De-risking Investments in Industrial Systems Using Real Options Analysis: Case of Phosphates Fertilizer Firm

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Abstract. Many industrial firms adopted a deterministic irreversible investment plans without any pro-active risk management strategy. The existing literature of the Supply Chain Design does not value the managerial flexibility as enabled by the Real Option (RO) theory. However, this latter considers only single project and not adapted to supply chain investments. This opens a new area of research. Thus, this paper is concerned with providing a practical and novel framework for de-risking future investments of large-scale, capital-intensive interdependent industrial projects, in an uncertain and risky environment. The suggested framework is based on real option analysis and aims to integrate managerial flexibility in terms of "real options" to efficiently adjust the investment plans to the evolution of uncertainties over time, considering interdependencies between projects, while reducing downside risks and increasing potential opportunities. This framework has been tested to assess potential risks, define and value flexible strategies to deal with the construction delays and the cost overruns in the investment planning of phosphates fertilizer firm. The insights indicate that flexibility lead to higher expected performance while reducing downside risks and raising potential upside gains.

Keywords: Managerial Flexibility, Real Option Analysis, Uncertainties, Risks, Real options.

1 Introduction

Complex industrial systems strategic planning involves capitalistic investments expenditures and depends upon the future evolution of the global market which is highly risky. Many firms adopt a deterministic irreversible investment plan without any proactive risk management strategy. This could lead the firm to considerable economic losses. This paper is concerned with providing a practical framework for de-risking future investments of complex industrial systems in an uncertain and risky environment, especially cost overruns and time construction delays. This problem may be significantly critical when investing in a commodity-based integrated chemical supply chain such as oil and gas or phosphates-based mining and chemical industry. These industries invest in capital intensive projects whose value chains are usually vertically integrated from mining to distribution and include complex logistic infrastructure and multi-products chemical transformation facilities and infrastructures that are hieratically dependent.

The most common approaches to deal with uncertainty in the strategic investment planning are the Stochastic Programming and Robust Optimization (RO). RO provides reliable but too conservative solutions [1] since it either maximizes the profit of either the worst-case scenario or the profit of the scenario with highest deviation. SP assumes a risk-neutral decision-maker and focuses only on finding the best design that performs best on average; by optimizing the expected economic value. Thus, the optimal stochastic design could be over-sized and generates losses or under-sized and miss opportunities when the future departs significantly from expectations. This is because, the value of the overall distribution of uncertainties is different than the value associated to the average [2]. Some studies [3, 4, 5,6,7] have integrated risks measures into their design, but these concern mainly the minimization of downside risks. In short, they are reactive to risks and do not provide proactive measures to increase the flexibility of the system for future to deal with unexpected events. However, good strategic investment planning will not only recognize the distribution of possible futures but also proactively take steps to de-risk and future-proof the investments. It will take steps to reduce the possible downsides, investing in ways to deal effectively with eventualities and to unlock future market opportunities. The design should integrate managerial flexibility into the system in terms of "real options" to efficiently adjust the supply chain to the evolution of uncertainties/risks over time. Real options provide the ''right, but not the obligation, to change the system easily in the face of uncertainty, such : option to abandon, to defer, to relocate and to expand/ contract the capacity.

Despite the flexibility in engineering systems being promising approach to deal with uncertainty [2], its effective deployment into the system can be a challenge. It depends highly on the choice of the future alternatives actions (real options); the timing and the location of flexibility in the system. The most common forms of Real Option Analysis (ROA) used in the literature are based on analytical methods (based on dynamic programming) or on lattices (binomial or multinomial). These are typically used to analyze and price financial options. But they do not apply to physical systems for which there is no ready market, in which arbitrage-enforced pricing does not apply, and for which managerial independence invalidates potential assumptions about path independence. To cope with these challenges in valuing flexibility, novel approaches based on decision rules, linking the observations of uncertainty data to decisions, were recently proposed, as by [2]. However, many applications are limited, for example to one type of flexibility (single real options) [10] or to a single project/supply chain component [8,9] which cannot be applied to multiple interdependent projects/components.

Considering the background above, the main contribution of this research paper is to provide a practical approach to flexibility analysis that effectively integrates real options in large-scale complex systems involving interdependent projects. Its novelty lies in the scope and its approach:

As for its scope: we particularly interested in de-risking investment in dependent industrial projects, operating in a commodity based global market, characterized by the need for large capital resources, and where the impact of uncertainties on one potential project will consequently impact the operational functioning of her projects that depend on it.

