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Decision support with ill-known criteria in the collaborative supply chain context

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ABSTRACT

In the field of Supply Chain Risk Management, the attitude of managers toward risk affect the tactical decision-making process in collaborative supply chains under an uncertain environment, concerning especially capacity levels, lot-sizing rules, purchasing strategies, production scheduling,…, etc. The issue can be formulated as a sequential decision problem under uncertainty where the customer decisions affect the decisions made by the supplier. In this paper we deal with two kinds of uncertainties. The first one is the uncertainty on the indicators of performance (which are not comparable) used by the decision maker to choose a solution (for example: service quality or inventory cost). Hence, we propose an approach based on subjective probability to evaluate the probability that a decision is optimal for the first actor and the probability that it is optimal for both. From these two evaluations, we propose a ranking function to help the first actor to take into account the second one when selecting a decision. The second kind of uncertainty pertains to the demand. A classical criterion under total uncertainty is Hurwicz criterion where a weight expresses a degree of pessimism. Nevertheless, the degree of pessimism is itself ill-known. Thus, it becomes difficult to take into account the behavior of the actors. Hence, we propose an approach based on possibility theory and the so-called pignistic transform, which computes a subjective probability distribution over the criteria. Then, we apply the method used for uncertain criterion. This approach is illustrated through an example and an industrial case study.

1. Introduction

In an increasingly competitive business world, where the sources of disturbance are drastically changing and increasing, supply chains actors are faced with the necessity to constantly improve their decision-making practices. The companies identifying supply chain risk as "an unavoidable and necessary task that continues to pose certain problems" (Lavastre et al., 2012). Faced with a "networked environment", "companies deepen their relationship with partners and thus become more dependent on each other" (Hallikas et al., 2005). Risk, in the context of an enterprise, is defined by Zsidisin (2003) as: "the danger that events or decisions will obstruct the company's achievement of its objectives". In this context, "The process of supply chain actors main can either amplify or absorb the effect of risks in the supply chain" (Juttner, 2005) when the principal risk comes from supply and demand. Mastering the decision making processes of actors is therefore a key to minimizing the risks.

In this paper, we focus on the problem of designing the collaborative purchasing processes in the supply chain context under uncertainty. Moreover, we specifically consider a supplier-customer relationship in a dyadic supply chain where actors are independent. This situation may be described as a 2-actor sequential decision problem. For an industrial Decision-Maker (DM) in a supply chain, the anticipation of the decisional behavior of his/her partners is common practice (capacity level, lot sizing rules, purchasing strategies, production scheduling…). He/she knows that his/her decision will be followed by a series of partner's decisions, which will impact the performance of his decision. The decisional behaviors of independent partners are extremely difficult to anticipate. These potential different behaviors can be interpreted as different sources of uncertainty for a particular actor of the chain.

In this paper, we deal with two sources of uncertain behavior. First, we consider the uncertainty of an actor about the performance criteria of the other actor (for instance one considers the inventory level whereas the other the service quality), criteria that are not commensurate. Moreover, we deal with behaviors under uncertainty

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(the pessimism or optimism of decision maker) which comes down of the occurrence of uncertain events (scraps, breakdowns, delays, demand fluctuations…) for which a probability distribution may not be accessible. Hence, in the context of uncertainty, the criterion should take into account the level of pessimism of decision makers.

This paper is organized in 7 sections. First, a literature review on supply chains is made (Section 2), then we provide some background on decision trees, possibility theory, pignistic probability, criteria under uncertainty and multi-actors decision that will be used in our proposal (Section 3). In the fourth section, we present our approach to model and support the decision-making process with one DM and then we propose a model for sequential multi-DM problem (Sections 5 and 6). Finally, Section 7 illustrates this proposal through an industrial case study.

2. Literature review

In our review, we distinguish the literature that focuses on minimizing risk in supply chains under uncertainty and the literature on coordination mechanisms inside the supply chain.

On the first topic, mostly optimization approaches have been proposed with a global supply chain optimization model and a single decision maker (Liang and Cheng, 2009; Peidro et al., 2009; Wang and Shu, 2005; Petrovic et al., 1999). Besides there exist robust optimization methods where suppliers share information with the customer (Guillaume et al., 2012, 2013). In these studies, the sources of uncertainty pertain to the demand, supply and process. Nevertheless, predefined criteria are used and the problem of distributed decision is not investigated, whereas it creates risks since the decisions made by suppliers impact decisions made by the customer.

