Trust-Based Contracting

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Abstract. While most work on forming contracts in supply chains have focused on pricing schemes, auction mechanisms and production scheduling strategies, little attention has been paid to establishing and maintaining stable relationships based on trust. We study trust in supply-chains in the context of reliably meeting negotiated contract deadlines. We investigate scenarios where contractors prefer to assign contracts to contractees who are significantly more consistent in meeting deadlines. Contractees who seek to establish such trusted partnerships need to model variabilities in their own task completion times as well as that of their subcontractors. We present a probabilistic analysis that enables such contractees to strategically bid on tasks to earn the trust of their contractors. Our analysis also identifies situations when such trust relationships are not viable. Results from simulated experiments corroborate the effectiveness of the prescriptions of our probabilistic analysis.

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 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 supplier j to process tasks is drawn. For continuous distributions, this means $\int_l^h \mathcal{P}_j(x)dx = 1$ 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

$$\gamma * t_{\underline{b}} < t_{\overline{b}}, \tag{1}$$

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.

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

$$\int_{bl}^{bh} r(j, y)T(y) \left(\int_l^y \mathcal{P}_j(x)dx \right) dy, \tag{2}$$

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. The *success rate* represents the expected number of assigned tasks successfully delivered by their deadline.

Note that this is a simplification of the real-world contracting process. In particular, we have left out the consideration of the price in the bid while awarding contracts! This, however, is a deliberate attempt on our part to focus on the issue of developing trusted relationships in supply chains. We believe that real-world stable supply chains incorporate trust as a key consideration for awarding contracts. We acknowledge that even in such situations, trust is one of several key parameters that determines contract awards. In this study, however, we wanted to focus exclusively on trust considerations as there has been very little work in agent based systems on the use of trust in supply chain contracting. We also acknowledge that the above model of trust-based contracting is just one of several plausible schemes that can be used by contractors.

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:

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 the TB agents 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 number of contractees using the G and TB strategy are known and given by N_G and N_{TB} respectively. Note that $N = N_G + N_{TB}$.

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. To analytically derive this threshold, D, we assume that the task arrival distribution T and the performance distribution of all agents are common knowledge. As we are primarily interested in the effects of the trust-building mechanism, we further assume that all agents have the same performance distribution $\mathcal{P}$. The Figure 3 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

$$\bar{P}(bl, bh) = \frac{1}{\mathcal{T}_{bl,bh}} \int_{bl}^{bh} T(y) \left(\int_{l}^{y} \mathcal{P}_j(x)dx \right) dy, \tag{3}$$

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 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. From Equation 1 we then have the following inequality:

$$\bar{P}(D_{ss}, h) > \gamma \bar{P}(l, D_{ss}). \tag{4}$$

This implies that at the steady state, the TB agents have at least γ times higher trustworthiness at steady state. Equations 3 and 4 can be used to calculate D_{ss}.

The assumption implicit in Equation 4, that the TB agents win whenever they bid, is not valid at the outset when the TB contractees have not been able to demonstrate their superior trustworthiness in meeting deadlines. 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:

$$\frac{N_{TB}}{N}\bar{P}(D_I,h) > \gamma\left(\frac{\mathcal{T}_{l,D_I}\bar{P}(l,D_I) + \mathcal{T}_{D_I,h}\frac{N_G}{N}\bar{P}(D_I,h)}{\mathcal{T}_{l,h}}\right). \tag{5}$$

The left hand side 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 of the inequality 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. To calculate D_I we simplify Equation 5

$$\bar{P}(D_I,h) > \frac{N\gamma\mathcal{T}_{l,D_I}}{N_{TB} - \gamma N_G\mathcal{T}_{D_I,h}}\bar{P}(l,D_I), \tag{6}$$

where the simplification uses the fact that $\mathcal{T}_{l,h} = 1$ and that

$$N_{TB} > \gamma N_G\mathcal{T}_{D_I,h}. \tag{7}$$

The inequality in Equation 6 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 in Equation 7.

In this paper we use equal number of TB and G agents and hence Equation 6 simplifies to

$$\bar{P}(D_I,h) > \frac{2\gamma\mathcal{T}_{l,D_I}}{1 - \gamma\mathcal{T}_{D_I,h}}\bar{P}(l,D_I), \tag{8}$$

and Equation 7 simplifies to $\mathcal{T}_{D_I,h} < \frac{1}{\gamma}$.

