual configurations, and (ii) from “1- not critical” to “3- highly critical” for the elementary objects (see Table 4 and Table 5).

- **Scope.** The scope is an important criterion to consider, either to select the right contractual configuration, or to assess the criticality of the elementary objects in order to help identify possible objects assemblies. It has been broken down into three sub-criteria:
 - ✓ The company’s ability to handle scope uncertainty;
 - ✓ The company’s ability to handle modification during execution;
 - ✓ The company’s ability to handle risks occurring during the project.
- **Cost/ budget reliability.** For some configurations cost estimates are more reliable than for others, as well as for the elementary objects.
- **Technical.** Some configurations or objects can be exposed to technical difficulties and complex interfaces which can affect the performance of the installations.
- **Planning.** Risky configurations or objects can cause some schedule creep, either it is before the launch of the development project, or during the execution phases of the project.
- **Local context.** Local constraints can make certain configurations or scopes difficult or even impossible to achieve. Thereby, the following criteria have been considered:
 - ✓ Ability to handle the uncertain local work environment;
 - ✓ Ability to handle complex contracting approval process.
- **Market situation.** The market situation is a key factor to determine the most suitable contractual strategy to an upstream development project. Indeed, it is important to ensure a maximum competition to obtain competitive prices, either it is at basic engineering phase or the execution phases (Detailed engineering to commissioning).
- **Company’s organization.** For some options, the oil company may not be able to manage the scope, for various reasons (Complex interfaces, lack of competencies, tools/ software, resources, etc.).

Chapter 1: Industrial Context

Estimation of Contractual configurations. The performance of the identified 6 contractual configurations on each of the criteria described above, have been summarized in Table 4 below (1 in red, means that the contractual configuration has a poor performance against the identified criteria):

	Evaluation Criteria	EPC LS	EPC (C not fixed)	EPC with OBT	EP + C	EPC _m	E + P + C
Scope (cost mgt)	Ability to handle scope uncertainty	1	2	2	3	3	3
	Ability to handle modification during execution	1	2	2	3	3	3
	Ability to handle risks occurring during the project	1	2	2	3	3	3
Cost (estimation)	Cost / budget reliability	3	2	2	1	1	1
Technical	Ability to handle interfaces during execution	3	3	3	2	2	1
	Performance garanty of installations	3	3	3	1	2	1
Planning	Performance in pre-project schedule	1	1	2	3	3	3
	Performance in execution schedule	3	2	2	1	1	1
Local context	Ability to handle the uncertain local work environment	1	3	3	3	3	3
	Ability to handle complex contracting approval process	3	3	3	1	1	1
Market	Competition/ Attraction of Basic engineering contractors	3	2	1	2	1	2
	Competition/ Attraction of contractors for the execution phases	1	2	2	3	3	3
CPY organizatio	Ability to manage the scope	3	2	2	1	2	1

Performance Indicator

	1 = Poor
	2 = Average
	3 = Good

Table 4 – Estimation of the performance of contractual configurations on PNG project

Estimation of Elementary objects criticality. The criticality of the elementary objects against the criteria described above, have been summarized in Table 5 below (3 in red, means that the criticality of the elementary object is high against the identified criteria).

	Evaluation Criteria	Upstream facilities			Pipeline		LNG facilities			
		CPF	Wellpads	Infield flowlines	Onshore export	Offshore export	Liquefaction	Cryo Tanks	Utilities / power	Jetty / Offloadi
Scope (cost mgt)	Ability to handle scope uncertainty	2	1	2	2	1	3	2	1	3
	Ability to handle modification during execution	2	1	1	1	1	3	3	1	3
	Ability to handle risks occurring during the project	2	1	1	1	1	3	3	1	3
Cost (estimation)	Cost / budget reliability	2	1	1	1	1	3	3	2	3
Technical	Ability to handle interfaces during execution	2	1	1	1	1	3	3	2	3
	Performance garanty of installations	2	1	1	1	1	3	3	2	3
Planning	Performance in pre-project schedule	2	1	1	1	1	2	2	2	2
	Performance in execution schedule	2	1	1	1	1	3	3	2	2
Local context	Ability to handle the uncertain local work environment	3	3	3	3	1	2	2	2	2
	Ability to handle complex contracting approval process	1	1	1	1	1	1	1	1	1
Market	Competition/ Attraction of Basic engineering contractors	2	1	1	1	1	2	2	2	2
	Competition/ Attraction of contractors for the execution phases	3	2	2	2	1	3	3	3	3
CPY organizatio	Ability to manage the scope	2	1	1	1	1	3	3	3	3

Scope Criticality

	1 = Small Criticality
	2 = Average Criticality
	3 = Large Criticality

Table 5 – Estimation of elementary objects criticality on PNG project

Note that the given performances may be affected by the local environment of the project, and also decision maker(s) expertise. In another context these evaluations could have been different.

We have noticed through the internal document that the evaluation phase has been limited to only the separate estimation of the contractual configurations and elementary objects. It would have been interesting to cross the contractual configurations estimations to the elementary objects estimations in order to determine and assess possible contractual strategies.

Step 3: selection of the contractual strategy options

Once the alternatives evaluated, the last step of the process consists in assessing relatively the contractual strategies, in order to come up with a proposal to the upstream development project.

Unfortunately, the comparison part is missing on the PNG document; it only states that two contractual strategy (CS) proposals have been made (see Figure 12), no information was given about the transition between the separate estimation of contractual configurations and elementary objects, and the two CS proposals.

In what follows, we discuss the faced issues and challenges during the contractual strategy selection process. Indeed, our analysis, lead to the conclusion that oil companies suffers from three recurring difficulties during the selection process: (i) there are a large number of possible contracts and contracts combinations to form contractual strategies, (ii) the difficult formalization and aggregation of criteria to estimate and evaluate the options, and (iii) the need to justify the proposed contractual strategy solution.

1.4. Industrial challenges and difficulties within the CS selection process

During the design and execution of the contractual strategy (CS) selection process, TOTAL faces several difficulties, which may have negative effects, in terms of performance and risks on the selected CS. In what follows, we detail and explain each of these difficulties.

1.4.1. Decision options generation problem

The first difficulty concerns the generation of CS options. Indeed, oil and gas companies face a large number of alternatives when it comes to define the CS of upstream development project. This is true either in the assembly of the cells of the project architecture matrix to form feasible contracts, or in the assembly of feasible contracts to form CS alternatives (for which the interfaces between contracts should be manageable by the company). Indeed, a contractual strategy (as shown in Section 1.3.1) consists in a combination of several contracts, with several alternatives for their perimeters (scopes), selection modes, and types of contract. Knowing that these options should be evaluated then compared, a group of person cannot consider all of them.

This difficulty has been detected during the identification phase of the PNG project. Indeed, only six contractual configurations, combining selection modes, temporal cuts, and types of contract have been identified, while theoretically it may be 60 possibilities (4 selection modes, 3 types of contracts, 5 temporal cuts are combined). In addition, the question of objects assemblies (when combined to feasible contractual configurations, it allows to define feasible contracts) has not been treated. Indeed, even by not considering potential objects assemblies, there are 9 elementary objects, hence, we are left with 540 (60 x 9) CS options.

Furthermore, the proposed configurations are not complete. Indeed, the types of contracts appear in certain contractual configurations (EPC Lump sum, EPC with C not fixed, EPC with OBT), but not in others (EP + C, EPCm, E + P + C). Similarly, the selection modes appear at EPC with Open Book Tender, and as Call for tender in other contractual configurations, but not in all of them. This reflects the difficulty faced by TOTAL while identifying feasible alternatives.

However, depending on some drivers (described in Section 1.3.2), the context of the project, and the experience of the decision maker(s), the number of possible options can be significantly reduced. This will be developed later.

1.4.2. Performances aggregation problem

Several drivers intervene during the design of a CS, some of them allow to assess the alternatives as evaluation criteria (as shown in Figure 10). However, the company faces challenges when it comes to formalize and aggregate them. The sources of this difficulty are numerous, among them we can cite: the presence of qualitative and quantitative criteria, the components to be evaluated (objects assemblies, temporal cuts, selection modes, type of contracts), the different levels (elementary cells, contracts, contractual strategies), the uncertainty related to their assessments (inaccurate data), a large number of alternatives to assess, etc. We were asked by the decision-makers to work on structuring a process, not working on the data and their reliability. All the estimates used all along the process are out of the scope of this PhD, they are considered as inputs.

In the PNG case, this issue appears in both evaluation and selection phases. On the one hand, the criteria were poorly formalized. Indeed, among the considered criteria, many reflect risks from different kinds and natures (related to the Scope, technical risks, Local context, etc.). However, their level of importance, probability of occurrence, and impact on the project as a whole, have not been formalized. In addition, criteria such as cost estimates and schedule estimates, which are the main drivers of upstream development projects, have not been considered to differentiate between the options. On the other hand, the aggregation of the evaluations has not been formalized; no aggregation method has been proposed to evaluate the contractual configurations and objects assemblies, neither separately nor as combinations. These two difficulties raise a third one, which is the need to justify the proposed CS.

1.4.3. Supporting and justifying the recommendations

The CS proposal has to be validated by a committee. This requires to give the justification of certain choices made throughout the CS selection process. Many choices that need to be clarified have been detected, while analyzing the selection process of PNG project.

The first ones are related to the identification phase, as only few incomplete contractual configurations are considered, based solely on TOTAL's experience on past projects. The second choices are related to the evaluation phase, in which there is no precise description on criteria formalization, and no aggregation functions to evaluate contracts and CS alternatives. The last choices and not the least are related to the selection phase, as CS proposals have been made directly using the 2 assessment tables (Table 4 and Table 5) with no evaluation crossing the contractual configurations and elementary objects or object assemblies. These choices result in non-justified contractual strategy solutions.

Interestingly, the identified difficulties are not independent. Indeed, reducing the number of alternatives will mitigate the difficulties related to their formalization and evaluation. The less alternatives we have, the less effort it is possible to put on their assessment. Moreover, using a more structured process to identify, then assess and evaluate alternatives, gives opportunities to justify the proposed CS.

1.5. Chapter Conclusion

Through this chapter, upstream development oil and gas projects have been introduced as multidimensional and complex. A critical and important phase to their success is in the design of their contractual strategy (CS), notably due to their huge budgets (up to tens of billions of dollars for some extreme deep offshore projects). The design of a right CS may save millions of dollars, based on previous experience and historical losses associated to wrong CS definition. But the question is: how to know that the proposed strategy is the most performing? A CS is the combination of several components, which may take several values depending on numerous drivers. These drivers have a significant influence on the identification, estimation and evaluation of CS alternatives. The process currently in place takes into account these drivers, but is not enough formalized and method-based to consistently lead to a performing and justified CS proposal.

The industrial aim of this work is thus to build a structured decision aiding process allowing to come up with a legitimate and robust CS proposal meeting projects' objectives in terms of cost and schedule optimization, but also in terms of risk and vulnerability on these parameters.

In the next chapter, a state of the art based on this industrial question will be introduced. It concerns preliminary concepts for elaborating a CS, and a literature review on problem structuring and decision aiding, in order to raise the research question.

Chapter 2: Literature Review and Research Questions

Introduction

The main problem tackled in this work is how to recommend a contractual strategy (CS) for a given upstream development project? As we saw in previous chapter, a CS is characterized by the combination of several components: the scope of contracts, the selection modes of contractors and the type of remuneration associated to each contract. The combination of these components often leads to an important number of CS alternatives. As a result, a natural question is how to help build and generate a manageable number of relevant strategies by taking into account project requirements and context, such as cost, time, local constraints, experience with contractors, etc. Moreover, an important step is to evaluate and judge the different options to provide the recommendation that will be potentially implemented by the company for the project under development. Several questions arise: what information should be taken into account when assessing and evaluating these options? How to combine and aggregate this information to evaluate each option? Which evaluation system should be set up to offer both an overall view of the decision process, and a precise evaluation of each considered option?

The aim of this chapter is to provide an overview of approaches that have addressed these two issues, namely the generation of alternatives, and the implementation of an evaluation and selection approach for a recommendation. These two questions are including in the definition and implementation of a global decision-aiding process.

The chapter is therefore organized as follows. In the first section, we present a general overview on Multicriteria decision aiding (MCDA), in which some basic concepts of MCDA and a model of MCDA process are introduced. In the second section we present the alternatives generation problem: the idea is to first show that, in most decision problems the question is not always simple; then we will focus on the generation of the options that interest us namely "contractual strategies". Third section is dedicated to the problem of evaluating and selecting decision options. Indeed, selecting a strategy involves various information of different natures, where decisions are judged by different conflicting criteria (aspects, dimensions), we have thus naturally focused on MCDA aggregation procedures and the problem of selecting an aggregation method to a decision problem. The information from these sections will be used to enunciate the research problem, which is to answer the two following research questions: on the one hand, the question of identification and generation of a relevant set of contractual strategy alternatives (CSA). On the other hand, the question of estimation and evaluation of CSA, in order to come up with a justified proposal to any upstream development project.

2.1. A Multi-Criteria Decision Aiding (MCDA) methodology

Organizations often face decision problems for which they are only able to use experience and judgment to make their decisions. This is due to various reasons, such as complexity, conflicting objectives, criteria from different natures and scales, multi-dimensions, etc. Tackling such problems require the implementation of a decision aiding process. To design and structure such a process, it is important that the experts analyze first the problem, and understand the requirement of the different stakeholders.

By analyzing the CS selection process within TOTAL, recurring issues have been identified related to: 1) alternatives generation problem, both at contracts and CS level, and 2) estimation and evaluation of CS options, due to the difficulty related to the formalization and aggregation of criteria, which are from different natures and scales. In order to treat the decision problem, we got interested in the literature on “Problem Structuring”.

Indeed, research conducted in the field often state that, decision aiding is not just to provide solutions to an existing decision problem; it aims to support the entire decision process, from the representation of the problem and its formulation to the final recommendation. To do so, it is essential to first understand how the decision aiding may impact the current process, the users’ decisions, actions and final results (Barr and Sharda, 1997). It is known in literature as “problem structuring methodologies” (Mingers and Rosenhead, 2004; Franco et al., 2006, Courtney and Paradice, 1993; McGregor et al., 1991). For this purpose, we have based on a framework of MCDA process (Tsoukiàs, 2008) which will be introduce in this section, but first let’s give a look at some basic concepts of MCDA.

2.1.1. Basic Concepts of MCDA

Three concepts usually play a fundamental role for analyzing and structuring the decision aiding process, namely: actions (options, alternatives, etc.), family of criteria and problem statements (decision problems). The presentation of these concepts in what follows is succinct. It aims to introduce the different elements used in this work. For more details, we refer the reader interested, in the literature on this domain (Vincke, 1992; Roy, 1996; Figueira et al., 2005, Roy and Bouyssou, 1993; Bouyssou et al., 2006; Belton and Stewart, 2002).

- **Set of actions.** When facing a decision problem, the first step may be to identify the different objects submitted to the decision aiding process.
 - **Set of criteria.** A criterion is a tool constructed for evaluating and comparing actions according to a point of view which must be (as far as possible) well defined. This evaluation must take into account for each action, all the relevant effects or attributes associated to the point of view considered. Thus, a criterion plays an important role in the process of actions evaluations. Indeed, the construction of the set of criteria is a central activity in the decision aiding process (Bouyssou, 1990, Roy and Bouyssou, 1993). It can be either the result of a direct process (creating criteria from dimensions through direct questioning of the client) or of indirect process (establishing criteria “explaining” global preference expressed by the client on examples or already known cases (Bouyssou et al., 2006; Greco et al., 2008;

Jaquet-Lagrèze and Siskos, 2001)). In this work, we shall follow the first process. Moreover, it is possible to have preferential information on the set of criteria such as degrees of importance, an order on all criteria, or a weight associated to each criterion. Such information reflects either the fact that the decision maker attaches a particular importance to each criterion or that it exists trade-offs between criteria.

▪ **The problem statements.** It represents the way in which the decision aiding must be considered (the selection of an alternative, the ranking of the set of alternatives, etc.). 4 main categories of problems are usually considered (Roy, 1985):

- **Choice problem.** In this type of problem, the decision aiding is oriented in such a way that the result is a selection of a set of “very good” alternatives which is of the smallest possible cardinality. The ideal case would be to eliminate all alternatives except one, otherwise a selection procedure is drawn up, which, if used repeatedly would provide the best alternatives. The choice problem is known as the most classic decision problem and the foundation of optimization procedures.
- **Sorting problem.** In this type of problem, the decision aiding is oriented in such a way that, each alternative is assigned into a considered “appropriate” category among a set of pre-defined categories. The choice of the categories is justified by the type of judgment and treatment that one would like to make on alternatives.
- **Ranking problem.** In this type of problem, the decision aiding is oriented in such a way that, the result is a ranking of the set of alternatives from best to worst, generally after comparing alternatives pairwise. A ranking procedure is used and leads to a recommendation of a partial or complete order of classes formed by alternatives considered as being equivalent.
- **Description problem.** In this type of problem, the decision adding is oriented in such a way that the result is the identification of a set of potential alternatives or criteria. This problem is often combined with one of the three decision problems already mentioned.

▪ **The concept of aggregation method.** It represents the tool for performing the desired treatment on the set of alternatives, in order to offer a solution to a mathematically formulated problem. They are detailed in the following paragraph.

2.1.2. A model of MCDA process

A decision aiding context is quite different from the decision making. In fact, they are two different situations (Tsoukiàs, 2008; Bouyssou et al., 2006). In a decision making context we are only concerned by the decision maker (DM) activities and the hypothesis that he is endowed with decision power and therefore he is responsible for the decision to make. In such a setting, the DM might use a decision theoretic tool in order to establish potential actions to undertake. However, in a decision aiding situation there are at least two different actors: the client (or DM) and the analyst, both playing different roles with respect to the concerns of the client. The goal of such a context is to arrive to a consensus between the client and the analyst. On the one hand, the client has a domain knowledge. On the other hand, the analyst has a methodological knowledge that is domain independent.

In what follows, we will try to introduce a general description of what such a decision aiding process is. We refer to the model introduced by (Tsoukiàs, 2008) (see Figure 13):

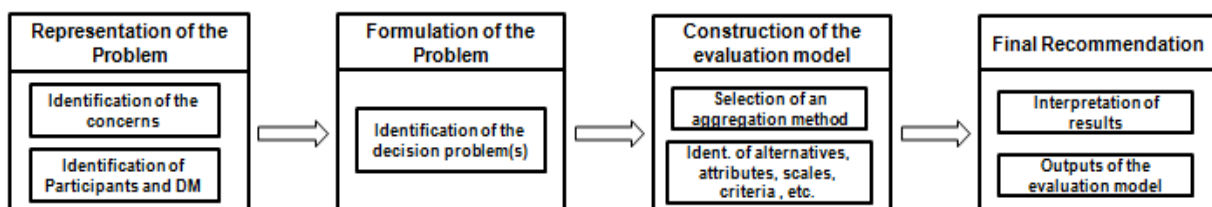


Figure 13 – A 4-step decision aiding model for complex decision problems (Tsoukiàs, 2008)

The model can be described by four artifacts:

1. **The representation of the problem.** This first step aims to identify the participants involved in the decision process and their role, the decision maker(s) with which the analyst must interact, as well as the concerns of the problem. This step allows, on the one hand, a better understanding of the position and the role of each one in the decision aiding process, on the other hand, a clarification of the needs, facilitating the interaction between the DM and the analyst.
2. **The formulation of the problem.** This second step aims to identify the decision problem. As seen in Section 2.1.1, there are four types of decision problems (Roy, 1985): choice, sorting, ranking and description.
3. **The construction of an evaluation model.** This third step consists of building the set of alternatives, identifying the set of criteria to evaluate the alternatives, the measurement scales associated to the criteria, and an aggregation method for carrying the required treatments to provide solution(s) to the faced decision problem(s).
4. **The final recommendation.** It is the final deliverable which translates the output of the evaluation model into the decision maker's language. The analyst must ensure that the results provided by his model are consistent and meet the expectations of the decision makers. Moreover, for the model to be validated, the proposed decision aiding process should respect any decision process that is currently implemented within the organization.

Chapter 2: Literature Review and Research Questions

In our context, the proposed process must respect the three phases of the CS selection process: identification, evaluation and selection (see Chapter 1, Section 1.3.3)

Thereby, this generic model served as a basis for building a decision aiding process for CS selection. It allowed identifying two distinct parts of our research: (1) the alternatives generation problem, and (2) the performances aggregation problem. The literature concerning both parts is discussed in the following two sections.

2.2. Generating and constructing decision options

The components that constitute a contractual strategy (CS) may take several values; the instantiation of each one to elaborate the CS of an upstream development project is largely influenced by the project context, which can be described in the form of drivers (discussed in Chapter 1, Section 1.3.2). This section aims to bring first answers to tackle the question of generation and construction of CS options. We will address this issue from two perspectives.

First we will position ourselves in the literature, notably in problem structuring, to have a general view on the alternatives generation problem. Then we will focus on how to instantiate the CS components given the project context: (i) the scope of contracts, for which research conducted in Work Breakdown Structure, Product architecture and Matrix based methodologies such as Domain Mapping Matrices (DMM) and Design Structure Matrices (DSM) appear to be suitable, (ii) the selection modes of contractors, and (iii) the types of contracts, for which we present analyzes shared in Contracts in the Construction industry to understand under what conditions a selection mode, respectively a contract type is more appropriate than another.

2.2.1. A general view on the alternatives generation problem

Generally, decision makers who seek to engage in a decision aiding process do so in the belief that they have a clear understanding of the set of alternatives (the set of relevant criteria) open to them, more often than not, it is not so simple (Belton and Stewart, 2010). Indeed, it may happen that this set must be designed, in the sense that such a set does not exist directly as it is, but must be elaborated and thought out from existing or collected information, it is known as problem structuring.

In Multicriteria Decision Analysis field (MCDA), a large literature has been devoted to problem structuring (Belton and Stewart, 2002; Bouyssou and al., 2006; Buchanan and al., 1998; Corner and al., 2001; Courtney and Paradise, 1993; Eden, 1988, 1994; Keeney, 1992; Landry and al., 1983; Rosenhead, 1989; Rosenhead and Mingers, 2001). Initially, MCDA discipline was developed with focus on methods; little attention was paid to methodology or process. However, there have been important advances in this field since, as consideration of methodological aspects started to grow, an important attention is given to the structuring of MCDA models (Belton and Stewart, 2010). The idea is that trying to fit a decision situation to a given MCDA model may result in solving the wrong problem correctly (Bouyssou and al., 2006).

The importance of problem structuring for MCDA is now widely recognized. (Keeney, 1992) wrote “what is missing in most decision making methodologies is a philosophical approach and methodological help to understand and articulate values and to use them to identify decision opportunities and to create alternatives”. It is a familiar and significant saying that a problem well put is half solved (Dewey, 1938). Furthermore, many authors stressed that problem structuring is now considered both as a mean of establishing potential alternatives and as an integral part of the MCDA framework (Belton and Stewart, 2002; Bouyssou and al., 2006). Thereby, several problem structuring methodologies have been proposed, dealing with alternatives generation problem.

Keeney (1992) proposed the Value Focused Thinking (VFT) method, which consists in using the decision frame, defined by the decision context and objectives, as basis for alternatives generation prior the evaluation of selected alternatives. He pointed the inter-related nature of the three components (frame, objectives and alternatives), as a modification of the frame can lead to a differentiated set of objectives and alternatives, which lead to an incorrect modeling. Other authors stressed these interactions, the need to explore them, and employ them in the decision aiding process. The “dynamic decision problem structuring” method, proposed by (Corner and al., 2001) aims to do just that. It offers a process of iteration between value focus thinking and alternative focused thinking (see Figure 14).

Other structuring problem methods have been proposed in the literature, the best known are: Cognitive mapping (See Eden, 1988, 1994; Eden et al., 1983), Strategic choice (see Friend and Hickling, 1987; Friend and Jessop, 1969), Soft Systems Methodology (Checkland, 1981), and Integrated approaches (see Belton and Stewart, 2002). The latter one aims to consider within the decision aiding process the use of diverse approaches and techniques, driven by the problem situation and not by a particular method.

To summarize, alternatives generation is an important step in many decision problems, and must be considered more seriously, as it constitutes the set of possible decisions. While identifying alternatives, one should take into account the inter-relation with both the decision context and project’s objectives. This not only helps to identify a relevant set of alternatives, but also to better represent the problem situation.

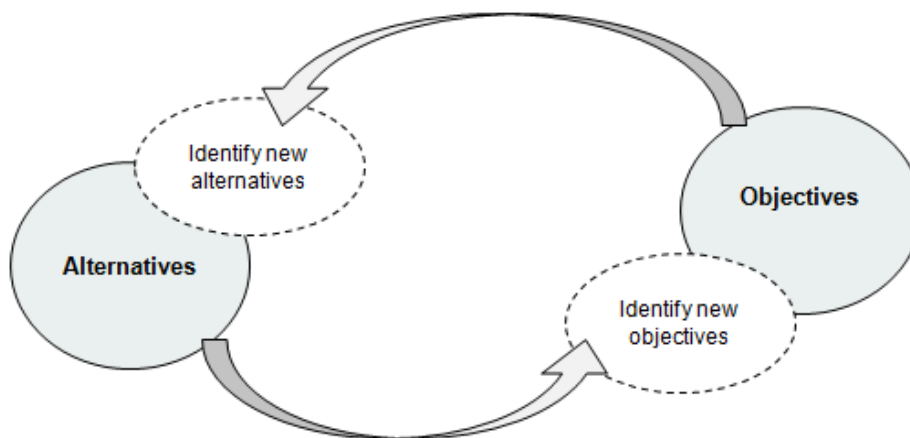


Figure 14 - Modelling of the dynamic decision problem structuring method, proposed by (Corner and al., 2001)

2.2.2. A focus on the components of contractual strategy options

In this work we want to answer the question of how to build contractual strategy (CS) options taking into account both its components (contracts scope, selection modes, and types of remuneration) and the requirements of the development project, regarding its context. Before answering the question, let's give a look at the literature to see how the components are characterized, and what their place is in a CS. The idea is to identify the information and constraints that may help to specify the values of each component, but also the possibilities of combining them to construct potential CS.

