

Sequential Capacity Allocation under Order Manipulation: Efficiency and Fairness

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1. Introduction and Contributions

An allocation of supplier's limited capacity to manufacturers has been an important issue in supply chain management. Recently, as the manufacturers usually have their own production and ordering cycles and suppliers are forced to respond more quickly to a manufacturer, it has been increasingly popular that capacity allocation is made in a sequential manner. For example, Qualcomm's mobile processor for the smartphone is supplied for various smartphone makers such as LG Electronics, Nokia, HTC, Huawei Technologies, and Google's Motorola, whose ordering times may be different due to each firm's own production schedule to introduce new products in a timely manner and faster than their competitors. If the supplier is not able to wait until collecting all orders from the manufacturers and responds to each order when it arrives, the supplier must allocate her capacity in a sequential manner. We refer to this allocation as *sequential allocation* and differentiate this from an allocation that is made when all orders are received simultaneously, which we refer to as *simultaneous allocation*.

The limited information on other manufacturers' order in a sequential allocation makes the objective of allocation more complex as well. In a simultaneous allocation, it is clear that the supplier's revenue maximization is guaranteed if the total orders exceed the capacity since it is easy to allocate the capacity once the supplier knows the total orders. However, in a sequential allocation where the total orders are not known until allocations finish, maximization of the supplier's revenue is achieved only if she allocates as each manufacturer orders in a sequential manner. While achieving maximum revenue of the supplier, such an allocation has a tendency to distribute relatively less capacity to the manufacturers who order later than to the manufacturers who order earlier. Considering the long-term relationship or loyalty, this allocation mechanism may not always be the best choice to the supplier; the manufacturer who orders later may be unsatisfied with his allocation and would search for other supplier, which eventually has a potential to decrease the supplier's revenue significantly. Thus, with a reasonable or relatively small reduction of the supplier's revenue, she may consider an allocation that takes care of manufacturers' profits in her sequential allocation mechanism.

If the supplier's concern is not only on maximizing her revenue but also on implementing a sustainable allocation, the supplier may consider reserving the maximum capacity (i.e., allocation limit) that can be allocated to each manufacturer for her purpose. However, such capacity reservation can be a challenging

task for the supplier in a sequential allocation; on one hand, if the supplier reserves too little capacity, the manufacturers who are allocated later may suffer from capacity shortage, which can be detrimental to the relationship and loyalty of them to the supplier. On the other hand, if she reserves too much capacity, the supplier may have some unused capacity after the allocation finishes, which is also detrimental to her revenue. To strike a good balance between these tradeoffs, we analyze the allocation limits and our numerical study finds that the manufacturers' total profit is maximized by reducing the supplier's revenue only within 1% on average. This suggests that such an allocation can be attractive to the supplier, considering her relationship to manufacturers.

In a sequential allocation, a more critical concern to the manufacturers can be not only on the amount of profit, but also on a fairness of allocation across all manufacturers. In order to measure allocation fairness, we calculate order fillrates of manufacturers. Then, we investigate the allocation limits that minimizing the differences in expected fillrates across manufacturers. We showed that for two manufacturers, the expected fillrates can be equated completely, while sacrificing relatively small percentage of the supplier's revenue on average. Also, comparing to the allocation that maximizes the total profit of manufacturers, the profit difference is relatively small on average. Thus, such an allocation with a fairness concern may satisfy all manufacturers and also the supplier reasonably well.

The analysis of the allocation mechanism becomes more complex if the manufacturers do not submit the order truthfully to the supplier. Since the supplier may not know the manufacturer's private information regarding manufacturer's customer demand, the allocation mechanism that is subject to the manufacturer's order manipulation becomes an important issue. However, to the best of our knowledge, this issue in a sequential allocation has not been studied in the literature yet. In a simultaneous allocation, Cachon and Lariviere (1999) showed that the manufacturer has an incentive to inflate his order to be allocated more favorably. In this paper, we also analyze the impact of manufacturer's order manipulation in the sequential allocations.

2. Model and Results

We consider a supply chain where one supplier distributes her capacity to two manufacturers. The supplier has a limited production capacity that is determined before an allocation begins and cannot be adjusted before the allocation ends. Allocation of capacity is made sequentially. The manufacturer has his private information regarding the desired order quantity that maximizes his own profit. We assume that only the distribution of desired order quantity of each manufacturer is known to the supplier from historical orders

from manufacturers. Thus, when allocating the capacity, the supplier not only considers the realized order of the manufacturer to distribute, but also the other manufacturers' uncertain orders that have not yet been distributed. We simplify the profit function of the manufacturer with a linear random demand. Then, we can easily derive each manufacturer's desired order quantity that maximizes his profit.

In our analysis, we first investigated how a sequential allocation mechanism would change if the manufacturers are allowed to manipulate their orders. We found that the allocations under order manipulation becomes an allocation mechanism where the manufacturer obtains his desired order quantity as long as capacity is available and the maximum allocation under the allocation rule allows it. Thus, the allocation mechanism can be controlled by properly setting the maximum allowable allocation to each manufacturer under order manipulation. This motivated us to consider how to set a capacity reservation (i.e., the allocation limit) to achieve the objective of an allocation.

We then study the allocation limits that maximize the total profit of the manufacturers under order manipulation, denoted by Allocation Mechanism *E* and derive the allocation limit for each manufacturer under Allocation Mechanism *E*. Since this allocation mechanism is not necessarily maximize the supplier's revenue, we verify the degree of the supplier's revenue loss incurred by implementing Allocation Mechanism *E*, which turns out to be very low (within 1%). This suggests that Allocation Mechanism *E* can be acceptable to all supply chain members.

To reflect a fairness concern in a sequential allocation, we next investigate an allocation mechanism that minimizes the maximum difference in fill rates under order manipulation, denoted by Allocation Mechanism *F*. We proved that the allocation limit that equates the expected fill rates of manufacturers is uniquely determined for a two manufacturer case. We also observe that the loss of supplier's revenue to implement Allocation Mechanism *F* can be only around 2 % on average, while the total profit of manufacturers compared to Allocation Mechanism *E* differs only within 3% on average. The result suggests that Allocation Mechanism *F* is an attractive alternative in a sequential allocation that achieves a near-optimal revenue of the supplier and the profit of the manufacturers while achieving an equal fillrates across all manufacturers. We believe that these results shed a light on the relatively less-explored but interesting issue of sequential allocation mechanisms under order manipulation in the literature.

References

Cachon, G. P., M. A. Lariviere. 1999. Capacity choice and allocation: Strategic behavior and supply chain performance. *Management Science* **45**(8) 1091–1108.