Note that this analysis is focused on earning the trust of the consumer. It does not require that the TB agents successfully complete more assigned tasks than does G agents. The goal of the contractee, however, is to maximize its success rate as described in Section 2. Hence, a contractee must evaluate whether it will have a better success rate if it decides to be TB or G agent. If all agents were of type G, then from the expression in 2, and given that G agents bid over the entire range $[l, h]$, the success rate of each agent is

$$\frac{1}{N}\int_l^h T(y)\left(\int_l^y \mathcal{P}_j(x)dx\right)dy, \tag{9}$$

as all contractees will be awarded tasks with equal probability, i.e., $\forall j, r(j, y) = \frac{1}{N}$. If on the other hand, N_G and N_{TB} agents are greedy and trust-building

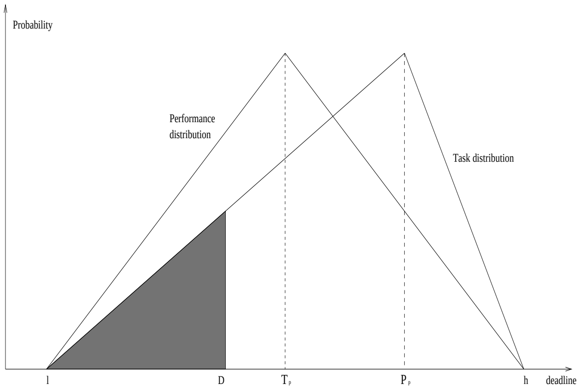

Fig. 1. Example triangular task deadline and performance distributions.

respectively, the success rate of a TB agent for a bidding deadline threshold of D_I, calculated from a given γ as above, is given by:

$$\frac{1}{N_{TB}} \int_{D_I}^{h} T(y) \left(\int_{l}^{y} \mathcal{P}_j(x)dx \right) dy. \tag{10}$$

Hence, in addition to satisfying the inequality in 6 and 7, the D_I value chosen must satisfy the following inequality obtained by requiring that the expression in 10 be more than the value of the expression in 9:

$$\int_{D_I}^{h} T(y) \left(\int_{l}^{y} \mathcal{P}_j(x)dx \right) dy > \frac{N_{TB}}{N} \int_{l}^{h} T(y) \left(\int_{l}^{y} \mathcal{P}_j(x)dx \right) dy. \tag{11}$$

For some T and $\mathcal{P}$ distributions, we designate by γ_{max} the maximal γ value for which there exist a value of D_I that satisfies all these conditions.

3.1 Analytical predictions

To simplify the calculation of the deadline thresholds we work with discrete distributions developed by sampling from continuous distributions of the desired shape and then normalizing the sampled values. We believe that triangle shaped distributions can be used as coarse approximations of realistic task deadline and perform distributions. Examples of such distributions defined over the range $[l, h]$ are presented in Figure 3. The shaded region corresponds to the task deadlines for which TB agents will not bid. T_p and P_p denotes the highest likelihood points for the task deadline and performance deadline distributions respectively.

We now present. in Figure 3.1, the success rates of G and TB contractees as γ is varied for different task distributions. For this figure the range of the task and performance distributions is $[0, 120]$. The highest likelihood point of the triangular performance distribution is chosen at $P_p = 60$. Three sets of

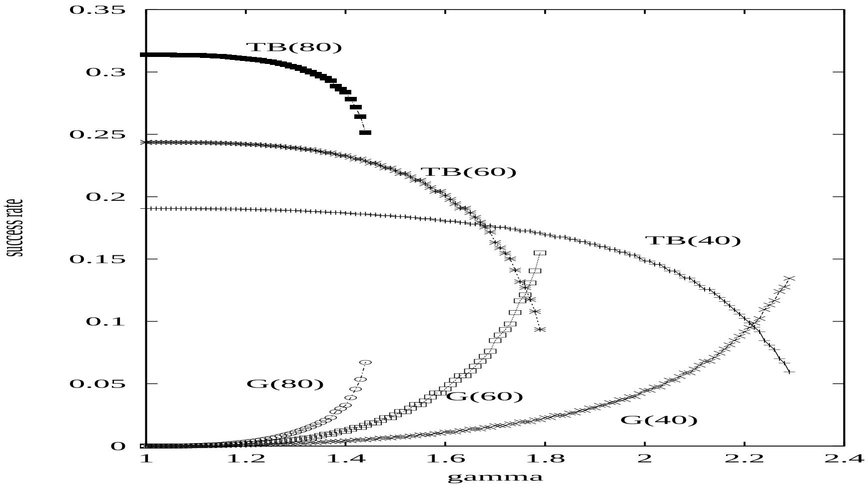

Fig. 2. Variation of success rates with γ for different task distributions ($T_p =$ in parentheses).