Besides, the studies on coordination mechanisms focus on the minimization of sub-optimality of the distributed decision in the supply chain. Hence, an important part of the literature proposes and studies coordination mechanisms to obtain the optimal decision for the supply chain as a whole. For example, game theory is used for designing coordination mechanisms that may optimize the distributed system and studying coordination mechanisms as a form of cooperative advertising; see Aust and Buscher (2014) for a recent review. On their side, Chen, 2007, 2012 and Li et al., 2005 focus on procurement policy (price-only policies, quantity discount policy, etc.). Recently, Xiao et al. (2014) added the lead time as decision variable, on top of the price in context of make to order supply chains. Furthermore, the supply chains studied in this literature are mostly manufacturer-retailer supply chains, and these studies do not consider the planning process. Another part of this literature proposes coordination mechanism when the actors use linear mathematic models for production planning (Dudek and Stadtler, 2005) under perfect demand. In this part of the literature, the criterion of decision makers is predefined and the uncertainty is not taken into account. Moreover, in addition to this important academic research works, empirical analysis based on industrial case studies and decision-maker interviews have emphasized the fact that conceptual research has focused on the supply disruption risk with a little attention to the questions:

(i) “How views of supply disruption risk are developed and how these views affect the decision-making process” (Ellis et al., 2010),
(ii) What are supply chain managers' attitudes toward risk?
(iii) What are the ways in which decisions are made? (Lavastre et al., 2012)?

Moreover, Singh and Benyoucef (2013) emphasize the role of decision-making processes inside collaborative supply chains. It shows the difficulty to establish decisions when confronted with conflicting individual interests and where “every company is responsible for its own risks and identifies the risks from its own viewpoint” (Hallikas et al., 2005).

3. Background

In this section, we recall formal tools we shall use to build the proposed approach.

3.1. Tools for decision under imprecision

In this section, we recall a model to represent the imprecision on the information (possibility distributions), how to derive a subjective probability from it (pignistic probability), a well-known criterion under total uncertainty.

3.1.1. Possibility distributions

Imprecise information is modeled by expressions of the form $v \in A$ where A is a subset of S that contains more than one element. Imprecision is always expressed by a disjunction of values (Dubois and Prade, 2009) that form a possibility distribution on S. The assertion $v \in A$ implies that all values from v outside A are supposed to be impossible.

A possibility distribution π_v attached to an ill-known quantity v quantifies the plausibility of values taken by v (Dubois and Prade, 1988). It is a function from S to a plausibility scale L ([0,1] for numerical possibility). A numerical possibility distribution taking a finite number of values $\lambda_i \in [0, 1]$, for $i=1,\ldots,M$, may express imprecise probabilistic knowledge of the form $P(E_i) \geq 1-\lambda_i$, $i=1,\ldots,M$, where E_i is a confidence set provided by the DM (Dubois and Prade, 2009). It can also be viewed as a random set $(m,F)_\pi$, with focal sets E_i and masses $m(E_i)$, such that:

$$\begin{cases} E_i = \{x \in S \mid \pi(x) \geq \lambda_i\} \\ m(E_i) = \lambda_i - \lambda_{i-1} \end{cases} \tag{1}$$

The possibility distribution is then such that: $\pi(x) = \sum_{x \in E_i} m(E_i)$ (Dubois and Prade, 1982).

3.1.2. Pignistic probability distribution

The so-called pignistic probability extends Laplace principle of insufficient reason to possibility theory and to belief functions. It presupposes the idea that, while the knowledge or an actor can be too imprecise to be represented by a single probability distribution, the latter is needed when evaluating decisions in order to comply with the classical (Savage) decision theory (Smets, 2005). This probability distribution reflects betting odds used by the actor possessing a certain body of information. When the actor has no information, all alternatives are viewed as equally possible and the actor will bet on them at equal odds. Deriving the pignistic probability from a belief function consists in equally sharing the masses (m,F) over each element of focal set E for a random set (m,F)

$$Pg^s(x) = \sum_{E \subseteq S} \frac{m(E)}{|E|} \; \forall x \in S \tag{2}$$

It can be viewed as the subjective probability distribution the decision-maker would provide via betting rates, had his knowledge been faithfully represented by the possibility distribution π_v. This probability distribution has been proposed by Dubois and Prade (1982) and axiomatized by Smets (2005), who coined it “pignistic”. It coincides with the (older) Shapley value (Shapley, 1953) in the game theory. The pignistic probability distribution can be applied to possibility distributions and is also used in the simulation of “fuzzy variables” (Chanas and Nowakowski, 1988).