

Exploring auction-based leveled-commitment contracting

Part II: Dutch-type auctioning

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Abstract

A key problem addressed in the area of multiagent systems is the automated assignment of multiple tasks to executing agents. The automation of multiagent task assignment requires that the individual agents (*i*) use a common protocol that prescribes how they have to interact in order to come to an agreement and (*ii*) fix their final agreement in a contract that specifies the commitments resulting from the assignment on which they agreed.

This report is part of a broader research effort aiming at the design and analysis of approaches to automated multiagent task assignment that combine auction protocols and leveled commitment contracts. The primary advantage of such approaches is that they are applicable in a broad range of realistic scenarios in which knowledge-intensive negotiation among agents is not feasible and in which unforeseeable future environmental changes may require agents to breach their contracts. Examples of standard auction protocols are the English auction and the Dutch auction. In [2] a combination of English-type auctioning and leveled commitment contracting has been described. In this report the focus is on the combination of Dutch-type auctioning and leveled commitment contracting.

1 Introduction

The area of multiagent systems (e.g., [6, 9, 17]), which is concerned with systems composed of technical entities called agents that interact and in some sense can be said to be intelligent and autonomous, has achieved steadily growing interest in the past decade for two major reasons. First, it provides innovative methods and concepts for designing, realizing, and handling modern—distributed, large-scale, dynamic, open, and heterogeneous—information processing systems. The Internet is just the most prominent example of such systems; others are multi-database systems and in-house information systems. Second, it offers useful technology for developing and analyzing models and theories of interactivity

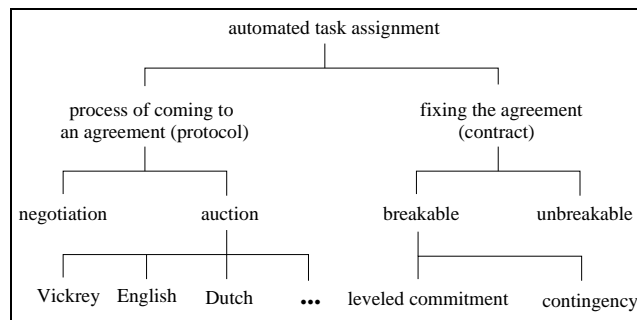


Figure 1: Automated task assignment.

among humans. Humans, like other intelligent natural beings, do not function in isolation, but interact in various ways and at various levels; however, the relationships between intelligence and interactivity are still poorly understood.

A key problem addressed in this area is the automated assignment of multiple tasks to executing agents under criteria such as efficiency and reliability. The automation of task assignment requires that the agents *(i)* use a common protocol that prescribes how they have to interact in order to come to an agreement on “who does what” and *(ii)* are willing to fix their final agreement in a formal or “legally valid” contract. The protocol concerns the act or process of finding an appropriate task assignment, while the contract concerns the consequences and commitments resulting from the assignment on which the agents agreed. Two standard types of task assignment protocols are negotiation-based protocols (e.g., [4, 8, 16]) and auction-based protocols (e.g., [3]). Examples of widely applied auction protocols are the English auction, the Dutch auction, and the Vickrey auction (e.g., [11]). Compared to negotiation-based protocols, auction-based protocols show several distinct and advantageous features: they are easily implementable, they enforce an efficient (low-cost and/or low-time) assignment process, and they guarantee an agreement even in scenarios in which the agents possess only very little domain- or task-specific knowledge. Two standard types of task assignment contracts are unbreakable contracts (e.g., [7, 12, 13]) and breakable contracts, where common forms of breakable contracts are contingency contracts (e.g., [10]) and leveled commitment contracts (e.g., [1, 5, 14, 15]). Compared to unbreakable contracts, breakable contracts offer a significant advantage: they allow agents acting in dynamic environments to flexibly react upon future environmental changes that make existing contracts unfavorable. Figure 1 summarizes this rough overview of available approaches to automated task assignment.

This report describes work that aims at investigating automated task assignment in multiagent systems that combines auction-based protocols and breakable contracts. More specifically, an approach to multiagent task assignment is introduced that is based on a Dutch-type auction protocol *and* leveled commitment contracting. The advantage of such a combination is that it is applicable in a very broad range of realistic scenarios in which knowledge-intensive negotiation among agents is not feasible and in which future environmental changes

may require agents to breach their contracts. To our knowledge such a combination has not been investigated so far. In [2] a combination of English-type auctioning and leveled commitment contracting has been described. In the work described here the focus is on the combination of a Dutch-type auction protocol and leveled commitment contracting. This work is structured as follows. Section 2 describes the contracting framework, and Section 3 explains our variation of the Dutch auction. Section 4 presents experimental results that indicate the benefits of this approach. Finally, Section 5 concludes the report with a brief overview of potential research directions evoked by the idea of combining auctioning and leveled commitment contracting.

2 Auction-Based Contracting (ABC)

We consider a group of agents that contains two different types of business partners. *Contractors* CR_i ($i = 1 \dots m$) who offer a unique task i and *Contractees* CE_j ($j = 1 \dots n$) who are willing to execute tasks. A contractor CR_i is capable of executing task i by himself for his prime costs¹ $C[CR_i]$. A contractee CE_j is able to do each task i for $C[CE_j, i]$.

