A MULTI-AGENT APPROACH FOR LEATHER PROCESSING MONITORING AND QUALITY CONTROL

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Currently there is no reliable mechanism available to allow continuous monitoring of all process conditions and leather characteristics inside the closed reactors during leather processing, so no real control. Conditions inside the reactors can only be monitored by stopping the reactor to sample the solution and leather. The automation systems for leather industry rely on stale centralised architecture, a critical point of failure imposing operational bottleneck. To improve the efficiency of leather manufacturing process the paper proposes a multi-agent system (MAS) architecture that is fault tolerant, and that provides high flexibility and agility needed by the turbulent environment of leather industry.

Keywords: multi-agent systems, leather processing, tanning, leather industry

1. Introduction

The central activity of leather industry is transformation of decayable raw skins and hides into a stable material called leather that is used for production of a wide range of goods (shoes, bags, garments, upholstery). Leather processing consists of numerous chemical and mechanical operations which are interlinked and determine the quality, cost of final product, and also the environmental impact.

Leather processing requires large quantities of water of precise volume, at an exact temperature, and at the right time. A wide range of chemicals in either solid or liquid form are used during leather processing in order to obtain a leather of consistent quality. A systemic overview of leather manufacturing processes depicting the inputs, outputs and the major disturbances that occur is illustrated in Fig.1.

Leather industry figures on the list of “The World’s Worst Pollution Problems” [1]. Poor uptake and excessive use of chemicals during leather processing operations generate pollutants which are toxic to both human health and to the environment, having a negative impact on all forms of life. Chromium (III), the “perfect” tanning agent in terms of leather performance [1], represents

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the most used tanning agent for producing around 85% of the leather worldwide [2], however, under some complex mechanisms, it can be converted into chromium (VI), which is toxic and carcinogenic [3].

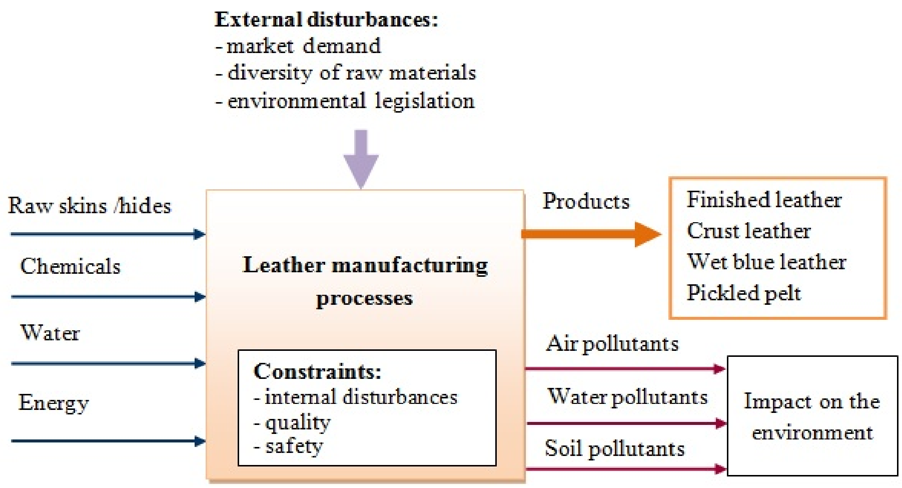

Fig. 1 Systemic overview of leather manufacturing processes

Tanneries, the plants in which leather is processed, are aggressive and corrosive environments of high complexity and diversity, comprising a large number of subsystems distributed geographically. Traditional control systems of tanneries are based on monolithic structure [4], which concentrate all control functions in a single central controller that is responsible for global production planning and scheduling of production activities. This approach provides long-term optimization of production in case of stable, deterministic manufacturing environments, but low agility and flexibility to unexpected disturbances [5]. However, in tanneries, the occurrence of disturbances is unavoidable due to the structure and characteristics of raw hides and skins, complexity of processing operations, demand volatility, equipment breakdown, and availability of raw materials, to mention only a few. In [6], the author asserts that it is possible to go a long way towards predicting the outcome of leather processing operations. Thus a control system that tightly monitors the processes and performs corrective action is needed.

