STAIRS 2012
K. Kersting and M. Toussaint (Eds.)

doi:10.3233/978-1-61499-096-3-228

Multi-Attribute Auction Mechanism for Supporting Resource Allocation in Business Process Enactment

Albert Pla[1] and Beatriz López [1] and Javier Murillo[2]
[1]*University of Girona,* [2]*Newronia, Spain*
{albert.pla,beatriz.lopez}@udg.edu, javier.murillo@newronia.com

Abstract. Resources are taking into account when designing business processes, but, under certain circumstances, they should be scheduled when business processes are enacted. Nowadays, the decentralization of the activities and outsourcing of certain tasks to third party companies is increasing the complexity of the resource allocation for business process. Moreover, some activities cannot be scheduled in advance, because they depend on some decision points in the business process, forcing the allocation of resources to tasks on the go. To deal with these issues we present a multi-attribute auction mechanism. Auctions are a market mechanism that facilitate the resource allocation in open, distributed scenarios. The auction model we are presenting is multi-attribute, so in addition to deal with the economic costs of the allocations, it enables the inclusion of other attributes, such as finishing on time or the quality of the outcomes. We have tested our proposal in a simulated framework and the results show about the benefits of using different attributes, in addition of providing privacy relationships among business process and resource providers.

Keywords. Business Process Enactment, Resource Allocation, Workflow Management Engine, Multi-Attribute Auctions

1. Introduction

The economy globalization is driving many organizations towards the definition of business processes which activities can be performed any place in the world, increasing the complexity of the business process management [1,2]. Regarding business process enactment, when resources (e.g. technicians, transports, services, etc.) should be allocated to the activities, several options are available, as for example, by using resources internal to an organization or by outsourcing the tasks to other third companies. The availability of the resources in both situations is uncertain. In the former case, the status of the resources is uncertain since they can have commitments with other business processes instances from different departments inside the organization. On the other hand, outsourcing companies can provide services to several organizations; they have their own schedules with customers that need to be kept in privacy. Therefore, the optimization of the resource allocation process need to be re-designed, taking into account the possible confrontation between managers, which try to obtain the lowest resource price at the higher

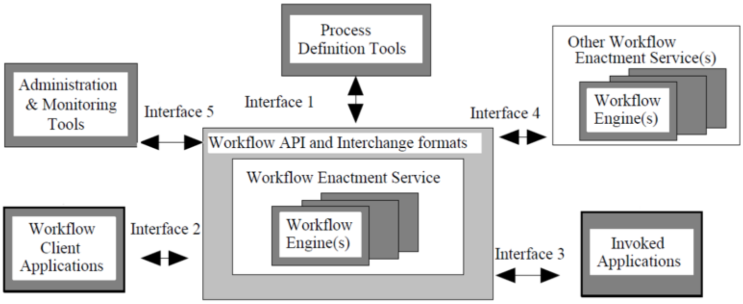

Figure 1. Workflow reference model according to [7].

quality, and the internal or external resources which try to maximize their occupation and benefits.

In addition, production methodologies such as *Lean Manufacturing* [3], are demanding additional flexibility in the operational process. The Lean philosophy can be used in embedding processes where the customer can personalize its order, assembling only the required pieces and without having pre-assembled stock, saving storage space and reducing the number of waste stocks. Resources associated to each of the activities of the business process need to be defined at a high abstract level [4] and when the business process is enacted, the resource specification should then be decided and allocated accordingly.

In this new scenario, auction mechanisms, offer the possibility to the organizations to allocate the resources in a market, competitive framework, while optimizing the outcome from all of the participants (business process owners and resource providers, both, either internal or external to the organization) [5]. Thus, given a business process task, resource providers bid for it, and the winner bid is the one that best fits the required resource specifications. There are several auction models, most of them focus on the resource price as the attribute which determines the winning bid. However, other resource attributes should be considered too. For example, in our previous work [6], we analyze the consequences of selecting one attribute or another, and we highlighted the necessity of defining new mechanisms to deal with several resource attributes at a time. For doing so, the auction model becomes more complex to guarantee that no cheater bidder can cause undesired outcomes.

The contribution of this paper is the definition of a multi-attribute auction mechanism for resource allocation to business process tasks which allows to combine several attributes (as the starting time, price, quality), while incentivize the bidders to bid truthfully. The mechanism is designed as a functionality of a workflow management system that supports business process enactment (see Figure 1). We test our allocation mechanism in a simulated framework showing the advantages and limitations of our proposal.

