Trust-Based Contracting in Supply Chains

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1. INTRODUCTION

Engineering robust, vibrant supply chains that allow flexibility, modularity, and scalability present open, important, and unsolved research challenges. As a result, supply chain management where rational agents represent interests of individual entities and organizations have been an area of active research [1]. Agent-based approaches typically attempt to optimize the profitability of entities with emphasis on pricing and scheduling. Researchers in business and management science, however, have recognized that a key component of decision-making in real-world supply chains is the consideration of trust between the contracting organizations [2].

We use a contracting framework to allocate tasks: manufacturers announce contracts for tasks with given deadlines; suppliers bid on these tasks; and the contract is allocated to a highly trusted bidder. Trust of an agent is measured as the fraction of assigned tasks for which the agent could meet the deadline. We assume that the trust preferences of the contractor, the task deadline distribution and the performance distribution of the contractees are known. We then develop a precise bidding strategy for trust-building contractees. The motivation is to bid only on those tasks for which they have a high likelihood of meeting deadlines. However, not bidding on tasks also reduces the success rate of completing tasks. We provide a probabilistic analysis to handle this tradeoff.

2. CONTRACTING MODEL

The Request For Quote (RFQ) of each task T_i contains an associated deadline $d(T_i)$ drawn from a distribution $\mathcal{T}$. $\mathcal{P}j$, defined over the closed interval $[l, h]$, represents the distribution from which the actual time taken by the suppliers to process tasks is drawn. For continuous distributions, this means $\int_l^h \mathcal{P}(x)dx = 1$ and $\int_l^h T(y)dy = 1$.

Each contractor maintains a trust rating, t_c for each possible contractee, c, which is the proportion of time that contractee could meet an assigned task deadline. A contractor considers a contractee $\overline{b}$ to be more trusted than another contractee $\underline{b}$ if $\gamma * t_{\underline{b}} < t_{\overline{b}}$, where $\gamma > 1$ is a trust constant. The contractor of a task assigns it randomly to one of those contractees for whom there are no other more trusted contractees.

The goal of a contractee j is to maximize its success in procuring and delivering contracts, i.e., its *success rate*

$$\int_{bl}^{bh} r(j,y)T(y)\left(\int_l^y \mathcal{P}_j(x)dx\right)dy, \tag{1}$$

where $r(j, y)$ is the probability that a task of length y is assigned to agent j, the integration within the parenthesis represents the likelihood of meeting the deadline y and bl, bh are respectively the minimum and maximum deadlines for tasks on which j will bid.

3. TRUST BUILDING MECHANISM

We use two types of bidding strategies for a contractee j in response to an RFQ for a task t_i: (a) **Greedy (G)** agents bid for any task for which is a non-zero probability of meeting the deadline, i.e., $\int_l^{d(T_i)} \mathcal{P}_j(x)dx > 0$, **Trust-building (TB)** agents focus on building trust and hence bids only for tasks whose deadlines they are likely to meet. While this means that it will compete for less tasks, in the long run such agents expect to be favorably treated for awarding contracts with 'safer' tasks, i.e., tasks that they are likely to be able to complete by the deadline. The key consideration here is the choice of the minimum deadline threshold, D, for bidding such that the TB contractee is viewed by the contractor to be more trustworthy than a G contractee. The Figure 1 presents a typical situation with task and performance probability distributions and the deadline D below which TB agents will not bid.

The average expected success likelihood or *trustworthiness* of an agent who wins all tasks in the region $[bl, bh]$ is given by

$$\bar{P}(bl, bh) = \frac{1}{\mathcal{T}_{bl,bh}} \int_{bl}^{bh} T(y)\left(\int_l^y \mathcal{P}_j(x)dx\right)dy, \tag{2}$$

where $\mathcal{T}_{x,y} = \int_x^y T(z)dz$, is the cumulative probability of tasks arriving with deadlines in the region $[x, y]$. If an agent wins only a fraction f of tasks in that region, the corresponding average success likelihood is $f\bar{P}(bl, bh)$.

To facilitate the presentation of the analysis we consider the steady state case, where one of the TB agents always win the contract

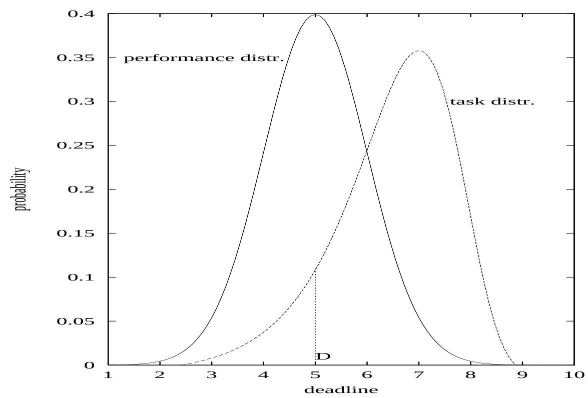

Figure 1: Example continuous task deadline and performance distributions.