The absence of mathematical models that accurately reflect the reality, nature and diversity of raw materials, discontinuity in processing operations and, last but not least, nonlinear behaviour and time-variance of leather processing operations impose the use of AI techniques. The paper proposes a multi-agent approach focusing on process control which aims to eliminate the disadvantages of rigid traditional, centralized, manufacturing control and provide the following benefits: 1) automated, flexible and optimized production planning, scheduling and monitoring, 2) reduction in the use of chemicals and water, 3) less exposure of human operators to dangerous chemicals, 4) consistent quality of leather. An insight into leather manufacturing processes and the rationales of an agent-based approach in leather industry has been reported in [7], this paper is being a continuation presenting an agent architecture and the way in which agents can be used to control the processes. Applications of multi-agent technology in batch process automation have been reported in [8, 9]. Multi-agent systems represent an approach based on decentralization of control functions over a collection of distributed autonomous, cooperative entities called agents. A brief comparison between traditional and distributed control approach is presented in Table 1.

Table 1

Comparison between traditional and distributed control

	Traditional control approach	Distributed control based on agents
Control structure	Rigid, static, centralized or hierarchical	Dynamic, flexible, heterarchical, semi-heterarchical
Relations among entities	Client-server	Peer-to-peer (agent-agent)
Decision-making mechanism	Top-bottom	Bottom-up
Communication	One-to-many	Many-to-many
Response to disturbances	Low	High

2. Leather manufacturing processes

Leather manufacturing processes consist of a long chain of chemical reactions and mechanical operations, up to 70, performed mainly in a discontinuous flow – batch processing. The raw material, skins and hides, has to follow the consecutive sequence of beamhouse (soaking, liming, deliming, bating), tanning (pickling, tanning), post-tanning (neutralization, dyeing, fatliquoring) and finishing processes without deviation in order to produce a specific assortment of leather. Although there is no unique procedure for leather processing, the major operations for converting the raw hides/skins to finished leather, performed in vast majority of tanneries, are the following:

- *Soaking* - skins or hides are immersed in water in order to remove unwanted components such as blood, dirt, salt. The central objective of this operation is the reversal of skins and hides to their natural condition as on living animal with approximately 65% humidity.
- *Liming* – the aim of this operation is removal of hair, flesh and splitting up of fiber bundles [10]. Lime and sodium sulphide are added during the operation, which increase the value of pH, and thus collagen swells leaving an open structure that allows removal of hair.

- *Deliming and bating* -the aim of deliming is elimination of swelling effect and residual lime produced during liming operation [11]. The pH value of the pelt is lowered from 12-13 to 5-8 by washing and addition of chemical substances, bringing the pelt to an optimum condition for the subsequent operation – bating. The objective of bating is the removal of the rest of unwanted components from pelt, which were not removed by previous operations. By using enzymes during this operation, pelt properties such as flexibility, softness, and elasticity are enhanced.
- *Pickling* - The skins and hides are treated with Sulphuric acid (H_2SO_4), Hydrochloric acid (HCl), Formic acid (CH_2O_2) to preserve them for up to two years.
- *Tanning* – is an essential operation of high complexity in which the pickled pelt is converted into a permanently stabilized material called wet blue by using a tanning agent. Various tanning systems can be used during this operation, namely mineral, vegetable, syntans, aldehydes, oils. However, the most commonly used mineral tanning agent is basic chromium sulphate involved in 80-85 % of all leather produced worldwide [2].
- *Neutralization, dyeing and fatliquoring* – through neutralization the pH of wet blue leather is brought to an optimal value for dyeing. Subsequently, the leather is dyed and treated with various oils that attach themselves to the leather structure and enhance its suppleness and flexibility.
- *Finishing* – the objective of finishing operations is to enhance the characteristics of leather in terms of colour, gloss, water resistance, perspiration fastness.