This paper is structured as follows. First, we comment some previous work related to our research in Section 2. Afterwards, in Section 3 we present our multi-attribute mechanism for business process resource allocation. In Section 5 we describe the experiments performed and discuss the results obtained. We end the paper in Section 5 with our conclusions and the future lines of research.

2. Related Work

The use of auctions for resource allocation in business process enactment is a complex problem due to the particularity that they contain decision points. For handling such uncertainty, there are two main approaches: interleaving resource scheduling with task execution [8], or scheduling tasks in advance as in [9] while allowing resource overlapping. We are in line with the former approach, but using other attributes in addition to resource price, so our problem is much more complex. Other auction approaches as [10], and specially from the grid computing domain [11], also only consider prices, instead of other attributes as time or quality.

On the scheduling community, the problem of considering multiple attributes for resource allocation is known as the multi-mode resource-constrained project scheduling problem and, when the resource is a person that masters one or several skills, as the multi-skill project scheduling problem [12]. The problem is known to be quite complex, and the available methods provide solutions for a relative low number of tasks (30) in a considerable amount of time (10 minutes) [12]. We are trying to leverage the complexity on the problem by interleaving scheduling with task execution, so the resources are allocated on demand.

Regarding multi-attribute auctions, a key work is [13], where the author describe different scenarios regarding the payment rule and demonstrate that the attributes should match the second best bid, but not exactly, to be incentive compatible. In business process, quality issues are defined as non-functional requirements, that can be measured when a task is finished. Thus, we differ from this previous work in which we are requiring at least the quality bid, while the price to be paid to the resources is the second best one. [14] follows also [13], using a first-price, sealed bid auction. Conversely to ours, we follow a second-price auction so as our model is incentive compatible.

In a posterior work, [15] proposes an adaptation of the Vickrey-Clarke-Groves [16] (VCG) for multi-attribute auctions under an iterative schema. That means that bidders are allowed to modify their bids in response to the bids from other agents. In our approach, we do not allow iteration due to the dynamics of our problem: allocation of resources to tasks are performed in a continuous basis. We think that this kind of approaches are more suitable for long-term contracts with companies, but not at the operational level as we do. On the other hand, every time a business process is enacted, the resource allocation problem starts, so agents have the possibility to learn from one allocation to the next one and modify their bids accordingly.

[17] presents a multi-attribute auctioning mechanism where agents use preference orders to express their bids instead of globally comparable function values. In a posterior work [18] generalize the approach on what is known Qualitative Vickrey auctions. However, the authors focus on defining a mechanism so that bidders can express qualitative preferences. We are interested in having a set of different attributes per bid. Thus, handling different attributes increases the number of combinations to manage in a preference order solution. Numeric values are also more suitable when discussing with managers about resources in a business process than relative orders. Finally, [19] proposes a multi-attribute mechanism where the attributes vary depending on the resource bundle assigned to tasks instead of the resource by itself. This is a complementary approach towards we need to extend our work in a future research.

[20] presents an mechanism for auctions with temporal constraints based on VCG with a new payment method. Time constraints are used to filter the participating bids, but

time is not considered when evaluating the bids, leaving aside whether time improves a bid or not. With our method, we take into account all of the attributes (thus also time) to optimize the allocation.

Multi-attribute auctions have been also used in the electronic advertisement markets [21], e.g. [22] proposes the adaptation of the GSP auctions in order to include an extra *quality* attribute, however this attribute is provided by the auctioneer itself, not by the bidder. This approach could be similar to trust-based approaches as [23]. In out approach, attributes, including quality, come from the bidder. Both mechanism are complementary.

3. Resource allocation method with multi-attribute auctions

Our proposal involves the use of an auction mechanism for deciding which resources to allocate to the tasks of an enacted business process. Due to the uncertainty involved in business process (decision points), the tasks that should be executed are known when they are about to start. For that reason, we interleave resource allocation with tasks execution. Other approaches are possible, as commented in Section 2, but we prefer this one because it does not cause overlapping and pre-booking situations in resources that could result in failures at run time.

The auction mechanism is embedded in a workflow management system that takes care of the operational issues of the business process (see Figure 1). The workflow management system follows a multi-agent architecture, as explained in [24] (see Figure 2). The auction mechanism explained in this paper provides resource allocation functionalities to the workflow management system.