2.2.2.1. *The scope of contracts*

A first element that characterizes a CS is the definition of the perimeters of future contracts involved in the development project. Indeed, upstream development projects are complex, involving technical objects from different characteristics, kinds and natures, it can be structures (Platforms, FPSO, pipelines), equipment (subsea manifolds, wellheads, drilling rigs), or even services in some cases (catering, supply of critical items, operation services). In addition, the elaboration of an object entails several phases (engineering, procurement, construction, etc.), and calls for skills from various fields; this is why the scope is divided into sub-systems. Oil companies must therefore decide the scope of each contract to carry out upstream development projects.

The methodology used to split the scope into technical objects and phases in the oil and gas industry is based on Work Breakdown Structure (WBS), well known in the literature (Chen and al., 2005; Danilovic, 2006; Haughan, 2002). The definition of a WBS aims to design the product architecture (Dahmus and al., 2000; Sosa and al., 2000; 2004, Stone and al., 2000), which defines in our case, the objects assemblies and temporal cuts of the projects and therefore allows the delimitation of contracts perimeters.

As indicated by (Danilovic, 2006), “the approach to manage complexity of a product is by a systematic decomposition of its components and elements into sub-systems”, however, the number of created contracts are all the more important. Indeed, project complexity increases gradually as the number of suppliers are involved in the project (Simon, 1962), on the other side, of few suppliers results high-priced contracts, maximizing the risk of costs and schedule creep, with less maneuver left to the oil company.

However, the product architecture is often difficult to design. To handle this complexity, Design Structure Matrix (DSM) for comparing two elements from the same domain and Domain Mapping Matrix (DMM) for comparing elements from two different domains (Browning and al., 2006; Danilovic and Browning, 2004; Steward, 2013; Eppinger and Browning, 2012), offer a global visualization of the project. They allow to perform analyzes in order to detect compatibilities, dependencies and differences between sub-systems. The project contractual strategy matrix crossing elementary objects to phases is an example of a DMM. The vulnerability of interfaces between two contracts can be represented by a DSM.

This literature enabled us to become familiar with tools used to identify and represent the scope of future contracts through the design of project architecture, but also to be aware of the importance of drivers such as compatibility and dependency in the identification of the contracts perimeters.

2.2.2.2. *The selection modes of contractors*

Many authors agree that the tendering process leading to the selection of a contractor is an important step to the design of a performing contract, especially in the construction industry (Perry, 1985; Aboushiwa & Bower, 2000; Smith, 2002). (Dhanushkodi, 2012) analyzed the benefits and drawbacks of each selection mode faced in construction projects, referring particularly to the works of (Wearne, 1989) and (Masterman, 2003). By adapting these works in the context of oil and gas upstream development projects we drew the pros and the cons of each selection mode, they are as follow:

- **Call for Tender (CFT).** The CFT when there are no constraints is the most advantageous selection mode. Indeed, it is the selection mode that insures the greater competition, and allows obtaining competitive prices. However, its design is completed before the tendering process, this implies a state of scope clarity;
- **Design Competition (DC).** The DC implies an undivided responsibility for both design and construction, it is therefore recommended for complex or uncertain design. Moreover, the fact that the design is performed by several contractors helps the oil company to have a clearer vision on the specification of its needs, especially in terms of construction. However, suppliers' competition is necessary to the realization of this selection mode;
- **Open Book Tendering (OBT).** The OBT is relevant when there is high scope uncertainty particularly at design phase; it allows clarifying the scope in order to make accurate costs and schedule estimates for the following execution phases. However, the potential thread is when the Company has trouble to specify their needs after the achievement of the design. This selection mode is inevitable when few contractors are available;
- **Single Source (SS).** The SS is usually carried on when faced constraints, such us: no competition or very little, the host country imposes a local contractor, very critical schedule, etc.

Thereby, one sees here the importance of design uncertainty and the presence of suppliers in the choice of a selection mode. As it is illustrated in Figure 15.

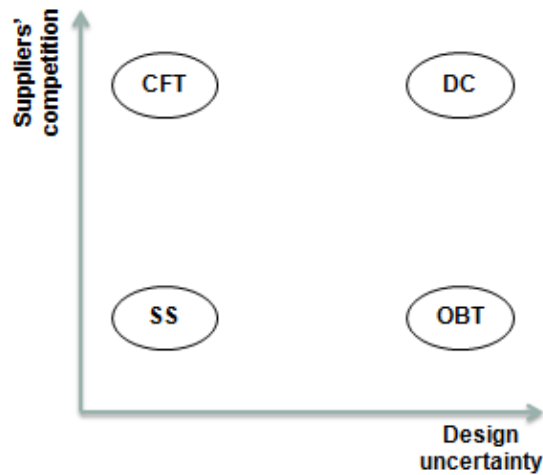


Figure 15 - Selection modes vs. Design uncertainty and Suppliers' competition

The literature made in the construction industry enabled us to draw our own analyzes and conclusions on the proper context of each selection mode. Indeed, it allowed us to highlight the importance of drivers such as Suppliers' Competition and Design uncertainty in the choice of a selection mode to a contract perimeter.

2.2.2.3. The types of contracts/ remunerations

In the construction industry, a contract/ contracting strategy is the term used for the process leading to the selection of a remuneration type (Vesay, 1991), it defines an agreement between 'The Client', as the party ordering goods, and the 'Contractor', as the party delivering goods in exchange of a remuneration and in a certain delivery time (Dhanushkodi, 2012). According to (Elbeltagi, 2009), contracts can vary from a fixed price to a totally reimbursable contract. He believes that the selection of a type of contract for a given scope highly depends on the level of risk in it. We have represented in the following scheme each contract type compared to the level of risk for which it is most suited (Figure 16).

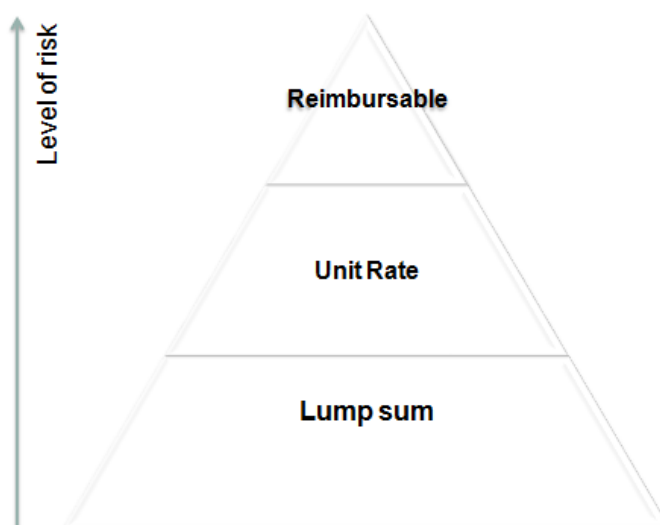


Figure 16 - Contracts types vs. Risk level

Thereby, we have the following cases:

- **Low level of risk.** In the case of scope clarity, cost and schedule estimates are accurate. The best option is to opt for a lump sum contract, which consists into an agreement of a fixed price before the execution of the contract;
- **Average level of risk.** In the case of an average level of risk, cost and schedule estimates are inaccurate. The best option is to opt for a unit rate contract, which consists on a measurable payment by milestones, according to the realized quantities;
- **High risk uncertainty.** In the case of scope uncertainty, cost and schedule estimates are unpredictable. The best option is to opt for a non-risky reimbursable contract, for which the contractor is reimbursed at the end of the deliverable.

Thus, the literature on contracting strategy showed that the selection of a type of remuneration is highly related, except for constraints, to the level of risk associated to the scope.

To summarize, we have been able to see in this section that the question of generation of alternatives is not always simple, which is the case of our encountered problem. Indeed, even if the literature allows providing information on how to instantiate the three parameters separately, there is a lack in the literature, treating the contractual strategy alternatives generation problem, combining the three parameters. However, independently of the determination of the scope of contracts, works have been done to analyze and highlight the encountered problems during the contracting strategy formation process in the oil and gas industry (see for instance (Ikhinmwin, 2014)), such as: (i) the CS selection processes are too lengthy and perspective, (ii) the risk of selecting a suboptimal CS is very high, and (iii) oil companies tend to prefer Lump sum contracts. Through our approach we aim to provide solutions to the mentioned problems.

We discuss in the next section the performances aggregation problem, and the relevance of the MCDA field to estimate and evaluate contractual strategy alternatives. We will make a literature review on the selection of an aggregation method for Multicriteria decision problems.

2.3. Evaluating and selecting decision options

2.3.1. MCDA aggregation procedures

In the literature, there are two main families of MCDA methods: the first represents the methods using a single aggregation criterion, the second represents the methods based on an outranking relation. We present hereunder the main characteristics of the two families:

- **Methods using a single aggregation criterion.** The principle of these methods consists in the aggregation of the performance of each alternative into a single criterion. It enables to make a direct comparison between alternatives. These methods exclude therefore the incomparability problem and give a structure of complete order, easy to use in various decision problems. The most popular methods include the weighted sum, the AHP (Saaty, 1977; 1994), UTA (Jacquet-Lagrèze and Siskos, 1982), UTADIS (Devaud and al., 1980), to cite few.
- **Methods based on an outranking relation.** The principle of these methods is to compare alternatives pairwise on the basis of an outranking relation. According to (Roy, 1985), an alternative A outranks an alternative B if, given the preferences of the DM, the quality of the evaluations, and the nature of the decision problem, there are enough evidence to admit that A is at least as good as B, and there are no important arguments to the contrary (veto). The most popular outranking methods are ELECTRE (Roy, 1978), PROMETHEE (Brans and Mareschal, 2002), RUBIS (Bisdorff and al., 2008), to cite few.

Other Families of MCDA methods are mentioned in the literature. (Guitouni and Martel, 1998) distinguish the elementary methods (weighted sum, lexicographic method, maximin method ...) and the mixed methods, which are not totally of one or the other approach presented above (Borda, Condorcet, QUALIFEX procedure ...). Rule-based methods, such as DRSA (Greco and al., 2001) have also been proposed, whose objective consists in inferring a set of rules of the type “if condition then decision”. In other works, such as in (Roy, 1985), interactive methods are also introduced. They successively carry out calculation and dialogue phases. They first determine a starting solution and then try to find a better one around that solution, searching a better result to model the preferences of the DM.

In this work, we are interested in the methods based on an outranking relation, as the alternatives (options) need to be compared in order to screen out the less performing ones, and rank the most interesting ones.

2.3.2. The problem of selecting an aggregation method

As discussed in Chapter 1, TOTAL faces difficulties during the contractual strategy (CS) selection process. These issues prompted the company to rethink their process and express their need of a justifiable and robust decision aiding process. This involves the identification of a set of alternatives, criteria, measurement scales, but also aggregation methods.

In the field of Multicriteria Decision Aiding (MCDA), numerous aggregation methods have been presented. However, despite the development of a large number of methods, none can be considered appropriate for all decision aiding situations. Indeed, Belton and Stewart (2002) consider that the choice of an appropriate method is one of the most difficult problems that the analyst faces in MCDA. To this end, several guidelines have been proposed in the literature, they are detailed in Table 6.

Guidelines	Description
<i>(Roy and Slowiński, 2013)</i>	The guideline starts by asking a crucial question, whose answer leads to a list of applicable MCDA methods, it is followed by five key questions, and secondary questions. Responding to these questions leads to a choice of the most appropriate MCDA method.
<i>(Guitouni and Martel, 1998)</i>	The guideline' aim is to establish a conceptual framework articulating seven guidelines for the choice of an appropriate method, emphasizing the importance of structuring and characterizing the decision situation. It proposes to define the decision situation, and then to choose an appropriate method according to the result.
<i>(Deason, 1984)</i>	The model is based on a set of descriptors to characterize the decision situation. It considers four steps: 1) defining the list of MCDA methods, 2) selecting a subset of descriptors, 3) eliminating MCDA methods based on the descriptors, 4) defining additional criteria leading to the selection of a MCDA method.
<i>(Gershon, 1981)</i>	The model starts by defining criteria gathered in four categories to evaluate the MCDA methods. Once the decision situation is defined, a subset of weighted criteria is selected, for which a distance from the maximum rate on criteria scales is calculated. The MCDA method with the minimum distance from the maximum rate is then selected.
<i>(Teclé, 1988)</i>	The model of Teclé consists on the following steps: 1) defining the objectives, 2) selecting criteria adapted to the objectives, 3) defining the list of MCDA methods, 4) evaluating the methods on the basis of the selected criteria, 5) defining weights on criteria, 6) selecting a MCDA method based on its performance on the criteria using the Teclé Composite Programming algorithm.

Table 6 - Guidelines helping the choice of a MCDA method to a decision problem

Chapter 2: Literature Review and Research Questions

Other guidelines exist in the literature, albeit they are not detailed here. Kornyshova and Salinesi (2007) propose a state of the art of nine other approaches helping the choice of an MCDA method. To compare the approaches, the authors suggested a comparison framework composed of criteria that describe the characteristics of the aggregation methods. The article concludes that there is no “good” selection approach, and that one can develop his own approach, depending on the faced decision problem, by taking into account some requirements.

Thus, in order to build an approach helping the choice of aggregation methods to our decision problems, we have drawn on the guidelines and models presented above, as well as a number of case studies (Al-Shemmeri and al., 1997; De Montis and al., 2000; Polatidis and al., 2006; Sadok and al., 2009). We present our work in the next chapter (see Section 3.3).

Now that we have introduced the literature regarding our work, in the next section we will formulate and raise the research questions.

2.4. Research questions

As previously mentioned, during the CS selection of upstream development projects, TOTAL encounters several difficulties related to: the identification of a reasonable and relevant set of alternatives, alternatives assessment, the evaluation and the selection of these alternatives, and finally the justification of the proposed solution. The encountered issues during the CS selection process lead to the definition of the following requirements:

- a. The assembly of cells to form relevant contracts.** There are large number of possible cells assemblies from the project architecture matrix to form contracts perimeters to an upstream development project, knowing that theoretically this number is combinatory. In addition, the selection modes (CFT, DC, SS, and OBT) and types of contracts (LS, UR, and R) that are associated to each contract perimeter are also to consider, which increases the number of alternatives.
- b. The assembly of feasible contracts to form workable contractual strategy alternatives (CSA).** To form a workable CS, it is not enough just to determine the contracts, the interfaces between the contracts should also be considered, and manageable by the company. In addition, the assembly of the contracts should cover the whole scope of the project. Thereby, since there are large number of feasible contracts and interfaces, an important number of contractual strategies can be built.
- c. Identifying criteria and measurement scales to estimate CSA.** The performance of a CSA depends on criteria, such as: cost, schedule, level of uncertainty or local content. These criteria are from different kinds and natures, and they are expressed by diverse and different measurement scales, which make the formalization of the evaluation criteria difficult to realize. Thus, our work is to identify with the DMs a set of generic criteria and their associated measurement scales.
- d. Building aggregation methods to evaluate CSA.** In addition to the formalization of criteria to estimate CSA, TOTAL faces another issue related to the aggregation of the estimations, whether it is to assess alternatives individually or in comparison in order to come up with a robust and appropriate proposal.

The two requirements (a and b) rise a first problem, which consists on how to generate a relevant set of CSA. The last two requirements (c and d) lead to the identification of a second problem, which consists on the building of a system of evaluation and comparison of CSA.

Constructively, following these difficulties, we were able to identify a global research question, associated to two sub-questions, as evidenced in Figure 17:

How to build a structured decision aiding process to assist selecting contractual strategy?

To answer this question, we have started by analyzing the CS selection process, in order to establish its different steps and thus to unseal the faced problems. The construction of the decision aiding process in order to reply to the question “which contractual strategy to recommend?” has raised the following two sub-questions:

1) How to identify/generate a set of relevant contracts and contractual strategy alternatives?

As mentioned above the requirements related to “the assembly of cells to form relevant contracts” and “the assembly of feasible contracts to form workable CSA” lead to the identification of the first research question, for which the literature introduced in Section 2.2, will serve as basis to our reflection in order to bring solutions.

2) How to estimate and evaluate identified alternatives in order to make a recommendation?

The requirements related to “Identifying criteria and measurement scales to estimate CSA” and “building aggregation methods to evaluate CSA” lead to the identification of the second question, for which the research works presented in Sections 2.1 and 2.3, will be used to bring answers to the question.

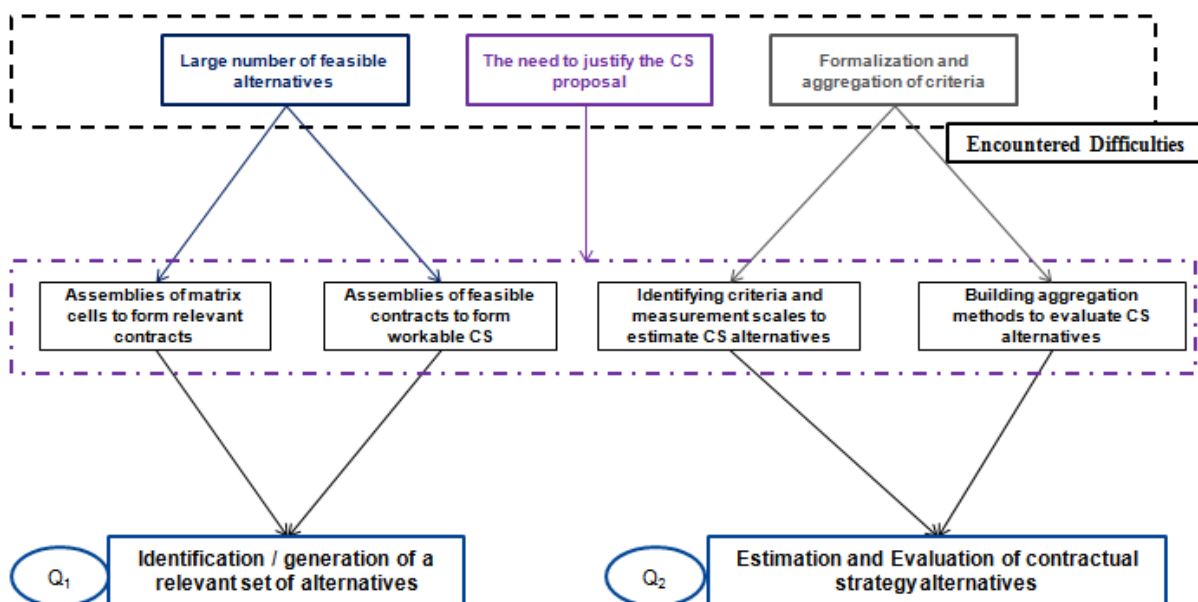


Figure 17 – Identification of research questions from the encountered issues during CS selection

Thereby, to cope with the encountered difficulties, we will rely on the existing literature, described throughout the chapter, as represented on Figure 18:

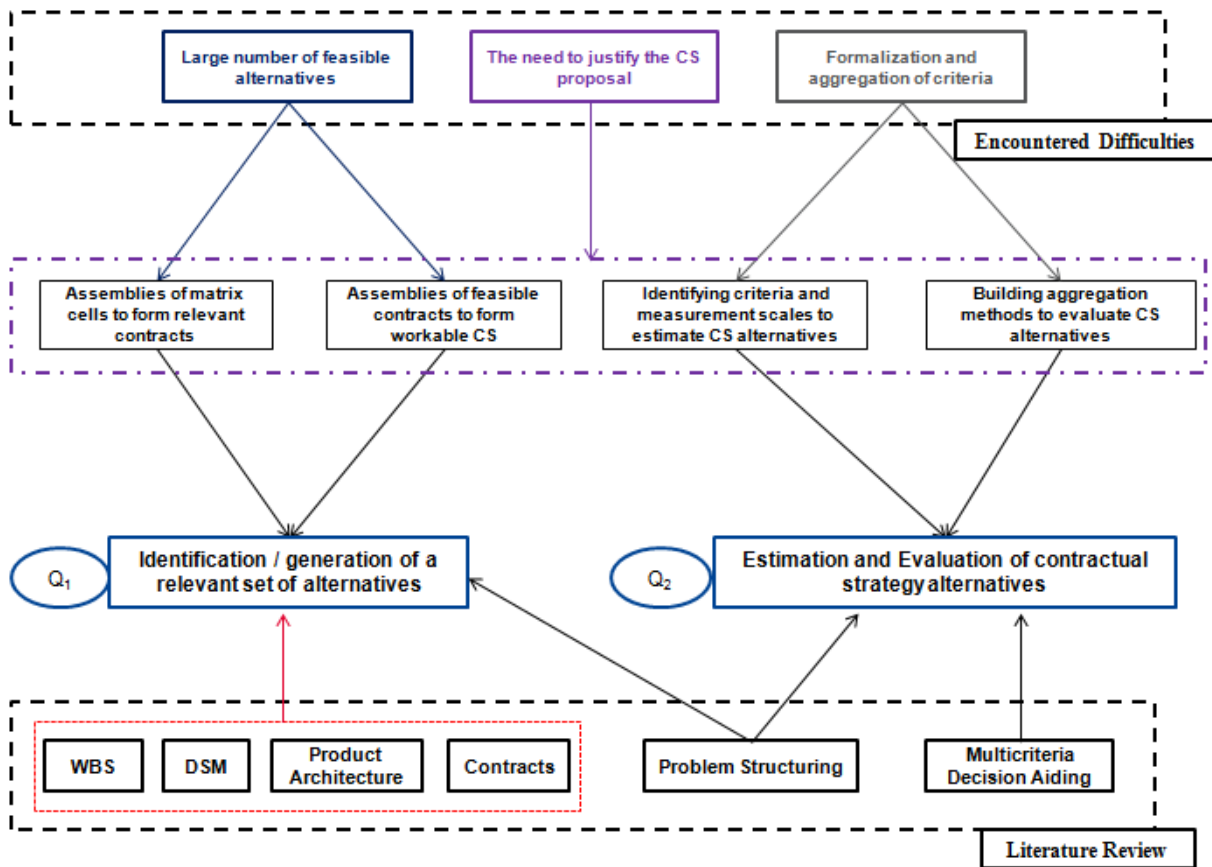


Figure 18 - Research questions and related literature

To be more specific, the literature on Work Breakdown Structure, Design Structure Matrix, Product Architecture and Contracts in Construction industry will help for the identification of a relevant set of CSA (Section 2.2), and the literature on MCDA will be used to construct aggregation methods to estimate and evaluate contractual strategies (Section 2.3). In addition, in order to build a decision aiding methodology treating both research questions, we will rely on a 4-steps descriptive-based decision aiding process to complex industrial problems (Tsoukiàs, 2008) from the representation of the problem and its formulation, to the construction of an evaluation model and final recommendation (see Section 2.1.2).

2.5. Chapter Conclusion

As a whole, the main purpose of this chapter is to give a first insight on the elements and concepts on which to base in the literature, to enunciate the research problem, dealing with the difficulties encountered during the CS selection process through the proposal of a robust and justifiable resolution system.

From the main research question, which is “how to build a structured decision aiding process to assist selecting contractual strategy?” We have been able to raise two research sub-questions:

- How to identify/generate a set of relevant contracts and contractual strategy alternatives?
- How to estimate and evaluate identified alternatives in order to make a recommendation?

To deal with the first question, we got first interested on the literature on “problem structuring”, which showed that the alternative generation problem is a crucial part of most decision problems. Indeed, in order to identify a relevant set of decision options it is important to consider their interrelation with the decision context and objectives. Then, we got interested to each of the three components of a CS, namely, (i) the scope of contracts, for which the literature on Work Breakdown Structure, Project architecture and Matrix based methodologies, gives first answers to their identification, (ii) the selection modes, and (iii) the types of contracts, for which the literature on Contracts in the Construction industry helped to identify drivers allowing to instantiate the values of the two components.

To deal with the second question, we got interested in the Multicriteria Decision Aiding field, to give a look at the aggregation methods best suited to our decision problem. We saw that the selection of an appropriate method is a difficult problem, and to cope with this difficulty guidelines and models helping the choice of an aggregation method have been proposed in the literature.

Finally, in order to treat the general question, the built of a decision aiding methodology is required, in order to bring solutions to the two sub-questions. To do so, (Tsoukiàs, 2008)’s 4-steps descriptive model, will serve as basis to our approach, whose content is described in the next chapter.

Chapter 3: A Decision Aiding Methodology for the Contractual strategy selection process

Introduction

The overall ambition of this chapter is to describe and justify the decision aiding process supporting contractual strategy selection, and the methodological choices for identification and evaluation of alternatives.

In the first section, our first proposal is presented, which is to structure the global decision aiding process for contractual strategy selection according to Tsoukiàs' 4-step model, introduced in the previous chapter (see Section 2.1.2).