As for its approach: to make the best use of managerial flexibility on proactively dealing with uncertainties in the chemical supply chain investments, we first model uncertainties considering their correlation, then we quantitatively evaluate their impact including financial risks underlying an investment plan. Based on this evaluation, we explore the options on investments that could be susceptible to increase the expected value from the industrial investments and reduce downside risks.
The remainder of this paper is organized as follows: Section 2 provides the details of the proposed approach. In Section 3, illustrates the use of the suggested approach to the case of an integrated chemical company. The final section summarizes the major findings by providing conclusions and future research perspectives.

2 Proposed Framework: Real compound option analysis

The proposed framework demonstrates how to adapt investment plans to future uncertainties based on proactive and flexible strategies. It aims to avoid future downside risks and take advantage of new opportunities. It involves 5 steps as shown in fig.1:

2.1. Step 1: Meta-Model construction

As many investment planning models are complex in nature, the evaluation of comprehensive flexibility to incorporate into the planning requires the use of meta-models. They could be developed in three ways [2]: **Bottom-up approach**: the meta-model is built upon the aggregation of the detailed description of the model by reducing the inputs and simplifying the formulation of the model without omitting interesting details. **Simulator models**: mimic detailed descriptions of the system or the model responses. It considers the model as a black box, does not consider its technical details. **Top-down approach**: it consists in defining conceptual representations of the overall pattern of the system behavior, such as systems dynamics.

2.2. Steps 2 and 4 : Uncertainty analysis

These steps model potential input uncertainties and investigate the consequent uncertainty of the performance of the investment plan. They enable us to assess the risk-reward of different investment strategies (initial and flexible investment). The risk of loss could be evaluated by the Value at Risk – indicating the 5 or 10% probability of low returns or the complementary Value at Gain , the possible gain for given level of probability.

2.3. Step 3: Flexibility analysis

This step explores proactive strategies and ways to reduce risks (assessed in step 2) and increase opportunities given of the investment plan. This can be done by responding systematically to the questions: where, when and how the flexibility should be incorporated into the design? What flexibility? The answer to the "where" comes by analyzing the most interdependent projects in the alternative design, this comes with the deep knowledge of the supply chain/value chain. The answer to "when" is related to the timing of the risk occurrence. For example, if the potential risk is the project execution delay, then we could distinguish two delay periods: either in the design or in construction phase of the critical project. The answer to the “how” comes by defining the combination of flexible options and the decision rules (“If…Then”) that will structure the use of these flexibilities. These rules both state the conditions under which designers would choose to act and implement the decisions in the meta-model/ the initial model to change the design. According to [1], these rules should mimic what management would do if they had to deal with a changing situation.

2.4. Step 5: Options comparison

Finally, we have to assess the value of flexibility underlined with these compound options and appreciate the risk-reward trade-off between candidate options. One measure of the option value is the difference between the overall design value with and without compound options., as calculated in Step 2, as Equation 1 indicates:

$$Flexibility\ Value = max\ (0, ENPV ¿¿ Best\ Flexible\ design - EN \quad (1)$$

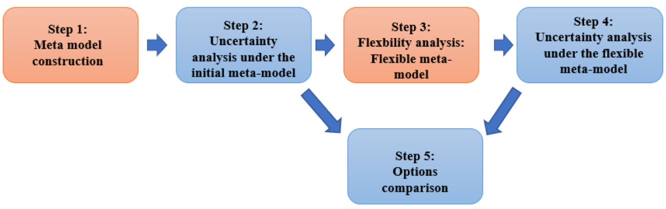

Fig. 1. Real compound options analysis framework

3 Case Study

The presented framework has been tested in the case of our industrial partner (OCP.SA) leader in the phosphate mining and chemical production industry in Morocco. Its logistics chain is spread over three independent axes "northern axis", "central axis" and "southern axis". Each axis is vertically integrated: from the extraction of phosphate ore through the chemical valorization (phosphoric acid and fertilizers). The Group has embarked on an ambitious investment program for the period 2008 to 2030. The first wave of investments focused on the extension of mining and chemical capacities located on its northern axis. The second wave of investments concerns the reconfiguration of the central axis by implanting: a new port in Safi, new acid and fertilizer plants and an acid pipeline that will link acid plants in Youssoufia with fertilizer plants in Safi. For confidentiality reasons, we will consider a fictious investment plan and normalize real data by taking the expected performance of the initial investment plan (Table 1). For the space limit, we do not present the meta-model.