calculations are performed for different values of the highest likelihood point of the triangular task distribution T_p equal to 40, 60, and 80 respectively. As γ increases, the TB agents have to relinquish more and more tasks in order to be sufficiently more trustworthy. As D_I increases, though the trustworthiness (refer expression in Equation 3) of TB agents increases, they will actually be awarded less tasks while G agents are awarded more tasks. As winning more contracts facilitates higher success rate [1], the success rate of G contractees increases and the success rate of the TB contractors decreases. Note that as T_p decreases, i.e., tasks with shorter deadline becomes more prevalent, the performance of both TB and G contractees decrease, though γ_{max} increases (this latter observation is discussed in more detail while discussing Figure 3.1).

In Figure 3.1 we have presented results with the choice of D_I required to satisfy only the trust building condition specified in inequality 8. We observe that for T_p equal to 40 and 60, beyond a certain trust threshold the TB contractees have lesser success rates than G contractees. This reinforces the necessity of enforcing the performance condition specified in inequality 11. We find that the crossing points are just beyond γ_{max}. In practice, therefore, a rational contractee will revert to G behavior for γ values just lower than the value where these curves meet.

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[1] Since in the current model success rate is measured as the number of awarded tasks whose deadlines were met, this metric is a non-decreasing function of the number of tasks awarded. If failure to meet deadlines had an associated penalty, our expected utility maximization framework would have resulted in a tradeoff of penalty of failure versus utility of successful delivery of a task.

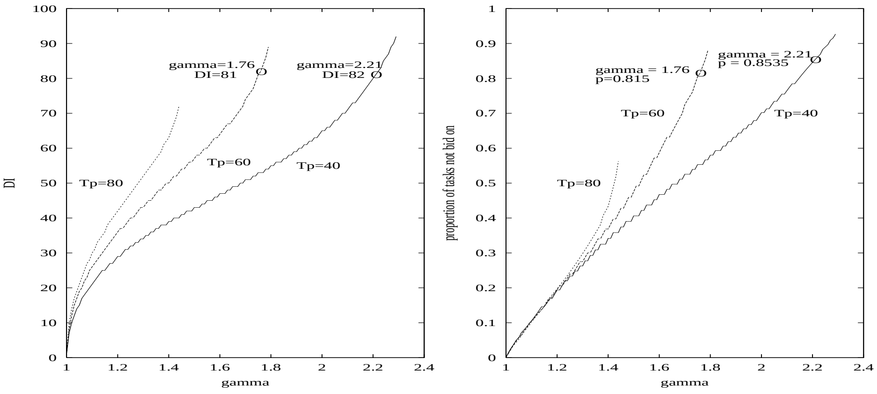

Fig. 3. Variation of D_I (left) and percentage of tasks not bid on by TB contractees (right) with γ for different task distributions.

In Figure 3.1, we plot the minimum value of D_I for which the inequality in Equation 6 can be satisfied for different trust constants, γ. Note that increasing γ implies the TB agents must have that much higher success likelihood compared to G agents. This necessitates using a higher value of D_I, thus bidding only for tasks which has longer deadlines which are more likely to be met. In effect, the TB agents are relinquishing a higher portion of the market share to be able to exclusively "own" (win) contracts for which there is a greater chance of meeting the deadline. Beyond a certain value of γ, however, no value of D_I that satisfies the inequalities in Equations 7 and 11 can be found. Note that for a given γ, as T_p, the peak of the triangular task distribution, increases, D_I value increases. This is both because relatively more number of tasks appear with a longer deadline and because there is a higher probability of successfully meeting their deadlines. More interestingly, as T_p increases, the maximum γ for which an acceptable D_I is found decreases. When tasks have longer deadlines, the TB agent finds it more difficult to be significantly more trustworthy as this significance threshold is increased. This is because longer deadlines allow even the G bidders to successfully complete tasks. Simply picking a higher D_I is not sufficient to be significantly more consistent in meeting deadlines.

