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Technical Paper

# Decentralized capacity allocation of a single-facility with fuzzy demand

Min Huang [a], Min Song [a,*], V. Jorge Leon [b,c], Xingwei Wang [a]

[a] College of Information Science and Engineering, Northeastern University; State Key Laboratory of Synthetical Automation for Process Industries (Northeastern University), Shenyang, Liaoning, 110819, China
[b] Department of Industrial and Systems Engineering, Texas A&M University, College Station, TX 77843-3131, USA
[c] Department of Engineering Technology and Industrial Distribution, Texas A&M University, College Station, TX 77843-3367, USA

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ABSTRACT

Capacity allocation under uncertainty environment is an important decision problem in manufacturing. The decentralized capacity allocation of a single-facility among different organizations with fuzzy demand is investigated in this paper. The objective and demand of each organization are assumed to be private information that other organizations and the facility cannot access to. In addition, we assume organizations have limited view of the capacity and loading of the facility. First, fuzzy optimization models associated with each organization and the facility are set up. Then, based on fuzzy theory, the fuzzy optimization models are converted into parametric programming models and subsequently an interactive algorithm is proposed to solve those parametric programming models. The extra benefit of this algorithm is that the whole solving process is amenable to decentralized implementation. Finally, experimental results illustrate the effectiveness of this work under two levels of information sharing: capacity information of the facility unknown to organizations and capacity information of the facility partially known to organizations.



## 1. Introduction

Capacity allocation is a common occurrence in a supply chain and arises whenever the demand exceeds the capacity. For example, we need capacity allocation when several product lines compete for the scarce capacity. Capacity allocation decisions are widely recognized as very important strategic decisions in a supply chain [1]. There exists a large body of literature that deals with the capacity allocation problems [2–4]. Generally speaking, based on the access to the modeling information and the decision making authority, supply chain systems can be roughly categorized into four categories (see Fig. 1). The term 'centralized' is used to refer to a multi-member system where there is a single decision maker who has authority to make decision for all the members in the system while the term 'decentralized' is used to qualify a multi-member system where no member has authority to make decision for other members in the system. The term 'complete information' refers to a system where the decision-maker(s) has complete access to modeling information throughout the system while 'partial information' refers to a system in which the decision-maker(s) has access to only limited information of the system (e.g., private information).

Historically, capacity allocation research has focused on the 'centralized' supply chain systems [5]. Although these references have contributed centralized decision rules for the capacity allocation problems, in fact, in today's highly globalized and competitive environments, with the rapid developments in computers and communication technology, most real word supply chains are 'decentralized' systems. During the past years the emphasis of the study of the capacity allocation problems has changed from the centralized systems to the decentralized systems [6,7]. The streams of literature in the field of decentralized capacity allocation can roughly be differentiated into the fields of contract theory on the one hand [8,9], and coordination approaches for mathematical programming models on the other hand [10,11]. Although these modeling views represent real world problems more accurately, a significant shortcoming of all these models is that they did not take private information factor into consideration. With the development of the research, it is widely recognized that the most persistent obstacle in the capacity allocation of the 'decentralized' supply chain systems is the existence of private information [12]. Although the full information exchange is technically feasible, often the members in the supply chain will be reluctant to freely share private information, because of the fear of industrial espionage, diversion of people's attention from

* Corresponding author. Tel.: +86 24 83671469; fax: +86 24 83688608.
*E-mail addresses:* bingning1982330@126.com, songmin0330@126.com (M. Song).

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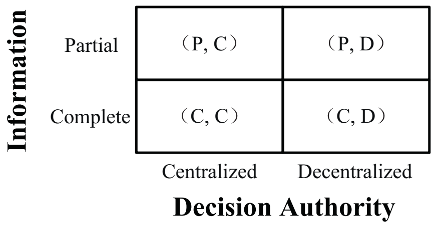


**Fig. 1.** Supply chain systems categories.

their work, and role conflict. An obvious example is a supply chain where some of its members are highly competitive organizations [13]. Recently, private information in supply chain systems has attracted a lot of interest among researchers [14–16]. However, most of the results are limited to deterministic environments or stochastic environments. In fact, with increasing globalization, there are many sources of uncertainty across the entire supply chain, such as demand uncertainty, supply uncertainty, and the sudden breakdown of production facilities [17]. These problems lead to poor service levels, high inventories, and frequent stock-outs [18]. Thus, it is very necessary to study 'decentralized' supply chain systems with private information in an uncertain environment. Traditionally, uncertain parameters in the capacity allocation problems have been considered as stochastic variables and modeled by probability distributions [19]. A probability distribution is usually derived from evidence recorded in the past. However, the standard probabilistic reasoning methods will fail when historical data is unavailable. In this case, uncertain parameters only can be specified based on the experience and managerial subjective judgment. Fuzzy set theory provides the appropriate framework to describe and treat uncertainty related to imprecisions.

