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MULTI-AGENT ARCHITECTURE BASED ON AUCTION PROTOCOL FOR A WIRE ROD MILL ROLLS REPLACEMENT SYSTEM.

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Wire rod rolling is a complex manufacturing process where the raw material goes through a set of rolls assembled along the process line. One of the most important tasks is to determine the rolls to be assembled to make the desired product with the required dimensions and quality properties. The process has a series of determining factors which make this process complex: the number of assembled rolls is high (more than one hundred when all the rolling mill set is replaced) and this kind of mills has several sections, each one with specific requirements depending both the position where they are going to be assembled and the kind of product to be rolled, as well as diameter restrictions for the rolls. The inventory of rolls in this kind of facilities is very high. The process managers have to manage thousands of them, and the decision-making process is complex because each one has specific features (dimensions, geometries, alloys). Due to such complexity, there is a clear need for a decision support tool. This is a constraint satisfaction problem that can be faced with multi-agent systems. This paper presents a model for solving this problem based on a new multi-agent auction protocol.

Keywords: Multi-agent system; auction protocol; steelmaking; rolling process.

ARQUITECTURA MULTI-AGENTE BASADA EN PROTOCOLO DE SUBASTA PARA SISTEMA DE REEMPLAZO DE RODILLOS EN UN TREN DE LAMINACIÓN DE ALAMBRÓN.

La laminación de alambrón es un proceso de fabricación complejo en el que la materia prima pasa por un conjunto de rodillos ensamblados a lo largo de la línea de proceso. Una de las tareas más importantes es determinar los rodillos a ensamblar para fabricar el producto deseado con las dimensiones y propiedades de calidad requeridas. Se trata de un proceso complejo: el número de rodillos ensamblados es elevado (más de cien cuando se reemplaza todo el conjunto) y este tipo de instalaciones tiene varias secciones, cada una con requisitos específicos según la posición donde se van a ensamblar y el tipo de producto a laminar, además de restricciones de diámetro. El inventario de rodillos en este tipo de instalaciones es muy alto. Los gestores del proceso deben gestionar miles de ellos y el proceso de toma de decisiones es complejo porque cada uno tiene características específicas (dimensiones, geometrías, aleaciones). Debido a tal complejidad, existe una clara necesidad de una herramienta de apoyo a la toma de decisiones. Este es un problema de satisfacción de restricciones que se puede afrontar con sistemas multi-agente. Este artículo presenta un modelo para resolver este problema basado en un nuevo protocolo de subastas.

Palabras claves: Sistemas multi-agente; protocolo de subastas; producción de acero; proceso de laminación.

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1. Introduction

The rolling process is the most common industrial process in steel manufacturing, which is used for making large length cross section like sheets and plates of steel and aluminum for structures. Rolling mills are used for performing the rolling process. Wire rod is one of the resulting products from rolling process, which is mostly used as a quality raw material to produce screws, tires or construction materials among others. It has a hot rolled round section that is turned into wire through cold rolling processes or wiredrawing. The raw material are billets of variable length heated in a reheating furnace at a very high temperature, around 1.115 ºC.

The rolling process has several sections. The roughing mill is located at the beginning. It has usually three rolling stands and is used to reduce the section of the billet. Next it is divided in two parallel threads each of them having a second roughing mill, an intermediate section and a finishing area consisting of two sections: 'block' and 'RSM' (Reducing Sizing Mill) that provide the final quality to the product. Finally, there is a pair of rolls for keeping the traction, just before the coils of wire rod are formed.

During the wire rod mill operation, the raw material goes through the rolls to achieve the required cross-section profile, having minor changes in its configuration at every stage. The rolls, which are assembled in stands, work usually in pairs and have a specific function in the manufacture of the piece.

There is a limited but huge stock of rolls in the factory, being usually greater than 4,000 the number of registered rolls and its features are not common to all of them as each one has its own specific such as geometry, dimension, alloys, etc. A roll has one or more tracks that must be grinded and shaped accordingly to the position of the roll within the mill and the product to be made. The use of each track is independent from that of the rest of the same roll, so a track is used for a specific assembly and once it is worn, the roll is disassembled and the track which was used is marked, being the roll ready to be assembled once again while there are left unused tracks. The tracks of new rolls and those of the rolls that have of all of them used are prepared to get ready to be assembled again.