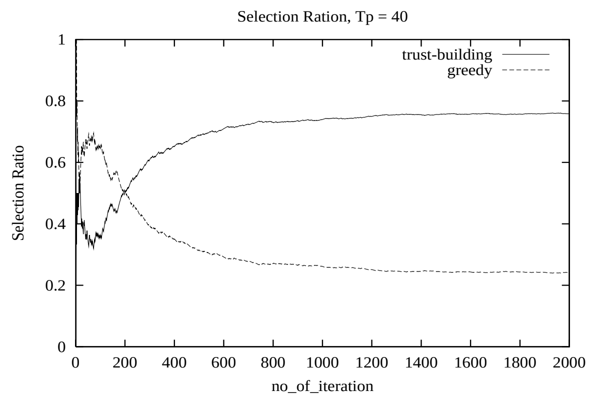

Figure 2: Selection Ratio ($T_p = 40$, $\gamma = 1.25$).

when they bid (because they have been recognized to be more trustworthy than greedy contractees), and at other times one of the G agents win the contract. First we note that there is no reason for the TB agents to not bid on tasks at the higher end of the task deadline distribution. Hence, the upper limit of the range of task deadlines a TB agent will bid, bh_{TB} is equal to h. Therefore, at steady state, the TB agents will win all the tasks for deadlines in the range $[D_{ss}, h]$ and G agents will win all contracts in the region $[l, D_{ss})$, where D_{ss} is the deadline threshold above which TB agents will bid in steady state. For the TB agent to be viewed to be more trustworthy the following inequality must be satisfied:

$$\bar{P}(D_{ss}, h) > \gamma \bar{P}(l, D_{ss}). \quad (3)$$

This implies that at the steady state, the TB agents have at least γ times higher trustworthiness at steady state. Equations 2 and 3 can be used to calculate D_{ss}.

The assumption of TB agents winning whenever they bid is not valid at the outset when they are yet to be recognized as more trustworthy than greedy agents. Hence D_{ss} is not the appropriate choice for the initial minimum task deadline to bid for, D_I, by TB agents. To calculate D_I, we assume that tasks are initially assigned randomly between all bidders in the population. So, while all the tasks with deadlines in the range $[l, D_I)$ will be assigned to G contractees, tasks in the region $[D_I, h]$ will be assigned to G versus TB bidders in the ratio of N_G to N_{TB}. The choice of D_I should be such that it allows a TB agent to have at least γ times higher trustworthiness when tasks are being assigned randomly between bidders:

$$\frac{N_{TB}}{N} \bar{P}(D_I, h) > \gamma \left(\frac{\mathcal{T}_{l,D_I} \bar{P}(l, D_I) + \mathcal{T}_{D_I,h} \frac{N_G}{N} \bar{P}(D_I, h)}{\mathcal{T}_{l,h}} \right). \quad (4)$$

The LHS of the inequality represents the proportion of tasks expected to be successfully delivered by TB agents when tasks are randomly assigned between all bidders and the TB agents bid only in the interval $[D_I, h]$. The term within the parenthesis on the RHS denotes the proportion of tasks successfully delivered by G agents in this period. The terms $\mathcal{T}_{l,D_I}$ and $\mathcal{T}_{D_I,h}$ are used to normalize the trustworthiness in the regions $[l, D_I]$ and $[D_I, h]$ respectively. The inequality in Equation 4 can be satisfied for a range of D_I values. The TB agent uses the minimum value in the range which also satisfies the inequality $N_{TB} > \gamma N_G \mathcal{T}_{D_I,h}$.

4. EXPERIMENTAL RESULTS

We use triangular performance and task distributions defined in the range [0,60] with the highest likelihood point at T_p= 40. From the ratio of selection of one Greedy and one TB agent by a contractor (shown in Figure 2) we observe that the TB contractee clearly outperforms the greedy contractee as it succeeds in winning almost three times as many contracts. Though winning contracts do not necessarily mean successfully fulfilling them, as TB contractees bid for tasks of longer deadline, the actual ratio of their success rates is likely to be even higher. Initially, the customer makes awards randomly between the bidders, and the greedy agent is selected more often as it bids over the entire task range compared to the TB agent who bids only if the task deadline is greater than D_I. Over time, as the TB contractee is significantly more successful in meeting contract deadlines compared to the greedy agent, it gains the trust of the contractor and is thereafter selected whenever it bids.

5. OBSERVATIONS

We investigate a particular trust-based contracting framework where contractees with significantly higher historical success rates in meeting contract deadlines are preferentially selected over less "punctual" agents. We argue that in order to build and maintain the trust of their contractor, contractees will need to avoid bidding on risky tasks, i.e., tasks for which there is a significant risk of failing to meet deadlines. The goal of such strategic bidding is to more than recover the loss from not bidding on such high-risk tasks by more consistently winning the contracts on tasks with longer deadlines. As a result, such trust-building agents bid less often for tasks, but win and successfully meet the deadline of tasks they bid for in comparison to "greedy" agents who bid for all tasks.

We have calculated the initial and steady state bidding threshold to earn trust. An interesting, open question is how to vary the threshold over time to get from D_I to D_{ss} while consistently maintaining the trust of the contractor. That process might lead to TB agents monopolizing the market!

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