In the second section, we will present our 3-level decision aiding proposal dealing with both research questions. The proposal is to progressively build and evaluate alternatives that assemble to one another at three distinct levels: Elementary level, Intermediary level and Contractual strategy level. The first and lowest level, called Elementary, consists in the identification and estimation of potential objects assemblies, followed by the temporal cut, selection mode(s), and contract type(s) associated to each potential object assembly, forming Elementary alternatives (EA). The second level, called Intermediary, consists in mapping the project scope into breakdowns, formed by one or several EA. In each breakdown, Intermediary alternatives (IA) are identified as being all possible combinations of EA covered by the breakdown. The IA are then estimated and screened out. The third and highest level, called Contractual Strategy level, consists in the identification, estimation, sorting and ranking of Contractual Strategy alternatives (CSA). They are the selection of exactly one IA per breakdown. Avoiding incompatible IA couples allows identifying a set of workable and manageable CSA. The model's goal is to come up with a justifiable and robust contractual strategy proposal.

In the third section, we will present our proposed approach to assist the selection of MCDA aggregation methods to the faced decision problems based on guidelines and models introduced in Section 2.3.2. The approach is illustrated by the steps leading to the selection of a sorting aggregation method, given that alternatives must be sorted at both Intermediary and Contractual strategy (CS) levels, in order to screen out unsatisfactory ones. The selection of an aggregation method to our ranking decision problem met at CS level is also briefly discussed at the end of the section.

Finally, some conclusions will be drawn about this chapter, which aims to have a global view on the decision aiding process that is detailed in the following chapter.

3.1. First Proposal: description of the decision aiding methodology based on Tsoukiàs (2008)

We have seen in Section 1.3.3 that the process leading to the selection of a contractual strategy of upstream development projects within TOTAL is generally developed in 3 phases: (i) *an identification phase*, which consists in the identification of all feasible contractual strategies alternatives (CSA), (ii) *an evaluation phase*, which consists in the evaluation of the identified alternatives, and (iii) *a selection phase*, which consists in the proposal of a contractual strategy after analysis of the identified alternatives.

During this process, TOTAL encounters 3 recurring difficulties (Section 1.4): (1) a large number of feasible contracts to form workable CSA, (2) Criteria formalization and aggregation for the evaluation of CSA, and (3) the need to justify the selected option.

To tackle these difficulties and help the company better manage its upstream development projects, we provide a formal 3-level process based on a 4-step descriptive model described in Section 2.1.2 (see the figure hereunder).

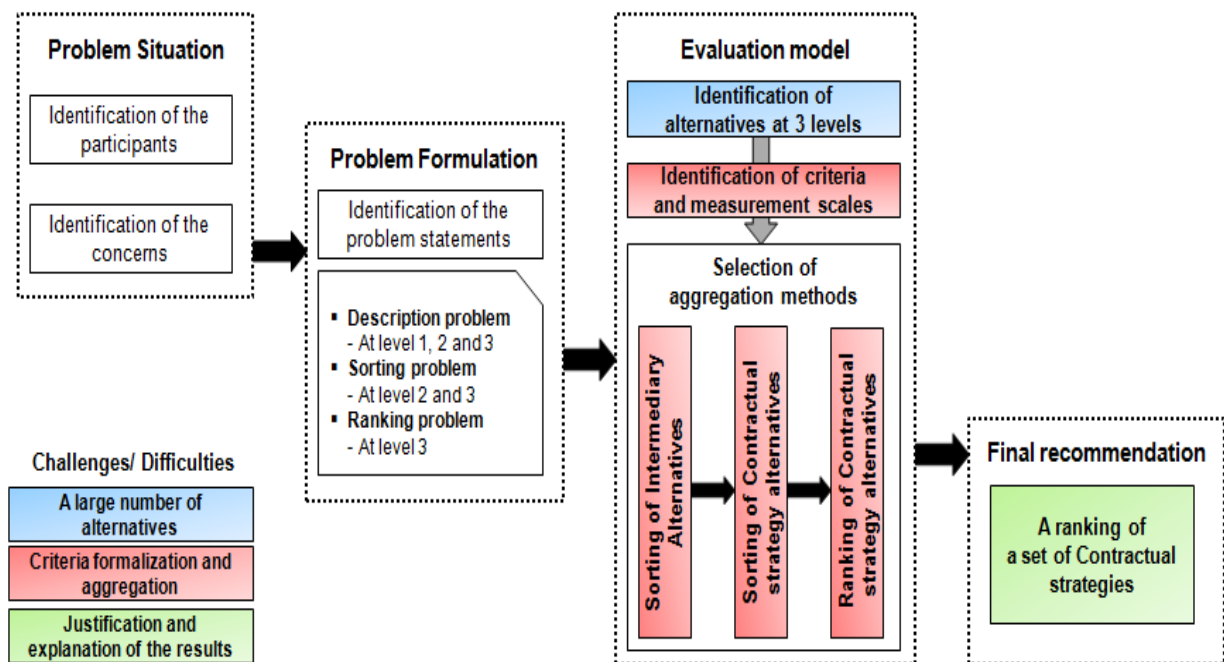


Figure 19 - Decision aiding methodology for contractual strategy selection based on (Tsoukiàs, 2008)

As shown in Figure 19, the 3-level process (level 1 for Elementary, level 2 for Intermediary, and level 3 for contractual strategy) has been identified and structured according to Tsoukiàs (2008) framework. We detail in what follows the four steps of the framework.

3.1.1. The representation of the problem situation

This step gathers the information about the participants and their objectives, and about the constraints and difficulties of the problem.

- **Identification of the participants.** The need of decision support has been formulated by two entities: 1) the Project office entity, responsible for the monitoring of the contractual strategy selection process, and 2) the Contracts & Procurement entity, responsible for market studies and setting up contracts, which cooperate with the project entity to design the contractual strategy of TOTAL upstream development projects. We collaborated during the thesis with teams from both departments but also other entities which provide data, such as, cost and schedule estimates, risk assessment studies, market intelligence studies, local industrial surveys, etc. (see Section 1.1.2).
- **Identification of the concerns.** The concerns encompass objectives, constraints and difficulties encountered during the CS selection process:
 - ✓ **Objectives:** the final aim of our decision aiding process is to provide the most performing CS to upstream development projects. The selected CS has to make the best compromise between four different conflicting objectives to minimize: (i) Cost, (ii) Schedule, (iii) Cost Vulnerability, and (iv) Schedule Vulnerability, the latter two being measured by the level of risk associated to the CS. Other objectives may be considered in certain projects, such as maximizing the value brought to the local country, or improving the image of the company. In the framework of this thesis, we have limited ourselves to the four criteria.
 - ✓ **Constraints:** The built of a workable contractual strategy is constrained by a number of drivers, presented in Section 1.3.2. Some of these drivers represent constraints, which make it possible to delimit the project context and restrict the range of possibilities, and others serve as evaluation criteria. Among the drivers representing constraints, we can cite: H₃SEQ policy, in-country value and local constraints, the market situation and contractors capabilities, the project architecture, the skills of the company to manage contracts and interfaces, etc. Some constraints will directly affect the construction of the CS, during the identification of feasible alternatives, while others intervene indirectly in an upstream phase (such as H₃SEQ policy or local constraints which affect the market situation by reducing the number of available contractors, or possible project architectures by excluding the construction of certain objects and installations).
 - ✓ **Difficulties:** three recurring issues are faced during the contractual strategy selection process, due to multiple sources (see Section 1.4), namely: (1) a large number of alternatives, (2) the estimation and evaluation of such alternatives based on criteria from different scales and nature, and thus difficult to aggregate by the advice of experts, (3) the necessity to have justified results, as the recommendations are submitted to a decision committee. These difficulties will be tackled thorough our decision aiding process, detailed in Chapter 4.

3.1.2. The formulation of the problem

In our context, the aim of the decision aiding is to provide a methodology for the selection of a contractual strategy to any upstream development project, for this end we propose a process in which multiple decision problems are formulated:

- ***One description problem.*** As mentioned in the previous chapter, our first research question seeks to identify and generate a relevant set of contractual strategies. To deal with this question and the difficulty related to a large number of feasible alternatives, we propose a 3-level modeling, in which we define alternatives that gradually assemble to one another: 1) Elementary alternatives, to determine the set of feasible contracts by making use of drivers that allow to delimit the project context (market situation, project architecture, local constraints, level of risk, scope uncertainty, etc.); 2) Intermediary alternatives, to detect incompatible interfaces between contracts and build a manageable number of contractual strategy alternatives; 3) Contractual strategy alternatives (CSA), to come up with a justifiable proposal. As for the criteria, we have identified four with the participants involved in the decision process: Cost; Schedule, Cost Vulnerability, and Schedule Vulnerability. Other criteria can be considered in some specific projects.
- ***Two sorting problems.*** To reduce the number of feasible alternatives and assessment during the CS selection process, and to deal with the difficulty related to criteria formalization and aggregation for estimation and evaluation of CSA, our contribution is to sort alternatives into predefined ordered categories, using a MCDA aggregation method at both Intermediary and CS levels. The purpose is to screen out alternatives judged “unsatisfactory”, and only keep those that can be reused to constitute a relevant set of workable CS.
- ***One ranking problem.*** To deal with the difficulties related to criteria formalization and aggregation for estimation and evaluation of CSA, and come up with interpretable and justified results, our contribution is to establish an order among the alternatives, from best to worst. The decision problem concerns the CS level in which a relevant set of CSA are compared through a MCDA aggregation method in order to establish a ranking leading to the selection of the best option.

3.1.3. The construction of an evaluation model

In this step, the evaluation model is built, which consists in the determination of the set of alternatives, the set of criteria and their corresponding scales, as well as aggregation methods. In our particular context, we make use of several types of alternatives and multiple aggregations methods (see Figure 19):

- **Identification of alternatives.** In order to assist the company in the selection of a contractual strategy, we identify three kinds of alternatives, one at each level of the process: elementary alternatives at elementary level, Intermediary alternatives at intermediary level, and contractual strategy alternatives at CS level.
- **Identification of criteria and their scales.** For our purpose which is to measure the performance of the identified alternatives, after discussion with DMs, we consider as inputs the four most recurring criteria:
 - *The Cost:* complex upstream development projects may cost up to tens of billions of dollars. Choosing a CSA over another may save several million dollars. We have valued the cost in million dollars as it is the unit used by the company to make cost estimates;
 - *The Schedule:* choosing an appropriate CS may save a few weeks or months. Knowing that the longer is the realization time the greater are the cost expense, delivering projects on time is a key decision criterion, as in some projects the over-cost is of one million per late day. We have valued the schedule in months as it is the unit used by the company for planning;
 - *The Cost Vulnerability:* scope uncertainty makes cost estimate not completely reliable, as the occurrence of certain risks during the realization of the project may induce some cost creep. It is therefore important to consider this criterion, since it could be a better choice to select a more expensive but more reliable alternative. We have valued the cost vulnerability on a qualitative scale varying from “slightly” to “very vulnerable” in order to simplify the evaluations. This is also in relation with another PhD performed during the Chair, which introduced this concept of vulnerability in TOTAL’s project management documents and processes (Ventroux, 2016).
 - *The Schedule Vulnerability:* risk occurrence may also cause schedule creep; it is therefore important to also consider this criterion. As same as for the previous criteria, we have valued the schedule vulnerability on a qualitative scale varying from “slightly” to “very vulnerable”.
- **Selection of aggregation methods.** Our decision context implies to evaluate alternatives, according to the introduced criteria, using three MCDA aggregation methods in order to get a final recommendation (see Evaluation model box in Figure 19). The first MCDA aggregation method aims to deal with a sorting problem at the intermediary level, in order to eliminate unsatisfactory alternatives and be able to identify a manageable number of IA. The second MCDA aggregation method aims also to deal with a sorting problem at the CS level, in order to screen out alternatives and constitute a relevant set of workable CSA. The

third MCDA aggregation method aims to deal with a ranking problem at the CS level, in order to rank the remaining CSA from best to worst and come up with a justified proposal.

3.1.4. The final recommendation

The output of the 3-level decision aiding process is a ranking of the set of CSA, with a trace on how they have been built, estimated and evaluated. Eliminated alternatives can also be traced, with a justification of the reasons for which they have been eliminated. Therefore, the proposed model aims to provide solutions to the CS selection process and gives results that are easy to interpret. Its use and implementation by the Company is an important concern.

3.2. Second proposal: the 3-level progressive building of the Contractual strategy

Our ambition through this work is to provide a decision support system which brings effective and accountable solutions to the contractual strategy (CS) selection problem. It consists in a three-level model constructing progressively alternatives from bigger sizes that assemble to one another (see Figure 20). This progressive building is summarized in this section, and will be detailed with a case study in Chapter 4.

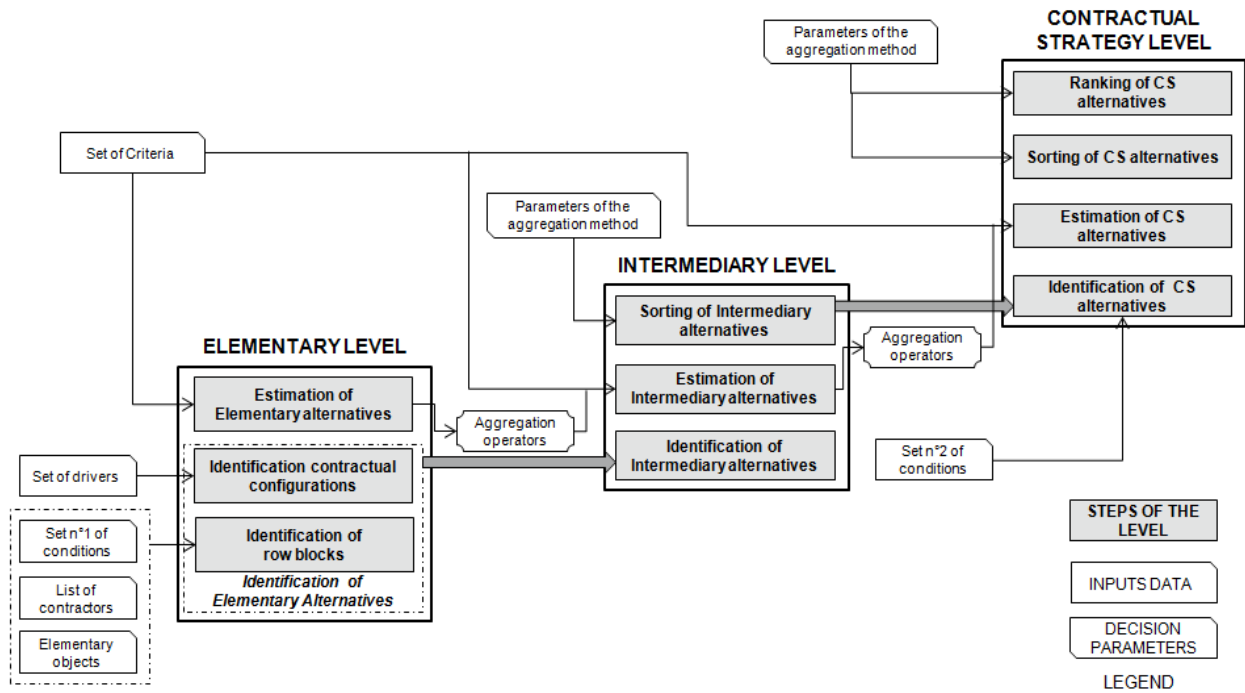


Figure 20 – A 3-level decision aiding process for contractual strategy selection

3.2.1. The Elementary level

The starting point of our work is the decomposition of the project scope into homogeneous objects, containing elementary objects, and their life cycle, represented through the project architecture matrix. The first question that arises is how to assemble elementary objects and disassemble their life cycle to form the perimeters of future contracts, to which is associated a selection mode and a remuneration type, what we call “Elementary alternatives” (see Figure 21).

Project Architecture Matrix		Basic Engineering	Detailed Engineering	Procurement	Construction	Transport & Installation	Commissioning
Object 1	Elementary object 1,1						
	Elementary object 1,2						
	Elementary object 1,3	Contract 1 - Call for Tender EP Lump Sum →				← Contract 2 - Call for Tender C Reimbursable	
Elementary object 2,1							
Object 2	Elementary object 2,2						
...	...						
Object k	Elementary object k,1						
	Elementary object k,2						
	Elementary object k,3						

Elementary alternative

Figure 21 - Contracts identification of the project architecture matrix

3.2.1.1. Step 1 - Identification of Elementary alternatives

We identify an Elementary alternative as a subset of rows of the project architecture matrix with a specific temporal cut and a particular setting of selection mode and remuneration type. To do so, the proposal is to first identify elementary objects assemblies into what we will call “row blocks”, then identify the temporal cut(s), selection mode(s) and remuneration type(s) associated to each row block, what we will call “contractual configurations”. It is described in what follows.

1. Identification of row blocks

The first step is to determine a set of elementary object assemblies into row blocks (see Figure 22). The row blocks must be carefully identified as some combinations are technically not possible.

Project Architecture Matrix		Basic Engineering	Detailed Engineering	Procurement	Construction	Transport & Installation	Commissioning
Object 1	Elementary object 1,1						
	Elementary object 1,2						
	Elementary object 1,3	Potential Row Block??					
Elementary object 2,1							
Object 2	Elementary object 2,2						
...	...						
Object k	Elementary object k,1						
	Elementary object k,2						
	Elementary object k,3						

Figure 22 - Identification of potential elementary objects assemblies into row blocks

Starting from the set of elementary objects and the list of potential contractors, the identification of such blocks is guided by three conditions (inputs) based on different studies performed on the design of the objects:

1. All object assemblies into potential row blocks should insure a minimum competition; the minimum number of contractors capable of realizing a potential row block is fixed at the beginning of each project by the project entity team, who works on the design of the CS;
2. All objects of a potential row block should be technically compatible and not complex to gather (in case of local constraints or complex interfaces). Some objects may have different technical characteristics, and high interface risks to manage, there is therefore no interest to put them together (it is up to the company to judge whether 2 objects are technically compatible or not);
3. The pre-project studies of objects from a potential row block should be compatible. Indeed, the pre-project studies of a facility might be carried out well before another. Also, it is unsuitable to gather elementary objects for which the design is uncertain with others for which it is not the case.

Each sub-set from the set of elementary objects satisfying the above three conditions is considered as a feasible row block by an identification procedure.

The row blocks identification procedure. At each iteration k , $k \geq 1$, a set of row blocks of size $k + 1$ is identified (the row blocks of size 1 are the elementary objects). The identification of row blocks of size $k + 1$ takes into account the constraints at iteration k (the three conditions, and a fourth to ensure that the created row blocks do not contain twice the same elementary object), but also the constraints of all previous iterations $k' < k, k' \in \{1, k - 1\}$. The identification procedure is described in more details in the next Chapter (see Section 4.1.1.1).

2. Identification of contractual configurations

The second step is to determine the contractual configurations (CC) of each identified row block, that is to say, their temporal cut (which corresponds to a subset of columns of the project architecture matrix, see Figure 21) and to choose both a selection mode and a remuneration type. To do this, we rely on a list of drivers, identified by analyzing the CS selection process of PNG project, whose context is described in Section 1.3.3.1, and through discussions and exchanges made during meetings and brainstorming with the Company's project entity team to benefit from their experience on handling upstream development projects. They are the following: size of the scope, schedule criticality, risk of temporal interfaces, basic engineering uncertainty, construction uncertainty, scope uncertainty, and suppliers' competition, each one of them represented by a qualitative scale (for instance, the uncertainty of the scope can have three values: small, average or high).

The contractual configurations identification procedure. The drivers helping the identification of the CC are organized under the form of a decision tree (represented in Chapter 4, Figure 29), where each leaf corresponds to a CC; the path leading to a CC being a combination of the values taken by the considered drivers. Thus, the Elementary alternatives are identified after having specified for each row block its evaluation on the set of considered drivers. The procedure is detailed in Section 4.1.1.2.

Thereby, these two steps aim to deal with our first decision problem, which is a description problem that helps the Company to identify a relevant set of alternatives at contract level.

3.2.1.2. *Step 2 - Estimation of Elementary alternatives*

In this step the performance of each identified Elementary alternative (EA) is estimated. As mentioned in Section 3.1.2, we propose to measure the performance of alternatives according to four criteria: the cost (measured in million dollars), the schedule (in months), cost vulnerability, and schedule vulnerability (both valued on a qualitative scale varying from slightly to very vulnerable).

With the agreement of the decision makers (DMs), we have chosen to consider EA estimations as inputs to our decision aiding process. Thereby, once EA identified, the DMs are asked to fill up estimation tables. The estimation of EA performances will be used later in the second level to estimate Intermediary alternatives.

An illustration of EA estimates on PNG project is given in Chapter 4 (see Figure 31).

3.2.2. The contribution: adding an Intermediary level

The first level of our decision aiding process allowed opening up to a set of EA at contract level, which are a combination of one or more potential contract(s) associated to each feasible objects assembly. At this second level, broader alternatives are identified, estimated and then sorted. These alternatives are somewhere between the set of feasible contracts and the set of workable contractual strategies. The use of an intermediary level is a modeling choice which allows two things. On the one hand, it allows for assembling the EA into non-overlapping perimeters and thus breaking down the selection problem into sub-problems corresponding to Intermediary alternatives (IA) selection. On the other hand, it allows for screening out some irrelevant IA, in order to have at the highest level a manageable number of relevant Contractual Strategies alternatives (CSA), and consequently to avoid unnecessary estimations and evaluations.

During this part, we briefly describe how the identification, estimation and sorting of IA is performed. For more details, we invite the reader to browse Section 4.2 from Chapter 4.

3.2.2.1. Step 1 - Identification of Intermediary alternatives

The identification of IA is performed in two steps: (i) the cutting of the project architecture matrix into “Intermediary breakdowns”, identified from the EA (Figure 23), (ii) the identification of IA per breakdown, which correspond to all feasible combination of EA within each Intermediary breakdown.

1. Identification of Intermediary breakdowns

In order to build a manageable number of feasible CSA, and to help to reduce the evaluation effort on a later phase of the selection process, we propose to identify limited areas that do not overlap. We have given the name of “Intermediary breakdown” to each area limited by boundaries (see Figure 23). These areas are identified from the EA and allow to draw perimeters for which there are no contracts combining elementary objects from two different breakdowns (e.g. the insulation of the elementary object 2,1 into IB2, means there is no feasible contract combining 2,1 to elementary objects from the Intermediary breakdowns IB1 and IB3 in any feasible CSA). This intermediary structure aims to treat each of these blocs separately in order to reach a reasonable and relevant number of CSA at a 3rd level.

		Basic Engineering	Detailed Engineering	Procurement	Construction	Transport & Installation	Commissioning
Object 1	Elementary object 1,1	Intermediary Breakdown IB1					
	Elementary object 1,2						
	Elementary object 1,3						
Object 2	Elementary object 2,1	Intermediary Breakdown IB2					
	Elementary object 2,2						
...					
Object k	Elementary object k,1	Intermediary Breakdown IB3					
	Elementary object k,2						
	Elementary object k,3						

Figure 23 - Cutting the project architecture matrix into Intermediary breakdowns

2. Identification of Intermediary alternatives

The IA of each Intermediary breakdown represent all possible combinations of the EA covered by the breakdown in such a way that they do not overlap. Building a feasible CSA amount to select exactly one IA per breakdown while avoiding incompatible couples. Figure 24 shows an example of a CSA combining one IA per breakdown, for instance, IA_{3,2} stands for the 2nd Intermediary alternatives of the intermediary breakdown IB₃.

Such alternatives allow on the one hand determining workable options within each breakdown. On the other hand, to make a first comparison of alternatives at an intermediary level and screen out the less performing ones.

Illustration of a Feasible CS		Life Cycle
IA1,5	Elementary object 1,1	CFT EP+C UR
	Elementary object 1,2	CFT EP+C UR
	Elementary object 1,3	
	Elementary object 2,1	
IA2,1	Elementary object 2,2	CFT E+P+C LS
...
IA3,2	Elementary object k,1	DC EP UR C not fixed R
	Elementary object k,2	CFT EPC LS
	Elementary object k,3	DC EP UR C not fixed R

Figure 24 - illustration of a feasible contractual strategy combining intermediary alternatives

3.2.2.2. Step 2 - Estimation of Intermediary alternatives

To prevent the decision makers to fill estimation tables at each level of the decision aiding process, we propose to perform the estimation on IA using EA estimates but also EA interfaces. Indeed, interfaces between the diverse contracts can generate some additional cost and delay or cause even more vulnerability, they are therefore important to consider.

In order to proceed from EA and EA interfaces estimates to IA estimations the proposal is to rely on aggregation operators for each of the four considered criteria. They are presented in Section 4.2.2.2.

3.2.2.3. Step 3 - Sorting of Intermediary alternatives

The IA identified and estimated in the previous steps are not all interesting to consider to form CSA in the next level; this step addresses an evaluation process to screen out uninteresting IA. The methodological choice of how to do this screening will be described in Section 3.3.

This Sorting phase allows keeping a reduced set of IA within each breakdown. These alternatives will serve later to identify a manageable and relevant number of CSA.

3.2.3. Contractual Strategy level

The third level of the decision aiding process concerns the built of contractual strategy alternatives (CSA), which correspond to the combination of compatible IA to cover the complete project scope. The CSA are estimated sorted and ranked through aggregation methods, to come up with a CS proposal. It is explained in what follows.

