Dynamic Recommendation at Checkout under Inventory Constraint

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Recommendation at checkout is a growing trend. An online retailer would suggest additional items to a customer based on the items in her shopping cart, allowing for recommendations more relevant to the existing order. Our work was motivated by Walmart’s online grocery, which has begun to deploy such a system. There is a tradeoff between recommending popular, high-revenue items, versus recommending items with leftover inventory.

We formalize this tradeoff in an online assortment planning problem. Each item has an unreplenishable starting inventory. Customers arrive sequentially, each with an item of primary interest. If a customer’s primary interest is available, then she is willing to also purchase the items recommended to her, with given probabilities. These probabilities can depend on the overall set of items recommended, and the recommended items can be offered at a discount from their usual prices. The goal is to adaptively recommend an assortment of add-ons to each customer, with the objective of maximizing expected revenue before all items stock out, or customers stop arriving.

We evaluate online algorithms using the metric of competitive ratio against adversarial arrivals—the algorithm must make decisions without assuming anything about future customers, and is com-

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pared to an offline benchmark which knows all customer arrivals from the start. Existing algorithms are ineffective in our setting because they do not consider protecting inventory of one item so that a different item can be recommended along with it. We develop an online algorithm based on the new notion of a protection level in expectation. Our algorithm aims to maximize the immediate revenue from each customer, but avoids recommending items with low expected inventory remaining, where the expectation is over the random purchase decisions of past customers.

Executing an algorithm dependent on expected inventory is challenging, because it requires tracking all states that are possible at the current time step. The algorithm’s decision (on the realized sample path) then depends on the decisions it would’ve made on other sample paths, due to the constraint on expected inventories. We explain how to guarantee that an algorithm can satisfy these constraints while maximizing revenue. During each time step, we use iterative sampling to account for the exponentially-many possible states.

We provide a lower bound on the competitive ratio of our algorithm using a primal-dual proof, and an upper bound on the competitive ratio for our problem from Yao’s minimax principle. We compare our bounds with bounds from related papers. Specifically, our algorithm and analysis combine ideas from papers which address:

1. **balancing** the inventory of multiple substitutes, each of which is sold at a fixed price [GNR14, MP12, AGKM11, BJN07];

2. **protecting** the inventory of a single item which could be sold at multiple prices [BQ09, LGBK08].

Our techniques can be generalized to other settings, beyond recommendation at checkout, where challenges 1–2 need to be addressed simultaneously.

We compare our algorithm to others in simulations, verifying that our algorithm also performs well on average, over a wide range of instances. Finally, our notion of a protection level in expectation provides new insights for the tradeoff between immediate revenue and controlling inventory.

[Link to manuscript](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2853093)
References