Several business process can be enacted at a time. We assume that each business process is being handled by the same auctioneer or BP agent. Thus in a given moment, a BP agent can be in charge of one or more business process instances. On the other hand, resources providers are represented as agents (RP) in our architecture too. Thus, agents allow us to encapsulate whenever they belong to third companies or not [25].

When a business process is enacted, the corresponding BP agent auctions the first tasks. Once it is completed, next task. So our auction mechanism is sequential, since the decision of submitting a bid to an auction or not will condition the next auctions of the resource agents [26]. For example, an agent participating in an auction, and compromising its occupancy during the next 3 hours prevents it to participate in the next auction that could be more profitable for him (it has already commit its occupancy). Dealing with strategically issues regarding sequential auctions is out of the scope of the paper, and we assume that resource agents will not take care of tasks dependencies when bidding. However agents learn from an auction to the next one to improve their bids and profit.

We are interested in quality attributes of resources in addition to price, as position auctions. Despite position auctions are a good starting point for our purpose, Google is dealing with attributes provided by the auctioneer, not by the bidder. In consequence, it is assumed that the attribute values are always reliable. In our problem, when attributes are provided by resources, this assumption cannot be done. Bidders could lie when providing the attribute values in order to increase their utility. Thus, we need to follow other multi-attribute approaches as [13] or [14], while assuring truthful telling.

Moreover, in our approach, the auctioneer wishes to acquire resources from bidders for deploying a business process. So we follow a multi-attribute reverse sealed bid auc-

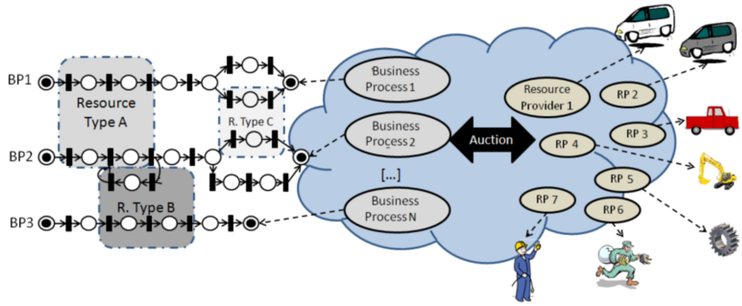

Figure 2. Schema of the multi-agent system: each business process is monitored by a BP agent while each resource is represented by a resource agent.

tion, meaning the following. First, in multi-attribute auctions a bid $B = (b, at)$ is evaluated according to its price b and a bundle of attributes at that characterize the good. Second, in a reverse auction the role between the auctioneers and the bidders is reversed as the auctioneer is the one who wants to buy a good, not to sell it. While ordinary auctions provide suppliers a chance to find the best buyers, reverse auctions give buyers the opportunity to find the lowest-price supplier. Finally, sealed bid means that the bidders do not know the other bids.

The steps followed in our auction mechanism are the following:

1. Request for proposals. The business process agent BP needs a resource to deploy a tasks. The resource and tasks requirements are characterized by a set of numerical attributes at (e.g. earliest starting time t, quality q, etc.). The BP agent summons an auction to demand the resource, defining the desired set of attributes AR.
2. Bidding. Resource agents RP_j satisfying the requirements can participate in the auction offering a bid $B_j = (b_j, at^j)$ where b_j is the price and at^j the attribute qualification.
3. Winner determination. The auctioneer (BP) evaluates the bids using an evaluation function $V(B_j)$ where $V(B_j)$ is a monotonic continuous function. As we are dealing with a reverse auction, the lower values represents higher satisfaction. BP cleans the market by ranking the bids from the lowest to the highest value. The bid with the lowest value is the winner of the auction.
4. Payment. When the winning agent RP completes the task, it receives a payment p. The payment would depend on whenever the task has been delivered according to the attributes bid or not.

3.1. Request for proposal

As explained above, we interleave resource scheduling and task execution. Thus, when a task is finished, the BP agent is able to define the requirements for the next task. For example, when there is a decision point (or condition), the BP can check it, and then proceed with the appropriate business process path accordingly.

Once the task to be performed is known, there is also known the earliest starting time and latest ending time; for defining them the BP has an estimation of the task duration to which it adds some slack time for flexibility purposes. Other task attributes are specified in the business process, as quality of the outcome, minimum skills (in case of persons), etc. Thus, the request for proposal consists of all of the attributes AR.