The rolls always work in pairs, so the manager must choose for each stand of the thread two rolls which have an available track whose geometry and shape meet those of the stand and are equal among them. To make the right choice, the manager must consider several factors such as the roll state or the number of accumulated rolled tons. All the data about the stock of rolls is stored in database, so the life cycle of the rolls is traceable. The rolls must meet different restrictions, for example, the rolls can only be assembled in one of the sections of the rolling mill and the diameters of the rolls assembled on different rolling stands must meet dimension restrictions.

In the wire rod mill, the determination of the set of rolls suitable for a specific set of orders is a task of great importance. This task is particularly complex as the number of assembled rolls is very high, more than one hundred, and each of the single sections of the rolling mill has its specific requirements which depend on the kind of product to be rolled and the track where the rolls are going to be assembled. Rolls also must meet diameter restrictions among rolls assembled in the same and successive stands.

The replacement of rolls is a very frequent task which takes place every several days because when the rolls are worn, they must be disassembled and then grinded so that they can be used again. This process reduces its diameter, and therefore, its lifetime. The wear the rolls suffer depends on several factors being the alloy of the roll, the tons of raw material rolled and the stiffness of the rolled material the most important. Each roll is an expensive asset because they are made with metal alloys prepared to work in hard conditions. Therefore, each roll life cycle is carefully managed until it is finally disposed. The reduction of its diameter is measured and registered as it is one of the factors included for the computation of the production cost. The reconditioned of the rolls (grinded, textured and chromed of the roll) is a very important operation where the goal is to reduce the diameter as little as possible.

Rolls are not changed separately unless there is a break of a particular roll when working. All the rolls of a section are usually replaced at the same time. Because the diameter restrictions previously indicated, it is particularly important to reduce the diameter of the set of rolls in a uniform way. Otherwise, if any of the rolls wears more (something that occurs because the wear depends on several factors as the rolls composition, track shape and working conditions), a mismatch will occur that may force the rest to reduce the diameter (unnecessarily), with the consequent loss of their useful life. Nowadays, the managers use a simplification replacing the assembled rolls with predefined sets of alike rolls working together, noted as 'families'. However, this is not an optimal approach and makes the rolls replacing process less flexible.

The replacement of the rolls can be seen as a Constraint Satisfaction Problem, as it consists of a set of variables, the domain of each of the variables and the constraints related with that variables. Constraint Satisfaction Problems can be solved in a distributed way by a set of autonomous agents, each owning its particular variables, which are related to those in other agents by its own constraints, that is using a Multiagent System (MAS).

This paper is concerned with developing a new approach for solving this problem with an autonomous system assisting the current human-decision process with a MAS using an auction-based negotiation approach. The system uses a simulator of the rolls replacement process carried out previously and described in (Junquera et al., 2020). The simulator can generate valid combinations of rolls that accomplish with the basic constraints (diameter combinations, etc.). The simulator also includes a predictive model able to forecast the wear that the rolls will have after a specific job. The simulator was developed to test further different approaches for selecting the appropriate rolls for the stands. The proposed MAS model is aim to find the most suitable combinations of rolls that could be used for a replacement accomplishing with the basic requirements and that entails the minimum cost. The cost is computed as the depreciation of the roll after performing its work, and is calculated considering the purchase value, the residual value, the initial diameter and the end of life diameter. The work is currently ongoing, so only the concept of the model is presented here. The paper is structured as follows: first, the concept of MAS is introduced, and the method is described. Then, the application to the case of the RSM section is described as case study. Finally, the conclusions and further works are presented.

2. Method

An agent is a computer system that is capable of flexible autonomous action in dynamic, unpredictable, typically multi-agent domains (Luck et al., 2005). Agent based technologies provide a way to conceptualize complex and dynamic systems. MAS are composed of several agents, capable of mutual interaction. The interaction can be designed in the form of message passing, requesting, negotiating or producing changes in their common environment. MAS provide a way to conceptualize adaptive systems and self-organization as comprising interacting autonomous agents, each acting, learning or evolving individually in response to interactions on their own environments (Madureira et al., 2014).