We assume that contractees can accomplish tasks cheaper than contractors by defining two intervals.

$$\begin{aligned} \forall i : C[CR_i] &\in [cr_{min}, cr_{max}] \\ \forall j, i : C[CE_j, i] &\in [ce_{min}, ce_{max}] \\ ce_{max} &\leq cr_{min} \end{aligned}$$

This ensures that both, contractors and contractees, are interested in signing contracts with each other.

Pursuing conflicting goals, both types of agents are “true capitalists”: contractors intend to pay the lowest feasible price for a task, while contractees try to earn as much money as possible.

During an auction round, each contractor offers his task, where the contractor sequence randomly varies from round to round. Applying an auction-based protocol the agents then come to an agreement which contractee will execute the task. A contractee is only able to accept *one* task per round. For this reason, we consider two basic types of contract obligation: *full commitment* (a contractee has to stay with the first deal he made) and *leveled commitment* (contractors can breach contracts by paying a fine $Penalty_j$ to the concerning contractor CR_i).

The penalty investigated in this report is called *price penalty* and is defined as a fraction of the contract value $P[i]$.

$$\textit{Price penalty: } Penalty_j = ppr \cdot P[i]$$

ppr is a constant called price penalty rate. After buyer CE_j and seller CR_i negotiated a price $P[i]$ for task i , profits of both agent types are defined as follows.

¹All prices and bids are integers.

$$\begin{aligned}
CR_i : Profit_i &= C[CR_i] - P[i] \\
CE_j : Profit_j &= P[i] - C[CE_j, i] - PenaltySum_j
\end{aligned}$$

$PenaltySum_j$ is the sum of penalties CE_j paid during one round.

3 Dutch-type auction

The ABC system described in the previous section works with any (auction-based) protocol that defines how the agents have to interact to come to an agreement. The protocol investigated in this work is a variation of the Dutch auction.

A contractor offers his task for a –low– price. He then gradually rises his offer until one of the contractees accepts the contract. The accepted offer is the *price* of the announced task. This type of auction is an inversion of the original Dutch auction. The contractees are allowed to decommit from a contract whenever there is a more profitable task announcement by simply paying a decommitment penalty to the corresponding contractor. The penalties are assumed to be specified in the contracts. In particular, they are assumed to be variable and not conditioned on future events. These kinds of breakable contracts are known as *leveled commitment contracts*, in contrast to contingency contracts.

Figure 2 shows the basic algorithm of the auction. The set of contractees must be passed through in random order because there might be two or more contractees that accept the same offer. In this case, the winner has to be picked randomly.

3.1 Bidding Details

There is a whole spectrum of possible bidding strategies. The realization described in the following has been chosen because it is intuitively clear, easily extensible and efficiently realizable.

A contractor CR_i who wants to offer his task initiates a new auction by calculating an *opening (or initial) bid* Bid_i and announcing this bid to the contractees. Calculation is done according to

$$Bid_i = (1 - dp_i) \cdot C[CR_i] \quad (1)$$

where $dp_i \in [0 \dots 1]$ is a variable factor called desired profit (of contractor CR_i). If a contractee accepts the opening bid, then CR_i raises the factor dp_i according to

$$dp_i = dp_i + rob_i \cdot (1 - dp_i) \quad (2)$$

where $rob_i \in [0 \dots 1]$ is a contractor-specific constant called reduce-opening-bid factor. This ensures that a contractor who is successful with his opening offer (i.e., who finds a contractee willing to carry out the task for the price defined by the opening bid) will start with a lower opening bid in future auctions and thus

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FOR Round = 1 TO Max_Rounds
  CR_Set := {CR_i: i = 1 ... m};
  CE_Set := {CE_j: j = 1 ... n};
  WHILE CR_Set ≠ {} AND CE_Set ≠ {}
    CR := Choose_random(CR_Set);
    CR_Set := CR_Set \ CR;
    CE := null;
    round := 0;
    WHILE CE = null
      offer := CR.Offer(round);
      FOREACH c ∈ CE_Set // in random order
        IF c.accept(CR.task,offer) THEN CE := c;
      ENDFOREACH
      round := round+1;
    ENDWHILE
    Contract(CR,CE,offer);
    IF Commitment = full THEN CE_Set := CE_Set \ CE;
  ENDWHILE
ENDFOR

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Figure 2: Conception of the Dutch-type auction and contracting framework.

will try to further increase their profits. If none of the contractees responds to the opening bid, then CR_i calculates and announces a new bid, called *regular bid*, according to

$$Bid_i = Pre_Bid_i + rr_i \cdot (C[CR_i] - Pre_Bid_i) \quad (3)$$

where Pre_Bid_i is CR_i 's (unsuccessful) preceding bid and $rr_i \in [0 \dots 1]$ is a constant called reduction rate. The calculation and submission of regular bids is iterated by CR_i (*i*) until at least one of the contractees accepts the current bid or (*ii*), if CR_i reaches his prime costs and still no contractee is willing to accept the offer. In the second case, CR_i will execute the task by himself².