3.2. Bidding

Resource agents can receive more than one request for proposal at a time, $AR_1, \ldots, AR_m$, due to the fact that there are several auctioneers (BP) trying to allocate resources. We assume that RP agents treats them one after the other, otherwise we need to consider more complex auction models (combinatorial auctions [27]), in which the resource needs to deal with bundles of tasks. We will analyze combinatorial auctions in a future work.

RP have a truthful value for the requested attributes, at_j^v, and price b_j^v. In an incentive compatible mechanism, agents provide the true valuation in bids: $B_i = (at_j^v, b_j^v)$. Cheating agents provide bids with different values than the true valuations. For example, with a bid $B_i = (at_j, b_j)$ with $at_j > at_j^v$ and $b_j < b_j^v$, the cheating agent is offering higher attributes than its skills and at a lower price, with the aim of getting the task assigned.

If an agent does not win in an auction process, it changes their offer, by decreasing the price in the next auction with similar specifications, with the aim of getting the task assigned. We do not assume that the other attributes can be changed. Otherwise (the agent wins), it increases the price with the chance of increasing its profit.

3.3. Winner determination

To evaluate the score of a bid we propose to use a function that combines the bid price b with the bundle of the normalized attributes at. If at contains more than one attribute, those can be merged using an aggregation function $f(at)$ [28]. Thus, the winner determination problem consists on selecting the bid with the maximum value, as follows:

$$argmax_i(V(f(at_i), b_i)) \tag{1}$$

with $f(at_i) \in \Re$. Observe that any of the bids is a feasible allocations, since RP bid feasible (they provide bids inside the required time intervals for deploying the task).

Due to the characteristics of the problem we are dealing with, reverse auctions, the auction winner will be the bid with a lowest value; thus the evaluation function value must decrease when the bid quality increase. Below we list some possible evaluation functions: sum (Equation 2.1), product (Equation 2.2) and weighted sum (Equation 2.3).

$$\begin{aligned} V(f(at_i), b_i) &= b_i * f(at_i) \\ V(f(at_i), b_i) &= b_i + f(at_i) \\ V(f(at_i), b_i) &= \mu_1 b_i + \mu_2 f(at_i) \end{aligned} \tag{2}$$

where $\mu_i \in [0, 1]$ is the weight of each summation term, with $\sum_i \mu_i = 1$.

3.4. Payment

The payment method is inspired in position auctions but taking into account the peculiarities of the reverse auctions. This means that the winner bid receives just the necessary amount to beat the second highest bid (Equation 3), in other words, the payment the winner receives is the price it should have bid to obtain the same evaluation as the second higheest bid.

$$V(p, f(at_1)) = V(b_2, f(at_2)) \tag{3}$$

Where p is the payment of the single winner in our mechanism, at_1 the attributes of the winner bid, and b_2, at_2 the components of the second best bid.

However, this strategy does not prevent the bidders to lie regarding their attributes since including a false attribute could increase the chances to win the auction while not being penalized in the payment. For example, a bidder could submit a bid saying that it will finish its task in 10 minutes when actually it will finish the task in 15 minutes. This lie would have increased the chances of the bidder to win the auction.

Thus we adapt the payment mechanism in order to penalize dishonest bidders: when bidders intentionally lie to win the auction, payment is obtained by equating the initial bid evaluation (with the false value of the attribute) to the assessment of real goods (with the true value of the attribute).That is, since the payment is performed after a task has been completed, the BP can measure the quality of the results and realize that instead of achieving at_i, it got at_i^v. When that situation occurs, the payment mechanism is based on making the valuation of the obtained qualities same as the bid ones.

$$V(p, f(at_1^v)) = V(b_1, f(at_1)) \tag{4}$$

Where b_1 is the price offered by the winner bid, at_1^v the attributes got by the auctioneer after ending the task (and that we match as the true attributes of the bidder), and p, at_1 same as above.

Summing up, our payment proposal is a two case method:

- Truthful bidding (TB): when the attributes obtained by the auctioneer are at least the same as the ones offered by the winner bidder.
- Untruthful bidding (UB): when the attributes obtained by the auctioneer are lower than the ones provided in the winner bid.

In this way, the bidder is encouraged to bid truthfully. When he delivers its product or service, if the bidder provides its service or good as it was indicated in the bid, he will receive the economical amount that he was expecting or even more (the exact value to beat the following highest bid), increasing its utility. However, if the bidder lies and delivers it's product in worst conditions than the ones agreed it will not receive the payment he expected, reducing its utility. The prove that the mechanism is truthful telling can be found in [29].