A particularly challenging problem is the interaction among agents. Interaction may be aimed at enabling agents to coordinate their activities and behaviours, cooperate to reach common objectives, or compete to better achieve their individual objectives. Considering real manufacturing systems composed by multiple autonomous agents, negotiation is an important form of interaction that enables groups of agents to achieve at a mutual agreement regarding some objective or scheduling plan.

In MAS, agents should often work against each other due to the conflicts in their objectives, leading to competition. Competitive agents try to maximize their own benefits at the expense of others, and thus the success of one implies the failure of others. This is carried out by means of a negotiation process. Negotiation can be defined as the process by which a joint decision is reached by two or more agents, each one trying to reach an individual objective. The agents first communicate their targets, which may be conflicted, and then try to reach an agreement by making concessions or searching for alternatives (Weiss, 1999).

Generally, literature defines the following negotiation methods: Contract Net Protocol (Smith, 1980), Auctions (Wooldridge, 2009), Game Theory (Sandholm, 2002) and Argumentation (Jennings, 2001). The protocol and strategy are the main components of a negotiation mechanism. The protocol defines the common rules among the participants in the act of negotiate. In general, it includes a set of norms that represents the constraints for the proposals that participants can do. The strategy defines the possible actions (or sequence of actions) that an agent plans to follow during the negotiation process (Jennings, 2001).

Auctions is the approach followed in this work. This approach is particularly useful for allocating scarce resources that are typically desired by more than one agent. In our case the resources are the rolls. An auction mechanism is made up by a group of agents, where one agent has the role of auctioneer and the remaining agents are bidders. The classic scenario assumes that the auctioneer wants to sell an item at the highest price possible, while the bidders want to buy at the lowest price possible (Wooldridge, 2009).

Formally, the problem can be expressed as (Terán et al., 2013):

Suppose a group of agents $A = (a_s, A_i)$, where a_s is the auctioneer agent and A_i is the set of bidders agents defined by $A_i = \{A_1, A_2, A_3,, A_n\}$, an auction is defined by the tuple S:

$$S = \langle C_0, Of_i^j, \vec{\varepsilon_i}, a_i^j, C_p, C \rangle \qquad (1)$$

Where

- C_0 is the initial price of the auction, $C_0 \in \Re^+$
- Of_i^j is a offers matrix, $Of_i^j \in \Re^{(n+1)\times m}$ formed by the number of agents $i = \{1, \dots, n\}$ plus a row vector A_G which shows the winner of each round, and the number of rounds $j = \{1, , m\}$.
- $\vec{\varepsilon_i}$ is a vector, where each element represents the maximum amount that each bidder agent *I* can bid, ,$\vec{\varepsilon_i} = \{\varepsilon_1, \varepsilon_2, \cdots, \varepsilon_n\}$.
- a_i^j specifies a given proposal, being *a* the value proposed in the round *j*, and *i* the bidder agent.
- C_p is the condition for stopping the auction and may be of different types:

$$C_{p=}\begin{cases} t\ (time), if\ the\ auction\ is\ governed\ by\ time \\ j\ (number\ of\ rounds), whether\ it\ is\ governed\ by\ rounds \\ \alpha_i^j = 0\ \forall\ i = 1, \dots, n\ when\ there\ are\ not\ more\ bids\ from\ a\ given\ round \\ x_r\ (threshold), the\ threshold\ of\ minimum\ price \\ (for\ the\ case\ of\ the\ Dutch\ auction) \end{cases}$$

- C is the final price of the resource or item, it is the maximum value of the row vector A_G(for the case of the Dutch auction it is the minimum),$C = A_G^j, C \in \Re^+$ and the winner $A_G$may be any element of the set A_i, i.e., $\exists A_i : A_i = A_G$.

Furthermore, the offers matrix (Of_i^j) stores the proposals of the bidder agents involved and the highest bid (winning bid) made in a given round *j* by an agent *i* (winner). Each cell in the matrix contains:

$$Of_i^j = C_0^j + a_i^j\ where\ C_0^j = C_0\ if\ j = 1\ and\ A_G^{j-1}\ if\ j > 1 \qquad (2)$$

That is, in the first round each cell represents the value of the initial price proposal made by the agent, while in the next rounds that value is the winner value Of_i^j of the previous round *j+1* which is A_G^j, plus the proposal made by the agent. At the end the row vector A_G, identifies the winner in each round.