3.2.3.1. Step 1 – Identification of Contractual Strategy alternatives

A contractual strategy is the combination of exactly one intermediary alternative (IA) per intermediary breakdown. However, some IA may induce too risky interfaces. The incompatibility between IA can be explained by the following reasons: (i) a large number of interfaces to manage; (ii) a risk escalation due to risky interfaces; (iii) too large scope given to a single contractor. Each pair of IA that doesn't satisfy one of the incompatibility conditions (given as input) will be eliminated, and will therefore not be combined in any feasible CSA.

Eliminating incompatible IA not only allows the built of a manageable number of workable CSA, it also reduces the evaluation effort in the next steps.

3.2.3.2. Step 2 – Estimation of Contractual Strategy alternatives

For the same reason as for the Intermediary level, which is to prevent the decision makers (DMs) to fill table of estimates at each level, the estimation of CS alternatives is performed once again using aggregation operators on IA and IA couples' estimates.

3.2.3.3. Step 3 – Sorting of Contractual Strategy alternatives

The CSA identified and estimated at the previous steps are not all relevant; this step aims to screen out the less performing strategies.

3.2.3.4. Step 4 - Ranking of Contractual Strategy alternatives

In this last step the remaining CSA are ranked using a ranking aggregation method (the methodological choice of how to select a ranking MCDA aggregation method is briefly discussed in Section 3.3.6).

Thus, at the end of the decision aiding process we obtain a ranking of a relevant set of contractual strategies, which has been built, estimated and evaluated progressively through a 3 level model.

Given that we are facing sorting and ranking decision problems, we present in the next section an approach assisting the choice of MCDA aggregation methods corresponding to our decision context (sorting of IA and CSA, and ranking of CSA).

3.3. Third proposal: selecting aggregation methods involved in the decision process

As previously mentioned, several approaches helping the selection of a MCDA method to a decision problem have been introduced in the literature (Roy and Slowiński, 2013; Guitouni and Martel, 1998; Deason, 1984; Gershon, 1981; Teclé, 1988). However, many authors including (Kornysheva and Salinesi, 2007) recommend to analysts confronted with this situation to build their own approach adapted to their decision context. For this purpose, we will make use of the models and guidelines presented in Section 2.3.2 (see Table 6) to construct our own approach for the selection of an aggregation method to deal with the faced sorting and ranking problems. The proposed approach is the result of a research work carried out as part of this thesis (Lakhmi, 2017), it considers the problem of selecting an aggregation method as a multi-criteria problem; the steps are represented in Figure 25 below:

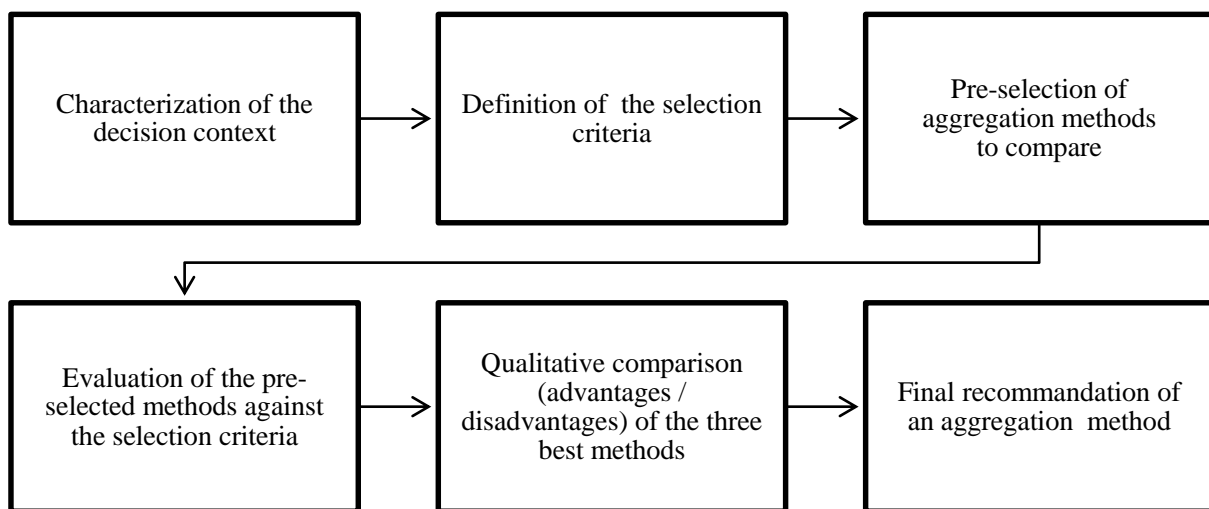


Figure 25 - Approach helping the selection of an aggregation method to our case study

We illustrate each of these steps for selecting an MCDA aggregation method to our sorting decision problem faced at both intermediary and contractual strategy levels. The same approach applies to the ranking problem faced at contractual strategy level, which will be discussed at the end of the section.

3.3.1. Characterization of the decision context

In our context, the faced decision problem is a sorting problem to determine the alternatives that will be kept and those that will be eliminated, whether it is at intermediary level or at contractual strategy level. The sorting categories are ordered and pre-defined as follow: “Not eliminated” > “Eliminated”.

With regards to the evaluation criteria, they are analyzed in Table 7 below:

Evaluation criteria	Nature of criteria	Rating scales	Measurement Units
Cost	Quantitative	Cardinal	Million dollars
Schedule	Quantitative	Cardinal	Months
Cost Vulnerability	Qualitative	Ordinal	Level of risk
Schedule Vulnerability	Qualitative	Ordinal	Level of risk

Table 7 - Analysis of the evaluation criteria

The evaluation criteria are from different natures; they are evaluated on different scales with different units of measurement. In our context, the evaluation criteria are assumed to be independent, the purpose being to screen out alternatives that have poor performance.

3.3.2. Definition of the selection criteria

To define the criteria to select an aggregation method, we have based on the guidelines previously cited as well as the requirements identified by characterizing our decision context. Thereby, we defined two types of criteria: mandatory criteria that must be met, and satisfactory criteria. They are presented in Table 8:

a- Mandatory Criteria	Justification
1. Ordered sorting categories	Our decision problem requires the case of ordered sorting categories: “Not eliminated” > “Eliminated”.
2. Consideration of ordinal scales	The criteria cost and schedule vulnerability are evaluated using ordinal scales, thus the chosen method must take into account ordinal scales.
3. No preferential dependency between criteria	There are no synergies between the criteria defined to evaluate CS alternatives, thus the methods that take into account preferential dependencies are eliminated.
b- Satisfactory criteria	Justification
4. Consideration of qualitative and quantitative inputs data	The criteria cost and schedule vulnerability are represented by a qualitative scale. To avoid recoding them, it is desired that the method takes into account both quantitative and qualitative inputs data.
5. Incommensurability of scales	
6. Partial compensation between criteria --> veto threshold	We want to privilege methods that use veto thresholds to take into account the partial compensation that may exists between the criteria.
7. Existence of a tool	The existence of a tool to apply the method would facilitate its implementation and use by the oil company.
8. A manageable number of decision parameters	To limit the margin of error on the results and to facilitate the handling and understanding of the method by the DMs and users, the methods with few decision parameters and easy to understand (either from the point of view of the parameters, Or the functioning of the method) are favored.
9. Ease of understanding of the method’s decision parameters	
10. Ease of understanding of the method’s functioning	
11. Level of competence required for the application of the method	Some decision parameters used by MCDA methods are difficult to instantiate and require advanced skills, which complicates the implementation and acceptance of the method by the DMs. This selection criterion allows to favor the simplest methods.

Table 8 - Selection criteria to help the choice of a sorting aggregation method

To build our evaluation system, we were inspired by the models of (Gershon, 1981) and (Teclé, 1988). Indeed, two types of selection criteria have been defined: mandatory criteria (which allow the elimination of certain methods) and non-mandatory (satisfactory) criteria (See Table 9). For each criterion an evaluation scale and a weight have been defined, as presented below:

Evaluation criteria	Nature of criteria	Scales	Weights
1. Ordered sorting categories	Mandatory	0/1	x
2. Consideration of ordinal scales	Mandatory	0/1	x
3. No preferential dependency between criteria	Mandatory	0/1	x
4. Qualitative and quantitative inputs data	Non-mandatory	0/1	0,2
5. Incommensurability of scales	Non-mandatory	0/1	0,2
6. Partial compensation between criteria --> veto	Non-mandatory	0/1	0,1
7. Existence of a tool	Non-mandatory	0/1	0,1
8. A manageable number of decision parameters	Non-mandatory	0-10	0,1
9. Ease of understanding of the method's decision parameters	Non-mandatory	0-10	0,1
10. Ease of understanding of the method's functioning	Non-mandatory	0-10	0,1
11. Level of competence required for the application of the method	Non-mandatory	0-10	0,1

Table 9 - Nature, scales and weights of the selection criteria

The satisfaction of the mandatory criteria is necessary for any aggregation method. For the non-mandatory (satisfaction) criteria, a higher weight was associated to criterion 4, because the step of "converting" the evaluation criteria may be difficult to achieve, and criterion 5, because the criteria are from different scales. For the rest, the same weight of 0.1 was given.

3.3.3. Pre-selection of aggregation methods to compare

As mentioned previously, several guidelines and models exist to help the selection of a multicriteria aggregation method. In order to make a pre-selection of aggregation methods to compare, we based on (Roy and Slowinski, 2013), which present a first question on the nature of the addressed problem whose answer makes it possible to establish a list of potential aggregation methods. However, since this list is incomplete, we decided to add other aggregation methods to the list based on a literature review on sorting methods (Zopounidis and Doumpos, 2002; Sobrie, 2016).

We ended with a list of 16 pre-selected methods: AHP Sort (Ishizaka et al., 2012), DISCARD (Kadziński and Słowiński, 2013), DRSA (Greco and al., 2001), ELECTRE TRI (Yu 1992), ELECTRE TRI-C (Figueira and al., 2011), ELECTRE TRI-NC (Almeida-Dias and al., 2012), FlowSort (Nemery and Lamboray, 2008), MR Sort (Bouyssou and Marchant, 2007), Ntomic (Massaglia and Ostanello, 1991), PAIRCLASS (Doumpos and Zopounidis, 2004), PROAFTN (Belacel, 2000), THESEUS (Fernandez and Navarro, 2011), TOMASO (Marichal and al., 2005), TRICHOTOMIC SEGMENTATION (Moscarola and Roy, 1977), TRINOM FC (Léger and Martel, 2002), UTADIS (Jacquet-Lagrece and Siskos, 1982).

3.3.4. Evaluation of the pre-selected methods against the selection criteria

The evaluation of MCDA aggregation methods, to select the most relevant one is performed in two steps:

Step 1 - Evaluation of the methods on the mandatory criteria

To be retained, a method must fulfill all the mandatory criteria. This allows us to make a first filter on the set of methods. At the end of this first step three methods are eliminated: PROAFTN, TRINOMFC and TOMASO as they violate at least one of the mandatory criteria. The remaining methods are evaluated in the second step on the non-mandatory (satisfactory) criteria.

Step 2 – Evaluation of the methods on the non-mandatory (satisfactory) criteria

The remaining methods from the first step are evaluated according to criteria 4 to 11. For each method a score is computed by using a distance function, adopted from the works of (Gershon, 1981). It consists in evaluating the distance of the studied methods on each criterion, in relation to the “optimal” aggregation method, represented by the vector [1, 1, 1, 1, 10, 10, 10, 10] (the “worst” aggregation method is represented by the vector [0, 0, 0, 0, 0, 0, 0, 0]) and then to aggregate the evaluations by weighting them to the relative weights of the selection criteria, as follow:

$$Distance(x) = \sum_{i \in [4,11]} \alpha_i \times \frac{f_i^* - f_i(x)}{f_i^* - f_i^{min}}$$

Where, α_i : the weight of criterion i , $i \in [4,11]$; f_i^* : the highest value on criterion i ; f_i^{min} : the worst value on criterion i , and $f_i(x)$: the performance of the method 'x' on criterion i .

The ranking of the aggregation methods, on the basis of the computed distances are presented in Table 10 below. (The table of the methods comparison is given in Appendix 1).

	Distance	Rank
ELECTRE TRI	0,16	1
DRSA	0,19	2
MR Sort with veto	0,19	2
UTADIS	0,2	4
ELECTRE TRI-C	0,2	4
MR Sort without veto	0,27	6
AHP Sort	0,27	6
THESEUS	0,28	8
ELECTRE TRI-NC	0,29	9
TRICHOTOMIC SEGMENTATION	0,3	10
FlowSort	0,36	11
PAIRCLASS	0,39	12
NTOMIC	0,4	13

Table 10 - Ranking of aggregation methods on the basis of (Gershon, 1981) function distance

Distance calculations from the optimal method showed that the three most suitable methods for our context are: ELECTRE TRI, DRSA and MR Sort. In order to make a final selection of a MCDA aggregation method, we study the pros and cons of the three methods in the following step. A brief definition of the methods is also given.

3.3.5. Comparison of the three best methods

The remaining methods from the previous step are: ELECTRE TRI, DRSA and MR Sort. Before comparing the methods, we give a brief definition of the three methods.

Presentation of the selected methods

- **DRSA model** (Greco and al., 2001)

The model is parameterized by a set of rules allowing classifying alternatives in ordered categories. A rule $r = (a_h, C_h)$ is a pair composed of an antecedent and a consequent. If a given alternative a satisfies the antecedent of a rule $r = (a_h, C_h)$, it will be affected to a category at least as good as C_h .

Example: $a_h = \{(g_2, 14,73); (g_4, \text{"good"})\}$ if for an alternative a , we have $g_2(a) \geq 14,73$ and $g_4(a) \geq \text{"good"}$, then a will be affected to a category at least as good as C_h .

- **ELECTRE TRI model** (Yu, 1992)

The ELECTRE TRI model is part of the family ELECTRE; the principle of ELECTRE methods is to compare alternatives pairwise through an outranking relation S . Such that “*an alternative a outranks and alternative b and we note $a \mathbf{S} b$, if there are sufficient arguments to admit that a is at least as good as b (concordance index), and there are no significant arguments to the contrary (discordance index)*” (Roy, 1985).

ELECTRE TRI model consists in comparing the alternatives to limit profiles b^h of categories $C_h \in C$, $h \in \{1, \dots, |C|\}$, the value of the outranking relation S is calculated by using indifference, preference, and veto thresholds on each criterion $j \in J$ with its associated weight $w_j \in [0, 1]$, such that, $\sum_{j \in J} w_j = 1$, and a majority threshold $\lambda \in [0,5; 1]$, such that, $a \mathbf{S} b^h \leftrightarrow \sum_{j \in J | a_j \geq b_j^h} w_j \geq \lambda$. The affectation of the alternatives into categories can be done by 2 different procedures, depending on the expert:

- **Pessimist procedure:** whereby an alternative a is affected to a category C_h , if and only if, $a \mathbf{S} b^h$ and $\neg(b^{h+1} \mathbf{S} a)$;
- **Optimist procedure:** whereby an alternative a is affected to a category C_{h-1} , if and only if, $a \mathbf{S} b^{h-1}$, $b^h \mathbf{S} a$, and $\neg(a \mathbf{S} b^h)$.

- **MR Sort model with veto** (Bouyssou and Marchant, 2007)

MR Sort model with veto is a simplification of ELECTRE Tri model, ignoring indifference and preference thresholds. Thus, an alternative $a \in A$ is assigned to a category at least as good as $C_h \in C$, $h \in \{1, \dots, |C|\}$, if and only if the coalition of criteria $J \subseteq J$ in favor of the allocation of a to C_h is sufficient: $\sum_{j \in J} w_j \geq \lambda$, and the veto thresholds v_j on each criterion $j \in J$ is satisfied. In other words, an alternative a is classified in a category C_h , if a is at least as good as the limit profile b^h ($\sum_{j \in J | a_j \geq b_j^h} w_j \geq \lambda$), and worse than the profile b^{h+1} ($\sum_{j \in J | a_j \geq b_j^{h+1}} w_j < \lambda$), while satisfying the veto thresholds.

Advantages and disadvantages

The main advantages and disadvantages of each of the three selected MCDA sorting methods are summarized in Table 11:

Models	Advantages	Disadvantages
DRSA	<ul style="list-style-type: none"> - Provides an immediate justification of its recommendations in a natural language. - The preferences of the DMs are relatively simple to model. - The rules are not final and can be modified at any time. 	<ul style="list-style-type: none"> - The use of the method assumes that a large number of past decisions are available. - A model with too many rules can be very complicated to understand. - It is necessary to build a model for each upstream development project (or at least projects from the same size).
ELECTRE TRI	<ul style="list-style-type: none"> - ELECTRE TRI is more comprehensive and rigorous compared to the other methods, as it takes into account more decision parameters. - The results of the models are often relevant and representative of the reality. 	<ul style="list-style-type: none"> -An important number of decision parameters that need to be fixed. -It's difficult for the DMs to understand the logic of the method and to set the preference and indifference thresholds.
MR Sort with veto	<ul style="list-style-type: none"> - Easy to understand, implement and use. - Few decision parameters to take into account. - The assignment rule to categories is relatively simple. 	<ul style="list-style-type: none"> - Non-robust method due in particular to the disregard of Indifference and preference thresholds. - The limit profiles of categories must be carefully selected as the affectation of an alternative in a category depends solely on its comparison to the limit profile.

Table 11 - Pros & Cons of the selected MCDA Sorting methods

The comparison between the three methods showed that ELECTRE TRI is the most rigorous model as it takes into account all thresholds of preference, indifference and veto, however an important number of parameters must be fixed, it is therefore difficult to implement. The DRSA method, present the same disadvantage, as decision rules will have to be built for each project by the DMs (the size and complexity vary from one project to another). Thereby, the method that represents the best compromise after comparison is MR sort with veto model, as there are few parameters to fix, easy to implement, and remains acceptable considering the fact that it takes into account the veto threshold. It is therefore the final recommendation of the process, which we will apply in the sorting decision problems, encountered both at the intermediary and contractual strategy levels, given the fact that both problems have the same characteristics.

3.3.6. Discussions & Generalization

This approach helping the selection of a MCDA aggregation method has been proposed as a guideline to justify the selection of MR Sort with veto model to our sorting decision problems. However, this approach can be applicable independently to our context to other decision problems. Indeed, in the same way as for the sorting problem, we made use of the same approach to help selecting a MCDA method to rank contractual strategy alternatives (CSA).

After comparing the methods, three appeared to be applicable: AHP (Saaty, 1977; 1994), ELECTRE III (Roy, 1978) and S-RMP (Rolland, 2013). The S-RMP method has been chosen because it is user-friendly, and takes into account simple parameters (which is not the case of ELECTRE III) easy to instantiate, as it compares the alternatives to profiles (For n alternatives S-RMP performs n comparisons, while AHP performs $n^2/2$). Because of redundancy we do not detail the approach in this dissertation. The S-RMP method will be described in Chapter 4, Section 4.3.4 while dealing with the ranking of CSA.

3.4. Chapter Conclusion

As a whole, the aim of this chapter is threefold: (i) to show how our decision aiding process has been built, (ii) to describe the steps of the decision aiding process, (iii) to justify certain choices made during the development of the process, notably the ones related to the built of 3-level progressive alternatives, and the selection of MCDA aggregation methods for the screening and ranking of such alternatives.

The construction of a decision aiding system within an organization is sometimes difficult to achieve. It requires not only a scientific justification of model robustness, but it also must be easy to implement and handle, while ensuring to meet the outlook of all the concerned parties, which is the case of our research problematic. In addition, several decision problems are simultaneously faced: one description problem, two sorting problems and one ranking problem. In order to build such a system, we relied on a 4-step descriptive model for complex industrial problem proposed by (Tsoukiàs, 2008).

We built a 3-level model allowing to cope with the difficulties encountered during the CS selection process. The content of the model has been described in the second section of the chapter in order to give the reader a preview of the content of Chapter 4.

Finally, the third section of this chapter justified the choices made for the selection of two aggregation methods to deal with the faced sorting and ranking decision problems.

Chapter 4: A 3-level Decision Aiding Process for Contractual strategy selection

Introduction

This chapter aims to present our 3-level decision aiding process for contractual strategy selection. The process will be detailed and exemplified with the PNG project.

In the first section, the elementary level is described, which consists in: (i) identification of elementary alternatives (EA), and (ii) estimation of elementary alternatives. To identify the EA we proceed by two steps. The first one is to assemble the elementary objects into what we will call “row blocks”, using drivers identified through different studies and interviews. The second step is to identify for each row block their possible temporal cuts, and to choose both a remuneration type and a selection mode, forming the EA, composed of one or more contracts. The identified EA are then estimated according to four evaluation criteria: cost, schedule, cost vulnerability and schedule vulnerability.

In the second section, the intermediary level is described, which consists in the identification, estimation and screening of intermediary alternatives (IA). To identify IA, the proposal is to first map the project scope into breakdowns. An IA corresponds to the combination of one or more EA within a specific breakdown. The IA are estimated according to the same four criteria, and then screened out through a sorting aggregation method (MR Sort with veto). This eliminates the ones with poor performance and allows for building a relevant set of workable contractual strategies.

In the third section, the contractual strategy level is described which consists in the identification, estimation, screening, and ranking of contractual strategy alternatives (CSA). The CSA are identified by selecting exactly one IA per breakdown, while avoiding incompatible IA pairs. The CSA are then estimated and screened out similarly to the intermediary level. The remaining CSA are ranked in one last step using a ranking aggregation method (S-RMP) leading to the proposal of a final strategy to the upstream development project decision committee.

4.1. The Elementary level

There is large number of possibilities to form feasible contracts in upstream development projects. For instance, for PNG project, with 9 elementary objects, 5 temporal cuts (EPC, EPC with C not fixed, EP+C, EPCm, E+P+C), 3 types of remuneration (Lump sum, Unit Rate, Reimbursable), and 4 selection modes (Call for Tender, Single source, Design competition, Open book tender), we end up with 511 possible objects assemblies ($C_9^1 + C_9^2 + \dots + C_9^8 + C_9^9$), and thus, $511 \times 5 = 2555$ scope of contracts and 30660 possible contracts ($2555 \times 4 \times 3$). In order to deal with this combinatorial, the proposed approach is based on our analysis of the current CS selection process. It showed that the identification of alternatives is conditioned by a set of drivers that appear during the process, whose values constraint the set of possibilities and considerably reduce the combinatorial.

We describe in this section how the identification of what we have termed as “Elementary alternatives” (EA) is made to deal with the large number of feasible contracts. It starts by identifying possible assemblies of elementary objects into “row blocks”, following inputs and drivers, then the feasible contractual configurations per row block (temporal cut, selection mode, and remuneration type), guided by other drivers which will be presented during this section. The identified EA will then be estimated according to evaluation criteria. We will make use of PNG project presented in Section 1.3.3.1 to illustrate our work.

4.1.1. Identification of Elementary alternatives

The EA are a combination of one or more contracts; they aim to represent the set of possible contracts, which theoretically, depending on the size of the project, can be a combinatorial number. To identify such alternatives, we rely on a set of drivers allowing to considerably reduce the number of contracts. We explain in what follows how the identification is performed in two main steps: (i) the identification of objects assemblies into “row blocks”, (ii) the identification of temporal cuts (forming contracts perimeters), selection modes and types of remuneration associated to each row block, what we have called “contractual configurations”.

4.1.1.1. Identification of row blocks

Contracts with larger scopes reduce the number of interfaces and allow a lighter management. The combination of several elementary objects, called “row block” may be an opportunity. Indeed, the first step of the contractual strategy (CS) selection process is to study the similarity between elementary objects in order to identify potential assemblies into row blocks. The assembled elementary objects may belong or not to the same Object, meaning for instance that they serve as a physical or functional interface between those Objects, as illustrated in Figure 26, representing the scope of work matrix of PNG project, with a row block combining the Flowlines from ‘Upstream facilities’ Object with ‘Onshore Gas Pipe’ from ‘Pipelines’ Object.

PNG Scope of Work		Basic Engineering	Detailed Engineering	Procurement	Construction	Transport & Installation	Commissioning
Upstream Facilities	CPF						
	Wellpads						
	Flowlines	Row block assembling the Elementary objects Flowlines and Onshore Gas Pipe					
Onshore Gas Pipe							
Pipelines	Offshore Gas Pipe						
	LNG Process						
LNG Facilities	LNG Tanks						
	Power Plant						
	Jetty						

Figure 26 - PNG scope of work - Row block assembling

Based on our analysis on the CS selection process of PNG project and meetings with TOTAL project team, the identification of elementary objects assemblies into row blocks are only possible under three conditions, related to the studies made on the design of each individual elementary object:

1. All potential row blocks should insure a minimum competition; the minimum number of contractors is fixed at the beginning of each project by the project entity. Table 12 gives the potential contractors involved in the PNG project, they have been anonymized. The minimum number of contractors has been fixed to 3;
2. All objects of a potential row block should be technically compatible and not complex to gather. For instance, one cannot group the LNG process with Wells, as they have different technical characteristics, and present interface complexity (they are connected by a Pipeline). It is up to the company to judge whether 2 objects are technically compatible or not;
3. The pre-project studies of elementary objects from a potential row block should be compatible. Indeed, the pre-project studies of a facility might be carried out well before another. Also, it is unsuitable to gather elementary objects with uncertainty on the design with others for which it is not the case. Thus, the pre-project compatibility between objects may change from one project to another.