Considering the above discussion, this paper considers the problem associated with the decentralized allocation of the finite capacity of a single facility among different business organizations with fuzzy demand. In the decentralized allocation, decision authorities and the system information are dispersed amid the facility and organizations. Due to the existence of private information and fuzzy demand, the capacity allocation problem in this paper is so difficult to solve for the global optimal solution. Therefore, we propose a heuristics to treat the fuzzy demand and private information separately. For fuzzy demand, we convert the decision making problems with fuzzy demand constraints into parametric programming models by the "$\alpha$ level cut set" method [20]. An algorithm based on Cooperative Interaction via Coupling Agent (CICA) [21] is proposed to solve the resulting parametric programming models where private information still exists. The main idea of the CICA-based algorithm is as follows: the facility and organizations interact by passing partial information between them. By receiving system-wide information vectors from iteration-to-iteration from the facility, the coupled organizations gradually gain global knowledge and the lack of global information is compensated by a partial information exchange through collaborative interactions. Finally, this work is tested by extensive experiments for two levels of information sharing, namely capacity information of the facility unknown to organizations and capacity information of the facility partially known to organizations. Exhaustive results analysis illustrates the efficiency of this work despite the loss of optimality.

The rest of this paper is organized as follows. The capacity allocation problem is formulated in Section 2. In Section 3 the solution approach, a CICA-based algorithm, is proposed to solve the capacity allocation problem. In Section 4 experimental results are presented to demonstrate the effectiveness of this work. Section 5 concludes this paper.

## 2. Problem formulation

In this paper, capacity allocation refers to the problem of allocating the finite capacity of a single-facility to satisfy the demand associated with multiple organizations within a given planning horizon. We assume that the facility and all organizations are affiliated with the same company, but they are independent as is often observed in practice. In this setting, these organizations would like to participate in the capacity planning of the company, but in order to maximize their individual profits, they are understandably unwilling to fully disclose their sensitive data with other organizations. In this paper, we assume that:

- Decision authorities are dispersed amid the participating organizations,
- Each organization only views its local objective,
- Each organization only views its demand,
- Organizations have limited view of the facility's capacity and loading,
- The demand of each organization is fuzzy demand.

The notation used for the development of models is given as follows.

*Superscripts*

$op$ the notation that means the variable is the private information of the organization,
$fp$ the notation that means the variable is the private information of the facility,
$n$ the number of iterations.

*Subscripts*

$k$ the index for production horizons, $k = 1, 2, \ldots, t$,
$i$ the index for organizations, $i = 1, 2, \ldots, m$.

*Decision variables*

$x_{ik}$ the production quantity of product $i$ at time interval $k$ proposed by organization $i$,
$y_{ik}$ the production quantity of product $i$ at time interval $k$ proposed by the facility.

*Parameters*

$b_{ik}^{op}$ the benefit of selling unit of product $i$ for organization $i$ at time interval $k$,
$a_{ik}$ the processing time of unit of product $i$ at time interval $k$,
$c_k^{fp}$ the available service time of the facility at time interval $k$,
$\tilde{d}_i^{op}$ the fuzzy demand of organization $i$,
$\cong$ the fuzzy equation that implies the equation is met in terms of a degree of truth.

The above capacity allocation problem is described in Fig. 2.

Two types of constraints are considered: demand constraints and capacity constraints. Demand constraints ensure that organizations schedule production on the facility so that their demands are satisfied at the end of the planning horizon. Capacity constraints ensure that the production scheduled on the facility does not exceed its available capacity at any time period. Such a capacity allocation strategy could be found in many industries, such as the transportation industry with shared carriers, the semiconductor manufacturing industry with shared machines, and the food production industry with shared outlets.

**Note**: In this paper, two cases are considered for the facility's capacity constraints in order to study the impact of information sharing levels on the proposed methodology. In the first case each organization has no access to the facility capacity. This case is the so called "without capacity information" (*WOCI*). In the second case every organization has access to the facility capacity for each time period. This case is known as "partial information about capacity" (*WPCI*). In *WPCI* each organization ensures that its requirement does not exceed the facility capacity. However, it has no view on the load imposed by other organizations.