In our case, the auctioneer agent auctions the warehouse rolls (those that are ready to be used for the job to be performed). Each bidder agent codifies initially a feasible (but not optimal) solution for the replacement of rolls, that is, a set of rolls that could be assembled in the rolling mill to perform the required job. The solution is feasible because it was generated by the simulator, so it accomplishes with the basic constrains but it is not optimal because any issue regarding to the cost and degradation of rolls was considered. It is a way to get stochastics solutions. In case that the rolling managers proposes some initial solution (set of rolls), it can also be codified as bidder agent, in this case as a human agent. So, the algorithm considers *n* agents that codify *n* possible solutions.

Each bidder agent calculates the wear their rolls will have due to the work to be done. It is done using the wear predictive model of the simulator described in (Junquera et al., 2020). This wear is converted into cost. The case that the rolls used wear unevenly is considered as well. This calculation is made considering that if the wear of a roll is great, the rest will have to be rectified more than is strictly necessary.

The rolls that are not included in any of the solutions are auctioned by the auctioneer agent. Each bidder agent checks if the roll is valid to replace some of the proposal for some stand within the solution that codified and, in that case, if the cost would be reduced. If that, the bidder agent bids for the roll the cost that is reduced. Because each bidder agent contains a complete and valid solution, the new ‘purchased’ roll will replace one of the existing that will be returned to the pool of available rolls and that will be auctioned (the roll can be useful to other solutions). When all the agents have bid (if an agent is not interested it bids 0), the highest is the winner.

The process is repeated for all the rolls in the pool while there are rolls that have not been auctioned. When empty, a round is completed. The process runs again a new round. If no progress is made (no cost reduction is gain), the process finishes and the agent which codifies the solution with less cost is the winner.

The algorithm process is depicted in figures 1 and 2:

Figure 1: Algorithm flowchart

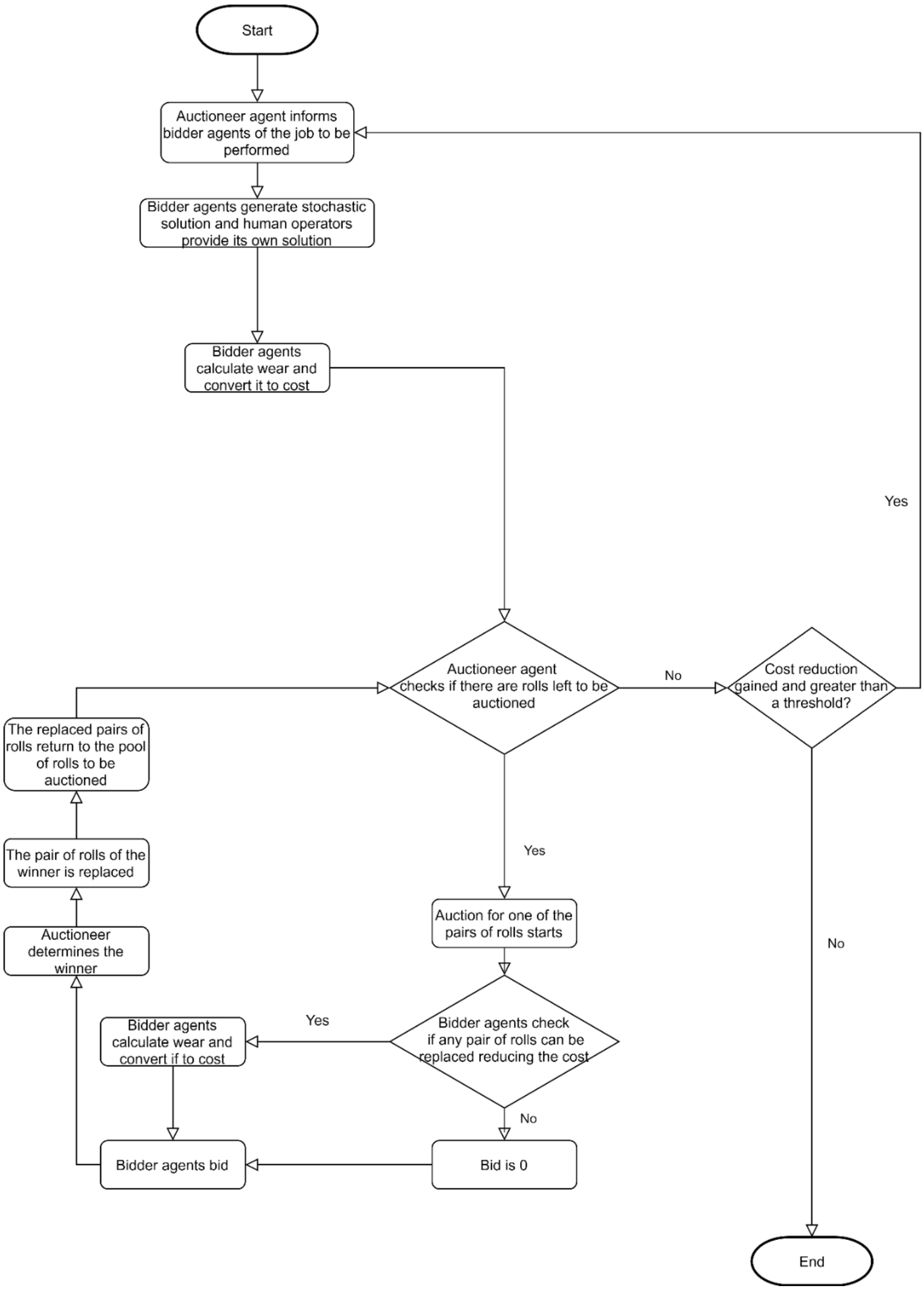
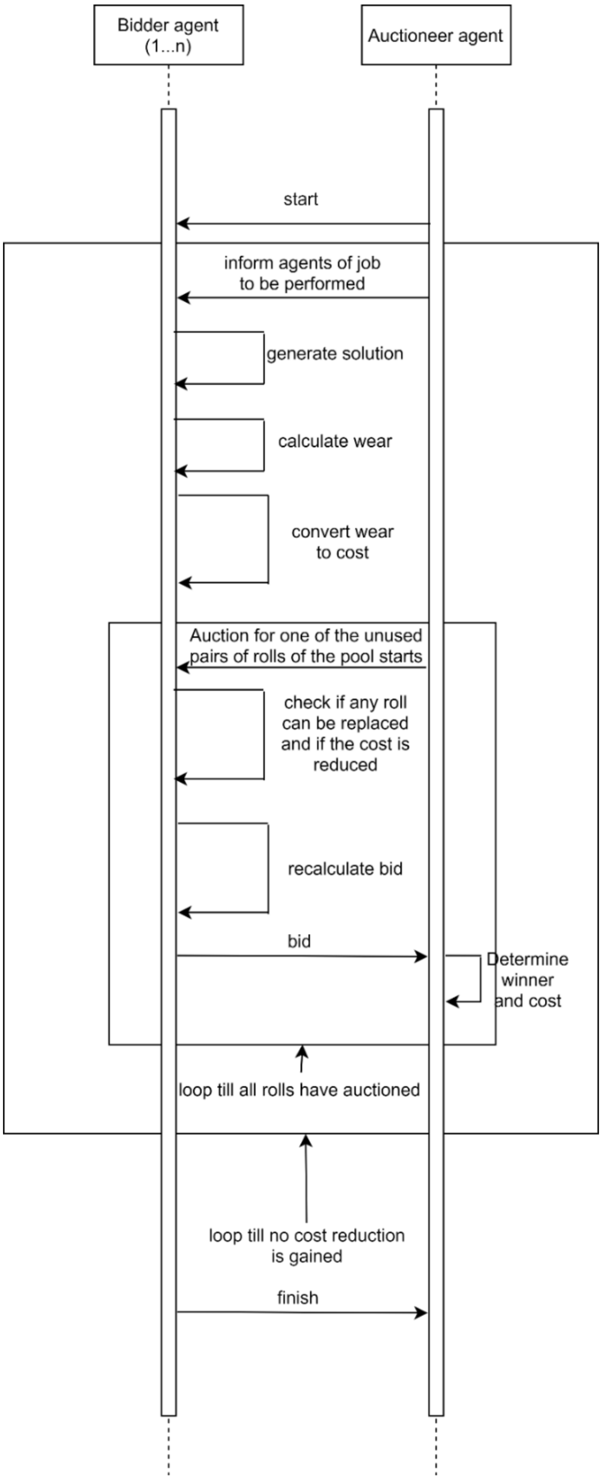