Chapter 4: A 3-level Decision Aiding Process for Contractual strategy selection

EPC Potential Contractors	<i>CPF</i>	<i>Wellpads</i>	<i>Flowlines</i>	<i>Onshore Export Line</i>	<i>Offshore Export Line</i>	<i>Liquefaction Process</i>	<i>Liquefaction Tanks</i>	<i>Power Plant</i>	<i>Jetty</i>
<i>Contractor 1</i>	no	no	no	no	yes	no	no	no	no
<i>Contractor 2</i>	yes	yes	no	no	no	no	no	no	no
<i>Contractor 3</i>	no	no	no	no	yes	no	no	no	no
<i>Contractor 4</i>	yes	yes	no	no	no	yes	yes	yes	yes
<i>Contractor 5</i>	no	yes	yes	yes	no	no	no	no	no
<i>Contractor 6</i>	no	no	no	no	no	yes	yes	yes	yes
<i>Contractor 7</i>	no	yes	yes	yes	no	no	no	no	no
<i>Contractor 8</i>	yes	yes	no	no	no	yes	yes	yes	yes
<i>Contractor 9</i>	no	no	no	no	no	yes	yes	yes	yes
<i>Contractor 10</i>	yes	yes	no	no	no	yes	yes	yes	yes
<i>Contractor 11</i>	yes	yes	yes	yes	yes	no	no	no	no
<i>Contractor 12</i>	no	no	no	no	yes	no	no	no	no
<i>Contractor 13</i>	no	no	no	no	yes	no	no	no	no
<i>Contractor 14</i>	yes	yes	no	no	no	no	no	no	no
<i>Contractor 15</i>	yes	yes	no	no	yes	yes	yes	yes	yes
→Nb CTR	7	9	3	3	6	6	6	6	6

Table 12 - List of contractors and their capabilities (PNG project)

Any assembly of elementary objects satisfying each of the three conditions will be added to the set of potential row blocks. Figure 27 shows the three inputs of the row blocks identification procedure on PNG project. The presence of a 1 in the first matrix, crossing the list of contractors (CTRs) with the elementary objects, means that the contractor is able to realize the elementary object. A qualitative scale varying from -1 to +1 is determined for both technical and pre-project compatibility (-1 for not compatible, 0 for neutral, +1 for highly compatible).

Chapter 4: A 3-level Decision Aiding Process for Contractual strategy selection

Input 1 - List of Contractors									
List of CTRs	CPF	WellPads	Flowlines	Onshore	Offshore	Liquefac	Tanks	Power P	Jetty
Contractor1	0	0	0	0	1	0	0	0	0
Contractor2	1	1	0	0	0	0	0	0	0
Contractor3	0	0	0	0	1	0	0	0	0
Contractor4	1	1	0	0	0	1	1	1	1
Contractor5	0	1	1	1	0	0	0	0	0
Contractor6	0	0	0	0	0	1	1	1	1
Contractor7	0	1	1	1	0	0	0	0	0
Contractor8	1	1	0	0	0	1	1	1	1
Contractor9	0	0	0	0	0	1	1	1	1
Contractor10	1	1	0	0	0	1	1	1	1
Contractor11	1	1	1	1	1	0	0	0	0
Contractor12	0	0	0	0	1	0	0	0	0
Contractor13	0	0	0	0	1	0	0	0	0
Contractor14	1	1	0	0	0	0	0	0	0
Contractor15	1	1	0	0	1	1	1	1	1

Input 2 - Technical Compatibility									
Technical	CPF	Wellpads	Flowlines	Onshore	Offshore	Liquefac	Tanks	Power P	Jetty
CPF	1	1	0	0	0	-1	-1	-1	-1
Wellpads	1	1	0	0	0	-1	-1	-1	-1
Flowlines	0	0	1	1	1	-1	-1	-1	-1
Onshore	0	0	1	1	1	-1	-1	-1	-1
Offshore	0	0	1	1	1	-1	-1	-1	-1
Liquef	-1	-1	-1	-1	-1	1	0	1	0
Tanks	-1	-1	-1	-1	-1	0	1	1	0
Power P	-1	-1	-1	-1	-1	1	1	1	0
Jetty	-1	-1	-1	-1	-1	0	0	0	1

Input 3 - Pre project Compatibility									
Pre project	CPF	Wellpads	Flowlines	Onshore	Offshore	Liquefac	Tanks	Power P	Jetty
CPF	1	0	1	1	0	0	1	0	0
Wellpads	0	1	0	0	1	-1	0	1	-1
Flowlines	1	0	1	1	0	0	1	0	0
Onshore	1	0	1	1	0	0	1	0	0
Offshore	0	1	0	0	1	-1	0	1	-1
Liquef	0	-1	0	0	-1	1	0	-1	1
Tanks	1	0	1	1	0	0	1	0	0
Power P	0	1	0	0	1	-1	0	1	-1
Jetty	0	-1	0	0	-1	1	0	-1	1

Figure 27 - Inputs of the row block identification procedure

Row block Identification procedure

The aim of the procedure is to generate the set of feasible row blocks by taking into account each of the three conditions described above. A row block is the assembly of elementary objects, given by: (1) Inputs: the list of elementary objects and the list of potential contractors, (2) Conditions: Suppliers' availability, Technical compatibility, Pre-project studies compatibility, which are necessary conditions for the creation of a row block.

While describing the algorithm, the following notations will be used:

Notations

- M : The number of potential Suppliers.
- N : The number of elementary objects.
- e_i : The elementary object i , $i \in \{1, \dots, N\}$.
- RB^{k+1} : The set of feasible row blocks of size $k + 1$ (assembling $k + 1$ elementary objects) identified at the iteration k , $k \geq 1$. Each row block can be represented by a vector $B^N = \{0, 1\}^N$. The row blocks of size 1 are the elementary objects.
- rb_j^k : The j^{th} row block from the set of row blocks of size k , $j \in \{1, \dots, |RB^k|\}$.
- λ : The minimum number of suppliers required to gather elementary objects into potential row blocks.
- SA^k : The matrix suppliers' availability for row blocks of size k . It provides the number of suppliers capable of realizing the row blocks RB^k , such that:

$$sa_{ij}^k = \begin{cases} 1 & \text{if the supplier } S_i \text{ is capable of realizing the row block } rb_j^k \\ 0 & \text{else,} \end{cases} \quad \forall i \in \{1, \dots, M\} \quad \forall j \in \{1, \dots, |RB^k|\}$$

- MP^k : The matrix provides at each iteration k , the number of suppliers that are capable of realizing both the elementary object e_i , and the row block rb_j^k , such that: $mp_{ij}^k = \sum_l sa_{li}^1 \times sa_{lj}^k$, $\forall l \in \{1, \dots, M\}$, $\forall i \in \{1, \dots, N\}$, $\forall j \in \{1, \dots, |RB^k|\}$. It aims to identify the set of potential row blocks of size $k + 1$.
- TC^k : The matrix allows to estimate at each iteration k , the technical compatibility between the elementary objects e_i , and the row blocks RB^k , such that:

$$tc_{ij}^k = \begin{cases} -1 & \text{if the elementary object } i \text{ and the row block } j \text{ are highly incompatible} \\ 0 & \text{if } i \text{ and } j \text{ are lowly incompatible} \\ +1 & \text{if } i \text{ and } j \text{ are compatible,} \end{cases} \quad \forall i \in \{1, \dots, N\}, \forall j \in \{1, \dots, |RB^k|\}$$

- CP^k : The matrix allows to estimate at each iteration k , the pre-project studies compatibility between the elementary objects e_i , and the row blocks RB^k , such that :

$$cp_{ij}^k = \begin{cases} -1 & \text{if the elementary object } i \text{ and the row block } j \text{ are highly incompatible} \\ 0 & \text{if } i \text{ and } j \text{ are lowly incompatible} \\ +1 & \text{if } i \text{ and } j \text{ are compatible,} \end{cases} \quad \forall i \in \{1, \dots, N\}, \forall j \in \{1, \dots, |RB^k|\}$$

Algorithm description

At each iteration k , $k \geq 1$ the algorithm identifies a set of row blocks RB^{k+1} of size $k + 1$ (the row blocks of size 1 are the elementary objects). The algorithm first creates the suppliers availability matrix SA^k for the row blocks RB^k , identified at iteration $k - 1$. Then, it calculates the matrix $MP^k = SA_1^t \times SA_k$ to obtain the number of suppliers that are capable of realizing potential row blocks of size $k + 1$. Each created row block should then verify the following constraints:

- The number of suppliers capable of realizing the elementary objects of potential row blocks of size $k + 1$ must exceed a certain threshold λ .
- All the elementary objects of a potential row block of size $k + 1$ must be technically compatible. We have set qualitative evaluations $\{-1, 0, 1\}$, potential blocks with an evaluation equal to -1 are eliminated. The ratings 0 and 1 are used to distinguish the averagely compatible row blocks of those that are highly compatible.
- The Pre-project studies of the elementary objects of a potential row block of size $k + 1$ must be compatible. We have set qualitative evaluations $\{-1, 0, 1\}$, potential blocks with an evaluation equal to -1 are eliminated. The ratings 0 and 1 are used to distinguish the averagely compatible row blocks of those that are highly compatible.
- Ensure that the potential row blocks created don't contain twice the same elementary object. Indeed, the case crossing an elementary object e_i , with a row block of size k containing e_i can happen.

The identification of row blocks of size $k + 1$ is done through a system of linear equations, which takes into account the constraints at iteration k , but also the constraints at all previous iterations $k' < k$, $k' \in \{1, k - 1\}$. Indeed, the case where the created potential row blocks at the iteration k contain combinations of elementary objects that do not satisfy the constraints generated in the previous iteration should be avoided. All potential row blocks verifying these constraints (all solutions of the system of linear equations) will be added to the list of row blocks of size $k + 1$, RB^{k+1} .

Furthermore, the build of potential row blocks RB^{k+1} from the set of row blocks RB^k , identified at the previous step (using SA^k matrix), can reduce the identification effort. Indeed, every potential row block of size $k + 1$, containing eliminated row blocks won't be considered. Thus, by construction large part of potential row blocks are excluded, which reduces the number of iterations of the algorithm.

Variables

$$x_i^k = \begin{cases} 1 & \text{if } \exists \text{ a row block } rb_i^{k+1} \in RB^{k+1}, \text{ such that the elementary object } e_i \subset rb_i^{k+1} \\ 0 & \text{else, } \forall i \in \{1, \dots, N\} \end{cases}$$

Procedure

a. Row blocks of size 2

- **Iteration (1):**
- **Stop Condition:** $RB^2 = \emptyset$.
- **Result:** RB^2 , the list of row blocks of size 2.

$$(a) \begin{cases} x_i^1 + x_j^1 \leq 1, \forall i, j \in \{1, \dots, N\} | (mp_{ij}^1 < \lambda) \text{ or } (tc_{ij}^1 = -1) \text{ or } (cp_{ij}^1 = -1) \dots (1) \\ \sum_{i=1}^N x_i^1 = 2 \\ x_i^1 \in \{0, 1\}, \forall i \in \{1, N\} \end{cases}$$

Any solution $X^N = \{0,1\}^N$ of the system of linear equations (a) represents a feasible row blocks of size 2, $rb_j^2 \in RB^2, j \in \{1, \dots, |RB^2|\}$.

b. Row blocks of size k+1

- **Iteration (k):**
- **Stop Condition:** $RB^{k+1} = \emptyset$.
- **Result:** RB^{k+1} , the list of row blocks of size k+1.

$$(b) \begin{cases} (1), (2), \dots, (k-1) \text{ inequations resulting from previous iterations} \\ x_i^k + \sum_{t|e^t \in rb_j^k} x_t^k \leq k, \forall i \in \{1, \dots, N\}, j \in \{1, \dots, |RB^k|\} | (mp_{ij}^k < \lambda) \text{ or } (tc_{ij}^k = -1) \text{ or } (cp_{ij}^k = -1) \dots (k) \\ x_i^k + \sum_{t|e^t \in rb_j^k} x_t^k \leq k \quad \forall i \in \{1, \dots, N\}, j \in \{1, \dots, |RB^k|\} | \exists rb_j^k \text{ s.t. } e_i \in rb_j^k \quad (\text{overlapping objects}) \\ \sum_{i=1}^N x_i^k = k + 1 \\ x_i^k \in \{0, 1\}, \forall i \in \{1, N\} \end{cases}$$

Any solution $X^N = \{0,1\}^N$ of the system of linear equations (b) represents a feasible row blocks of size k+1, $rb_j^{k+1} \in RB^{k+1}, j \in \{1, \dots, |RB^{k+1}|\}$.

The procedure of identification of feasible row blocks applied to PNG project is given in what follows.

Application of the Row block identification Procedure on PNG project

- At initialization $s = (0)$

For PNG project, the procedure takes as an input the elementary objects: CPF, Wellpads, Flowlines, Onshore Gas Pipe, Offshore Gas Pipe, Liquefaction process, Tanks, Power Plant, and Jetty assigned to the set of row blocks of size 1 RB^1 , and the matrix Suppliers' availability $SA(1)$, represented in Figure 27, input 1.

- At iteration $s = (1)$

Input: RB^1 , $SA(1)$.

Result: RB^2 , the list of row blocks of size 2.

Stop Condition: $RB^2(1) = \emptyset$.

The elimination matrices are first built:

- Building the matrix $MP(1) = SA(1)^t \times SA(1)$. We have set the threshold $\lambda = 2$ for PNG projects; all potential row blocks that don't exceed it, are eliminated (the colored boxes in red at Table 13).
- Building the technical compatibility matrix $TC(1)$. All potential blocks with an evaluation equal to -1 are eliminated (the colored boxes in red at Table 14).
- Building the matrix of pre-project studies compatibility $CP(1)$. All potential blocks with an evaluation equal to -1 are eliminated (the colored boxes in red at Table 15).

For each potential row block $\{e_i, e_j\}$ of size 2 that doesn't satisfy one of the three conditions: $(mp_{ij}(1) > 2)$, $(tc_{ij}(1) \neq -1)$, and $(cp_{ij}(1) \neq -1)$, the constraint $x_i + x_j \leq 1$ is added to the Integer Linear program (ILP), in order to be eliminated. The set of row blocks of size 2, $RB^2(1)$ given by all alternative optimal solutions of the ILP (a) for PNG project are the following:

$RB^2(1) = \{\{\text{Wellpads, Flowlines}\}; \{\text{Wellpads, Onshore Gas Pipe}\}; \{\text{Liquefaction process, Cryo Tanks}\}; \{\text{Liquefaction process, Jetty}\}; \{\text{Cryo Tanks; Power plant}\}; \{\text{Cryo Tanks, Jetty}\}; \{\text{Flowlines, Onshore Gas Pipe}\}; \{\text{CPF, Wellpads}\}\}$.

Chapter 4: A 3-level Decision Aiding Process for Contractual strategy selection

<i>MP(1)</i>	<i>CPF</i>	<i>Wellpads</i>	<i>Flowlines</i>	<i>Onshore export line</i>	<i>Offshore export line</i>	<i>Liquefaction process</i>	<i>Cryo Tanks</i>	<i>Power plant</i>	<i>Jetty</i>
<i>CPF</i>	7	7	1	1	2	4	4	4	4
<i>Wellpads</i>	7	9	3	3	2	4	4	4	4
<i>Flowlines</i>	1	3	3	3	1	0	0	0	0
<i>Onshore export line</i>	1	3	3	3	1	0	0	0	0
<i>Offshore export line</i>	2	2	1	1	6	1	1	1	1
<i>Liquefaction process</i>	4	4	0	0	1	6	6	6	6
<i>Cryo Tanks</i>	4	4	0	0	1	6	6	6	6
<i>Power plant</i>	4	4	0	0	1	6	6	6	6
<i>Jetty</i>	4	4	0	0	1	6	6	6	6

Table 13 - MPk matrix at iteration 1

<i>TC(1)</i>	<i>CPF</i>	<i>Wellpads</i>	<i>Flowlines</i>	<i>Onshore export line</i>	<i>Offshore export line</i>	<i>Liquefaction process</i>	<i>Cryo Tanks</i>	<i>Power plant</i>	<i>Jetty</i>
<i>CPF</i>	1	1	0	0	0	-1	-1	-1	-1
<i>Wellpads</i>	1	1	0	0	0	-1	-1	-1	-1
<i>Flowlines</i>	0	0	1	1	1	-1	-1	-1	-1
<i>Onshore export line</i>	0	0	1	1	1	-1	-1	-1	-1
<i>Offshore export line</i>	0	0	1	1	1	-1	-1	-1	-1
<i>Liquefaction process</i>	-1	-1	-1	-1	-1	1	0	1	0
<i>Cryo Tanks</i>	-1	-1	-1	-1	-1	0	1	1	0
<i>Power plant</i>	-1	-1	-1	-1	-1	1	1	1	0
<i>Jetty</i>	-1	-1	-1	-1	-1	0	0	0	1

Table 14 - Technical compatibility matrix at iteration 1

<i>CP(1)</i>	<i>CPF</i>	<i>Wellpads</i>	<i>Flowlines</i>	<i>Onshore export line</i>	<i>Offshore export line</i>	<i>Liquefaction process</i>	<i>Cryo Tanks</i>	<i>Power plant</i>	<i>Jetty</i>
<i>CPF</i>	1	0	1	1	0	0	1	0	0
<i>Wellpads</i>	0	1	0	0	1	-1	0	1	-1
<i>Flowlines</i>	1	0	1	1	0	0	1	0	0
<i>Onshore export line</i>	1	0	1	1	0	0	1	0	0
<i>Offshore export line</i>	0	1	0	0	1	-1	0	1	-1
<i>Liquefaction process</i>	0	-1	0	0	-1	1	0	-1	1
<i>Cryo Tanks</i>	1	0	1	1	0	0	1	0	0
<i>Power plant</i>	0	1	0	0	1	-1	0	1	-1
<i>Jetty</i>	0	-1	0	0	-1	1	0	-1	1

Table 15 - Pre-project compatibility matrix at iteration 1

- At iteration $s = (2)$

From the list of row blocks of size 1, resulting from the first iteration, the Suppliers' availability matrix $SA(2)$ is built (Table 16):

SA_2	Wellpads, Flowlines	Wellpads, Onshore	Liquefaction, Tanks	Liquefaction, Jetty	Tanks, Power plant	Tanks, Jetty	Flowlines, Onshore	CPF, Wellpads
CTR1	0	0	0	0	0	0	0	0
CTR2	0	0	0	0	0	0	0	1
CTR3	0	0	0	0	0	0	0	0
CTR4	0	0	1	1	1	1	0	1
CTR5	1	1	0	0	0	0	1	0
CTR6	0	0	1	1	1	1	0	0
CTR7	1	1	0	0	0	0	1	0
CTR8	0	0	1	1	1	1	0	1
CTR9	0	0	1	1	1	1	0	0
CTR10	0	0	1	1	1	1	0	1
CTR11	1	1	0	0	0	0	1	1
CTR12	0	0	0	0	0	0	0	0
CTR13	0	0	0	0	0	0	0	0
CTR14	0	0	0	0	0	0	0	1
CTR15	0	0	1	1	1	1	0	1

Table 16 - Suppliers' availability matrix at iteration 2

Input: $SA(1)$; $SA(2)$; RB^1 ; RB^2 .

Result: RB^3 , the list of row blocks of size 3.

Stop Condition: $RB^3(2) = \emptyset$.

As same as for the first iteration, the elimination matrices are first built:

- Building the matrix $MP(2) = SA(1)^t \times SA(2)$.
- Building the technical compatibility matrix $TC(2)$.
- Building the matrix of pre-project studies compatibility $CP(2)$.

From iteration 2, the algorithm has to ensure that the potential row blocks created don't contain twice the same elementary object. For each potential row block $\{e_i, rb_1^2\}$ that doesn't satisfy one of the 3 conditions, the constraint $x_i + x_j \leq 1$ is added to the ILP, in order to be eliminated. The set of row blocks of size 3, $RB^3(2)$ given by all alternative optimal solutions of the ILP (b) for PNG project are the following: $RB^3(2) = \{\{\{\text{Wellpads, Flowlines, Onshore Gas Pipe}\} \{\text{Liquefaction process, Cryo Tanks, Jetty}\}\}$

The algorithm goes through the same steps from iteration 2 until the set of created row blocks is empty, which is the case of iteration 3 in the running example, as no row block of size 4 is created.

4.1.1.2. Identification of contractual configurations

Once the row blocks created, the next step is to identify the contractual configurations associated to each of them. It consists in cutting the row blocks according to temporal phases, forming contracts perimeters, with associated remuneration type(s) and selection mode(s) (see Figure 28).

Project Architecture Matrix		Basic Engineering	Detailed Engineering	Procurement	Construction	Transport & Installation	Commissioning
Upstream Facilities	CPF						
	Wellpads						
Pipelines	Flowlines	Contract 1 - Call for Tender EP Lump Sum			Contract 2 - Call for Tender C Reimbursable		
	Onshore Gas Pipe						
	Offshore Gas Pipe						
LNG Facilities	Liquefaction Process	Elementary alternative			---		
	Cryo Tanks						
	Power Plant						
	Jetty						

Figure 28 - Identification of contractual configurations per row block

To do so, a list of drivers has been identified through our analysis of the contractual strategy selection process of PNG project as well as close out reports from past projects and brainstorming with the Company’s project office team.

List of Drivers:

- **Size of the scope.** To increase competition and ensure competitive prices, the best option is to split the Engineering (E), Procurement (P), and Construction (C) phases into three different contracts. However, in case of a large scope, the company has neither the skills, software, nor technology to handle the temporal interfaces. After discussions with decision makers, it has been stated that it is preferable to make: (i) a single EPC contract in case of a large scope, (ii) two contracts EP+C in case of a medium scope, (iii) three contracts E+P+C in case of a small scope.
- **Schedule criticality.** In case of high schedule criticality, the priority is to deliver the row block as quickly as possible. Therefore, the tendering process should be shortened and the Call for Tender avoided. In addition, since scopes with interfaces may cause some schedule creep, it is recommended to award a single EPC contract.
- **Risk of temporal interfaces.** In case of risky interfaces between the execution phases of a row block, it is recommended not to split the scope, and thus use a single contractor for the whole block.
- **Basic Engineering uncertainty.** To manage design uncertainty of a row block, the best option for the firm is to entrust its realization to several contractors, and then decide which one fits best the expectations. In this case, the Design Competition selection mode is recommended. In case of no or few competition, the Open Book Tender may be relevant.

- **Scope uncertainty.** As mentioned in Section 2.2.2.3, the level of risk in contract scope allows to determine its remuneration type. Thus: (i) in case of large scope uncertainty, a Reimbursable contract is most suited; (ii) in case of medium uncertainty, a Unit Rate contract is most suited; and (iii) in case of scope clarity, a Lump Sum contract is preferred.
- **Construction uncertainty.** Sometimes, even if the scope of a given object/ row block does not seem risky, its Construction phase may be risky, due in particular to the local environment of the project. In that case, temporal cuts such as EPCm and EPC with (C not fixed) are recommended, as well as a Reimbursable remuneration type for the Construction.
- **Suppliers competition.** A high presence of suppliers is generally desired to any type of project, as it allows obtaining quality works at a competitive price. In that case, the Call for Tender selection mode is highly recommended.

Decision tree for the identification of contractual configurations:

These drivers are organized under the form of a decision tree, where a leaf represents a possible contractual configuration; the path leading to a contractual configuration is the combination of values taken by the successive drivers, forming branches in the tree. The construction of the decision tree and the order of identification of the drivers leading to leaves (the contractual configurations) reflect the experience of the company to handle past upstream projects, it is shown in Figure 29. The decision tree procedure has been codified based solely on conditions on the values taken by the considered drivers.