The payment mechanism is conditioned by the evaluation function used to clear the market. Table 1 shows the payment functions p derived from the evaluation functions proposed in Equations 2.

	Product	Sum	Weighted Sum
$V(b, f(at))$	$b * f(at)$	$b + f(at)$	$\mu_1 b + \mu_2 f(at)$
TB payment	$\frac{b_2 * f(at_2)}{f(at_1)}$	$b_2 + f(at_2) - f(at_1)$	$\frac{\mu_1 b_1 + \mu_2 t_2 - \mu_2 f(at_1)}{\mu_1}$
UB payment	$\frac{b_1 * f(at_1)}{f(at_1^v)}$	$b_1 + f(at_1) - f(at_1^v)$	$\frac{\mu_1 b_1 + \mu_2 f(at_1) - \mu_2 f(at_1^v)}{\mu_1}$

Table 1. Payment functions (p) in the different cases (TB: truthful bidding; UB: untruthful bidding) when using the product, the sum and the weighted sum as evaluation functions $V(b, f(a_t))$.

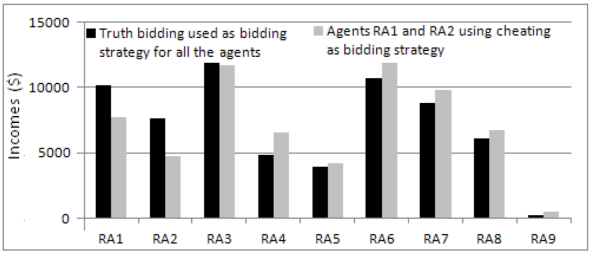

Figure 3. Mean Budged of the agents in Scenario1 (BP: Business process agents, RP: Resource agents).

4. Experimentation

In this section the previously presented methodology is tested using the workflow simulation engine presented in [24] a workflow environment with common resources have been simulated. In the simulator, business process types and instances are handled by business process agents (BP) while the resources are handled by resource provider agents (RP). The experiments are evaluated in terms of economic utility (agent benefits and costs) and delays in the process execution.

4.1. Experimental Set Up

To test the performance of our auction mechanism we modeled and simulated a set of three synthetic workflows. Each of these workflows is composed by four different tasks which have a duration compressed between 10 an 15 time units and needs a resource of a randomly assigned category (between A and F). In consequence, each workflow has a duration between 40 and 60 time units and requires between 1 and 4 different resources. In the simulation, the number of tasks that will be executed is unknown as it simulates and organization where workflows are not scheduled, they arrive under demand.

To study the behavior of the method presented in Section 3 (henceforth referred as SPMA^2, second price multi-attribute auctions) against cheating agents we used two different kinds of agents: ones which try to maximize their utility adapting their bids [30] and ones which cheat and try to win the maximum number of auctions. In the experiments we compare the benefits that the cheating agents obtain with the ones the would have obtained if they had bid truthfully, moreover, we compare the results obtained by our auctioning mechanism with the ones presented by [15] and how the cheating agents affect the efficiency of the production process. Each experiment has been repeated 100 times and has simulated the behavior of 3 workflow agents during 200 time units, while the number of resource agents and their strategies has been modified according to the goal of the scenario.

The experiments have been done using 3 scenarios:

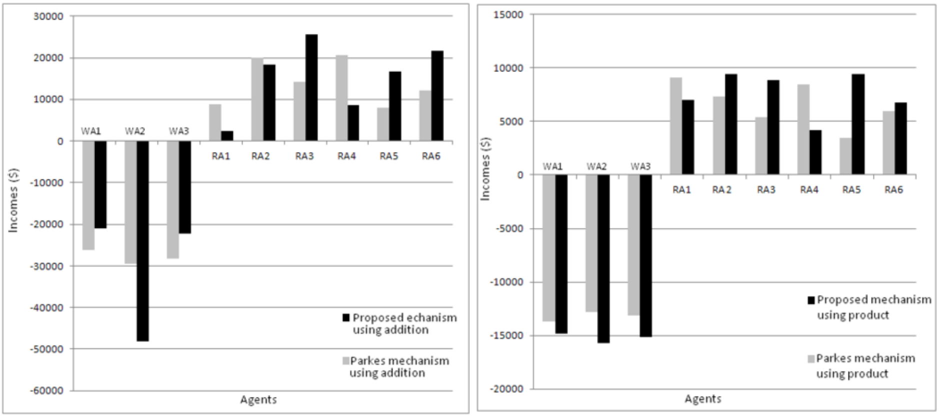

Figure 4. Comparison between the mean budget of the agents in scenario 2 when using our proposal and the Parkes mechanism. Left: using sum as evaluation function. Right: using product as evaluation function.