In deciding whether to accept a bid (i.e., to express interest in carrying out an announced task), a contractee CE_j distinguishes between two cases. The first case is that he is not yet committed to another contractor. In this case CE_j accepts a bid Bid_i iff

$$Bid_i \geq (1 + dp_{ji}) \cdot C[CE_j, i] \quad (4)$$

where $dp_{ji} \in [0 \dots 1]$ is a variable factor called desired profit (of contractee j w.r.t. the tasks announced by CR_i). CE_j increases (decreases) the factor dp_{ji} at the end of every auction initiated by CR_i in which he participated successfully (unsuccessfully). More precisely, CE_j adapts the factor dp_{ji} according to

$$dp_{ji} = \begin{cases} (1 + increase_{ji}) \cdot dp_{ji} & \text{if } CE_j \text{ was successful} \\ (1 - decrease_{ji}) \cdot dp_{ji} & \text{otherwise} \end{cases} \quad (5)$$

²This case never occurred during the experiments.

where $increase_{ji} \in [0 \dots 1]$ and $decrease_{ji} \in [0 \dots 1]$ are contractee-specific constants. The second case is that CE_j is already committed to another contractor CR_k , that is, he already signed a contract with another contractor CR_k in the current round ($k \neq i$). In this case CE_j additionally takes into consideration the difference $P[k] - C[CE_j, k]$ (i.e., his potential gain from the already existing contract) and the penalty $Penalty_j$. Formally, under the assumption that CE_j is already committed to CR_k in the current auction round, CE_j accepts CR_i 's current bid Bid_i iff

$$Bid_i \geq \max\{(1 + dp_{ji}) \cdot C[CE_j, i], \\ C[CE_j, i] + P[k] - C[CE_j, k] + Penalty_j\} \quad . \quad (6)$$

With that, a contractee decommits from a contract only if the new contract would result in a higher profit.

4 Experimental Results

All results presented in this section are based on the following parameter setting (for all i and j): $dp_i = 0.8$ (i.e., all contractors intend to make 80% profit), $rob_i = 0.2$, $rr_i = 0.1$, $dp_{ji} = 0.1$ (i.e., all contractees intend to make 10% profit), and $increase_{ji} = decrease_{ji} = 0.1$. At the beginning of each round none of the potential contractees is involved in a contract and all penalties $Penalty_j$ are set to zero. Other parameters are chosen as described below. In the following several scenarios are investigated, differing in the number of contractors and contractees.

4.1 1 Contractor and 2 Contractees (“1+2 Scenario”)

Figure 3 shows a plain scenario consisting of just one contractor and two contractees how the price evolves in 50 consecutive auctions. The first three offers are immediately accepted by CE_2 . The contractor reduces the offer each round hoping that CE_2 will still accept the deal. In the fourth round CE_2 refuses the first offer to accept the second, more lucrative deal. This repeats for the next 18 rounds until CE_2 only accepts the contractor's third offer, which yields even more profit. The price is raised by CE_2 this way until it reaches a level where CE_1 , whose prime costs are higher than those of CE_2 , is able to compete (round 34). The price stabilizes in a region where both contractees, CE_1 and CE_2 , can obtain the contract.

This rather simple example illustrates that the bidding mechanism described in 3.1 realizes what is intuitively expected from a (Dutch-type) electronic auction procedure.

4.2 3 Contractors and 4 Contractees (“3+4 Scenario”)

Table 1 shows the prime costs of three contractors and six contractees. The table entries are chosen from the intervals defined by the parameters $ce_{min} = 10$, $ce_{max} = 99$, $cr_{min} = 100$, and $cr_{max} = 200$. In this subsection a “3+4 scenario”