3.1.Step 1: Uncertainty analysis under fixed design

Among potential uncertainties that may lead to significant losses if proactive actions are not considered, are: prices of fertilizer products and raw materials inputs (Ammonia and Sulfur), the acid pipeline construction delays and cost overruns (Table 2). By simultaneously varying different uncertain parameters within their possible range of variation (Table 3), we obtain the distribution of the possibilities of the investment plan performance (Fig.2). This curve represents the cumulative chance of obtaining a result below any specific target value, according to ascending manner. We notice that there is 10% chance of losing respectively about 2092 MMAD or more, that is of missing around -2092 MMAD Target. This investment plan has about 40% chance of breaking (investment value =0) and could realize 1000 MMAD on average.

Table 1. Potential new projects

Asset	Opening date	CAPEX (MMAD)
Complex site 1	2023	358
Complex Site 2	2023	358
Complex Site 3	2024	358
Complex Site 4	2025	358
Complex Site 5	2026	358
Acid Pipeline	2023	116
New Port	2023	268

Table 2. Delays and costs overruns

Year of delays	Cost overruns
1 year	25%
2 years	50%
3 years	70%
4 years	85%

Table 3. Statistical distribution of potential uncertainties

Commodity Price	Statistical Distribution[1]	Parameters
Sulfur price ($)	Triangular	(33, 83, 806)
Ammonia Price ($)	Triangular	(125, 705,884)
Fertilizer Price ($)	Triangular	(200, 263, 1280)
Acid pipeline delays	Uniform	(0,4)

3.2. Step 2: Flexibility analysis

To counteract the risk of the acid pipeline construction delay, a distinction must be made between two cases depending, on the location of the delay in the progress of pipeline development (Fig.3). Similarly, a distinction will be made between ongoing projects (P1), those whose arrival date coincides with that of the pipeline, projects under study (P2), those whose arrival date is later than the initial arrival date of the pipeline (without delay) and the new projects (P3), those whose arrival date is later than the new arrival date of the pipeline (with delay) (Fig.3). If the delay is identified at the design phase of the acid pipeline, in our example in 2020, the firm will have disbursed part of the CAPEX for projects in phase with the pipeline, in particular the two complex site 1 and 2. Due to space limit, we will investigate only two options to limit the delay experienced at the design phase:

Option 1: This option is based on extending the construction of existing projects (P1), deferring the construction of projects under study (P2),and maintaining the ar-

[1] The observation of the historical data shows that the annual price, for a given commodity, is an independent variable that follow a statistical non-skewed distribution.

rival dates of the new projects (P3). Extending the construction of ongoing projects results in extending the CAPEX disbursement associated with these projects and postponing the activation of these projects, while postponing the construction of new projects results in postponing the CAPEX disbursements, as information on the pipeline arrival delay is identified prior to their construction start date. The deferral of the activation of projects results in the deferral of revenues and costs.

Option 2 : This option carries forward the same rules applied in Option 1 except for the maintenance of new projects. In this second option, we will postpone their activation date, in order to lighten the financial commitments in CAPEX.

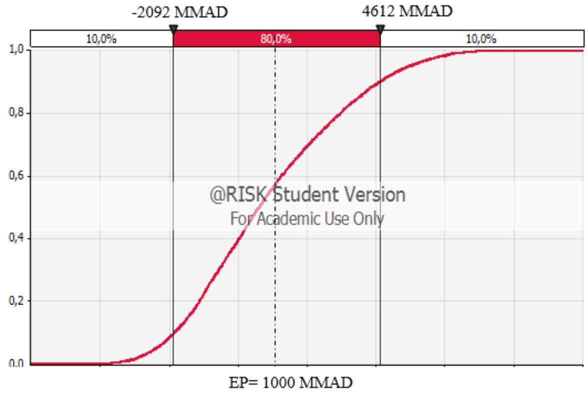

Fig. 2. Cumulative distribution function of the investment plan value (without option)