- **Scenario1:** This scenario has different BP executing processes and creating auctions while 9 RP are bidding. In this experiment product is used as evaluation function. The main goal of this scenario is to evaluate if for a resource agent is better to lie or to bid truthfully, in order to do so, the experiment is first realized with 2 cheating agents (RP1 and RP2) and 7 adaptative agents; then the experiment is repeated but changing the bidding strategy of RP1 and RP2 from cheating to truthful bidding.
- **Scenario2:** The aim of this scenario is to compare the behavior of the $SPMA^2$ with the Parkes' Vickrey multi-attribute auction mechanism [15]. To achieve this goal 6 resource agents have been used: 2 cheaters (RP1 and RP4) and 4 adaptative agents. The experiment have been repeated using the product and the sum as evaluation functions for both auctioning mechanisms.
- **Scenario3:** The goal of this experiment is to study how the presence of cheating agents affects the efficiency of a production process. To analyze the number of delays produced in the simulation, we use 10 resource agents which, initially, use truthful bidding as strategy. The experiment is repeated 11 times, changing one agent strategy from truthful bidding to cheating at each repetition. Thereby, at the first run of the experiment there are no cheating agent, at the second there is one cheating agent and so on until all the agents use cheating as strategy.

The results of the experiments are shown in figures 3 and 4.

Figure 3 presents the results of the first scenario, it shows the mean incomes of each agent after the simulation. The black bars represent the incomes of the agents when RP1 and RP2 are bidding using a cheating strategy while the gray bars illustrates the incomes of the agents when using a truthful bidding strategy. It can be clearly seen how RP1 and RP2 earn more money when they are bidding according to their true values. The fact that RP1 and RP2 does not significantly affect the budgets of WF1, WF2 and WF3 as they spend a similar amount of money, however we can see how the rest of the agents earn more money when RP1 and RP2 do not follow the truthful bidding strategy. It is important to remember that not all the resource providers have the same category, thus their incomes are conditioned by the type of resources which the workflows require.

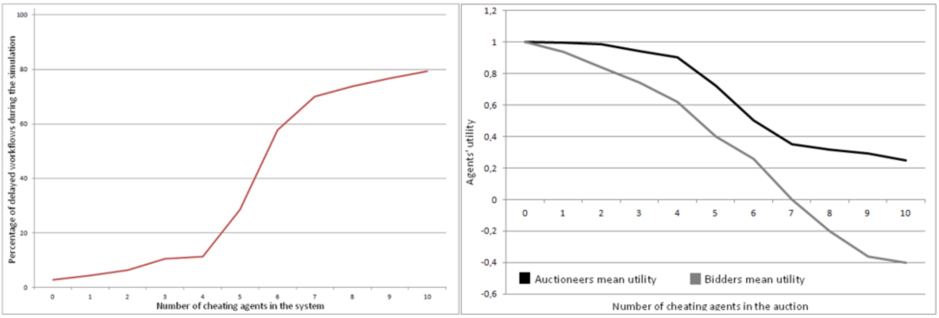

Figure 5. Left: Relation between the percentage of delays produced in the system and the number of cheating bidders (Scenario 3). Right: Relation between the mean utility of the agents and the number of cheating bidders (Scenario 3)

Figure 4 show the results of the second experiment. The left chart compares the Parkes mechanism with the SPMA^2 when using a product as evaluation function while the right one realizes the same comparison but using the sum as evaluation function. In both figures black lines correspond to the Parkes' Vickrey mechanism while the gray ones correspond to the SPMA^2. In Figure 4 left we can see how the income budget for the cheating agents (RP1 and RP4) is higher using the Parkes mechanism while the bidders following a truthful biding strategy have higher incomes when the SPMA^2 mechanism is applied. Another remarkable fact is that the expenditure incurred by workflow agents is higher when the SPMA^2 mechanism have been used. In Figure 4 right the facts listed above are repeated. Thus, on the one hand we can see how the SPMA^2 mechanism penalizes cheating agents but, on the other hand, it increases the price for the auctioneers. Besides, it is important to notice that, independently to the auction mechanism, the investment realized by the workflow agents is higher when the sum is used as evaluation function.