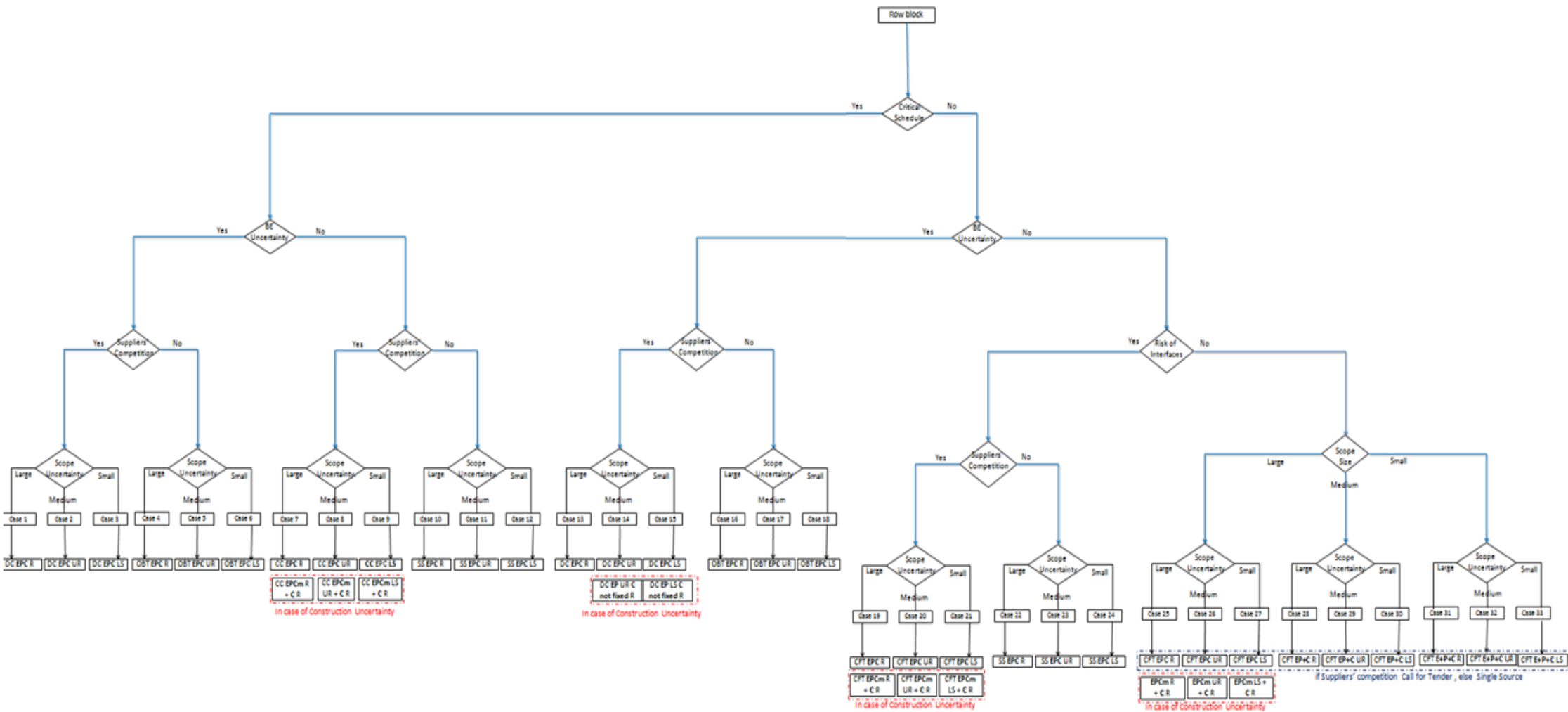


Figure 29 - Decision tree for the identification of contractual configurations

Application of the contractual configurations identification procedure on PNG project

The contractual configurations are identified after having specified for each row block the evaluations on the drivers. To do so, employees from TOTAL’s project team have been asked to fulfill information on the considered drivers, as illustrated in Figure 30. Each driver is represented by a qualitative scale, for instance, the uncertainty of the scope can have three values: small, average or high. It is also to be noticed that a cross (x) in the table means that the information is not required to propose the contractual configuration.

Row Blocks	Inputs / Drivers - Decision Tree							Elementary alternatives
	Schedule Criticality	BE Uncertainty	Suppliers' Competition	Risk Interfaces	Size of the Scope	Scope Uncertainty	Construction Uncertainty	Contractual Configurations
CPF	No	No	Yes	No	Medium	Medium	No	CFT EP+C UR
Wellpads	No	No	Yes	No	Medium	Medium	No	CFT EP+C UR
Flowlines	No	No	Yes	No	Small	Small	No	CFT E+P+C LS
Onshore Gas Pipe	No	No	Yes	No	Small	Small	No	CFT E+P+C LS
Offshore Gas Pipe	No	No	Yes	No	Small	Small	No	CFT E+P+C LS
Liquefaction Process	No	Yes	Yes	x	x	Small	Yes	DC EP LS + C not fixed R
Cryo Tanks	No	Yes	Yes	x	x	Small	No	DC EPC LS
Power Plant	No	No	Yes	Yes	x	Small	No	CFT EPC LS
Jetty	No	Yes	Yes	x	x	Medium	Yes	DC EP UR + C not fixed R
{Wellpads, Flowlines}	No	No	Yes	No	Large	Medium	Yes	CFT EPCm UR + C R
{Wellpads, Onshore}	No	No	Yes	No	Medium	Medium	No	CFT EP+C UR
{Liquefaction, Cryo Tanks}	No	No	Yes	No	Medium	Medium	No	CFT EP+C UR
{Liquefaction, Jetty}	No	No	Yes	No	Medium	Medium	No	CFT EP+C UR
{Cryo Tanks, Power plant}	No	Yes	Yes	x	x	Medium	Yes	DC EP UR + C not fixed R
{Cryo Tanks, Jetty}	No	Yes	Yes	x	x	Large	Yes	DC EPC R
{Flowlines, Onshore }	No	Yes	Yes	x	x	Small	No	DC EPC LS
{CPF, Wellpads}	No	Yes	Yes	x	x	Medium	Yes	DC EP UR + C not fixed R
{Wellpads, Flowlines, Onshore}	No	No	Yes	No	Medium	Medium	No	CFT EP+C UR
{Liquefaction, Cryo Tanks, Jetty}	No	Yes	Yes	x	x	Large	Yes	DC EPC R

Figure 30 - Contractual configurations identification procedure applied to PNG project

Thereby, these two procedures allowed for identifying Elementary alternatives (EA) at Contract level from a set of drivers and conditions. This reduces the combinatory related to the large number of feasibilities. Next section will be dedicated to the estimation of these EA using four criteria: Cost, Schedule, Cost Vulnerability, and Schedule Vulnerability.

4.1.2. Estimation of Elementary alternatives

This step aims at assessing the Elementary Alternatives identified in the previous step, using four criteria:

- **Cost.** For multi-billion projects, choosing a contractual strategy alternative (CSA) over another may save several million dollars;
- **Schedule.** Schedule performance is also a key decision criterion, as the difference between two CSA can be weeks or months. Extra delivery time may cause important profit decrease due to operation loss and liquidated damages;
- **Cost Vulnerability.** The occurrence of certain risks may have a significant impact on cost estimate. For instance, uncertainty in scope or in relationship with a new contractor makes cost estimate less reliable;
- **Schedule Vulnerability.** Risks occurrence can also have a significant impact on schedule estimate, making it irrelevant.

It is to be noticed that the list of criteria presented can be extended depending on the context and the project under analysis. Other criteria such as In-country value, H₃SEQ Policy, or Company’s image could be considered. The four presented are the most generic in upstream development projects.

EA are estimated by the decision makers (DMs) from project team, which collaborate with other entities who provide data, such as cost and schedule estimates and risk assessment studies.

Estimation of Elementary alternatives on PNG project

The EA identified in the previous step (see Figure 30), are estimated regarding the four criteria. Figure 31 shows a sample of these estimations on PNG project: the cost is valued in million dollars, the schedule in months, the cost and schedule vulnerability are valued on a qualitative scale varying from “1 - Slightly Vulnerable” to “4 - Very Vulnerable” to simplify the evaluations.

Elementary Alternatives		Cost Estimate	Schedule Estimate	Cost Vulnerability	Schedule Vulnerability
CPF	CFT EP+C UR	1640	36,5	2	2
Wellpads	CFT EP+C UR	1030	16	2	2
Flowlines	CFT E+P+C LS	400	12	1	1
Onshore Gas Pipe	CFT E+P+C LS	1100	24	1	2
{CPF ; Wellpads}	CFT EPCm UR + C R	2700	37	2	3
{Wellpads ; Flowlines}	CFT EP+C UR	1410	16,5	2	2
{Wellpads, Onshore}	CFT EP+C UR	2100	25	2	2
{Flowlines, Onshore }	CFT EP+C UR	1450	24	1	2
{Wellpads, Flowlines, Onshore}	CFT EP+C UR	2570	25	2	2

1	Slightly Vulnerable
2	Moderately Vulnerable
3	Vulnerable
4	Very Vulnerable

Figure 31 - Elementary alternatives estimation on PNG project

Chapter 4: A 3-level Decision Aiding Process for Contractual strategy selection

It is to be noticed that the data are not very accurate, but sufficiently to differentiate between the performances of the alternatives.

In the next section the Intermediary level is presented in which Intermediary alternatives are identified, estimated, and screened out, in order to build a manageable and relevant set of CSA in a final level. The estimations made on the EA are used in the intermediary level, in order to estimate and evaluate Intermediary alternatives.

4.2. The Intermediary level

In order to build a manageable number of feasible alternatives, and to help reduce the evaluation effort on the CS level of the decision aiding process, the aim of this second modeling level is to transfer to the final level a reduced number of relevant Intermediary alternatives (IA), formed by the assembly of several Elementary alternatives (EA).

We describe first in this section how the identification of what we have termed as “Intermediary alternatives” is made. The identified IA are then estimated against the same evaluation criteria as for the EA, and screened out, in order to exclude the alternatives with poor performance using a sorting MCDA aggregation method.

4.2.1. Identification of Intermediary Alternatives

The IA correspond to the combination of several EA within a specific perimeter, called “Intermediary Breakdown”. We explain in the following how the identification of these breakdowns is made, and then the identification of IA per breakdown. PNG case will be used as illustration for both identification procedures.

4.2.1.1. Identification of Intermediary Breakdowns

The definition of an area is that there is no Elementary alternative combining objects from two different breakdowns. For instance, the inclusion of the elementary object “Offshore Gas Pipe” into IB2 means that there will be no feasible contract combining “Offshore Gas Pipe” to elementary objects from the areas IB1 and IB3 (Figure 32). This intermediary structure aims to treat each of these areas separately, in order to reach a reasonable and relevant number of CS alternatives at the 3rd level. The decision problem will then be to make an assembly of decisions for each Intermediary Breakdown (IB).

In order to identify the IB of a project scope, we have proposed an identification procedure described in the following paragraph. The application of this procedure for PNG project led to the identification of three IB (see Figure 32).

		Basic Engineering	Detailed Engineering	Procurement	Construction	Transport & Installation	Commissioning
Upstream Facilities	CPF	Intermediary Breakdown IB1					
	Wellpads						
	Flowlines						
Pipelines	Onshore Gas Pipe	Intermediary Breakdown IB2					
	Offshore Gas Pipe						
LNG Facilities	Liquefaction Process	Intermediary Breakdown IB3					
	Cryo Tanks						
	Power Plant						
	Jetty						

Figure 32 - Cutting the project scope of PNG project into Intermediary Breakdowns

The Intermediary Breakdown identification procedure

a. Notation

- n : The maximum size of a row block.
- $B = \{0, 1\}$.
- RB^k : The list of row blocks of size k , $k \in \{1, \dots, n\}$.
- $RB^k[i]$: The i^{th} row block of size k , $i \in \{1, \dots, |RB_k|\}$, $k \in \{1, \dots, n\}$. Each row block can be represented by a vector B^N .
- l : The number of created Intermediary Breakdowns.
- IB : The list of created Intermediary Breakdowns.
- $IB[j]$: The j^{th} created breakdown, $j \in \{1, \dots, l\}$. Each IB can be represented by a vector B^N .
- *New*: A Boolean variable that takes the value true when a new breakdown is created.

b. Algorithm Description

The IB are identified from the perimeters of the EA (the row blocks). Thereby, the identification procedure takes as inputs n lists of row blocks. Each list RB^k , $k = 1, \dots, n$, contains the row blocks of size k (3 lists in the case of PNG). The outputs are the IB of the project architecture matrix.

The procedure starts by initializing the number of IB to $l = 1$, by creating a first temporary Breakdown $IB[1]$, from the first row block from the list of row blocks of size n , $RB^n[1]$. In PNG case $IB[1] = \{\text{Wellpads, Flowlines, Onshore Gas Pipe}\}$.

At each iteration $n - k + 1$, $k = \{n, \dots, 1\}$ (k decreases), the procedure compares each row block $RB^k[i]$, $i \in \{1, \dots, |RB^k|\}$, from the list of row blocks of size k , to all the created temporary Breakdowns $IB[j]$, $j \in \{1, \dots, l\}$. After each comparison, two cases are possible:

- $\exists j \in \{1, \dots, l\} (IB[j] \cap RB^k[i]) \neq \emptyset$, in that case: $IB[j] := IB[j] \cup RB^k[i]$;
- Otherwise, if $\forall j \in \{1, \dots, l\}, IB[j] \cap RB^k[i] = \emptyset$, a new breakdown $IB[l + 1] = RB^k[i]$ is created.

c. Input

- n lists of row blocks $RB^k : k \in \{1, \dots, n\}$.
- The procedure start to go from the row blocks of size n : $k = n$.
- A temporary breakdown $IB[l] = RB^n[1]$.
- The number of created temporary Intermediary Breakdowns $l = 1$.

d. Results. A set of Intermediary Breakdowns.

e. Procedure

- Stop Condition: $k = 0$
- Iteration $s = (k)$.

```

For ( $i = 1$ ) to  $|RB^k|$  Do
|
|   For ( $j = 1$ ) to  $l$  Do
|   |   If [ $(IB[j] \cap RB^k[i]) \neq \emptyset$ ] Then
|   |   |    $IB[j] := IB[j] \cup RB^k[i];$ 
|   |   |    $New := False;$ 
|   |   |   end if;
|   |   end for;
|
|   If ( $New = True$ ) Then
|   |    $IB[l + 1] := RB^k[i];$ 
|   |    $l := l + 1;$ 
|   |   Else  $New = True;$ 
|   |   end if;
|
end for;
 $k := k - 1;$ 
    
```

The procedure described above, has been built based on our analysis of the CS selection process of PNG project. Its application to the same project is given hereafter.

Application of the Intermediary Breakdown identification procedure on PNG project

In order to identify IBs, one needs to consider as input the perimeters of the EA, that is to say, the row blocks. The row block identification procedure applied to PNG case allowed to identify 19 row blocks, with the following configurations:

- **9 row blocks of size 1:** $RB^1 = \{CPF; Wellpads; Flowlines; Onshore Gas Pipe; Offshore Gas Pipe; Liquefaction process; Cryo Tanks; Power plant; Jetty\}$.

- **8 row blocks of size 2:** $RB^2 = \{\{Wellpads, Flowlines\}; \{Wellpads, Onshore Gas Pipe\}; \{Liquefaction process, Cryo Tanks\}; \{Liquefaction process, Jetty\}; \{Cryo Tanks; Power plant\}; \{Cryo Tanks, Jetty\}; \{Flowlines, Onshore Gas Pipe\}; \{CPF, Wellpads\}\}$.

- **2 row blocks of size 3:** $RB^3 = \{\{Wellpads, Flowlines, Onshore Gas Pipe\}; \{Liquefaction process, Cryo Tanks, Jetty\}\}$.

(0) At initialization:

$$IB[1] = \{Wellpads - Flowline - Onshore Gas Pipe\}.$$

(1) At iteration 1 ($k = 3$):

$$IB[2] := \{Liquefaction process - Cryo Tanks - Jetty\}.$$

(2) At iteration 2 ($k = 2$):

$$IB[1] := \{Wellpads - Flowline - Onshore Gas Pipe - CPF\}.$$

$$IB[2] := \{Liquefaction - Cryo Tanks - Jetty - Power Plant\}.$$

(3) At iteration 3 ($k = 1$):

$$IB[3] := \{Offshore Gas Pipe\}.$$

(4) At iteration 4 ($k = 0$):

Stop condition satisfied, end of algorithm.

Thereby, the procedure applied to PNG project has allowed the built of 3 Intermediary breakdowns (see Figure 33):

- $IB1 = \{CPF - Wellpads - Flowlines - Onshore Gas Pipe\}$,
- $IB2 = \{Offshore Gas Pipe\}$,
- $IB3 = \{Liquefaction Process - Cryo Tanks - Power Plant - Jetty\}$.

It is recalled that the physical meaning of these IB is that all EA are included in one IB, and no EA crosses two or more IBs.

Chapter 4: A 3-level Decision Aiding Process for Contractual strategy selection

		Basic Engineering	Detailed Engineering	Procurement	Construction	Transport & Installation	Commissioning
Upstream Facilities	CPF	Intermediary Breakdown IB1					
	Wellpads						
	Flowlines						
Pipelines	Onshore Gas Pipe	Intermediary Breakdown IB2					
	Offshore Gas Pipe						
LNG Facilities	Liquefaction Process	Intermediary Breakdown IB3					
	Cryo Tanks						
	Power Plant						
	Jetty						

Figure 33 - Intermediary Breakdowns identification on PNG project

4.2.1.2. Identification of Intermediary alternatives

The Intermediary alternatives (IA) represent all possible combinations of the EA in each IB, in such a way that they do not overlap.

On PNG project, three IB have been identified by the above procedure (Figure 33), each one being treated separately. Within each breakdown, IA are identified: seven in IB1, one in IB2, six in IB3 (see Figure 34). The selection of exactly one alternative per breakdown, while avoiding incompatible ones, constitutes at third level a complete contractual strategy alternative.

Elementary alternatives of IB1		Intermediary alternatives covering IB1						
		IA 1,1	IA 1,2	IA 1,3	IA 1,4	IA 1,5	IA 1,6	IA 1,7
CPF	CFT EP+C UR	1	0	0	1	1	1	1
Wellpads	CFT EP+C UR	1	0	0	0	0	1	0
Flowlines	CFT E+P+C LS	1	1	0	0	1	0	0
Onshore Gas Pipe	CFT E+P+C LS	1	1	0	1	0	0	0
{CPF ; Wellpads}	CFT EPCm UR + C R	0	1	1	0	0	0	0
{Wellpads ; Flowlines}	CFT EP+C UR	0	0	0	1	0	0	0
{Wellpads, Onshore}	CFT EP+C UR	0	0	0	0	1	0	0
{Flowlines, Onshore}	CFT EP+C UR	0	0	1	0	0	1	0
{Wellpads, Flowlines, Onshore}	CFT EP+C UR	0	0	0	0	0	0	1

Elementary alternatives of IB2		IA cov IB2
		IA 2,1
Offshore Gas Pipe	CFT E+P+C LS	1

Elementary alternatives of IB3		Intermediary alternatives covering IB3					
		IA 3,1	IA 3,2	IA 3,3	IA 3,4	IA 3,5	IA 3,6
Liquefaction Process	DC EP LS C not fixed R	1	0	0	0	1	0
Cryo Tanks	DC EPC LS	1	0	1	0	0	0
Power Plant	CFT EPC LS	1	1	1	0	1	1
Jetty	DC EP UR C not fixed R	1	1	0	0	0	0
{Liquefaction, Tanks}	DC EP UR C not fixed R	0	1	0	0	0	0
{Liquefaction, Jetty}	DC EPC R	0	0	1	1	0	0
{Tanks, Power Plant}	DC EPC LS	0	0	0	1	0	0
{Tanks, Jetty}	DC EP UR C not fixed R	0	0	0	0	1	0
{Liquefaction, Tanks, Jetty}	DC EPC R	0	0	0	0	0	1

Figure 34 - Intermediary alternatives identification on PNG project

4.2.2. Estimation of Intermediary alternatives

In order to estimate the IA identified in the previous step (see Figure 34 for PNG project), the proposal is twofold: first, interfaces between EA are estimated. Indeed, interfaces can cause additional cost, duration, more cost and schedule vulnerability, or may benefit from some synergy or scale effect. Second, the IA estimates are obtained using aggregation operators on the EA estimates and interfaces between EA. The following shows how the estimation is performed using the same upstream development project.

4.2.2.1. Estimation of Elementary alternatives interfaces

The risk of interfaces can be translated into some additional cost and delay, or even more vulnerability regarding the cost and the schedule. Thus, we propose to assess each couple of EA of a given IA according to our four criteria: Cost, Schedule, Cost Vulnerability and Schedule Vulnerability.

The estimations are performed by the company, which provides data on the four considered criteria. Figure 35 represents a sample of such estimations (EA of IB1). A cross (x) in the tables means the EAs are overlapping (see for instance CPF with {CPF, WP}). Also, the four matrices are symmetric; they are therefore filled only in the upper side.

Cost Interfaces	CPF	WP	FL	On	{CPF; WP}	{WP; FL}	{WP; On}	{FL; On}	{WP; FL; On}
CPF		25	80	0	x	95	25	80	95
Wellpads (WP)			40	70	x	x	x	100	x
Flowlines (FL)				0	110	x	40	x	x
Onshore Pipe (On)					70	70	x	x	x
{CPF; WP}						x	x	120	x
{WP; FL}							x	x	x
{WP; On}								x	x
{FL; On}									x
{WP; FL; On}									

Cost Vuln. Interfaces	CPF	WP	FL	On	{CPF; WP}	{WP; FL}	{WP; On}	{FL; On}	{WP; FL; On}
CPF		1	2	1	x	2	1	2	2
Wellpads (WP)			2	2	x	x	x	3	x
Flowlines (FL)				1	3	x	2	x	x
Onshore Pipe (On)					2	2	x	x	x
{CPF; WP}						x	x	2	x
{WP; FL}							x	x	x
{WP; On}								x	x
{FL; On}									x
{WP; FL; On}									

Schedule Interfaces	CPF	WP	FL	On	{CPF; WP}	{WP; FL}	{WP; On}	{FL; On}	{WP; FL; On}
CPF		0	2	0	x	2	0	2	2
Wellpads (WP)			0,5	1	x	x	x	1	x
Flowlines (FL)				0	2,5	x	0,5	x	x
Onshore Pipe (On)					1	1	x	x	x
{CPF; WP}						x	x	3	x
{WP; FL}							x	x	x
{WP; On}								x	x
{FL; On}									x
{WP; FL; On}									

Sched. Vuln. Inter.	CPF	WP	FL	On	{CPF; WP}	{WP; FL}	{WP; On}	{FL; On}	{WP; FL; On}
CPF		2	3	1	x	3	2	3	2
Wellpads (WP)			2	2	x	x	x	3	x
Flowlines (FL)				1	3	x	2	x	x
Onshore Pipe (On)					2	2	x	x	x
{CPF; WP}						x	x	2	x
{WP; FL}							x	x	x
{WP; On}								x	x
{FL; On}									x
{WP; FL; On}									

Figure 35 - Estimation of Elementary alternatives interfaces of IB1

4.2.2.2. *Estimation of Intermediary alternatives using aggregation operators*

To proceed from EA and EA interfaces estimation to IA assessment, while avoiding unnecessary assessment, the following aggregation operators have been considered:

- **Cost estimate aggregation operator.** Cost estimate of an Intermediary Alternative ($IA_{i,k}$) from an Intermediary Breakdown (IB_k), is defined as the sum of the costs of its Elementary Alternatives (EA_j) plus their interfaces. It is given as follows:

$$Cost(IA_{i,k}) = \sum_{j/EA_j \in IA_{i,k}} Cost(EA_j) + \sum_{EA_j, EA_{j'} \in IA_{i,k}} CostInterfaces(EA_j, EA_{j'}).$$

- **Schedule estimate aggregation operator.** Schedule estimate of an Intermediary Alternative ($IA_{i,k}$) from an Intermediary Breakdown (IB_k), is defined as the maximum duration between the Elementary Alternatives conception (EA_j), plus the possible delays due to their interfaces. It is given by the following formula:

$$Sched(IA_{i,k}) = \mathbf{Max}\{Sched(EA_j) \mid EA_j \in IA_{i,k}\} + \mathbf{Max}\{SchedInterf(EA_j, EA_{j'}) \mid EA_j, EA_{j'} \in IA_{i,k}\}.$$

- **Cost Vulnerability aggregation operator.** Cost vulnerability of an IA ($IA_{i,k}$) from an IB (IB_k), is defined as the maximum vulnerability value of its EA (EA_j) and their interfaces. It is given by the following formula:

$$CostV(IA_{i,k}) = \mathbf{Max}\{\mathbf{Max}\{CostV(EA_j) \mid EA_j \in IA_{i,k}\}; \mathbf{Max}\{CostV(EA_j, EA_{j'}) \mid EA_j, EA_{j'} \in IA_{i,k}\}\}.$$

- **Schedule Vulnerability aggregation operator.** The same aggregation function as for “cost vulnerability” is proposed. It is given by the following formula:

$$SchedV(IA_{i,k}) = \mathbf{Max}\{\mathbf{Max}\{SchedV(EA_j) \mid EA_j \in IA_{i,k}\}; \mathbf{Max}\{SchedV(EA_j, EA_{j'}) \mid EA_j, EA_{j'} \in IA_{i,k}\}\}.$$

We have made use of these operators to estimate IA of the PNG case. Figure 36 shows a sample of such estimation (the Elementary alternatives of IB_1).

		Cost Estimate	Schedule Estimate	Cost Vulnerability	Schedule Vulnerability
IB1	AI 1,1	4385	38,5	2	3
	AI 1,2	4380	39,5	3	3
	AI 1,3	4270	40	2	3
	AI 1,4	4315	38,5	2	3
	AI 1,5	4285	38,5	2	3
	AI 1,6	4325	38,5	3	3
	AI 1,7	4305	38,5	2	2

Figure 36 - Estimation of Intermediary alternatives of IB_1

Once the IA are identified and estimated, the last step is to know which alternatives to keep based on their performances.

4.2.3. Screening of Intermediary alternatives

In order to avoid the identification and assessment of a too large number of contractual strategy alternatives (CSA), we propose to first eliminate the less performing IA.

This evaluation phase is decomposed in two screening steps: (i) dominance-based elimination, and (ii) elimination using a MCDA sorting aggregation method.

4.2.3.1. Dominance-based elimination

The first elimination step is the one that appears as being the most obvious, as no aggregation method is needed to perform the elimination. Indeed, dominance-based elimination consists in a pairwise comparison between the IA, with regards to the considered criteria. For each comparison ($IA_{i,k}$, $IA_{i,k'}$), $IA_{i,k'}$ is eliminated if and only if $IA_{i,k}$ is at least as good as $IA_{i,k'}$ on each criterion.

For instance, in Figure 37, since $IA_{1,1}$ is dominated by the alternative $IA_{1,4}$ on each criteria, it is therefore removed from the process (the four criteria are to be minimized). This means it will not be considered as part of a potential CSA, knowing that each CSA containing $IA_{1,4}$ is more performing.