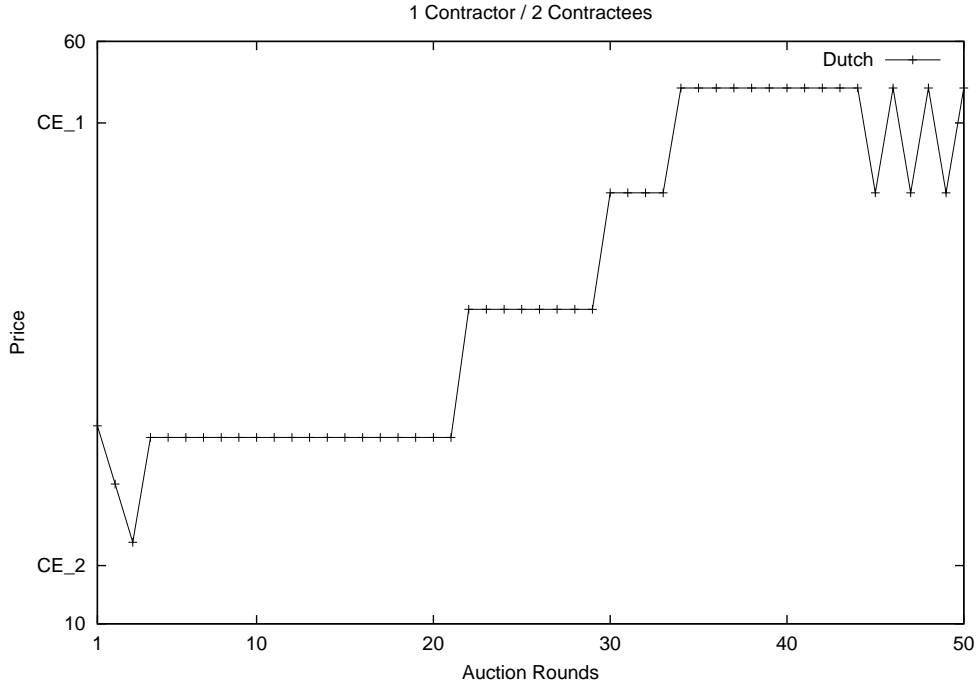


Figure 3: Price development in a simple 1+2 scenario.

is considered consisting of the three contractors and the first four contractees shown in this table.

Figures 4, 5, and 7 show how much profit the contractees accumulated in 100 auctions for different commitment levels (full and three different price penalty rates). Note that contractees that made no profit at all are not visible in the “accumulated profit” figures. A key observation with these data is that leveled commitment contracting is much fairer than full commitment contracting in that contractees having lower prime costs can effectively make more profit than contractees having higher prime costs. This fairness effect is correlated with the level of commitment. This can be best seen by taking a closer look on how the profit profiles of CE_4 (who is the “best” among all contractees because he can accomplish each task for the cheapest price) and CE_1 (who is the “worst” among all contractees). As the figures show, the lower the commitment level is, the more (less) profit was made by CE_4 (CE_1). (Note that CE_1 made no profit at all for $ppr = 0.5$ and $ppr = 0.25$.) The ordering of the contractees’ profits indicated by Figure 7 exactly reflects the ordering of the contractees’ average costs (the average costs of CE_1 , CE_2 , CE_3 , and CE_4 are 54, 38, 36, and 14, respectively).

Figures 8, 9, and 11 show how the prices develop under different commitment levels. A key observation here is that the price development shows a more convergent behavior under leveled commitment contracting with a penalty rate of 0.25 than under full commitment contracting.

	Task 1	Task 2	Task 3
CR_1	196	–	–
CR_2	–	193	–
CR_3	–	–	115
CE_1	42	68	53
CE_2	22	46	46
CE_3	24	27	59
CE_4	12	11	19
CE_5	31	64	37
CE_6	65	24	55

Table 1: Prime costs of contractors and contractees.

4.3 3 Contractors and 6 Contractees (“3+6 Scenario”)

In order to investigate what happens if the competition increases, two additional contractees were added to the 3+4 scenario, resulting in a 3+6 scenario that consists of the three contractors and the six contractees shown in the Table 1. The key observations stated above were also made for the 3+6 scenario. For reasons of limited space, detailed figures showing the price and profit curves for this extended scenario—as the Figures 4 to 11 do for the 3+4 scenario—are not included in this report. Instead, the Tables 3 and 2 summarize comparative results on these two scenarios. As these tables show, raising the competition through adding additional contractees tends to result in an increase of the contractors’ profits and in a decrease of the contractees’ profits in both the full and the leveled commitment situations. Moreover, Table 3 shows that the contractors’ profits decrease with the commitment level, and Table 2 shows that the contractees’ profits increase with the commitment level. Table 2 also shows how the overall number of broken contracts varies with the price penalty rate.

All together, these results further indicate and illustrate that the bidding mechanism proposed in the preceding section in fact realizes what is intuitively expected from a “Dutch-type leveled commitment task assignment.”

5 Conclusions

Automated task assignment that combines auction-based protocols and leveled commitment contracting defines a promising field of research in the area of multiagent systems. The work described in this paper and in e.g. [2] just does the very first steps toward a comprehensive understanding of the limitations and benefits of such a combination. Open issues that need to be addressed in future research are the following:

- The extension of the proposed approach toward scenarios in which both the contractees and the contractors are allowed to breach contracts.
- The extension toward parallel auctions.

Scenario	Commitment		Broken	Accumulated Profit						
	full	no penalty		CE_1	CE_2	CE_3	CE_4	CE_5	CE_6	$\sum_j CE_j$
3+4		no penalty	-	66	752	741	1,730	-	-	3,289
	leveled	ppt=1.00	8	48	625	477	1,348	-	-	2,498
		ppt=0.75	22	21	581	514	1,293	-	-	2,409
		ppt=0.50	42	3	516	393	1,824	-	-	2,736
		ppt=0.25	50	6	484	491	2,060	-	-	3,041
	ppt=0.00	69	3	339	451	2,232	-	-	3,025	
3+6		no penalty	-	0	390	263	1,396	335	180	2,564
	leveled	ppt=1.00	1	0	363	306	1,272	222	254	2,417
		ppt=0.75	3	0	421	219	1,315	219	244	2,418
		ppt=0.50	5	0	357	250	1,431	237	198	2,473
		ppt=0.25	22	0	371	234	1,483	240	192	2,520
	ppt=0.00	35	0	323	228	1,707	222	162	2,642	

Table 2: Number of broken contracts and contractees' accumulated profits in 100 rounds in the 3+4 and 3+6 scenarios for different commitments.