3. Technologies and methods used for leather processing

Technologies and standards adopted for leather processing vary massively from tannery to tannery. Recipes used for leather processing have been developed over generations and each tannery has its own recipes for getting the best quality of leather [12]. Applying non standard recipes and practices according to leather technician experience and talent is a rather common practice, especially in developing countries, but not limited to these. This situation is generated by the variety of hides and skins ranging from light to very heavy, unknown means of preservation, doubtful origin, “blind” process monitoring of closed reactors. In numerous tanneries around the world, chemical dosing, water batching, pH value adjustment are still performed manually [13], leading to operational inefficiency, inconsistent quality of leather and exposure of human operators to dangerous chemicals.

In leather industry the most common equipment for leather processing in wet phases (pre-tanning, tanning, post tanning) is the chemical reactor, also called a drum. Modern chemical reactors are equipped with PLCs (Programmable Logic Controller) which allow the following basic functions: 1) automatic temperature measurement of the float, 2) automatic measurement of pH values, 3) control of all processing times, 4) reactor rotations at different speeds. These automatic functions can be extended with systems developed by third parties. An example is the SCADA approach, a centralized control system which monitors and controls chemical reactors through an industrial server sending the processing instructions via an industrial network to the reactor's PLCs. In [4, 14] developers of the SCADA argue that their system provides data about plant productivity, time of run, time interval of stop, scheduled actions, unscheduled occurrences (errors), breakdowns, machine maintenance reminders, the trend of production parameters such as pH, temperature, pressure, volumes, number of leather processed, areas thickness. However, SCADA systems do not provide flexibility, scalability, resilience to failure or attack [15]. This is mainly due to the centralized approach of SCADA that represents a critical point of failure and impose operational bottlenecks to the system. Thus, if the industrial server goes down, the whole system will be affected.

4. Multi-Agent Architecture - TANMAS@

An agent, from computer science perspective, is a software entity that is immersed in an environment with a delegated set of goals and is capable of autonomous actions in order to attain its objectives [16]. Agents are generally deployed in complex environments, each of them having partial view and knowledge about the environment, being able to dynamically interact one with another to attain local and global objective of the system. This collection of cooperative agents forms a multi-agent system, generating an emergent behaviour capable to solve complex problems that could hardly be solved by a monolithic, centralized or hierarchical system. Agents are distributed across multiple devices that can be various microcontrollers, PLCs, ordinary PCs, industrial PCs. The effectiveness of a distributed MAS architecture takes an additional advantage of solving problems as close as possible to their source by delegating decision power to system nodes. A MAS can comprise various types of agents [17-19]: 1) reactive agents – execute tasks straightforward without reasoning about them, having no internal representation of the environment in which they are immersed and no reference to the past, 2) deliberative agents (cognitive agents, goal-oriented agents, intentional) – are proactive agents that can solve complex problems, have an internal representation of the environment in which they operate (world model), thus can perform deliberative reasoning based on previous information and current state; the deliberative behaviour is generally implemented using Belief-Desire-Intention (BDI) cognitive architecture, 3) mobile agents – migrate autonomously from one computer to another executing tasks on the destination host, 4) hybrid - combine one or more of the mentioned agent type characteristics into a single agent. To illustrate the benefits of multi-agent technology in leather processing we propose an agent structure named TANMAS@ (**TAN**nery **M**ulti-**A**gent **S**ystem **A**rchitecture) with the following roles:

Order Agents (OA) are associated with customers' orders storing information like ordered leather assortment (colour, thickness), quantity, quality and delivery time. Customers can interact with OAs through an interface that can be a web browser over the Internet through which they can express their demand. Subsequently of getting an order from a customer, OA, interacts with the supervisor agent that has access to the recipes database for manufacturing the leather assortment comprised in the order.