		Cost Estimate	Schedule Estimate	Cost Vulnerability	Schedule Vulnerability	Dominated by
IB1	IA 1,1	4385	38,5	2	3	IA 1,4
	IA 1,2	4380	39,5	3	3	IA 1,4
	IA 1,3	4270	40	2	3	
	IA 1,4	4315	38,5	2	3	IA 1,5
	IA 1,5	4285	38,5	2	3	
	IA 1,6	4325	38,5	3	3	IA 1,5
	IA 1,7	4305	38,5	2	2	

Figure 37 - Dominance based elimination of Intermediary alternatives applied on PNG project

This step is shown here as an illustration. It can be refined by adding indifference or preference thresholds. For instance, the difference in cost estimate between $AI_{1,1}$ and $AI_{1,2}$ is only 5 million. Both alternatives could be considered by the decision makers as being at equal cost, knowing that the estimation may be not very precise.

4.2.3.2. *Elimination using a sorting aggregation method*

This step is useful in the case where it is not possible to judge whether an alternative is better than another. The decision problem corresponds to a MCDA sorting problem consisting in assigning alternatives to one of the two ordered categories:

- ***‘Not eliminated’***: alternatives for which most of the evaluations on the considered criteria are positive, without major drawbacks;
- ***‘Eliminated’***: alternatives with a significant number of negative evaluations, leading to consider them as globally unsatisfactory.

The selected aggregation method in this step is MR Sort with veto (Bouyssou and Marchant, 2007), as justified in Chapter 3, Section 3.3. It consists in two parts:

▪ **A veto threshold elimination**

A veto threshold imposes a minimum performance on each criterion. Any alternative not satisfying this threshold is eliminated. The idea is to discard alternatives that do not fulfill a minimal requirement on each criterion, in order to build balanced CSA at a third level.

▪ **A limit profile elimination**

The proposal is to assign the alternatives to two categories “Not eliminated” and “Eliminated”, separated by a limit profile, which is a vector of evaluation on each of the considered criteria (Cost, Schedule, Cost Vulnerability and Schedule Vulnerability for PNG project). It allows for defining two segments of performances on each criterion: better than the profile (not eliminated) and worse than the profile (eliminated). This ensures that each alternative $IA_{i,k}$ is assigned to the “Not eliminated” category if and only if the coalition of criteria (defined by a set of weights) for which $IA_{i,k}$ is at least as good as the profile limit, exceeds a certain threshold λ .

Application on PNG project

The application of the method on PNG project is performed in two parts.

▪ **The veto threshold elimination**

It has been decided that each Intermediary alternative of IB₁ having a cost higher than 4350 is eliminated, regardless to the other criteria. In Figure 37, IA_{1,1} and IA_{1,2} do not satisfy the threshold.

▪ **The limit profile elimination**

The threshold λ has been fixed to 0.67 for PNG project. As illustrated in Figure 38, on the case study, IA_{1,3} is sorted in the “Eliminated” category, IA_{1,5} and IA_{1,7} are sorted in the “Not eliminated” one. It is to be noted that parameters, weights and limit profile are fixed by the DMs.

		Cost Estimate	Schedule Estimate	Cost Vulnerability	Schedule Vulnerability
IB1	IA 1,3	4270	40	2	3
	IA 1,5	4285	38,5	2	3
	IA 1,7	4305	38,5	2	2

	Cost	Schedule	Cost Vul.	Schedule Vul.
Weights w _i	0,31	0,27	0,21	0,21
Limit Profile	4300	39	2	2

Elimination Threshold (λ)	0,67
-------------------------------------	-------------

						Sum w _i	
IB1	IA 1,3	0,31	0	0,21	0	0,52	Eliminated
	IA 1,5	0,31	0,27	0,21	0	0,79	Not Eliminated
	IA 1,7	0	0,27	0,21	0,21	0,69	Not Eliminated

Figure 38 - Sorting Intermediary alternatives of IB₁ using MR Sort model

Thereby, this last step of the Intermediary level allowed for screening out uninteresting alternatives. This reduced number of alternatives will serve to identify and estimate potential CSA at the highest and final level of the decision aiding process, which is described in the following section.

4.3. The Contractual strategy level

The purpose of this third and last level is to select an appropriate contractual strategy which is the assembly of one alternative per Intermediary Breakdown (IB) in order to cover the complete project scope. This starts by the identification of contractual strategy alternatives (CSA), by selecting one Intermediary alternative (IA) per IB while avoiding incompatible IA combinations. Each identified CSA is estimated and then evaluated, in order to: (i) screen out unsatisfying ones, using the same sorting MCDA aggregation method as for the previous level (MR Sort with veto), and then, (ii) rank remaining CSA to come up with a final recommendation, using a ranking MCDA aggregation method (S-RMP). Each of the four steps are described and explained in what follows, using the same PNG example.

4.3.1. Identification of feasible Contractual strategy alternatives

A CSA is a combination of IA, one from each IB. Theoretically, all the combinations are possible. However, from a practical point of view, it is not always the case. Indeed, some combinations are not allowed or not possible due to technical reasons. In our case, we have considered the three following conditions to be met:

- **A large number of interfaces between contracts.** When the scope is divided into many contracts, the company may not be able to mobilize a large supervision team, as it doesn't possess the required skills, notably on interface management. It is therefore important to be sure that the number of interfaces is still manageable;
- **A high risk level on interfaces.** Complex interfaces, with high level of uncertainty may cause important cost and schedule creep. It is therefore recommended to consider a CSA with minimum risky interfaces in order to keep estimates as accurate as possible;
- **A large scope accumulation.** When suppliers are assigned to too large scopes, the bargaining power is in their favor. This is true for: (i) the contract award, as it may induce a lower competition and more expensive prices; and for (ii) its execution, as the contractors risk only minor penalties in case of cost or schedule creep, unlike the oil company that will suffer the consequences. In addition, in case of failure from the suppliers, the oil and gas Company is left with the inability to find alternative solutions for so big scopes.

Any IA couple that does not meet one of the three stated conditions is excluded from the process, i.e. any potential CSA combining the two IA will not be considered.

Elimination of incompatible intermediary combinations on PNG project

As an illustration, we have applied the decision aiding process as a whole to the PNG case. As shown in Figure 39, each IA from a given IB has been compared to IA from other IBs with regards to the three conditions. A qualitative criteria varying from -1 to 1 has been determined (-1 means that the condition is not satisfied). On the example, the couples (IA_{1,5}; IA_{3,1}) and (IA_{1,5}; IA_{3,5}) are eliminated, they will therefore not be combined in any CSA

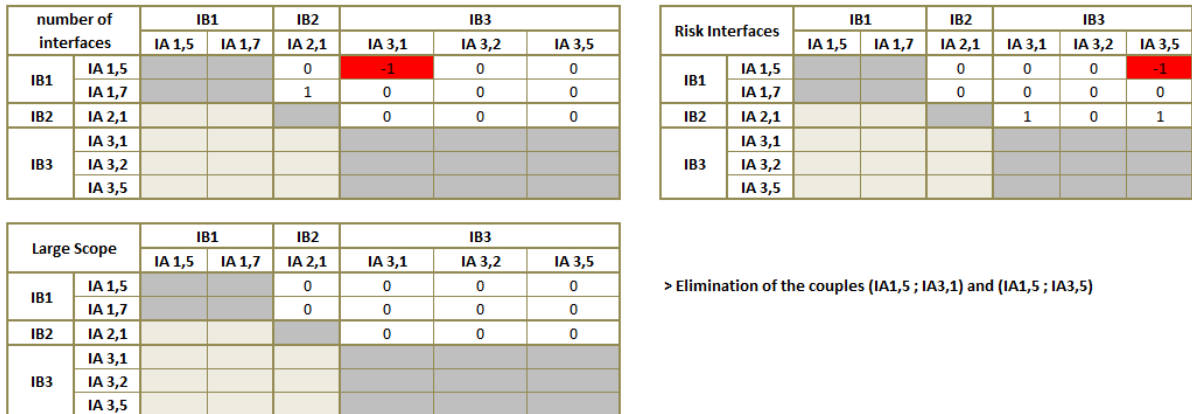


Figure 39 - Elimination of incompatible Intermediary alternatives couples on PNG project

The not eliminated IA pairs allowed for identifying four CSA, represented in Figure 40 below.

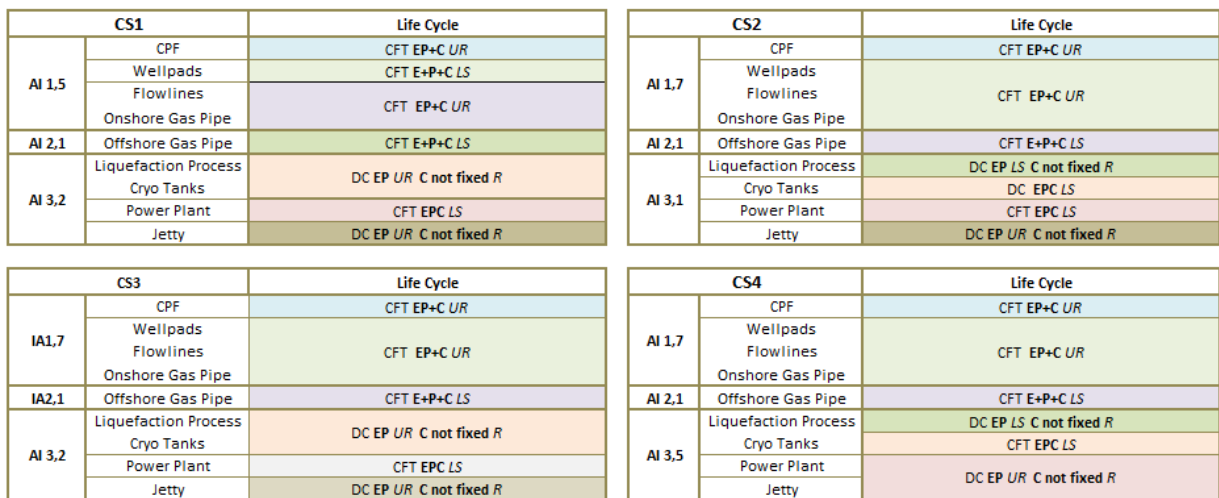


Figure 40 - Identification of Contractual strategy alternatives on PNG project

The following section describes how the identified CSA are estimated.

4.3.2. Estimation of Contractual strategy alternatives

This step is similar to the one used for IA estimation. Indeed, in order to prevent the oil Company to fill table of estimates at each of the three level of the decision aiding process, the identified CSA are estimated using as inputs the estimation on IA, previously filled, and tables corresponding to the estimation of interfaces between those IA. The same aggregation operators introduced in Section 4.2.2.2 for the Intermediary level are used. We illustrate in what follows the estimation step of PNG project.

4.3.2.1. Estimation of interfaces between Intermediary alternatives

Similarly to the previous level, the interfaces between IA can generate extra cost, delays or even more vulnerability. It is therefore important to consider IA interfaces on each of the four criteria. Figure 41 represents an illustration of IA interfaces estimates applied to PNG project.

		Cost Estimate	Schedule Estimate	Cost Vulnerability	Schedule Vulnerability
Interfaces (IB1, IB2)	(IA 1,5 ; IA 2,1)	30	1,5	2	3
	(IA 1,7 ; IA 2,1)	35	2	2	2
Interfaces (IB1, IB3)	(IA 1,5 ; IA 3,2)	0	0	1	1
	(IA 1,7 ; IA 3,1)	0	0	1	1
	(IA 1,7 ; IA 3,2)	0	0	1	1
	(IA 1,7 ; IA 3,5)	0	0	1	1
Interfaces (IB2, IB3)	(IA 2,1 ; IA 3,1)	25	3	2	2
	(IA 2,1 ; IA 3,2)	30	1,5	3	2
	(IA 2,1 ; IA 3,5)	25	2	2	2

Figure 41 - Estimation of Intermediary alternatives interfaces on PNG project

4.3.2.2. Estimation of Contractual strategy alternatives

As same as for the intermediary level, CSA are assessed using the aggregation operators on the IA and IA couples' estimates. Figure 42 shows the results of the calculated estimations of CSA of PNG project. They will be used for evaluation purpose, in order to first Sort the uninteresting ones, and then Rank the remaining ones from best to worst.

	Cost Estimate	Schedule Estimate	Cost Vulnerability	Schedule Vulnerability
CS1	9845	40	3	3
CS2	9765	41,5	2	3
CS3	9870	40,5	3	3
CS4	9815	40,5	3	2

Figure 42 - Estimation of Contractual strategy alternatives on PNG project

4.3.3. Screening of Contractual strategy alternatives

In order to come up with a CS proposal, one needs to rank the alternatives from best to worst. However, in some upstream development projects the decision makers may face a significant number of CSA and the ranking may be difficult to understand or explain.

To deal with this problem, the proposal is to first classify the CSA by assigning them to one of the two ordered categories: “Not eliminated” and “Eliminated”. To do so, the same MCDA aggregation method MR Sort with veto is proposed. The screening phase of the contractual strategy level of the PNG example is presented in what follows.

4.3.3.1. Dominance based elimination

As same as for the second level, dominated alternatives are screened out from the decision aiding process. Figure 43 shows the dominance-based elimination method on CSA of PNG project. The contractual strategy CS3 is eliminated as it is dominated by CS1.

	Cost Estimate	Schedule Estimate	Cost Vulnerability	Schedule Vulnerability	Dominated by
CS1	9845	40	3	3	
CS2	9765	41,5	2	3	
CS3	9870	40,5	3	3	CS1
CS4	9815	40,5	3	2	

Figure 43 - Dominance based elimination on Contractual strategy alternatives of PNG project

4.3.3.2. Elimination using MR Sort with veto model

This step of the process consists in sorting alternatives into one of the two categories: “Eliminated” and “Not eliminated”, following the same principles as the Intermediary level by relying on the MR Sort method.

As illustrated in Figure 44, the application of the model to our running example allowed the removal of the contractual strategy CS1 from the decision aiding process, as it is not better than the considered limit profile, following the rules of the method.

Chapter 4: A 3-level Decision Aiding Process for Contractual strategy selection

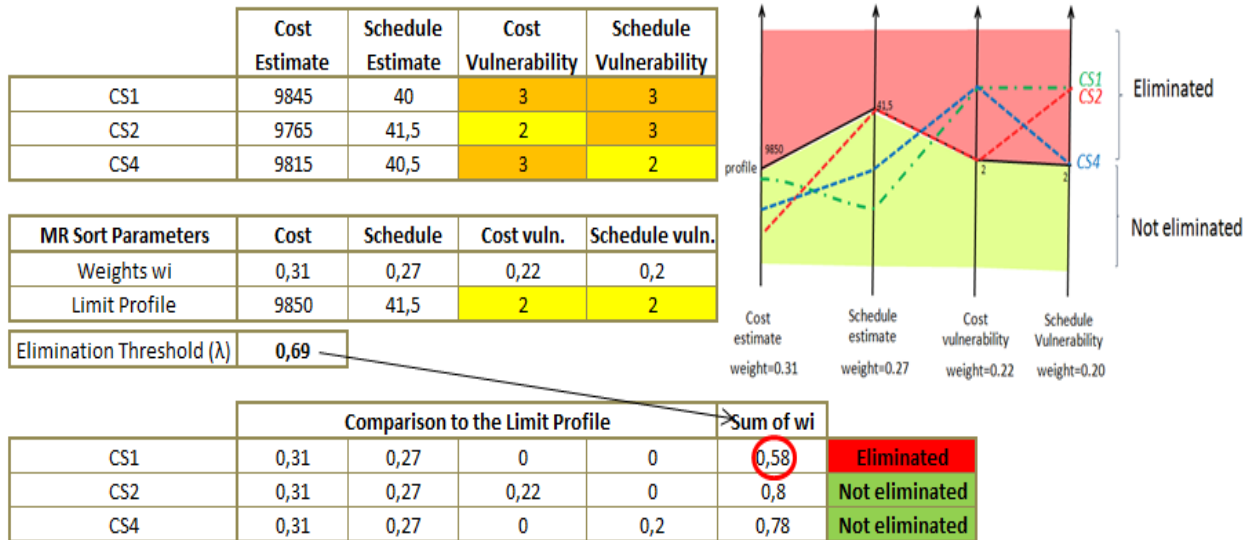


Figure 44 - Sorting contractual strategy alternatives of PNG project using MR Sort model

4.3.4. Ranking of Contractual strategy alternatives

The remaining CSA, considered as being the most performing alternatives, are ranked in this last step. The chosen MCDA aggregation method is S-RMP (Rolland, 2013), as explained in Section 3.3.6.

The S-RMP model, with a unique profile, allows for defining two segments of performance on each of the considered criteria: better than the profile (which can be interpreted as “very good”) and worse than the profile (which can be interpreted as “good”). The model first compares the alternatives to the profile, and then deduces an order of the alternatives based on the coalition force of criteria for which the alternatives are situated in the “very good” segment.

Figure 45 shows the ranking obtained in output of the considered model, which can be easily explained. Indeed, the profile allows the identification of an ordered encoding on each criterion into 2 ordered intervals of performances (*A* and *B*), such that performances below the profile are denoted as *A* and those above the profile as *B*. The S-RMP method ranks alternatives based on these ordered interval of performances.

For instance, CS2 has evaluations *A* on criteria “cost estimate” and “cost vulnerability” (weight sum=0.53), while CS4 has evaluations *A* on criteria “schedule estimate” and “schedule vulnerability” (weight sum 0.47). As the coalition of criteria supporting CS2 is greater than the coalition of criteria supporting CS4, CS2 is preferred to CS4.

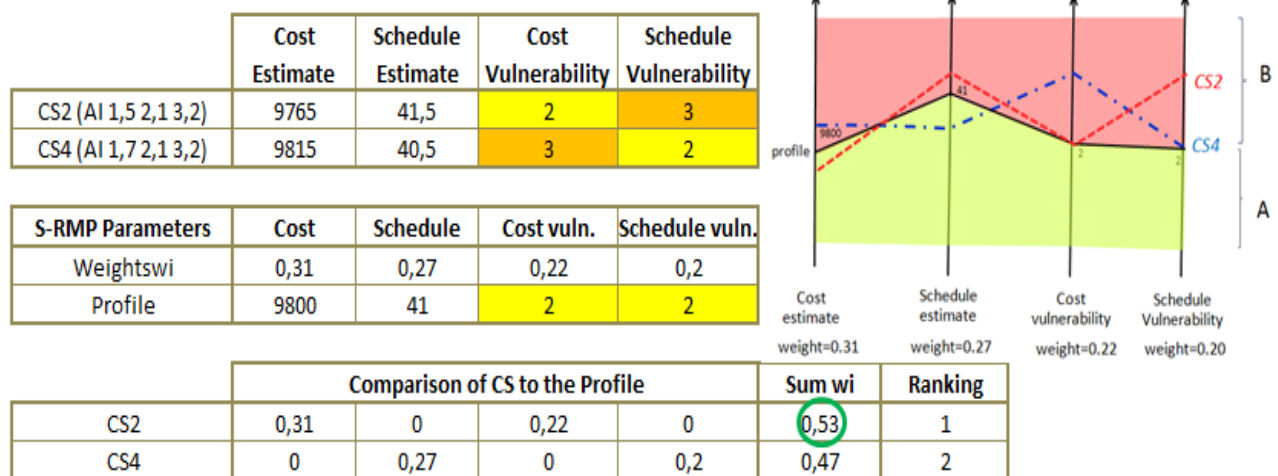


Figure 45 - Ranking contractual strategy alternatives of PNG project using MR Sort model

Note.

Since we did not have sufficient data on the CS selection process of PNG project (described in Chapter 1, Section 1.3.3), we could not compare the two contractual strategy proposals made by the Project office team (see Figure 12) with the recommendation provided by our decision aiding process. In addition, the used estimations are fairly fictitious and aim to illustrate the steps of the decision aiding methodology.

Chapter 4: A 3-level Decision Aiding Process for Contractual strategy selection

Thereby, to summarize, one of the aims of this work is to support the justification of recommendation to the different stakeholders through the proposed decision aiding process. On the one hand, we believe that the designed process will help in understanding and following the successive steps that conducted to the recommendation. On the other hand, the type of models used to derive the final recommendation provides the advantage to be easily interpretable and discussions can be done at each step to validate outputs, for instance elimination or ranking of some alternatives, the weights on criteria, the decision parameters, etc.

4.4. Chapter Conclusion

This research work aims to provide a decision aiding process for selecting a contractual strategy (CS) of upstream development projects in the oil and gas industry. The main goal is to propose a structured methodology to treat the encountered issues during the CS selection process: 1) there are a large number of possible alternatives both at contract level and CS level; 2) the criteria are from different scales and natures, difficult to compare and aggregate; 3) there is a need to justify the proposed solution.

As mentioned, the first difficulty is twofold: 1) there are a large number of possible contracts; 2) there are a huge number of contracts combinations to form CSA. To deal with the first part, we identified what we have called “Elementary alternatives” from a set of drivers, whose values reduce the set of possibilities and allows the identification of relevant contracts options. To deal with the second part, we proposed to split the scope into sub-scopes, called Intermediary breakdowns, for which there are no contracts making overlaps between two Breakdowns. This allows, on the one hand eliminating unsatisfying Intermediary alternatives per breakdown and Intermediary alternatives couples, on the other hand, identifying a set of manageable and relevant CSA.

To treat the second issue, the proposal is to progressively estimate and evaluate the performance of three kinds of alternatives and their interfaces, on the basis of the usual cost and schedule criteria, but also on their vulnerability due to risk occurrence. This process not only eliminates unsatisfying alternatives, but it allows for building progressively alternatives increasingly wide, to form relevant CSA. During the process, two decision problems are faced: a sorting problem, to keep only good enough alternatives, and a ranking problem, to rank contractual strategies and come up with a final recommendation to the project office team.

Finally, with regard to the last issue, we believe that our scientific approach allows justifying the proposed contractual strategy as a result of the process, which initially opens up to a set of feasible alternatives through conditions and drivers, and become restricted as alternatives are estimated, compared or assembled. The remaining CSA are then ranked, in order to allow the decision-makers (DMs) appreciate their assessments.

The next step would be to see in more details with DMs each part of the process in order to refine it, such as: the conditions and drivers allowing identifying Elementary alternatives and their consequent results, the construction of the rating scales on the evaluation criteria, the set-up of preference intervals to say that an alternative is better than another on a specific criterion, etc. Note that the model is a decision aiding process and can be applied partially or as a whole depending on the Company’s DMs.

Chapter 5: Conclusion and Perspective

The main purpose of the Ph. D. thesis was to provide a decision aiding methodology within the contractual strategy (CS) selection process of TOTAL's upstream development projects. As such projects are often multidimensional, complex and very expensive for oil and gas Companies, an important step is to pay a particular attention to pre-project studies, especially to the design/selection of the CS. Indeed, the selection of a high performing CS alternative may save several million dollars to the oil Company. However, due to some faced issues during the selection process, it is not always easy to appreciate the quality of the chosen CS option.

Indeed, the CS selection process goes through three phases: Identification, Evaluation and Selection, during which three recurring difficulties are faced, namely: (i) *the alternatives generation problem*, as alternatives are the combination of several parameters (objects assemblies, temporal cuts, types of remuneration, selection modes), the construction of alternatives is not a straightforward task. This combination leads to a large number of feasible options either it is at contracts level, or CS level, which cannot all be considered by the decision-makers; (ii) *the performances aggregation problem*, as the considered drivers and evaluation criteria are from different natures, which makes them difficult to formalize and aggregate; and (iii) *the justification of recommendations problem*, as the risk of non-consideration of relevant CS options is rather high due to the first difficulty, in addition rough estimates and evaluations are made on the considered options due to the performances aggregation problem. This often leads to unjustifiable CS proposals as a result of the selection process.

Thereby, a salient point of our work was to focus on how to treat these difficulties by proposing a decision aiding process allowing coming up with a justified CS proposal. Such proposal had to meet projects' objectives in terms of cost and schedule, but also vulnerability, as risk occurrence may cause uncertainties, which can lead to important cost and schedule creep during project execution.

From this industrial issue, a global research question has been identified, which is: "How to build a structured decision aiding process to assist selecting contractual strategy?" We have addressed the question by identifying and analyzing the decision problem, based on a descriptive framework proposed by (Tsoukiàs, 2008). This allowed us to raise two sub-questions: 1) "How to identify/generate a set of relevant contracts and contractual strategy alternatives?" for which the literature on Problem Structuring, WBS, Matrix based methodologies, and contracts in the construction industry, served as basis to our reflection 2) "How to estimate and evaluate identified alternatives in order to make a recommendation?" for which researches conducted in the MCDA field have been used to bring solutions.

In order to deal with the main research question and the research sub-questions a three level decision aiding process has been proposed. Indeed, alternatives were identified, estimated and evaluated at three distinct levels: (1) Elementary level (for contracts identification) (2) Intermediary level (for contracts combination) and (3) Contractual strategy level, leading to a final recommendation.

The Elementary level aims to generate and estimate the set of potential contracts, named "Elementary alternatives" (EA). The generation of such alternatives has been performed in two

steps: 1) the assembly of the physical objects into “row blocks”. They have been identified using all alternative solutions of an Integer Linear Program whose constraints are formed by conditions to be satisfied by potential objects assemblies; 2) the second step consisted in cutting the identified row blocks according to temporal phases, forming potential contracts perimeters, with associated remuneration and selection modes. It has been performed through drivers organized under the form of a decision tree, whose leaves lead to the identification of EA. We proposed to estimate alternatives in terms of the usual cost and schedule, but also two other criteria cost and schedule vulnerability as risk uncertainty can cause important cost or schedule creep. Other criteria can be added depending on the project.