Scenario	Commitment		Accumulated Profit			
			CR_1	CR_2	CR_3	$\sum_i CR_i$
3+4	full	no penalty	16,612	15,152	6,897	38,661
		ppr=1.00	16,451	15,506	7,108	39,065
	leveled	ppr=0.75	16,118	15,522	6,629	38,269
		ppr=0.50	15,361	12,130	6,411	33,902
		ppr=0.25	13,081	12,520	6,500	32,101
		ppr=0.00	14,446	10,462	5,353	30,261
3+6	full	no penalty	16,587	16,502	7,582	40,671
		ppr=1.00	16,615	16,305	7,927	40,847
	leveled	ppr=0.75	16,447	16,155	7,934	40,536
		ppr=0.50	16,417	15,991	7,762	40,170
		ppr=0.25	16,244	14,684	6,955	37,883
		ppr=0.00	15,085	13,674	6,768	35,527

Table 3: Contractors’ accumulated profits in 100 rounds in the 3+4 and 3+6 scenarios for different commitments.

- The extension toward multi-unit and combinatorial auctions.
- The extension toward learning agents and more adaptive protocols.
- The exploration of other bidding mechanisms and formulas than those described in 2.3.
- The use of other standard auctioning protocols such as Vickrey auctions in combination with leveled commitment contracting, and the comparison of the different variants.

We think that the importance of automated task assignment in multiagent systems, the broad applicability range of multiagent task assignment based on auctioning and leveled commitment contracting, and the encouraging results we have gained so far justify to explore these and related open issues. Our current work concentrates on the last mentioned item.

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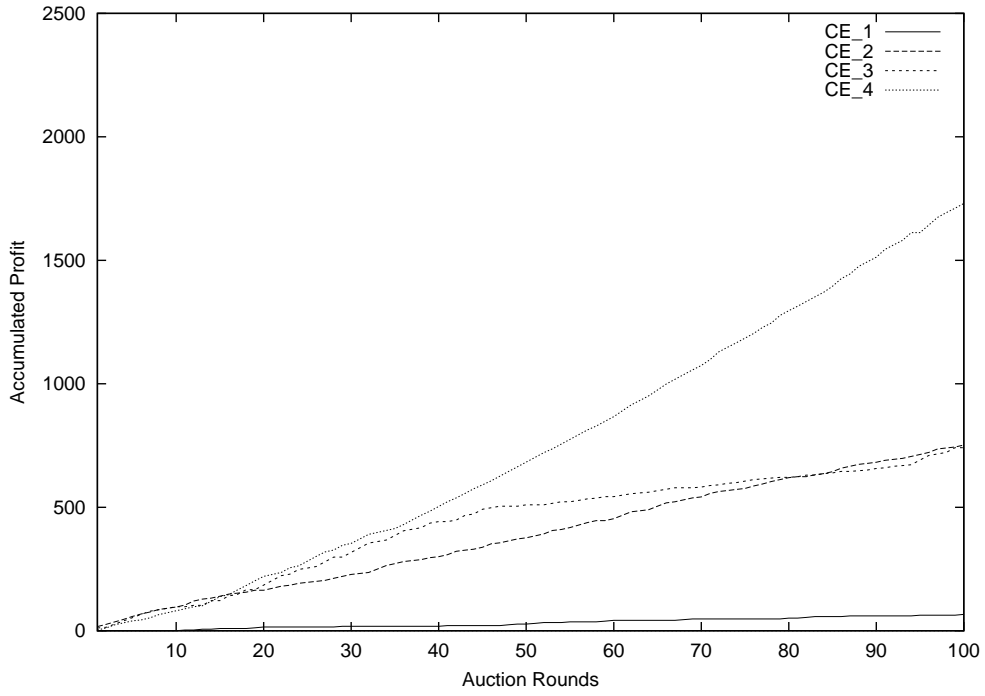


Figure 4: Accumulated profit in the 3+4 scenario with full commitment.

