Strategic Manipulation of Preferences in the Rank Minimization Mechanism – Extended Abstract

JAAMAS Track

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ABSTRACT

We consider one-sided matching problems, where agents are allocated items based on stated preferences. Posing this as an assignment problem, the average rank of obtained matchings can be minimized using the rank minimization (RM) mechanism. RM matchings can have significantly better rank distributions than matchings obtained by mechanisms with random priority, such as Random Serial Dictatorship. However, these matchings are sensitive to preference manipulation from strategic agents. In this work, we derive a best response strategy for a scenario where agents aim to be matched to their top-*n* preferred items using the RM mechanism under a simplified cost function. This strategy is then extended to a first-order heuristic strategy for being matched to the top-*n* items in a setup that minimizes the average rank. Based on this finding, an empirical study is conducted examining the impact of the first-order heuristic strategy. The study utilizes data from both simulated markets and real-world matching markets in Amsterdam, taking into account variations in item popularity, fractions of strategic agents, and the preferences for the *n* most favored items. For most scenarios, RM yields more rank efficient matches than Random Serial Dictatorship, even when agents apply the first-order heuristic strategy. In competitive markets, the matching performance can become worse when 50% of agents or more want to be matched to their top-1 or top-2 preferred items and apply the first-order heuristic strategy to achieve this.

KEYWORDS

Matching; Strategic Manipulation; Rank Minimization

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1 INTRODUCTION

Matching agents to items given agents' preferences is an essential problem with real-world applications such as school admissions and housing allocation. [6, 7]. Deferred Acceptance with Single Tie-Breaking (DA-STB) is the most well-known matching algorithm, providing stable, envy-free and Pareto-optimal matchings for two-sided preferences [14]. When preferences are one-sided, DA-STB reduces to Random Serial Dictatorship (RSD), and matches are no longer efficient [3, 8]. This inefficiency is reflected in the rank distributions [10] commonly reported by institutions that apply matching mechanisms [1, 2]. Recent works have proposed the rank-minimizing (RM) mechanism [4, 10, 13, 17], which minimizes the average rank received by all agents. Despite efficiency gains, implementing RM in the real world is risky as it is not strategyproof, and agents can receive better matches by misreporting their preferences [4, 17]. In matching problems with one-sided preferences, it is impossible for a mechanism to provide more efficient matches compared to RSD without being vulnerable to manipulation [15]. Troyan shows that although RM is manipulable, it is not an *obviously* manipulable mechanism [17], as no single strategy ensures beneficial gains over being truthful without complete knowledge of all other agents' preferences; suggesting that the shortcoming of non-strategyproofness in RM may not be so severe. Ortega and Klein show through an empirical study that when agents are strategic using i.i.d. preferences, they do not stand to gain significantly better allocations [13]. However, this study assumes that agents misreport preferences uniformly, and has a uniform distribution of preferences over items.

We motivate that agents can be strategic despite not having complete information of others' preferences, and the impact of strategic preferences can vary across markets with differing demand for items. This extended abstract summarizes our work which implements rank minimization using the well-known Hungarian Algorithm (RM-HAL), assuming linear cost over rank [16]. Our contributions are as follows: we derive a best response strategy for RM-HAL under a simplified cost function, propose a heuristic strategy when costs are linear, and measure the impact of these strategies on matching performance across various market conditions. We find that RM-HAL provides better rank efficiency than RSD, particularly when the number of strategic agents is limited.

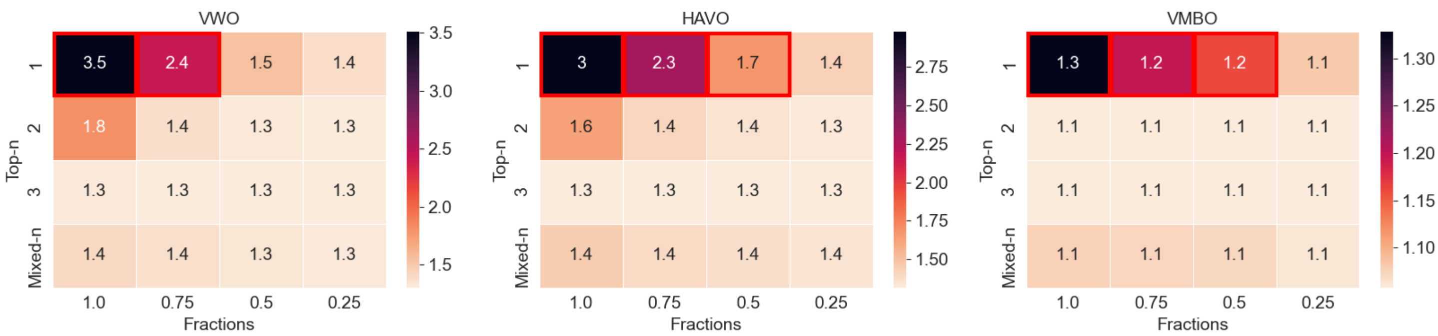

Figure 1: Average rank of RM-HAL matches when agents apply the first-order heuristic strategy for varying values of n and f. Scenarios where RM-HAL has a worse average rank than RSD are highlighted in red.

