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Decision making in smart supply chains: a case study on the energy industry

Florina Livia Covaci

Babeș-Bolyai University, Cluj-Napoca

Abstract: The dynamic economic environment is driving the evolution of traditional supply chains toward a connected, smart, and highly efficient supply chain ecosystem. Algorithms become powerfull tools that enable machines to make autonomous decisions in the digitized supply chain of the future. The present paper proposes an decision making mechanism for smart supply chain management in the petroleum industry. This industry has a strategic position as it is the base for other essential activities of the economy of any country. The petroleum industry is faced with volatile feedstock costs, cyclical product prices and seasonal final products demand. The current paper considers the position of a refinery as it is at the middle of the integrated petroleum supply chain, between the upstream and downstream. It procures crude oil from upstream assessing the price, quality, timing, and distance to the refinery in order to decide the optimal acquisition. Additionally, the refiner has to carefully monitor the price risk and manage the inventory. The manufacturing activities of the refiner requires thoroughly planning and scheduling the production levels and supply chains for all the derivates and feedstocks for petrochemical industry using tools for decision making in order to estimate market opportunities and threats under volatile market conditions.

In order to provide a reliable and practical decision making model, the current paper proposes a mechanism for decision support under uncertainty using maximum expected utility.

Keywords: supply chain, decision support, software agents, maximum expected utility, petroleum industry

1. Introduction

Delivering the right product to the right location at the right time at the right price is essential for nowadays actors in the economic environment. Agility and flexibility via clients and adaptability in the face of social and environmental economic constraints are the leverage to achieve sustainable progress. A controlled and agile supply chain becomes essential to the collaboration between suppliers at all levels in the supply chain.

The supply chain formation (SCF) problem has been tackled in the literature using several approaches. The first approaches addressed the problem by means of combinatorial auctions (W. E. Walsh, M.P. Wellman, F. Ygge, 2000) (W.E Walsh, M.P. Wellman, 2003). In (W.E Walsh, M.P. Wellman, 2003) the authors proposed a mediated decentralized market protocol with which uses a series of simultaneous ascending double auctions and recent papers are using a message passing mechanism in graphical models in order to solve the SCF problem (M. Winsper, M. Chli, 2013), (T. Penya-Alba, M. Vinyals, J. Cerquides, J.A. Rodriguez-Aguilar, 2012), (M. Winsper, M. Chli, 2012). All these approaches have the folowing limitations: 1) are using only cost as a parameter for contract negotiation between parties involed in the supply chain 2) the feasible supply chains that are obtained are evaluated using a profit maximization function and do not take into account any risk involved, as in an economic environment a higer profit is usually associated with a higher risk.

Our previous work in (Covaci, 2017) proposed means for contract negotiation and supply formation using multiple contract parameters (e.g. price, delivery time, quality constrains) in order to overcome to the first limitation of the previous approaches stated above. The current paper aims to overcome the second limitation of using a profit maximization function in order to make decisions about the best mix of possible supply chains. We are using the results obtained in our previous work (Covaci, 2017) and we further propose means for modelling decision support under uncertainty using as a measure the maximum expected utility, in order to incorporate risk in decision making.

Although the proposed model can be applied to any complex industry, for the present work we will apply it to the petroleum industry because the supply chain of the petroleum industry is extremely complex compared to other industries and provides the most complicated scenarios to validate our model. The petroleum industry is divided into two different, yet closely related, major segments: the upstream and downstream supply chains. The upstream supply chain involves the extraction of crude oil, which is the specialty of the oil companies. The upstream process includes the exploration, forecasting, production, and logistics management of delivering crude oil from remotely located oil wells to refineries. The downstream supply chain starts at the refinery, where the crude oil is manufactured into the consumable products that are the specialty of refineries and petrochemical companies. The downstream supply chain involves the process of forecasting, production, and the logistics management of delivering the crude oil derivatives to customers around the globe (R. Hussain, T. Assavapokee, B. Khumawala, 2006).