Our contribution to the contractual strategy selection process was adding an intermediary level, in which we identified limited areas that do not overlap containing Intermediary alternatives (IA) which are the combination of one or more EA. This structure’s aim is twofold: on the one hand, to screen out irrelevant IA and come up with a manageable and relevant number of CS, on the other hand, to avoid unnecessary evaluations at a third level. As oil Companies tend to neglect contracts interfaces, which can cause additional cost, duration or vulnerability, the proposal was to estimate the IA by making use of EA interfaces estimates. Finally, in order to select a sorting method to screen out unsatisfying IA, we built an approach helping the choice of an aggregation method to a decision problem. The use of such an approach is justified by the fact that the selection of a MCDA method to a decision problem is often complicated.

The final level has four steps: identification, estimation, sorting and ranking of contractual strategy alternatives (CSA). In order to ensure that the interfaces between the limited areas are not too risky or difficult to manage by the Company, a filter has been proposed on IA couples to construct relevant CSA. The estimation and sorting phases are similar to the previous level and led to a list of CSA. Given that the remaining CSA are the most performing ones, our proposal was not to make a choice on alternatives, but to establish a ranking of alternatives, to give a sight on their relative performances. Once again we used our approach to help the choice of an aggregation method to our ranking decision problem.

As a whole, the decision aiding process constructs alternatives that assemble to one another, in order to analyze at different level of details, contracts, contracts combinations, interfaces, and contractual strategies, in order to come up with a justifiable proposal using evaluation criteria and MCDA aggregation methods.

To summarize, in order to identify and treat the research questions of this Ph. D. thesis, we relied on several elements: (i) our analysis of TOTAL’s contractual strategy selection process to seal the faced challenges, (ii) a literature review on several fields, and (iii) a 4 steps descriptive framework for decision aiding (Tsoukiàs, 2008).

Otherwise, through our approach we provide solutions to some reported problems in the literature (see for instance (Ikhinmwin, 2004)), namely: (i) the CS selection processes are too lengthy and perspective, (ii) the risk of selecting a suboptimal CSA is very high, and (iii) oil companies tends to prefer lump sum contracts. Indeed, (i) the designed decision aiding allows to target a set of drivers in order to efficiently converge to a relevant set of alternatives, (ii) the methodology aims to identify, estimate, and compare options to come up with a justifiable contractual strategy, and (iii) we recommend lump sum contracts only in the case of low scope uncertainty (which is one of the identified drivers), as cost and schedule estimates are more accurate.

This research is also the opportunity to draw some perspectives. Indeed, as a short term perspective, a work of validation and insertion of the 3-level decision aiding process should be carried out. For this purpose and as a starting point, our process has been tested on a small-scale crude oil Pipeline project which will take place in East Africa (see Appendix 2), with the help of an expert from TOTAL. The expert has been asked to fill data on alternatives estimates and some decision parameters. As first feedback, he was satisfied with the results and the adaptability of the model despite the lack of precision on the estimations. The validation and insertion of the research work is underway, as two deliverables are being deployed, (1) a deliverable document, under the form of a “Guide & Manual”, and (2) an operational deliverable, under the form of a decision aiding tool to support the CS selection process.

As a medium term perspective, it would be wise to provide a more robust tool. Indeed, the decision parameters are at the moment considered as inputs; for the tool to deliver more constructive and convincing recommendations, a model of preference that accurately reflects the judgment of the decision-makers must be built on some decision parameters (such as, weights on criteria, elimination thresholds, limit profiles, etc.). However, such a model requires the acceptance of decision-makers and the presence of sufficient accurate data, which is not necessarily the case in practice.

As a long term perspective, similar decision aiding models treating other dimensions at different temporalities of the oil and gas upstream part can be brought, either it is (i) before the design of the CS, such as, the elaboration of local content strategies brought to host country, the selection of equipment, materials and facilities to define the project scope, (ii) or afterwards, such as, the selection of suppliers given a CS. On a later phase, it would be interesting to construct a generic tool allowing gathering these decision aiding models as one decision support system. This will allow analyzing the interactions that may occur on different dimensions and temporalities, to assess the impact of decisions taken in one dimension on others, and appreciate the consequences on the whole process.

**Appendix 1 – MCDA aggregation
Methods comparison for the faced Sorting
decision problem**

Appendix 1 – MCDA aggregation Methods comparison for the faced Sorting decision problem

Evaluation Criteria	Scale	Weights	DRSA	UTADIS	MR Sort with veto	MR Sort without veto	ELECTRE TRI	ELECTRE TRI-C	ELECTRE TRI-NC	PROAFTN	TRINOMFC	PAIRC LASS	THESEUS	Flow Sort	AHP Sort	NTOMIC	TRICHOTOMIC SEGMENTATION	TOMASO
a- Mandatory criteria																		
1. Ordered sorting categories	0/1	x	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1
2. Consideration of ordinal scales	0/1	x	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3. No preferential dependency between criteria	0/1	x	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
b- Non-mandatory criteria																		
4. Qualitative and quantitative input data	0/1	0,2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5. Incommensurability of scales	0/1	0,2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6. Partial compensation between criteria (veto)	0/1	0,1	0	0	1	0	1	1	1	1	0	0	1	0	0	0	1	1
7. Existence of a tool	0/1	0,1	1	1	0	0	1	1	0	1	0	0	0	0	1	0	0	1
8. A manageable number of decision parameters	0-10	0,1	10	8	7	8	5	4	4	3	4	6	6	5	7	6	3	6
9. Ease of understanding of the method's decision parameters	0-10	0,1	10	5	7	8	5	3	4	3	5	5	5	5	3	4	5	3
10. Ease of understanding of the method's functioning	0-10	0,1	7	9	8	8	7	6	6	5	7	6	5	7	6	4	6	7
11. Level of competence required for the application of the method	0-10	0,1	4	8	9	9	7	7	7	7	8	4	6	7	7	6	6	3
Distance			0,19	0,2	0,19	0,27	0,16	0,2	0,29	Eliminated	Eliminated	0,39	0,28	0,36	0,27	0,4	0,3	Eliminated

Table 17 - Comparison of MCDA aggregation methods for the faced sorting decision problem

Appendix 2 – East African Crude Pipeline (EACOP) project

Introduction

EACOP is an onshore crude oil Pipeline upstream development project which will take place in East Africa, crossing two countries Uganda and Tanzania. Similarly, for PNG project, we were asked to apply our decision aiding methodology to the contractual strategy selection process.

Having only the pipeline as a physical object, the contained elementary objects are all related, meaning there are no Intermediary Breakdowns (separated areas) in the project architecture matrix. This implies that the Intermediary level of our decision aiding process is skipped.

Through this example, we want to highlight the adaptability of the proposed process according to the complexity of the upstream development project under study. The input data was filled by an expert from TOTAL, the estimates have been made for comparative purposes (between potential options). The followed steps are detailed hereunder.

- **List of Elementary Objects.** Given that the pipeline crosses two different countries the scope for both Pipeline and Pumps stations has been divided. A terminal to process the crude oil is also considered in the scope of work, it is situated in the Tanzanian coasts. In addition, roads must be built in certain geographical locations to give access to the Pipeline, it is therefore considered as an elementary object. Thereby the list of elementary objects are summarized in Table 18:

Elementary Objects	Notations	% Scope
Pipeline Uganda	P-Uga	60%
Pipeline Tanzania	P-Tan	
Pumps Stations Uganda	S-Uga	20%
Pumps Stations Tanzania	S-Tan	
Terminal	T	10%
Roads	R	2%

Table 18- EACOP List of Elementary Objects

1. Elementary Level

As a reminder the Elementary level of our 3-level process contains two phases: Identification and Estimation, they are detailed in what follows.

1.1. Identification of Elementary alternatives

The Identification of the Elementary alternatives (EA) is performed in two main steps: (i) the identification of objects assemblies into “row blocks”, (ii) the identification of the “contractual configurations” (temporal cuts, selections modes and types of remuneration) associated to each row block.

1.1.1. Step EA-1 identification of row blocks

We have established objects assemblies are possible under three conditions: (1) all potential row blocks should insure a minimum competition; (2) All objects of a potential row block should be technically compatible and not complex to gather; (3) The pre-project studies of objects from a potential row block should be compatible. Since the elementary objects are all related to one object (Pipeline) the conditions (1) and (3) are satisfied. However, some objects may be complex to gather, due to several facts, for instance, since the Pipeline crosses two different countries it doesn’t make sense to gather P-Uga to S-TAN in the same row block, without including P-TAN (or P-TAN to T-UGA without including P-UGA), also, since the roads are part of both countries P-UGA + R (or P-TAN +R) cannot be gathered in one block, it also doesn’t make sense to put the Terminal (situated in the Tanzanian costs) and P-UGA or S-UGA in the same row block, etc. Thereby, at the end of this step the following row blocks are identified (Table 19):

Row blocks
P-UGA
P-TAN
S-UGA
S-TAN
T
R
P-UGA + P-TAN
P-TAN + S-TAN
P-UGA + S-UGA
S-UGA + S-TAN
P-TAN + T
S-TAN + T
P-UGA + P-TAN + R
P-TAN + S-TAN + T
S-UGA + S-TAN + T
P&S-UGA + P&S-TAN
S-UGA & TAN+ T + R
P&S-UGA + P&S-TAN + T
P&S -UGA+ P&S-TAN+T+R

Table 19 – Identified Row blocks on EACOP project

1.1.2. Step EA-2 – Identification of Contractual Configurations

The second step is to identify for each row block their temporal cut, and to choose both a remuneration type and a selection mode. To do this, we asked the expert to specify for each row block the evaluation on a pre-defined list of drivers. The Contractual Configurations identification procedure allowed obtaining the list of Elementary alternatives, as shown in Table 20. Note that, the considered inputs were completed later (see Section 4.1.1.2 for the final list of drivers), as the decision tree has been updated after the application of the decision aiding process on EACOP project.

Inputs							Outputs
Row Blocks	Scope Size	Scope Uncertainty	Schedule Criticality	Risk of Interfaces	Construction Uncertainty	Suppliers' Competition	Contractual Configurations
P-UGA	Large	Medium	no	no	yes	yes	CFT EPC UR
P-TAN	Large	Medium	no	no	yes	yes	CFT EPC UR
S-UGA	Medium	Small	no	no	yes	yes	CFT EP+C LS
S-TAN	Large	Small	no	no	yes	yes	CFT EPC LS
T	Medium	Small	no	yes	no	yes	CFT EPC LS
R	Small	Small	no	yes	yes	yes	CFT EPC LS
P-UGA + P-TAN	Large	Medium	no	no	yes	yes	CFT EPC UR
P-TAN + S-TAN	Large	Medium	no	no	yes	yes	CFT EPC UR
P-UGA + S-UGA	Large	Medium	no	no	yes	yes	CFT EPC UR
S-UGA + S-TAN	Large	Medium	no	no	yes	yes	CFT EPC UR
P-TAN + T	Large	Medium	no	yes	yes	yes	CFT EPC UR
S-TAN + T	Large	Small	no	yes	yes	yes	CFT EPC LS
P-UGA + P-TAN + R	Large	Medium	no	no	yes	yes	CFT EPC UR
P-TAN + S-TAN + T	Large	Medium	no	no	yes	yes	CFT EPC UR
S-UGA + S-TAN + T	Large	Medium	no	yes	yes	yes	CFT EPC UR
P&S-UGA + P&S-TAN	Large	Medium	no	no	yes	yes	CFT EPC UR
S-UGA & TAN+ T + R	Large	Medium	no	yes	yes	yes	CFT EPC UR
P&S-UGA + P&S-TAN + T	Large	Medium	no	no	yes	yes	CFT EPC UR
P&S -UGA+ P&S-TAN+T+R	Large	Medium	no	no	yes	yes	CFT EPC UR

Table 20 – Identified Contractual Configurations on EACOP Project

1.2. Estimation of Elementary alternatives

In this step we asked the expert to estimate the performance of each resulting option, on the four considered criteria, they are given in Table 21 below.

List of Elementary alternatives						
Row Blocks	Contractual Configurations	Notations	Cost Estimate	Schedule Estimate	Cost Vulnerability	Schedule Vulnerability
P-UGA	CFT EPC UR	EA1	700	35	3	3
P-TAN	CFT EPC UR	EA2	1 400	36	3	3
S-UGA	CFT EP+C LS	EA3	175	24	1	2
S-TAN	CFT EPC LS	EA4	525	30	1	2
T	CFT EPC LS	EA5	350	30	2	3
R	CFT EPC LS	EA6	70	6	4	4
P-UGA + P-TAN	CFT EPC UR	EA7	2 092	36	3	3
P-TAN + S-TAN	CFT EPC UR	EA8	1 917	36	3	3
P-UGA + S-UGA	CFT EPC UR	EA9	872	35	3	3
S-UGA + S-TAN	CFT EPC UR	EA10	697	30	2	2
P-TAN + T	CFT EPC UR	EA11	1 743	36	3	3
S-TAN + T	CFT EPC LS	EA12	872	30	3	3
P-UGA + P-TAN + R	CFT EPC UR	EA13	2 162	36	3	4
P-TAN + S-TAN + T	CFT EPC UR	EA14	2265,9	36	3	4
S-UGA + S-TAN + T	CFT EPC UR	EA15	1 046	32	3	4
P&S-UGA + P&S-TAN	CFT EPC UR	EA16	2 789	36	3	4
S-UGA & TAN+ T + R	CFT EPC UR	EA17	1 116	32	3	3
P&S-UGA + P&S-TAN + T	CFT EPC UR	EA18	3 137	36	3	4
P&S -UGA+ P&S-TAN+T+R	CFT EPC UR	EA19	3 207	36	3	4

Table 21 - Elementary alternatives estimation on EACOP Project

2. Contractual Strategy level

Given that the elementary objects are all related (see for instance the last row block P&S-UGA + P&S –TAN + T + R), the intermediary level is skipped. The CSA are thus identified directly from the Elementary alternatives (EA).

2.1. Identification of Contractual strategy alternatives

The CSA corresponds to the combination of EA in order to cover the complete project scope. Indeed, given that the elementary objects are all related to the Pipelines, the contract interfaces are not risky. Thereby, as shown in Table 22, 24 CS have been identified.

List of Elementary alternatives		List of potential Contractual Strategies																									
Row Blocks	Configurations	CS1	CS2	CS3	CS4	CS5	CS6	CS7	CS8	CS9	CS10	CS11	CS12	CS13	CS14	CS15	CS16	CS17	CS18	CS19	CS20	CS21	CS22	CS23	CS24		
EA of size 1	P-UGA	CFT EPC UR	1	0	0	0	0	0	1	0	0	0	0	0	1	1	0	1	0	0	1	1	0	1	0	0	
	P-TAN	CFT EPC UR	1	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	1	0	1	0	1	0	
	S-UGA	CFT EP+C LS	1	1	0	1	0	0	1	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	
	S-TAN	CFT EPC LS	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	
	T	CFT EPC LS	1	1	1	0	0	0	1	1	1	0	0	0	1	0	1	0	1	0	0	0	1	0	0	0	
	R	CFT EPC LS	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	0	0	1	1	1	0	1	0	
EA of size 2	P-UGA + P-TAN	CFT EPC UR	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	P-TAN + S-TAN	CFT EPC UR	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	P-UGA + S-UGA	CFT EPC UR	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	
	S-UGA + S-TAN	CFT EPC UR	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	
	P-TAN + T	CFT EPC UR	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	
	S-TAN + T	CFT EPC LS	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
EA of size 3	P-UGA + P-TAN + R	CFT EPC UR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	
	P-TAN + S-TAN + T	CFT EPC UR	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	
	S-UGA + S-TAN + T	CFT EPC UR	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	
EA of size 4	P&S-UGA + P&S-TAN	CFT EPC UR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	
	S-UGA & TAN+ T + R	CFT EPC UR	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	
EA of size 5	P&S-UGA + P&S-TAN + T	CFT EPC UR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
EA of size 6	P&S -UGA+ P&S-TAN+T+R	CFT EPC UR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Table 22- Identification of Contractual Strategy alternatives on EACOP Project

2.2. Estimation of Contractual strategy alternatives

This step aims to estimate the CSA using as inputs the estimations made on EA (see Table 21) and the estimation of interfaces between EA, as it may generate extra cost, delays and vulnerability. Figure 46 shows the estimates made on EA interfaces.

Appendix 2 – East African Crude Pipeline (EACOP) project

Cost Inter	EA1	EA2	EA3	EA4	EA5	EA6	EA7	EA8	EA9	EA10	EA11	EA12	EA13	EA14	EA15	EA16	EA17	EA18	EA19
EA1	0	5	0	3	1					6	3	3		3	10		11		
EA2			0	8	3	1			0	8		12			12		14		
EA3			0	3	1		5	0			3	3	5	3					
EA4				3	1		8		0		12		8						
EA5					0		4	5	4	5			4			6			
EA6							1	1	1	1	1	1		1	1	1		1	
EA7										15					17				
EA8								0											
EA9											3	3		3					
EA10										15			17						
EA11																			
EA12													15						
EA13																17			
EA14																			
EA15																			
EA16																			
EA17																			
EA18																			
EA19																			

Cost Vuln. Inter	EA1	EA2	EA3	EA4	EA5	EA6	EA7	EA8	EA9	EA10	EA11	EA12	EA13	EA14	EA15	EA16	EA17	EA18	EA19
EA1	1	1	1	1	1	1													
EA2		1	1	1	1	1				1	1	1							
EA3			1	1	1	1	1	1											
EA4				1	1	1	1	1			1	1							
EA5					1	1	1	1	1	1									
EA6						1	1	1	1	1	1	1							
EA7							1	1	1	1	1	1							
EA8								1											
EA9									1										
EA10										1									
EA11											1								
EA12												1							
EA13													1						
EA14														1					
EA15															1				
EA16																1			
EA17																	1		
EA18																		1	
EA19																			1

Schedule Inter	EA1	EA2	EA3	EA4	EA5	EA6	EA7	EA8	EA9	EA10	EA11	EA12	EA13	EA14	EA15	EA16	EA17	EA18	EA19
EA1		0	0	0	0	0,5		0		0	0	0		0	0		0,5		
EA2			0	0	0	0,5		0	0	0	0	0		0	0		0,5		
EA3				0	0	0	0	0		0	0	0		0	0				
EA4					0	0	0	0		0	0	0		0	0				
EA5						0	0	0	0	0	0	0		0	0				
EA6							1	0,5	0,5	0,5	0,5		0,75	0	1		1		
EA7									0		0						1		
EA8								0											
EA9										0	0		0						
EA10											0								
EA11												0							
EA12													0						
EA13														0					
EA14																			
EA15																			
EA16																			
EA17																			
EA18																			
EA19																			

Sched Vuln. Inter	EA1	EA2	EA3	EA4	EA5	EA6	EA7	EA8	EA9	EA10	EA11	EA12	EA13	EA14	EA15	EA16	EA17	EA18	EA19
EA1	1	1	1	1	1	1													
EA2		1	1	1	1	1				1	1	1							
EA3			1	1	1	1	1	1											
EA4				1	1	1	1	1			1	1							
EA5					1	1	1	1	1	1									
EA6						1	1	1	1	1	1	1							
EA7							1	1	1	1	1	1							
EA8								1											
EA9									1										
EA10										1									
EA11											1								
EA12												1							
EA13													1						
EA14														1					
EA15															1				
EA16																1			
EA17																	1		
EA18																		1	
EA19																			1

Figure 46- Estimation of Elementary alternatives interfaces of EACOP Project

The aggregation operators introduced in Section 4.2.2.2, served to proceed from EA and EA interfaces estimation to CSA assessment. Table 23 below presents the assessment on CSA. Note that the high number of alternatives is related to the synergy between objects.

Contractual Strategies		Cost Estimate	Schedule Estimate	Cost Vulnerability	Schedule Vulnerability
CS1	EA1; EA2; EA3; EA4; EA5; EA6	3 249	36,5	3	3
CS2	EA3; EA4; EA5; EA6. EA7	3 238	37	3	3
CS3	EA5; EA6; EA7; EA10	3 235	37	3	3
CS4	EA3; EA6; EA7; IA12	3 234	37	3	3
CS5	EA6; EA7; EA15	3 226	37	3	4
CS6	EA7; EA17	3 207	37	3	3
CS7	EA1; EA3; EA5; EA6; EA8	3 231	36,5	3	3
CS8	EA5; EA6; EA8; EA9	3 220	36,5	3	3
CS9	EA2; EA4; EA5; EA6; EA9	3 238	36,5	3	3
CS10	EA4; EA6; EA9; EA11	3 228	36,5	3	3
CS11	EA2; EA6; EA9; EA12	3 231	36,5	3	3
CS12	EA6; EA9; EA14	3 212	36,75	3	4
CS13	EA1; EA2; EA5; EA6; EA10	3 245	36,5	3	3
CS14	EA1; EA6; EA10; EA11	3 237	36,5	3	3
CS15	EA5; EA10; EA13	3 235	36	3	4
CS16	EA1; EA3; EA4; EA6; EA11	3 240	36,5	3	3
CS17	EA3; EA4; EA5; EA13	3 235	36	3	4
CS18	EA13; EA15	3 224	36	3	4
CS19	EA1; EA3; EA6; EA14	3 225	36,75	3	4
CS20	EA1; EA2; EA6; EA15	3 241	36,5	3	4
CS21	EA5; EA6; EA16	3 216	37	3	4
CS22	EA1; EA2; EA17	3 241	36,5	3	3
CS23	EA6; EA18	3 208	37	3	4
CS24	EA19	3207,4	36	3	4

Table 23 - Estimation of Contractual strategy alternatives on EACOP Project

2.3. Screening of Contractual strategy alternatives

The aim of this step is to eliminate the unsatisfying CSA in order to come up with manageable and relevant options for the last step.

- **Dominance-elimination:** this part aims to screen out the dominated alternatives. For instance, in Table 24, since CS1 is dominated by CS8 it is removed from the process. One can see that most CSA are eliminated, this is mainly due to the fact that some CSA are very similar, but also the fact that Indifference and Preference thresholds have not been considered (for example CS8 and CS10 are almost as good).

Contractual Strategies	Cost Estimate	Schedule Estimate	Cost Vulnerability	Schedule Vulnerability	Dominated by	
CS1	EA1; EA2; EA3; EA4; EA5; EA6	3-249	36,5	3	3	SC8
CS2	EA3; EA4; EA5; EA6; EA7	3-238	37	3	3	SC3
CS3	EA5; EA6; EA7; EA10	3-235	37	3	3	SC4
CS4	EA3; EA6; EA7; EA12	3-234	37	3	3	SC6
CS5	EA6; EA7; EA15	3-226	37	3	4	SC6
CS6	EA7; EA17	3 207,4	37	3	3	
CS7	EA1; EA3; EA5; EA6; EA8	3-231	36,5	3	3	SC8
CS8	EA5; EA6; EA8; EA9	3 220	36,5	3	3	
CS9	EA2; EA4; EA5; EA6; EA9	3-238	36,5	3	3	SC8
CS10	EA4; EA6; EA9; EA11	3-228	36,5	3	3	SC8
CS11	EA2; EA6; EA9; EA12	3-231	36,5	3	3	SC8
CS12	EA6; EA9; EA14	3-212	36,75	3	4	SC24
CS13	EA1; EA2; EA5; EA6; EA10	3-245	36,5	3	3	SC8
CS14	EA1; EA6; EA10; EA11	3-237	36,5	3	3	SC8
CS15	EA5; EA10; EA13	3-235	36	3	4	SC18
CS16	EA1; EA3; EA4; EA6; EA11	3-240	36,5	3	3	SC8
CS17	EA3; EA4; EA5; EA13	3-235	36	3	4	SC18
CS18	EA13; EA15	3-224	36	3	4	SC24
CS19	EA1; EA3; EA6; EA14	3-225	36,75	3	4	SC12
CS20	EA1; EA2; EA6; EA15	3-241	36,5	3	4	SC8
CS21	EA5; EA6; EA16	3-216	37	3	4	SC6
CS22	EA1; EA2; EA17	3-241	36,5	3	3	SC8
CS23	EA6; EA18	3-208	37	3	4	SC6
CS24	EA19	3207,4	36	3	4	

Table 24 - Dominance based elimination on Contractual strategies alternatives of EACOP project

- **Elimination using MR Sort with veto model:** since only three CSA are remained from the last steps, after consultation with the expert, we decided to keep the three options. Moreover, in his opinion the three options seem to be logical and can be considered as proposals to the EACOP project. They can be visualized in Figure 47.

Appendix 2 – East African Crude Pipeline (EACOP) project

CS6	Life Cycle
Pipe Uganda Pipe Tanzania	CFT EPC UR
Station Uganda Station Tanzania Terminal Roads	CFT EPC UR

CS8	Life Cycle
Pipe Uganda Station Uganda	CFT EPC UR
Pipe Tanzania Station Tanzania	CFT EPC UR
Terminal	CFT EPC LS
Roads	CFT EPC LS

CS24	Life Cycle
Pipe Uganda Pipe Tanzania Station Uganda Station Tanzania Terminal Roads	CFT EPC UR

Figure 47- Remaining contractual strategies after sorting on EACOP project

2.4. Ranking of Contractual strategy alternatives

As the project was under negotiation and discussions with potential contractors and local authorities, the experts and decision makers didn't felt the need to apply the decision aiding process to the end in order to classify the remaining CS options.

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