We also plot, in Figure 3.1 the percentage of tasks that TB agents choose not to bid on for the three different distributions and for different γ values. In both of these figures, and for $T_p = 40$ and 60, we have marked on the corresponding plots the maximum γ values for which the inequality in 11 can be satisfied. We find that for $T_p = 40$, in the extreme case of $\gamma = 2.21$, the TB contractee is able to outperform, in terms of success rate, the G contractee even though it does not bid for a whopping 85.3% of the tasks!

To better understand the range of performance of the TB contractees in different task distribution we summarize, in Table 1, the range of their success rates as well as the success rate if all contractees were using the greedy strategy.

T_p	All G	TB max	γ_{max}	TB min	D_I	% no bid
40	0.095	0.19	2.21	0.099	81	85.3
60	0.121	0.24	1.76	0.127	82	81.5
80	0.157	0.31	1.44	0.251	72	56.27

Table 1. Values for different T_p: success rates if all contractees were greedy, success rate of TB contractees when γ just greater than 1 γ_{max}. The following columns denote the values when $\gamma = \gamma_{max}$: success rate to TB contractees D_I, percentage of task that TB agents do not bid on.

For example, for $T_p = 40$, we find that if every contractee is greedy, their success rate is 0.095, while the best (γ just more than 1) and worst ($\gamma = 2.21$) success rate of TB contractees would be 0.19 and 0.099 respectively. In the latter case, $D_I = 81$ and the TB contractee is not bidding on 85.3% of the tasks. In all cases, the best TB success rate is almost twice that of the greedy contractees. This happens when the contractor is least stringent in the trustworthiness measure, i.e., γ is just greater than 1.

4 Experimental Framework

In our experimental setup we compared the behavior of two agents bidding, one T_B and one G agent, for a contract offered by the customer, the contractor. The deadlines for the contracts are generated randomly from a discretized triangular distribution. There are two suppliers under each of these two contractees, and the contractee agents must procure supplies from these downstream suppliers before it can process an assigned task.

Since the total time taken by the contractee is the sum of the time taken by its supplier to produce the necessary supplies plus the time it takes to use these supplies to process the tasks, the corresponding task distributions are chosen so that the resultant performance distribution range matches that of the task distribution We have used identical triangular distributions for the contractee and the suppliers defined over the range [0,60] with the highest point of the distribution at the midpoint of the range. The resultant performance distribution of the contractee then ranges over [0,120].

In our experiments, we iteratively generated new task deadlines from the task distribution. In a particular iteration, the T_B agent decides to bid if the deadline is greater than D_I. The G agent bids on all tasks. In the first 100 iterations the customer randomly selects between the agents to estimate the trustworthiness of the contractees. Thereafter a contractee for a task is chosen using the selection criteria specified in Section 2. When a contractee is awarded a task, it generates an quote request in turn to procure necessary supplies from the suppliers. The time taken by the suppliers followed by that of the selected contractee are then generated from their performance distributions using the standard inverse transform method and are added to calculate the contract fulfillment or delivery

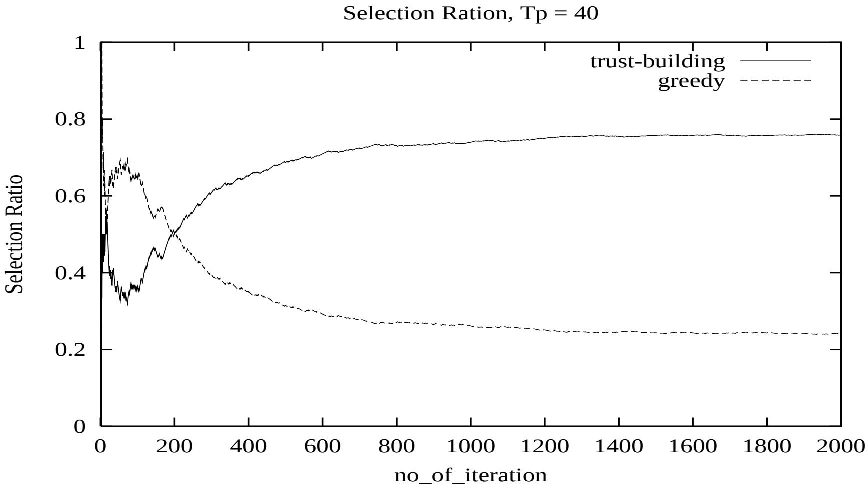

Fig. 4. Selection Ratio ($T_p = 40$, $\gamma = 1.25$).

time. The agent succeeds if the delivery time is less than or equal to the contract deadline, and fails otherwise.