Batch agents (BA), illustrated in Fig.2, are mobile agents that migrate from equipment to equipment escorting the batch of raw hides/skins throughout the whole sequence of processing operations. More precisely, BAs are software programs with a unique identity, being able to move their code, data and state between production equipments. They suspend their execution and continue to operate once resident in another production equipment [20]. The BAs have the recipes for leather processing, received from supervisors. Similar role as given to BAs have the *works in batch agents* (WIP) proposed in [21] as a part of the Holonic Component-Based Architecture (HCBA). In our approach, at some points during the technological process, for example after tanning operation, the leather is sliced into two splits, namely top grain leather and split leather, which are divided in separated batches and processed further in a different manner. Thus the BA generates a new BA agent to escort the new batch.

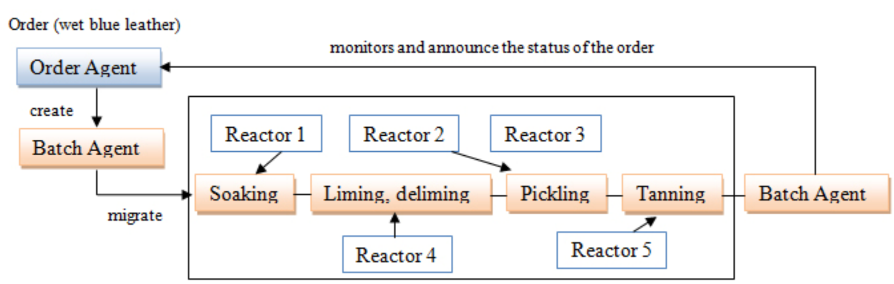

Fig. 2 Role of batch agent and its interaction with equipment agents

Supervisor Agents (SA) have a global view of the shop floor state, and are responsible for production equipment and resource supervision. Also, SA ensure that the process conditions within the reactor are kept within closer tolerances.

Planning Agents (PA) can be seen as a specialization of the SA; they are responsible for production scheduling, and they determine the resources that will perform manufacturing operations.

Resource Agents (RA) represent the physical equipments, utilities and the personnel involved in the leather making process or in one word - resources. We considered five specializations of RAs, namely:

1) *Equipment Agents* (EA) associated with processing equipments, such as reactors, dyeing machines, vacuum tunnels, etc.

2) *Water Batching Agent* (WBA) associated with the resources of water – responsible for batching water correctly at precise volume and temperature for different reactors,

3) *Chemical Dosing Agents* (CDA) are responsible for automatic preparation and dosing of chemicals, allow batch jobs to be queued and processed by priority and also record each batching job for later reference and trouble-shooting purposes.

4) *pH Monitoring Agents* (PMA) are continuously monitoring the pH values. It is a redundant agent as the same task is performed by the EA, however, for safety reasons, the result values of both EA and PMA are compared and checked to be within tolerance.

5) Quality Control Agents (QCA), associated with the personnel or some special tools responsible for performing quality control of processing operations.

5. Process control and production scheduling

Real process control implies not only monitoring the conditions inside the reactors, as performed by automatic systems, but also identification of mutual influences of processing parameters (pH, float length, temperature etc.) and continuous correction by addition of chemicals, heating or cooling the temperature of float, addition of base or acid for pH adjustment and so on [22]. Intelligent agents are autonomous entities that continuously adapt to changing circumstances in the environment, being suitable for the dynamic environment of leather manufacturing processes. The structure of the agent proposed in this paper for process control is shown in Fig.3. The agent has a world model (WM), a Knowledge Base (KB) for storing data, a Value Judgement (VJ) component that computes the benefits, the costs, the risks and expected payoff of a plan.