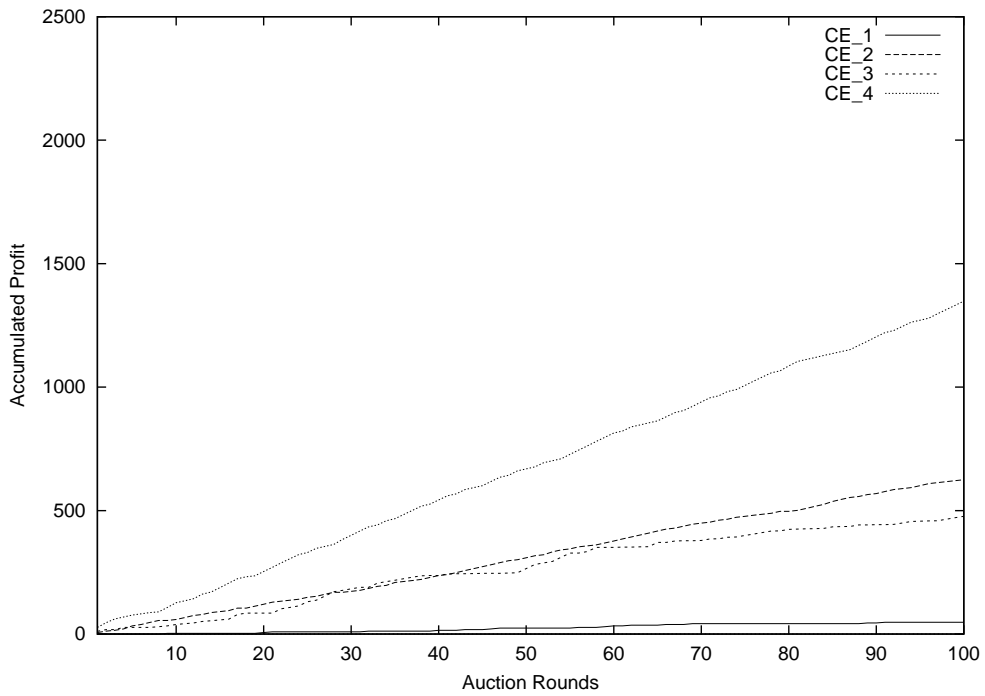


Figure 5: Accumulated profit in the 3+4 scenario with price penalty $ppr = 1.00$.

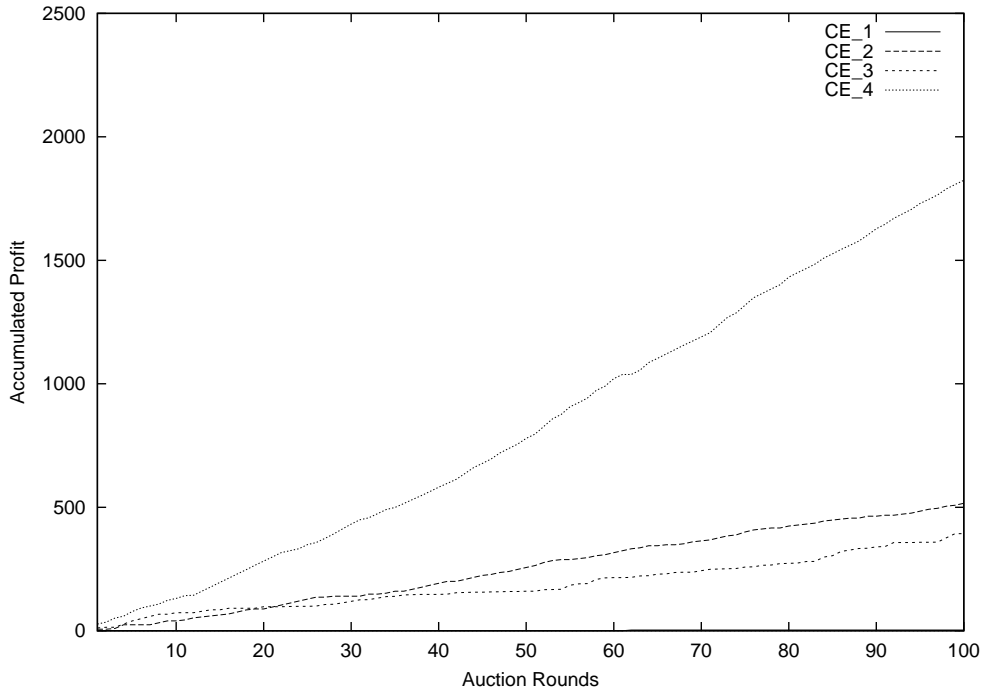


Figure 6: Accumulated profit in the 3+4 scenario with price penalty $ppr = 0.50$.