5 Experimental Results

In our first experiment, we compare the selection ratio of the two agents over 2000 iterations, where the selection ratio is the proportion of time the agent is selected. The experiment is repeated on three different task distributions: T_p= 40, 60 and 80 and for $\gamma = 1.25$. The results from the $T_p = 40$ scenario is shown in Figure 5 (plots for other values used for T_p are similar and are omitted due to space constraints).

From the figure 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. After about the 200 iterations, the selection ratio of the TB agent becomes greater than that of the greedy agent. We also observe that the difference between the two curves increase rapidly after the initial phase of random selection ends and finally reaches a saturation. This shows the transition from the trust-building stage to

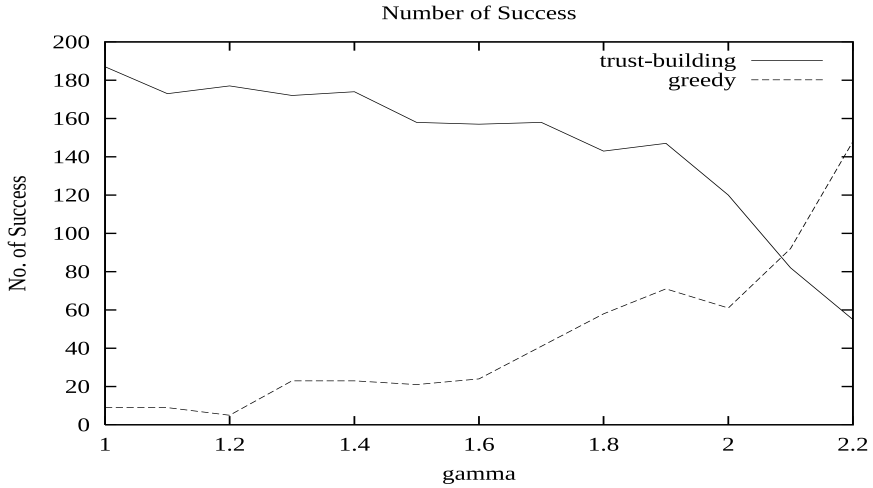

Fig. 5. Successful deliveries with $T_p = 40$.

the steady-state. At steady state, trust in the TB agent is firmly established and it wins every contract for which it bids.

We also plot the the total number of successful deliveries the agents make after 1000 iterations for different values of γ and $T_p = 40$ in Figure 5. From this figure, and others omitted due to space restrictions, we observe that in all the cases the experimental results closely match the theoretical predictions (see Figure 3.1). The greedy agent becomes more successful than the TB agent when $\gamma > 2.1$[2]. At this point, though the TB contractee wins all contracts for which it bids, it chooses not to bid on more than 76% of the tasks and hence the greedy agent is able to successfully deliver more tasks. Note that the TB agent will switch to G strategy at this high levels of γ because no acceptable value of D_I can be found that satisfies the inequality in Equation 11. So, in practice it is unlikely that TB agents will be outperformed by greedy agents.

6 Related work

Multiagent systems (MAS) researchers conceptualize a supply chain as a group of collaborative autonomous software agents [1]. Tackling coordination in supply chains using partial constraint satisfaction problems by mediating agents is investigated by [3].

Swaminathan *et al.* has provided a framework for efficient supply chain formation [4]. Multiagent Systems research has emphasized on the emergence of

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[2] The theoretically predicted crossover point, from Table 1, is for $\gamma = 2.21$. We observed similar small overestimations in the theoretical predictions for $T_p = 60$.

the optimal configuration of the supply chain. Walsh *et al.* has shown the optimal dynamic task allocation in a supply chain using combinatorial auction [1]. Collins and Gini has provided a testbed, MAGNET, for multiagent contracting for supply chain formation using a multiple criteria [5].