Figure 2: Algorithm sequence diagram



3. Case study

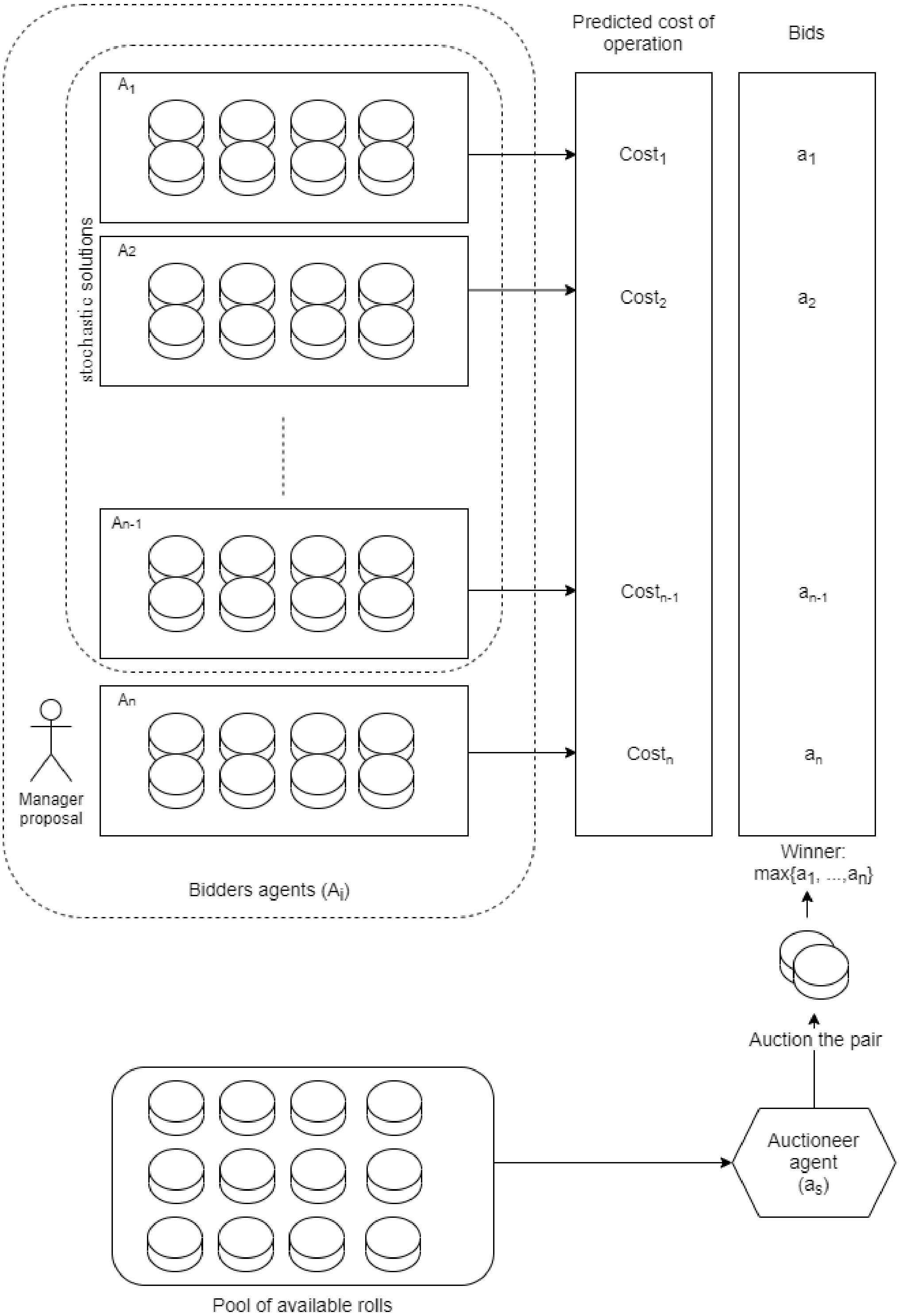
To illustrate how the model works, an example is considered for one of the rolling mill sections: the RSM. This section plays a key role in the finishing of the product as it is the final section in the rolling mill. It is therefore where the tolerances are most demanding. It is also the section that works at the highest speed (110 meters per second usually). It is formed by four rolling stands. The stands are mechanically coupled to a transmission driven by a single motor. The transmission is carried out by four gear boxes.