Among all stakeholers involed in the supply chain of the petroleum industry we particullary are focusing on the refinery, because it acts in the middle of the upstream and downstream supply chain. The classical way of operating the refinery takes into account the wide variation in price and the seasonality of consumption for the products. For the first one, some refineries are able to adjust quite quickly to the market value of the products and generate the optimal economical mix of products to maximize revenue. On the other hand, refiners also take into account the seasonality of consumption, usually producing more gasoline during the summer and more heating oil during the winter.

The paper is structured as follows: section 2 describes the stakeholders and the products of the petroleum industry, section 3 provides a resume of our previous work regarding supply chain formation, section 4 describes the proposed model for decision making under uncertainty and finally section 5 provides conclusions of our work.

2. Stakeholders and Products of the Petroleum Industry

Supply chain in the petroleum industry contains various challenges, which are not present in most other industries. The oil and petrochemical industries are global in nature. As a result, these commodities and products are transferred between locations that are, in many cases, continents apart. Commodities such as oil, gas, and petrochemicals require specific modes of transportation such as pipelines, vessels or tankers, and railroads. These commodities are produced in specific and limited regions of the world, yet they are demanded all over the globe since they represent an essential source of energy and raw material for a large number of other industries.

Crude oil and natural gas are the raw materials of the downstream petroleum industry. They are used for the production of petrochemicals and other oil derivatives. After the production of crude oil is complete from oil reserves, the crude oil undergoes a distillation process. As a result of the distillation process, various fractions of the crude oil are produced, such as fuel gas, liquefied petroleum gas, kerosene and naphtha.

After cracking operations, petrochemical products such as ethylene, propylene, butadiene, benzene, toluene, and the xylenes are supplied to petrochemical plants to produce even more specialized products, such as plastics, soaps and detergents, synthetic fibers for clothes, rubbers, paints, and insulating materials. Figure 1 shows the final products that can be obtained from processing crude oil and oil derivates.