In recent research, trust is established as a key factor to build profitable and long term B2B and B2C collaborations in the Industry [6]. Trust plays an even more critical and important role in the domain of Electronic commerce [7]. Several trust management systems have been proposed to handle the development of trust and its impact in such systems [8].

Use of trust as a basis for interaction strategies has been widely used in multiagent systems. Marsh was one of the first to attempt a computational model of trust [9]. Castelfranchi and colleagues have argued for the necessity of trust in social interactions between agents with complex mental attitudes [10]. Brainov and Sandholhm [11] have shown that trust based contracting can significantly increase market efficiency measured by social welfare, trade volume and agent utilities. Yu and Singh [12] have proposed a mechanism for combining reputation from multiple sources to obtain trust ratings.

7 Conclusions and future work

In this paper, we have argued for the use of trust models to award contracts in the context of supply chains. We work with 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. Our mechanism allows entities in a supply-chain to organize themselves into profitable, mutually beneficial, stable partnerships that is resistant to environmental noise and performance variations.

Given task deadline and performance, i.e., task processing, distributions, we use a probabilistic analysis to analytically derive the task deadline threshold below which a trust-building contractee will not bid for a task. We analyze several properties and features of such a bidding scheme and characterize its performance for varying task deadline distributions and trust thresholds. We also provide experimental verification on a small supply chain to demonstrate the competitive advantage of our trust-building strategy over a greedy strategy that bids for all tasks.

In this paper, the trust constant, γ, and the contract allocation procedure are assumed to be common knowledge. The task distribution is assumed to be constant and known a priori. Similarly, the performance distribution is fixed and is assumed to be identical for all contractees. Also, in practice tasks with different deadlines may fetch different profits and hence a utility function distinct from success rate should be considered to mirror real-life situations. We plan to relax some of this approaches in future work.

We have precisely calculated the initial bidding threshold to earn trust. We have also characterized the steady state value. 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. We are working on extending our analysis to include utilities for delivering contracts on time and penalties for missing deadlines.

Acknowledgments: This work has been supported in part by an NSF award IIS-0209208.

References

1. Walsh, W.E., Wellman, M.P.: Decentralized supply chain formation: A market protocol and competitive equilibrium analysis. Journal of Artificial Intelligence Research **19** (2003) 513–567
2. Welty, B., Becerra-Fernandez, I.: Managing trust and commitment in collaborative supply chain relationships. Communications of the ACM **44** (2001) 67–73
3. Beck, J.C., Fox, M.S.: Supply chain coordination via mediated constraint relaxation. In: Proc. of the 1st Canadian Workshop on Distributed Artificial Intelligence. (1994)
4. Swaminathan, J.M., Smith, S.F., Sadeh, N.M.: Modeling supply chain dynamics: A multiagent approach. Decision Sciences **29** (1998) 607–632
5. Collins, J., Ketter, W., Gini, M.: A multi-agent negotiation testbed for contracting tasks with temporal and precedence constraints. International Journal of Electronic Commerce **7** (2002) 35–57
6. Lederer-Antonucci, Y.L., Greenberg, P.S., zur Muehlen, M., Ralph, G.: Establishing trust in a business-to-business collaboration: Results from an international simulation. In: Proc. of the IRMA 2003 Conference. (2003) 922–924
7. Bhattacherjee, A.: Individual trust in online firms: Scale development and initial test. Journal of Management Information Systems **19** (2002) 211–241
8. Grandison, T., Sloman, M.: A survey of trust in internet applications. IEEE Communications Surveys and Tutorials **3** (2000)
9. Marsh, S.: Formalising Trust as a Computational Concept. PhD thesis, University of Stirling (1994)
10. Castelfranchi, C., Falcone, R.: Principles of trust for MAS: Cognitive autonomy, social importance, and quantification. In: Proceedings of the Third International Conference on Multiagent Systems, Los Alamitos, CA, IEEE Computer Society (1998) 72–79
11. Brainov, S., Sandholm, T.: Contracting with uncertain level of trus. Computational Intelligence **18** (2002) 501–514
12. Yu, B., Singh, M.P.: Distributed reputation management for electronic commerce. Compuational Intelligence **18** (2002) 535–549