However, performance declines when more than half of the agents apply the heuristic strategy to secure top-1 or top-2 matches.

2 STRATEGIES FOR RM-HAL

Let S and M denote sets of agents and items. P represents the set of all possible ordered preference lists, where each list has a fixed length l and $p_{i,n}$ denotes the n^{th} preferred item of agent i ($n \in \mathbb{Z}^+$). Let n-rank popularity of an item $f_{j,n}$ be denoted by the difference between the total number of agents picking item j within their top-n ranked choices and the capacity of j. Items with $f_{j,n} > 0$ are considered popular, those with $f_{j,n} \leq 0$ are less popular. Let N be the set of all popular items.

The rank minimizing (RM) mechanism finds a set of matchings $(i, j) \subset S \times M$ such that the average rank of the items to which the agents are matched is minimized. The RM mechanism is implemented using the Hungarian algorithm [5, 9, 11, 12], by assuming some cost $c(i, j)$ for matching agent i to item j. Henceforth we refer to this as RM-HAL.

Strategies for manipulating RM-HAL are considered for two scenarios: (i) single-step cost and (ii) linear cost. In the first scenario, cost is zero for matching agents to their top-n preferred items, and constantly high for others. We analyze the steps of the Hungarian algorithm to derive a best response strategy for a strategic agent with complete information on others' preferences. The use of this best response strategy by all agents results in a Nash equilibrium.

Theorem 2.1. *The best response strategy for agent i to be matched to their top-n preferred items with RM-HAL is* $(p_{i,1}, \ldots p_{i,n}, j_1, \ldots, j_{l-n})$ *where* $f_{j,n} > 0$, $j \notin \{p_{i,1} \ldots p_{i,n}\}$, *and* $|N| \geq l$.

Deriving a best response strategy when costs are linear over rank is non-trivial, as the agent has to consider the correlations between other agents' preferences. For this scenario, a *first-order heuristic strategy* is proposed: beyond top-n items, the agent selects items with $f_{j,1} > 0$ and orders them in descending order of popularity. This heuristic aims to delay the agent being matched to items beyond the top-n, but is not guaranteed to be optimal. Deriving a best response strategy for this case is left for future work.

3 EXPERIMENTAL RESULTS

A simulation study is conducted using both synthetic and real-world datasets to evaluate the impact of the first-order heuristic strategy in matches made using RM-HAL. The synthetic data set models three types of markets (logistic, linear, and exponential) with varying demand distributions of 10 items between 2000 agents. The real-world dataset, sourced from the Amsterdam school choice system, contains preferences of 7,500 students across three education levels (VWO, HAVO, VMBO). Strategic preferences are simulated using the first-order heuristic strategy, with the assumption that agents truthfully ranked their top-n choices. The matching performance of RM-HAL using strategic preferences is compared with RSD using truthful preferences. Four experiments were conducted, varying levels of strategic manipulation, number of strategizing agents and assessing its effects on overall rank efficiency and impact on strategic and truthful agents. Strategic scenarios involved varying n (acceptable top ranks) and f (fraction of strategic agents), as well as mixed-n cases, where groups of agents used different n values.

We find that despite strategic manipulation, RM-HAL provides matches with a better average rank than RSD in most scenarios, as shown in Figure 1. Only in extreme scenarios, where more than 50% agents apply the first-order heuristic strategy to be matched to their top-1 or top-2 items, the average rank of RM-HAL is worse than RSD. We also find that applying the first-order heuristic strategy is effective but risky for agents, particularly for $n = 1$. The rank efficiency of matches is also market-dependent, with RM-HAL performing significantly better than RSD in competitive markets. However, the impact of strategy is also worse in these markets. Strategic agents also always have a better average rank than truthful students, implying that using RM-HAL in practice can lead to unequal outcomes between the two groups.

This work aims to promote discussion on the nature of strategic manipulations and their impact for efficient mechanisms such as RM-HAL. While RM-HAL is not obviously manipulable, the first-order heuristic strategy is found to be effective and easy to apply, as it only requires information on the relative popularity of items. Our simulation study shows improved match probabilities for top-n preferred items when applying the heuristic strategy. Although the strategy is not devoid of risks, these results suggest an incentive for agents to employ strategic preference reporting.

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