The rolling mill has several sections, but the rolls are only valid for a specific section (and in most cases, only for certain stands within the section), so the problem can be divided and faced separately for each section. Although the rolling mill includes two threads from a certain point in the rolling process, for practical purposes it is possible to try to solve the roll replacement separately for each thread. This allows us to limit the problem to a specific section of a specific thread. Other simplification that we are considering is that each pair of rolls to be assembled in a stand is considered as a unit. This is because actually the rolls that are assembled in a stand have to be twins. Rolls are already purchased in pairs, and these pairs are kept throughout life. If one is damaged, its partner must be discarded as well.

Figure 2 shows the problem structure for this case. We have a set of bidders agents A_i. Each agent has a valid codification of rolls for the required replacement (four pairs of rolls in this case). These solutions are generated by a module in charge of generating stochastic solutions. The number of solutions can be parametrized (i.e., 20 solutions). Solutions proposed by managers can also be considered as input to the system. In this representation, only one is considered (A_n). This can represent the draft for the rolls replacement that would be prepared by the plant managers usually. Each agent calculates the cost of operation ($Cost_i$) by means of the wear predictive model included in the rolling mill simulator (Junquera et al., 2020). The cost of operation is part of the internal view of the agent (it is unknown for the other agents).

The auctioneer agent takes pairs of rolls from the poll of available rolls and proceed with the auction. Each agent bids for the pair if it could replace one of the included in its current solution and the cost can be reduced. The bid will be the amount by which the operating cost would be reduced. There is only a round. The winner will be the agent with the higher bidder. The winner sends to the pool of available rolls the pair that is replaced by the new one. This pair will be later auctioned. The process is repeated until no improvement in cost reduction is achieved. That is, rolls are auctioned but nobody bids for them.

Figure 3: Block diagram for the case study



Each time a pair of rolls is auctioned, one of the solutions of the bidder agents can be improved reducing its cost in the largest possible number taking into account the *n* previous solutions and the cost in which each one would be reduced. After doing so for all the rolls available in the pool, the cost of each of the initial solutions is reduced significantly. The algorithm performs monotonous increasing, as worsening of the solution is not allowed (in the event that the pair or rolls that are bided doesn't improve any of the existing solutions they will not be assigned to any agent). Of course, this can be a limitation that prevents reaching the optimal solution, but this is a heuristic approach that can converge towards good solutions. Other limitation is also that the improvement achieved would depend on the initial solution adopted by the bidder agent, so to guarantee that the final solution is enough good, the process is repeated several times (rounds) till no cost reduction is achieved or at least the reduction is less than a threshold defined previously.

4. Conclusions and future work

No concluding remarks can be drawn until now because the conceptual design presented here has not been develop yet. Next step will be built a prototype for testing the model. We expect to find that the auction negotiation approach is valid to solve this particular problem. Different values for the model parameters will be tested (the effect of the number of bidder agents over the solution, the effect of including more initial solutions provided by the operators, different stop criteria, introduction of some heuristics, etc.). Also, some variants that allow until some extend bidding for pair of rolls that doesn't entails direct improvement, so avoiding local optimal. There are many theoretical studies in the field of MAS but the number of works that have been actually deployed in real industry environments are limited. If the prototype success, we plan to deploy it on a real factory for validation.

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