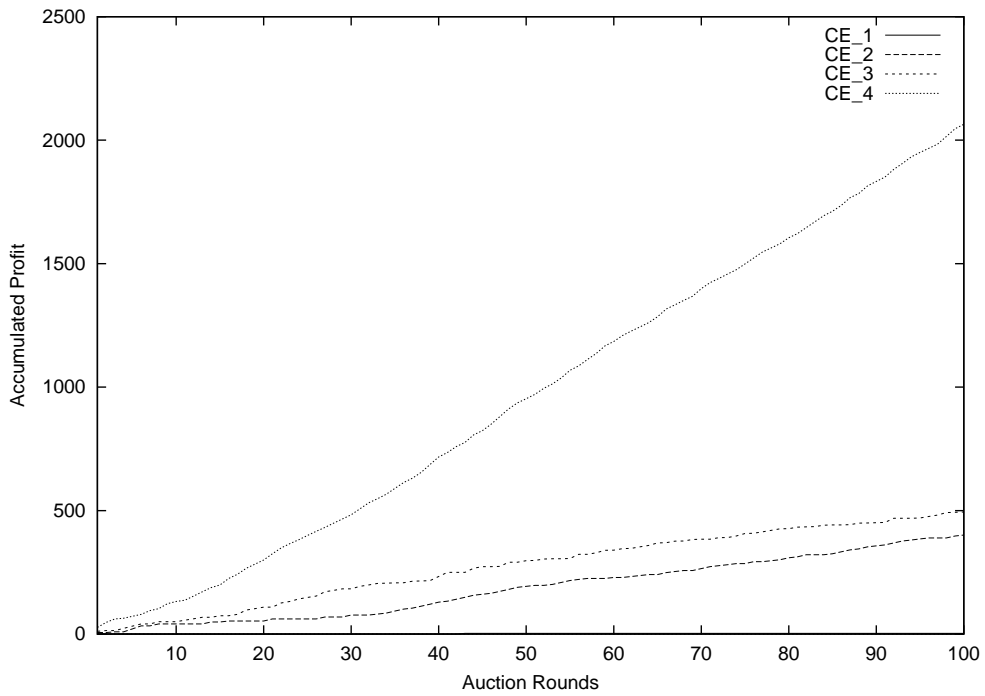


Figure 7: Accumulated profit in the 3+4 scenario with price penalty $ppr = 0.25$.

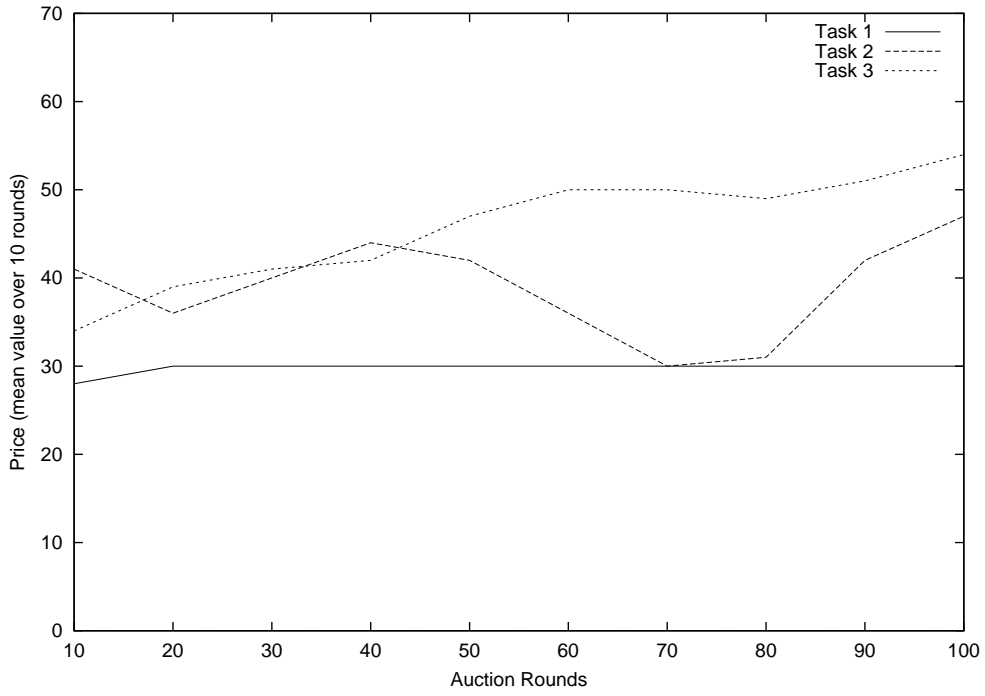


Figure 8: Price development in the 3+4 scenario with full commitment.

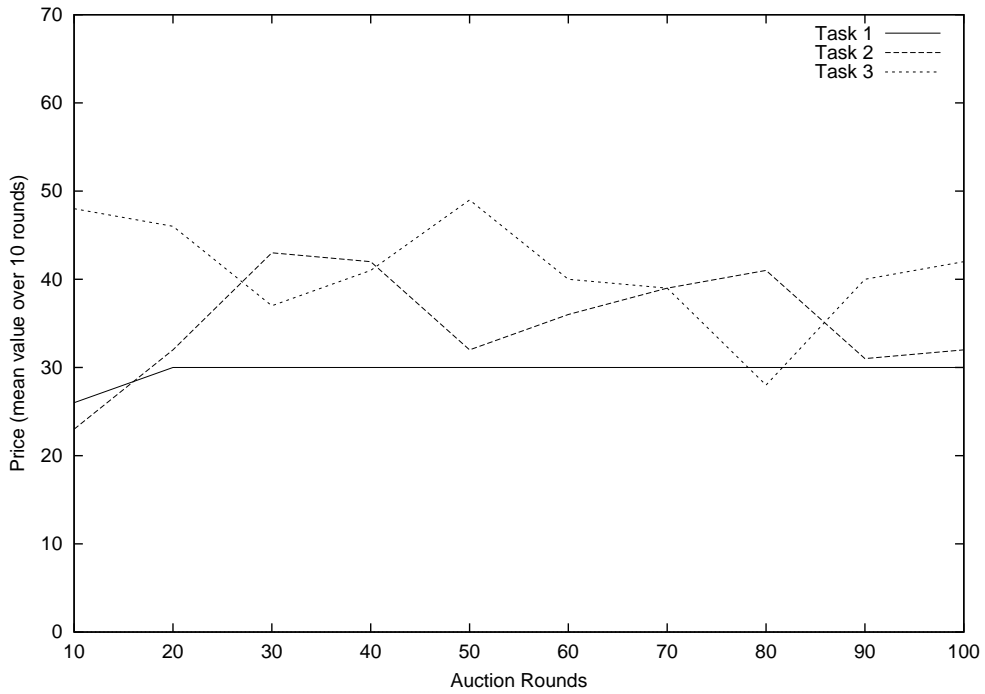


Figure 9: Price development in the 3+4 scenario with price penalty $ppr = 1.00$.