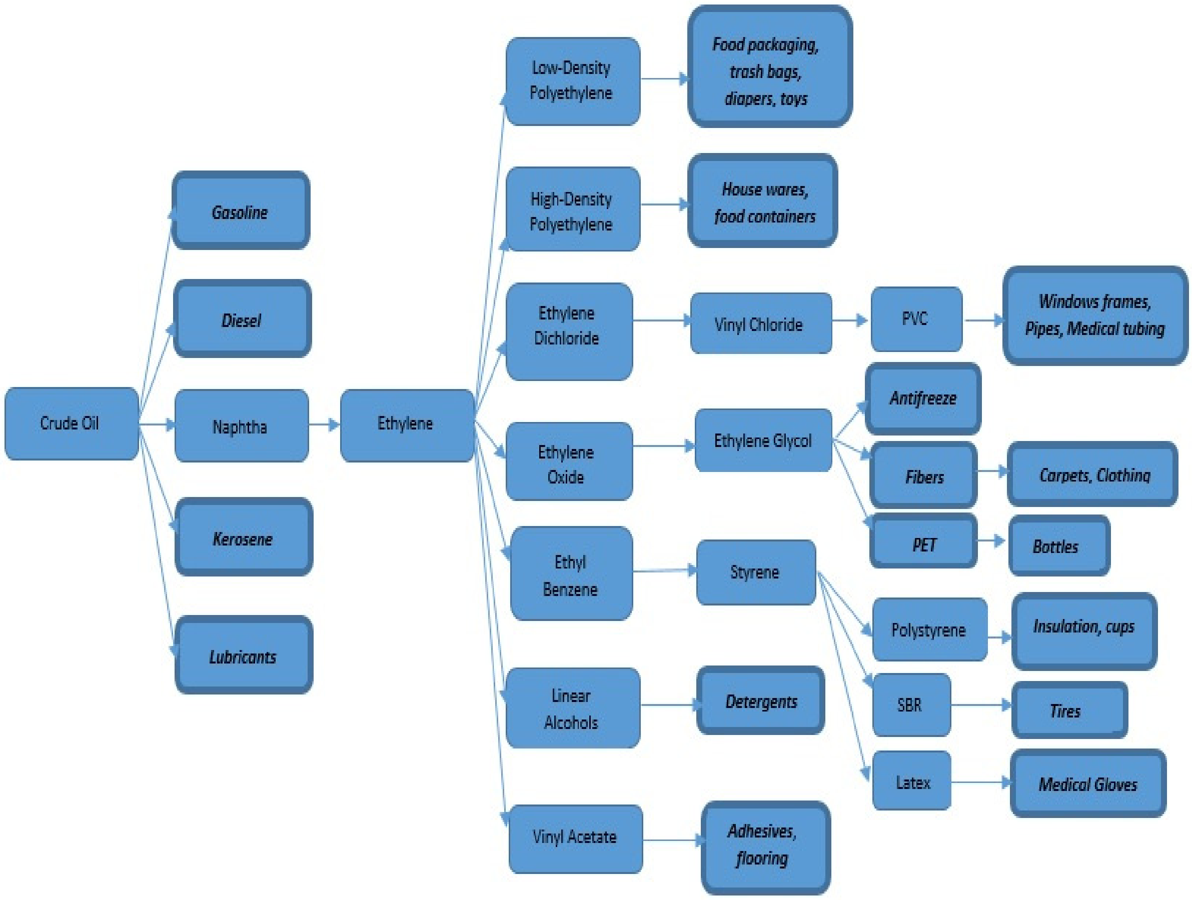


Figure 1. Petroleum Downstream Products (adapted from (Manzano, 2000) and (Profesional Logistics Group, 2013))

The downstream petroleum supply chain can be characterized as a global supply-driven structure with the main following stakeholders (Manzano, 2000):

- Suppliers of crude oil: as a natural resource the crude oil is located in certain areas of the World that usually are far from the main consuming countries, mostly the OECD (Organization for Economic Co-operation and Development) members. An important part of the crude oil supply and reserves is concentrated in the hands of a cartel: OPEC (Organization of Petroleum Exporting Countries).

- Refiners: with plants located all over the world and closer to final consumers. The main reason for this fact is the economies of scale of transporting crude oil in big supertankers versus transporting the final product in smaller lots, and the strategic value of the refining assets. This latter fact makes governments prefer having some of the refinery operations in their territories.
- Consumers: as stated before they are divided into small consumers (e.g., car owners buying gasoline) and wholesale consumers (e.g., power stations using heavy oil, petrochemicals plants receiving feedstock). Wholesale customers, composed by petrochemical facilities, power plants, big fuel consumers (airlines, shipping companies) and other industrial customers. Retail customers, who use the fuels essentially for transportation and domestic heating.

3. Agent-Based Smart Supply Chain using Message Exchange in Graphical Models

As the nowadays dynamic economic environment requires that the companies form and adjust as fast as possible their supply chain we have chosen in (Covaci, 2017) to model the supply chain formation problem using self-interested software agents. Agents are designed to be autonomous problem solvers, possibly communicating with other agents, and are therefore equipped with sufficient cognitive abilities to reason about a domain, make certain types of decisions by themselves, and perform the associated actions

We have modeled the supply chain by mapping the problem in terms of a directed acyclic graph where the nodes are represented by the suppliers/consumers acted by self-interested agents. The agents own utility functions and negotiate multiple contract parameters by message exchange directly with other participant agents representing their potential buyer or seller and take actions in order to maximize their utility functions. Agents send messages regarding multiple contract issues: price, time of delivery, different quality parameters, delay penalties etc.

The agreed values of the negotiated issues are reflected in a contract which has a certain utility value for every agent. By using utility functions, they can assess the benefits they would gain from a given contract, and compare them with their own expectations in order to make decisions.