The results of the third scenario are presented in Figure 5 left, it shows the relation between the delays produced in the system and the number of cheating agents which are bidding. We can see how the increase of bidders using cheating as bidding strategy increases the number of delays produced in the system. We can see how the number of delays is low (under the 10%) while there are 4 or less agents cheating (40% of the agents), when the fifth cheating agent apperas the number of delays raises drasticaly (28.53%), while when there are 6 or more cheating agents overcomes the half of the executed workflows. This ilustrates than this mechanism can hold a limited number of cheating agents (40%) before the reliability of the workflows fall off. However, as Figure 5 right shows, the utility for the participants of the auction is higher when there are no cheating agents. This ilustrates how the SPMA^2 mechanism prevents bidders to cheat as they obtain the highest utility when bidding truthfully. Thus, if bidding agents act rationally, the system should not collapse.

5. Conclusions and future work

This paper concerns the problem of resource allocation (technicians, transports, services, etc.) in a decentralized environment where multiple business process instances are taking place concurrently while maintaining resources providers schedules in privacy. Our work is specially indicated for those domains where the resource demand is unknown and it cannot be planned in advance, and the availability of resources is uncertain (either internal resources of an organization or third company providers). As a solution approach, we propose a reverse multi-attribute auction, so when a business process is enacted, an agent deals with the scheduling of the resource required by following an auction mechanism. Resources with the best combination of price and attributes are allocated to the tasks. Our mechanism incorporates a payment mechanism which penalizes the bidders which do not meet the conditions agreed, making truthful bidding the dominant strategy for bidders. To evaluate the performance of our mechanism, we have simulated different resource auctions using cheating and adaptive resource providers. Results show that agents obtain higher incomes when they bid truthfully than when they do not.

As future work we plan to extend the auction mechanism with new evaluation functions. Particularly, we are interested on using multi-objective functions instead of aggregation functions to combine different attributes. We also pretend to adapt our mechanism to deal with sequential auctions and to add some fairness mechanisms in order to balance resource usage.

Acknowledgments.

This research project has been partially funded through the projects labeled TIN2008-04547 and DPI2011-24929, and BR10/18 Scholarship of the University of Girona granted to Albert Pla.

References

[1] Peter J Buckley and Pervez N Ghauri. Globalisation, economic geography and the strategy of multinational enterprises. *Journal of International Business Studies*, 35(2):81–98, 2004.

[2] Y.a Lee, J.b Shin, and Y.c Park. The changing pattern of sme's innovativeness through business model globalization. *Technological Forecasting and Social Change*, November 2011.

[3] R. Shah and P.T. Ward. Lean manufacturing: context, practice bundles, and performance. *op. Management*, 21(2):129–149, 2003.

[4] S. Smirnov, M. Weidlich, and J. Mendling. Business process model abstraction based on behavioral profiles. In *Proceedings of the 8th International Conference on Service Oriented Computing (ICSOC)*, pages 1–16, San Francisco, CA, USA, December 2010.

[5] Y. Chevaleyre, P.E. Dunne, U. Endriss, J. Lang, M. Lemaître, N. Maudet, J. Padget, S. Phelps, J.A. Rodríguez-aguilar, and P. Sousa. Issues in multiagent resource allocation. *Informatica*, 30:2006, 2006.

[6] A. Pla, B. López, and J. Murillo. Workflow resource allocation through auctions. In *Proceedings of the 2nd Workshop on Artificial Intelligence and Logistics (AILog in IJCAI)*, pages 55–60, 2011.

[7] WFMC. *Workflow Management Coalition Terminology and Glossary (WFMCTC-1011).* Workflow Management Coalition, 1999.

[8] Ning Liu, M.A. Abdelrahman, and S.R. Ramaswamy. A complete multiagent framework for robust and adaptable dynamic job shop scheduling. *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, 37(5):904 –916, sept. 2007.

[9] Pavlos Delias, Anastasios Doulamis, and Nikolaos Matsatsinis. What agents can do in workflow management systems. *Artif. Intell. Rev.*, 35:155–189, February 2011.

[10] B. P. Gerkey and M. J. Mataric. Sold!: auction methods for multirobot coordination. *Robotics and Automation, IEEE Transactions on*, 18(5):758–768, October 2002.