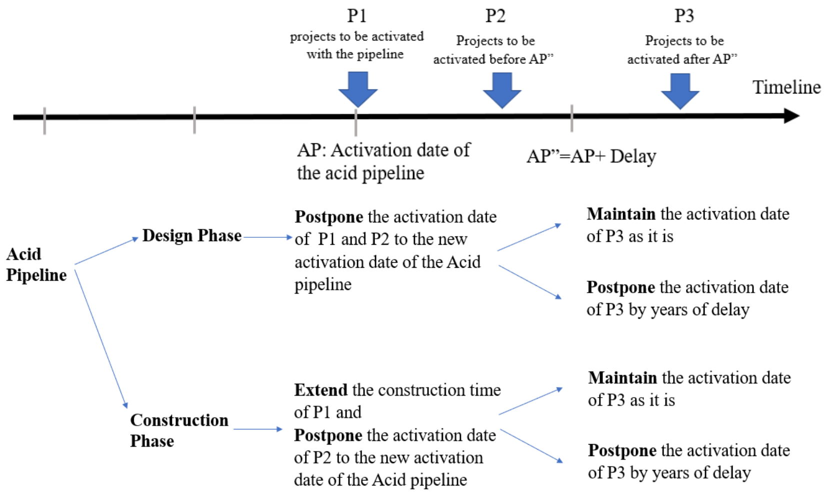

Fig. 3. Flexibility analysis

3.3. Step 3: Uncertainty analysis under flexible designs

By running 10000 Monte Carlo Simulations of the meta-model, using @Risk excel add-in, including option 1 and 2, separately, we obtain the cumulative distribution functions in Fig.4 and 5. Fig.4 indicates that the investment plan with option 1 realizes an Expected Performance (EP) of around 1223 MMAD and there is 10% chance of losing respectively about 1848 MMAD or more. Fig.5 indicates that the investment plan with option 2 realizes on average around 1055 MMAD and has 10% of chance of losing about 1953 MMAD.

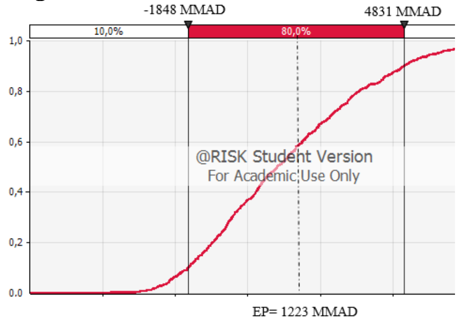

Fig. 4. Cumulative distribution function of the investment plan value (option 1)

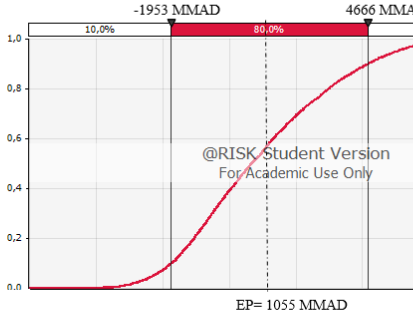

Fig. 5. Cumulative distribution function of the investment plan value (option 2)

Table 4. Statistical distribution of potential uncertainties

	Without option	Option 1	Option 2
Expected performance (MMAD)	**1000**	**1223**	**1055**
Option Value (MMAD)		**216**	**55**
10% VAR (MMAD)	**-2092**	**-1848**	**-1953**
10% VAG (MMAD)	**4612**	**4831**	**4666**

3.3. Step 4: Options comparison

Table 4 resumes the statistical metrics of each investment plan. We can conclude that the integration of the flexibility in investment planning provides better reward while reducing downside losses (Fig. 2, 4, 5). Indeed, both options lead to greater expected value. They lower VAR and and raise VAG. More remarkably, maintaining future projects dates is more interesting than postponing them, thus option 1 outperforms option 2 at all levels. Finally, the implementation of option 1 depends upon the trade-off between the option value and the cost underlying the postponement of projects type 1 and 2. This insight will support the industrial development department during its negotiation with its contractor, considering potential delays.

4 Conclusion and research perspectives

Major long-term investments are inherently risky, because future market, economic, and political conditions are highly uncertain. However, the literature has focused on finding the best design optimizing the expected performance and risks without integrating proactive measures to increase the flexibility of the system for future to deal with unexpected events. In order to address this problem, we suggested a proactive practical framework that integrates and value flexibility -real options- in large-scale complex systems involving interdependent projects. Given the complexity of the studied systems, we considered compound options, each option was applied on a specific project following a specific decision rule. Overall insight from our case study confirms that flexibility is an effective way to improve the expected performance of systems in uncertain environments. In our future work, we will provide guidance for supply chain decision makers on how and when to exercise flexibility to mitigate pandemic crisis.

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