The following paragraph provides a formal description of the supply chain formation problem in terms of a directed, acyclic graph *(X, E)* where $X = \{X_1, X_2, ..., X_n\}$ denote set of participants in the supply chain represented by agents and a set of edges E connecting agents that might buy or sell from another.

The agents negotiate on multiple contract parameters and negotiation finishes with a contract that is composed of the actual values of the issues that they have agreed on. Notation v_i represents the expectation of a participant in the supply chain on issue *i* of the contract and *U(v)* the utility that a participant obtains by receiving the actual value $v = (vi_1, vi_2, ..., vi_k)$. When a supplier (seller) negotiates with a consumer (buyer), both parties are interested maximizing their utility functions *U(v)*. This means that during the negotiation, the agent sends a messages to its neighbors regarding the states of his variables that is maximizing its utility function.

The utility functions *U(v)* are calculated by means of weighted sum as follows:

$$U(v) = \sum_{i=1}^{k} w_i * v_i \ , \ with \ \sum_{i=1}^{k} w_i = 1 \quad (1)$$

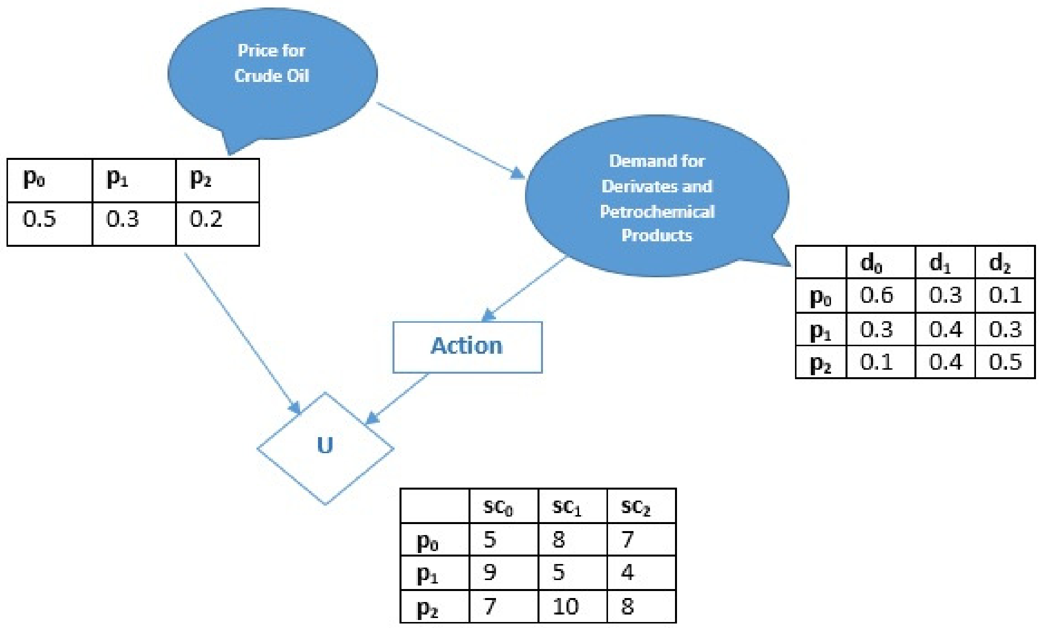
where $0 <= w_i <= 1$ represent the weights measuring the importance of a given issue *i* for a certain agent in the chain.

A feasible supply chain is an allocation representing a sub-graph $(X',E') \subseteq (X, E)$. For $X_i, X_j \in V'$, an edge between X_i, X_j means that agent X_j provides goods to agent X_i. An agent is in an allocation graph if it acquires or provides goods within the underlying partners' constraints.

Using the formalism stated above and message exchange mechanism used in (Covaci, 2017), we have showed that we are able to obtain feasible supply chains in an economic environment with multiple suppliers and consumers.