[11] Marek Wieczorek, Stefan Podlipnig, Radu Prodan, and Thomas Fahringer. Applying double auctions for scheduling of workflows on the grid. *SC Conference*, 0:1–11, 2008.

[12] Odile Bellenguez-Morineau. Methods to solve multi-skill project scheduling problem. *4OR: A Quarterly Journal of Operations Research*, 6:85–88, 2008. 10.1007/s10288-007-0038-4.

[13] Yeon-Koo Che. Design competition through multidimensional auctions. *The RAND Journal of Economics*, 24(4):668–680, 1993.

[14] Esther David, Rina Azoulay-Schwartz, and Sarit Kraus. Protocols and strategies for automated multi-attribute auctions. In *Proceedings of the first international joint conference on Autonomous agents and multiagent systems: part 1*, AAMAS '02, pages 77–85, New York, NY, USA, 2002. ACM.

[15] D C Parkes and J Kalagnanam. Iterative multiattribute vickrey auctions. *Management Science*, 51:435–451, 2005.

[16] Jeffrey K. MacKie-Mason and Hal R. Varian. Generalized vickrey auctions, 1994.

[17] Tamas Mahr and Mathijs M. de Weerdt. Multi-attribute vickrey auctions when utility functions are unknown. In Pierre-Yves Schobbens, Wim Vanhoof, and Gabriel Schwanen, editors, *Proceedings of the Belgium-Dutch Conference on Artificial Intelligence (BNAIC)*, pages 221–227. BNVKI, 2006.

[18] B. Paul Harrenstein, Mathijs M. de Weerdt, and Vincent Conitzer. A qualitative vickrey auction. In *Proceedings of the 10th ACM conference on Electronic commerce*, EC '09, pages 197–206, New York, NY, USA, 2009. ACM.

[19] Takayuki Suyama and Makoto Yokoo. Strategy/false-name proof protocols for combinatorial multi-attribute procurement auction. In *Proceedings of the Third International Joint Conference on Autonomous Agents and Multiagent Systems - Volume 1*, AAMAS '04, pages 160–167, Washington, DC, USA, 2004. IEEE Computer Society.

[20] Dengji Zhao, Dongmo Zhang, and Laurent Perrussel. Mechanism design for double auctions with temporal constraints. In *IJCAI*, pages 472–477, 2011.

[21] Susan Athey and Glenn Ellison. Position auctions with consumer search. *forthcoming Quarterly Journal of. Economics*, 126(3):1213–1270, 2011.

[22] Hal R. Varian. Position auctions. *International Journal of Industrial Organization*, 25(6):1163 – 1178, 2007.

[23] Sarvapali D. Ramchurn, Claudio Mezzetti, Andrea Giovannucci, Juan A. Rodriguez-Aguilar, Rajdeep K. Dash, and Nicholas R. Jennings. Trust-based mechanisms for robust and efficient task allocation in the presence of execution uncertainty. *J. Artif. Int. Res.*, 35:119–159, June 2009.

[24] A. Pla, B. Lopez, J. Melendez, and P. Gay. Petri net based agents for coordinating resources in a workflow management system. In *ICAART*, pages 514–523, Rome, Italy, February 2011.

[25] Michael Wooldridge. *An Introduction to Multiagent Systems*. Wiley, Chichester, UK, 2. edition, 2009.

[26] Mireia Jofre-Bonet and Martin Pesendorfer. Optimal sequential auctions. Working paper, London School of Economics and Political Science, 2006.

[27] Simon Parsons, Juan A. Rodriguez-Aguilar, and Mark Klein. Auctions and bidding: A guide for computer scientists. *ACM Comput. Surv.*, 43(2):10:1–10:59, February 2011.

[28] Michel Grabisch, Jean-Luc Marichal, Radko Mesiar, and Endre Pap. *Aggregation Functions (Encyclopedia of Mathematics and its Applications)*. Cambridge University Press, New York, NY, USA, 1st edition, 2009.

[29] Albert Pla and Beatriz López. Truthful bidding prove for multiatribute auctions. Research report IIiA 12-01-rr, Institute of Informatics and Applications, University of Girona, 2012.

[30] J. Lee and B.K. Szymanski. A novel auction mechanism for selling time-sensitive e-services. In *IEEE Conference on ECommerce Technology (CEC'05*, pages 75–82. Press, 2005.