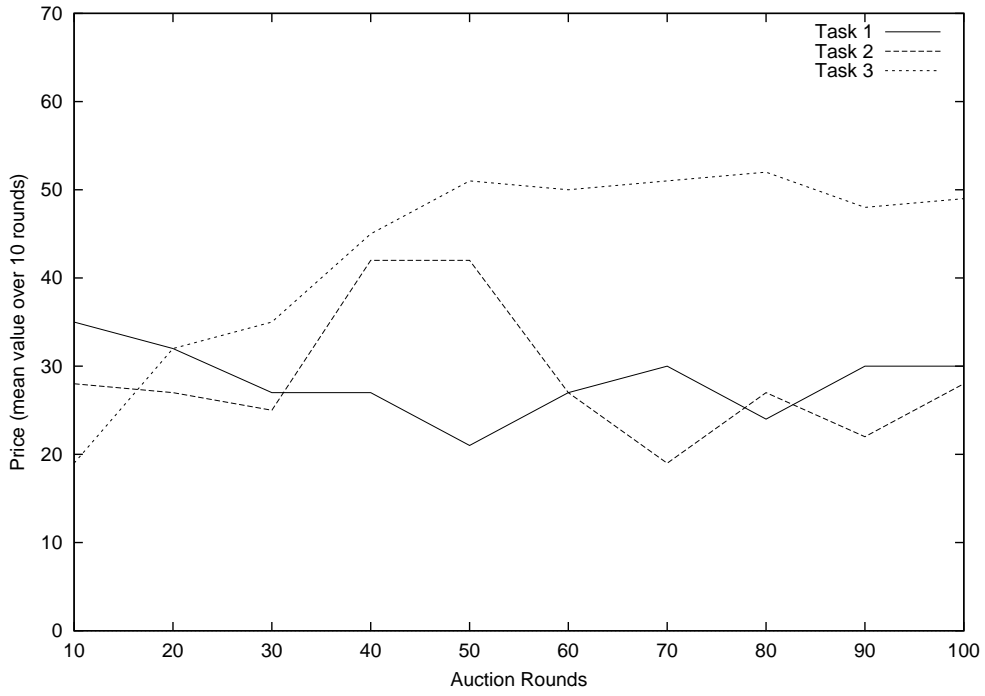


Figure 10: Price development in the 3+4 scenario with price penalty $ppr = 0.50$.

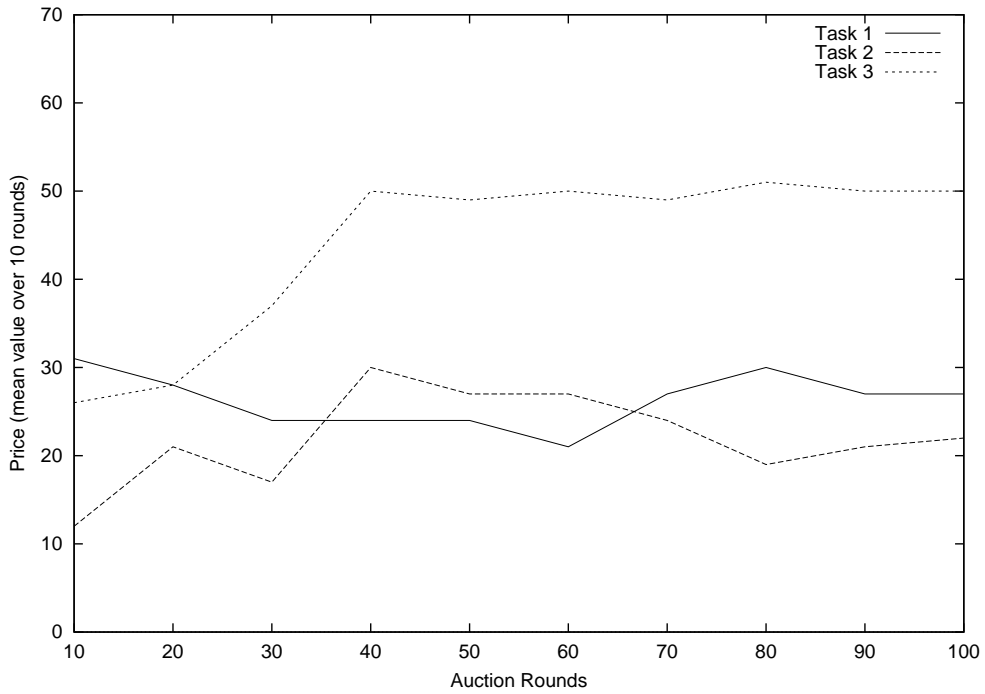


Figure 11: Price development in the 3+4 scenario with price penalty $ppr = 0.25$.