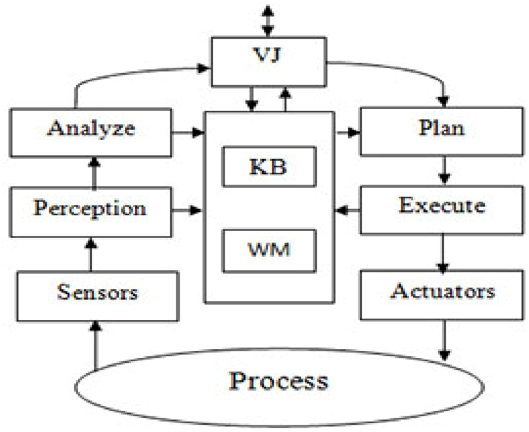

Fig. 3. Agent structure

Integration of agents in process control needs to take into consideration the aspect of integrating agents with physical equipments. The issue of constructing an environment inside existing Programmable logic controller (PLC) for supporting holonic operations was presented in [23]. The coupled architecture of an agent with physical equipments is referred to as holon [24]. The architecture of a holon consists of splitting the hardware control into three layers namely low level control layer (LLC), high-level control layer (HLC) and a middle layer working as an interface between LLC and HLC for managing their interactions. The LLC is responsible for providing real-time responsiveness incorporating a reactive behaviour, collects data from sensors and performs various actions. The HLC represents the deliberative layer or agent, commonly developed in C++ or Java, which is responsible for planning and sending the control actions to LLC. The integration of all three mentioned layers can reside on a single controller, a PLC or on separate device [25].
To further demonstrate the capabilities of a MAS, Table 2 briefly presents the technological algorithm used for producing a batch of pickled pelt based on a customer order.

Table 2

Technological algorithm for processing pickled pelt

No	Operations	Procedure		Controls
1	Soaking I	250 % water at 22 ^{0}C 0,2 % soaking agent	Stirring 30 ' Static 30'	pH 8-9
2	Soaking II	70 % water at 24 ^{0}C + 0,5% soda salt + 0,5 sodium hydrosulfide + 130% water at 20 ^{0}C	Stirring 120 ' Add soda salt and sodium hydrosulfide Stirring 60', add water	pH < 9,5
3	Liming	70 % water at 24 ^{0}C	Stirring 30 ', static 30 '	$pH, t \circ C$

4	Deliming	70% water at 33 (NH4)2SO4	Stirring 45-60'	$pH, t \circ C, \varnothing$
5	Pickling	70% water at 22 ^{0}C 7% NaCl + 0,8 % formic acid CH_2O_2 + 0,8 % sulphuric acid H_2SO_4	Stirring 15 ' Stirring 30 ' Stirring 210 '	$\rho = 1,055 - 1,07o$ pH = 2,7-2,9

Subsequently, Fig. 4. presents a multi agent approach for processing a customer order, and the steps involved are:

1) A customer sends an order to the OA.
2) The OA sends the leather assortments comprised in the order to the SA.
3) The SA seeks the corresponding recipe for producing the products comprised in the order. Subsequently the SA defines the processing operations and their sequence and sends them to the PA.
4) The PA has a global view of the shop-floor state, by looking up in Gantt chart database, determines the resource that can perform the sequence of operations, estimates the completion time and sends this information to the SA.
5) SA sends the manufacturing schedule comprising also the estimated completion time to the OA.
6) The OA decides whether the order is feasible or not based on current resource load, the time for completing the order and due date. If the order is not feasible, the OA can negotiate new terms and conditions. The OA could ask the customer if he agrees with a delay in exchange for some commercial benefits - price reduction for example, in order to permit an optimum tanning facility load, high-priority orders execution or to mitigate the effects of unexpected events that disrupt the tanning's plant functions and require technical interventions. Ultimately, if the order is not feasible, the OA refuses the customer and the order is placed in non feasible orders database.