4. Modelling Decision Support under Uncertainty

The supply chain in petroleum industry presents challenges mainly due to high volatility of the prices of the raw materials and seasonal demand for the final products when compared to other commodities. We are modelling decision support for a refinery and we will consider the petroleum downstream with the activities which take place between the purchase of crude oil and the use of the oil products by the end consumer. This covers performing buying crude oil, refining the crude oil, and distributing the refined products output.



p_0	p_1	p_2
0.5	0.3	0.2

	d_0	d_1	d_2
p_0	0.6	0.3	0.1
p_1	0.3	0.4	0.3
p_2	0.1	0.4	0.5

	sc_0	sc_1	sc_2
p_0	5	8	7
p_1	9	5	4
p_2	7	10	8

Figure 2. Influence diagram

Having obtained several feasible supply chains using the mechanism stated in the section above, we consider uncertainties in crude oil prices and demand in petrochemical products.

In order to model the decision mechanism for a refinery we use the influence diagram in Figure 2. The price for crude oil and predicted demand are in the form of a probability distribution and we will notate it with *P(d)*. The price variable tells the probability that the price of the crude oil will go up, go down or stay at the same level (p_0, p_1, p_2). The demand variables tells the probability for the evolution of the demand (d_0, d_1, d_2) for petrochemical products when the price for the raw material will change *P(d|p)*. We introduce, an action variable that provides a decision rule δ_A at action node A (Action), that is conditional probabilistic distribution P(A|Parents(A)). Parents (A) are the variables that the agent observed prior to making a decision, in the example below being the predicted demand evolution *(P (A|d))*.

Hence, the action variable provides the agent with a decision situation D. Let A= {sc_0,sc_1,...,sc_m} be a set of possible actions, we want to solve the equation (2) according to the decision rule $D[\delta_A]$ of maximizing the expected utility.

$$a* = argmax_a\ EU[D[\delta A]] \qquad (2)$$

The influence diagram in Figure 2 can be translated as a product of factors in equation (3). The first three of them are probabilistically factors and there is one numerical factor U(p,A) which represents the utility obtained by the agent depending on the evolution of the oil price and the action of choosing one of the possible supply chains (sc_0,sc_1,sc_2).

$$EU[D[\delta A]] = \sum_{p,d,A} P(p)P(d|p)\delta A\,(A|d)U(p,A) \quad (3)$$

As we want to maximize over the decision rule $\delta_{A,}$ the equation (3) can be written as in equation (4) and if we marginalize out *p,* we get a factor *μ(d,A).* Hence, the agent has now a simple expression that is trying to optimize in equation (5), a summation over all possible values of *d* and *A* of the decision rule δ given the predicted evolution of the demand, multiplied by the factor *μ(d,A)* that we just computed.

$$EU[D[\delta A]] = \sum_{d,A} \delta A\,(A|d) \sum_{p} P(p)P(d|p)U(p,A) \quad (4)$$

$$EU[D[\delta A]] = \sum_{d,A} \delta A\,(A|d)\mu(d,A) \quad (5)$$

In order to maximize the expected utility the agent will take the action *A* of choosing that supply chain (sc_0,sc_1,sc_2), that will maximize his utility taken into account the predicted evolution of the demand *d*.

5. Conclusion

Optimizing the supply chain is critical to achieving operational excellence and the overall objective of maximizing utility, particularly return on capital while ensuring safety and sustainability.

Within the supply chain, in order to complete their tasks, the supply chain participants, are often reliant on the completion of subtasks (the production of their input goods) by producers upstream in the supply chain. The digitization of supply chains requires intelligent and efficient algorithms that can capture the complexity of real scenarios and establish the new end-to-end processes connecting suppliers and customers. Hence there is needed research to create models that have flexible contract parameters that incorporate risk and asses the supply chains from the perspective of an integrated supply chain.

The current work proposed a decision support mechanism within the SCF process. As opposed to the previous approaches, our approach translates the SCF optimization problem not as a profit maximization problem but as a means for maximizing expected utility. Hence, it incorporates multiple negotiated issues and uses utility functions and action variables in order to compute maximum expected utility.

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