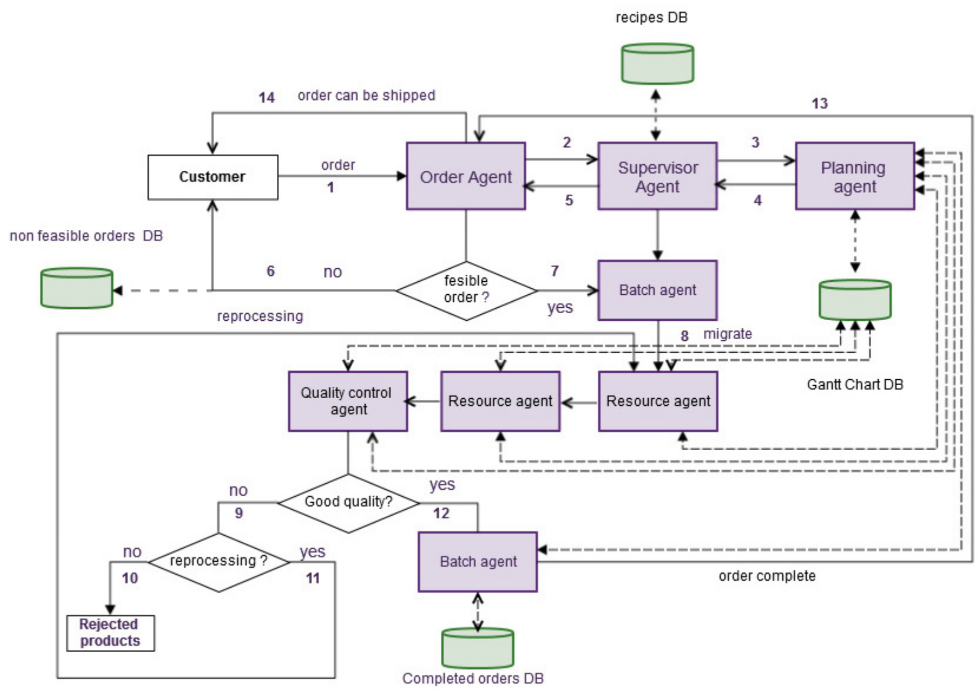

Fig. 4. Multi-agent model architecture for leather processing

7) If the order is feasible, the OA creates a BA and gives it the recipe for the batch of leather and also the SA gives it an optimal processing route to follow. In case of a disturbance, such as a machine breakdown, the BA has autonomy to change the route.
8) The BA migrates from one production equipment to another guiding the EA in performing the right operations and ensuring the processing parameters are kept within accepted tolerance. The EA executes the operations and informs the BA about the status of the operation. The BA and EA reside at a certain moment on the same equipment, thus the communication is kept private, communication overhead is reduced and the status of the order is known at any moment in time.
9) The QCA checks the quality of leather by comparing the quality obtained with quality requirements. If the quality requirements are not met, it is evaluated whether the quality of leather can be upgraded or not.
10) If the quality of the leather does not meet the requirements of the customer and the quality cannot be upgraded, the processed leather is rejected.
11) If the quality of the leather can be upgraded, this is sent back to the RAs in order to perform corrective actions and subsequently the loop continues with the evaluation of leather quality.

12) Finally, if quality requirements are reached, the BA places the order in completed orders database and informs OA about this. Subsequently the BA agent is dissolved, as it reached its purpose.
13) The BA announces the OA that the order was completed.
14) At the time when all the leather assortments comprised in the order have been successfully manufactured, the OA announces the customer that the order is ready and can be shipped.

5.1 Interactions between agents

Agents part of MAS environment can be in a situation when, due to partial knowledge or limited capabilities, they cannot solve a problem without support or assistance from other agents. In order to fulfill their objectives, agents need to cooperate, so they interact with one another, either directly, through message exchanging or indirectly, through a common environment such as a backboard area (Gantt chart database) or a supervisor agent, as presented in Fig.4. The inter-agent communication is done via an agent communication language, namely FIPA-ACL [26]. The meaning of messages exchanged by agents is comprised in the TANMAS@ ontology [27], which defines a vocabulary used by agents in order to have a common and unambiguous understanding. Cooperation and negotiation between agents are done based on Contract Net Protocol (CNP) presented in [28], however, in our approach, it is more compatible with the real manufacturing environment allowing additionally an agent to bid for a task, even though the current task is not completed. The interaction process between agents when dealing with a customer order is depicted in Fig.5.

Through message exchanging as presented in Fig.5., the agents update their WM and KB, and thus VJ (see Fig.3.) provides a more accurate and appropriate result, an intelligent decision. For example, the PA generates dynamically a manufacturing schedule, on which the OA concludes whether the order can be processed or not. Also, if an error occurred and an operation had not been completed, the other agents adapt to the situation, the BA requests another agent to perform the operation, the Gantt chart is updated with the operation and the PA generates a new schedule based on current shop floor state. This has also impact on the OA, which adapts its strategy and can propose new terms in order to obtain mutual benefits.

In contrast with traditional job-shop scheduling, inflexible due to centralised control/decision, the proposed MAS architecture allows distributed real-time dynamic scheduling and greater agility due to distributed control in hands of intelligent agents, an aspect that will be presented in a future work.

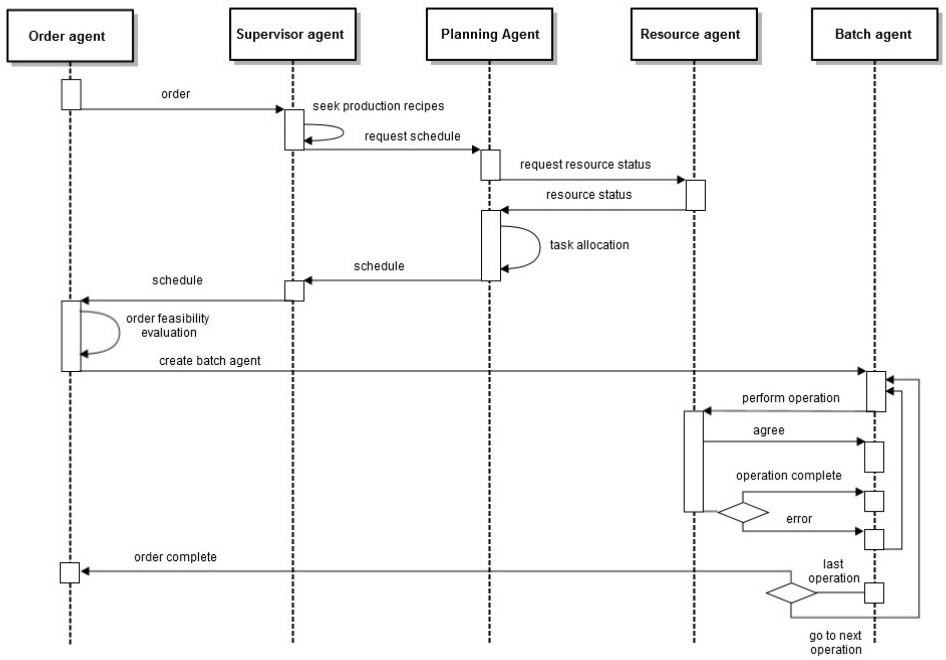

Fig. 5. Interaction diagram between agents for processing an order

6. Conclusions and future work

A distributed multi-agent architecture, TANMAS@, for leather processing monitoring and control has been proposed. Different types of agents with autonomous behaviour and their role in solving various problems in different phases of treatment and processing of skins/hides are presented. The interaction mechanisms including agent language communication, ontology, coordination protocol (CNP) are considered. The paper attempts to prove the high capability of this architecture, considering the diversity of material, the complexity of processing operations and the difficulty to fit some precise mathematical models of different processes. The architecture presented based on agent concept emphasizes its superiority in terms of control reconfigurability, adaptation to changing manufacturing conditions, robustness, modularity, flexibility contrast with conventional automation solution. Preliminary steps were taken to simulate the correctness of the mentioned approach using an agent development environment with production data from an existing tannery.

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