

# A multi agent based system to enable dynamic vehicle routing

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**Resumo:** A realização das atividades de transporte comumente envolve diferentes atores e veículos dispersos numa rede, de forma que responder aos eventos dinâmicos presentes nas operações é uma tarefa complexa. Neste contexto, o uso de sistemas baseados em agentes (MAS) na tomada de decisões autônoma tem se mostrado potencialmente interessante e sido discutido na literatura recente. Neste artigo, é apresentado um sistema baseado em agentes para lidar com o problema de roteirização dinâmica de veículos, mais precisamente em um problema de coleta de peças e componentes, onde parte das tarefas previamente alocadas ao veículo pode ser eventualmente transferida para outros veículos, sempre que o MAS constatar que o tempo de ciclo pode exceder o limite diário da jornada de trabalho. A transferência das tarefas entre agentes é realizada através do método de negociação de Vickrey. O sistema proposto permite tomada de decisão de forma colaborativa entre os agentes envolvidos, permitindo a realização de ajustes durante a realização da rota inicial.

*Palavras-chave:* agentes, roteirização dinâmica de veículos, leilão vickrey, negociação.

**Abstract:** The transport activities usually involves several actors and vehicles spread out on a network of streets. This complex system intricate the techniques to deal with dynamic events usually present in transport operations. In this context, as could be noted in the literature review, the use of multi-agent systems (MAS) seems suitable to support the autonomous decision-making. This work presents an agent based system to deal with a dynamic vehicle routing problem, more precisely, in a pick-up problem, where some tasks assigned to vehicles at the beginning of the operation could be transferred to others vehicles. The task transfer happens when the vehicle agents perceive that the cycle time can exceed the daily limit of working hours, and is done through a negotiation protocol called Vickrey. The proposed system allows a collaborative decision-making among the agents, which makes possible adjustments during the course of the planned route.

*Keywords:* agents, dynamic vehicle routing, vickrey auction, negotiation.

## 1. INTRODUCTION

The proper planning and operation of logistics processes is a complex task, which becomes harder when dynamic aspects of logistics operations are taken into account. Actually, could be seen different information systems used to support these operations. However, these systems usually do not consider the dynamics events in the operations. This kind of disturbs could prejudice the overall operation, once logistics process involves several actors, with numerous decision stages while performing different logistics services (Chow *et al.*, 2007). Thus, managing logistics integrated systems must occur dynamically, revising plans and schedules whenever necessary and when system failures require corrective interventions (Novaes *et al.*, 2012).

The dynamic environment in which firms operate, where rapid changes occur in the economy and in new technologies and consumer trends, requires companies to be agile and flexible when dealing with critical situations caused by these changes and unexpected events. These new requirements have led to the emergence of distributed control and intelligent systems, which provide the adaptability and flexibility required by companies. The concept of agents in this scenario has been studied for the past 20 years. Agent-based approaches are suitable for the management of transportation operations (Davidsson *et al.* 2005). Examples of

applications of agents in this area can be observed in the studies of Fox *et al.* (2000), Julka *et al.* (2002), Karageorgos *et al.* (2003), Roorda *et al.* (2010), Vokrinek *et al.* (2010), and Maciejewski and Nagel (2012).

The theory of computational agents or intelligent agents originated approximately twenty years ago with research on distributed artificial intelligence. There have been significant advances in this field since some research on AI (Artificial Intelligence) started to go beyond individual entity boundaries, taking into account multiple cognitive entities acting in communities. Such advances coincided with the evolution of network-based computing (Monostori *et al.*, 2006) and led to the emergence of a new paradigm, that of distributed agents. According to Wooldridge (2002) and Monostori *et al.* (2006):

- an agent is a computational system that is situated in a dynamic environment and is capable of exhibiting an intelligent and autonomous behaviour.
- an agent may have an environment that includes other agents. The community of interacting agents as a whole operates as a multi-agent system (MAS).

A multi-agent system (MAS) is one that consists of a number of agents which interact with one another, typically by exchanging messages, through some computer network infrastructure (Wooldridge, 2002). In this scenario, an agent would be able to perceive the characteristics of its environment through sensors and act on the environment by means of operational components (Russel and Norvig, 2003).

Davidsson *et al.* (2005) in their bibliographic review identified that agent technology has been applied to many different problem areas within transport logistics. Often these agent approaches are distributed and very complex in nature, including planning and scheduling, fleet management, transport scheduling, traffic management, and traffic control. In the papers on road transportation analysed by the

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authors, most of them are concerned with transport scheduling, i.e., allocating transport tasks to vehicles. The agents in these applications represent different roles – e.g., a company, a vehicle, a customer – and alternative methods for agent technology in road transport are classical mathematical methods and operations research (Davidsson *et al.*, 2005).

Classical optimization methods usually applied to vehicle routing problems (VRP) are not suitable to solve the Dynamic Vehicle Routing Problem (DVRP). The latter can take into account incident occurrences during the operations, requiring a quasi-real time response in order to carry out interventions during the route course.

The aim of this paper is to propose a MAS platform to support autonomous decisions by the agents in order to consider the dynamic events in the logistics operations. Therefore, the proposed MAS platform must deal with coordination between different activities (e.g., production and transportation), different negotiation strategies between companies, and unplanned events and failures. We address the pick-up problem in an Original Equipment Manufacturer (OEM) environment where an assembly company receives components from suppliers. In this case, a third-party logistics is in charge of performing all inbound activities, including pick-up of components from different suppliers.

This paper is organized as follows: Section 2 reviews the literature on use of agents in production-transportation integrated problems, introducing some MAS settings proposed to solve this question. Section 3 details a pick-up problem in an integrated and dynamic environment, presenting an agent-based model. Section 4 presents the proposed application, including the different agent classes involved and the negotiation process. Finally, Section 5 includes the conclusions and final remarks.

## 2. THE PROBLEM OF INTEGRATING PRODUCTION, TRANSPORTATION, AND MULTI-AGENT SYSTEMS

Transportation management decoupled from production creates inefficiencies for business operations, since the optimization of some operations could result in additional costs for others. According to Chen (2010), it is well understood that integrated production and distribution planning can significantly reduce costs and improve customer service levels across many situations. Regarding inbound logistics, transportation between suppliers and an assembly company is also critical, as stated by Schuh (2006), once flexible production systems are enabled through adaptive inbound logistics.

Traditionally, production and transport solutions are not designed for systems operating in dynamic environments, where events are often unpredictable and provoke unexpected or emergency changes to previously optimized plans. Examples of such unpredictable events include last minute order changes, manufacturing machinery breakdowns (which require or cancel tasks), delays in the manufacturing process, downtime due to vehicle breakage, traffic jams in the transport network, material delivery delays, and other unexpected situations. Indeed, production and transport operations control should consider autonomous decisions in order to respond to dynamic events, ensuring

better results. According to Parunak (2000), one of the justifications for agents is that the whole system can be more than the sum of the parts. A collection of relatively simple agents can yield surprisingly rich and complex interactions.

Several MAS applications for the transport and production domain are identified in the literature. Davidsson *et al.* (2005) provide a survey of existing research on agent-based approaches to transportation and traffic management. Mes *et al.* (2007) present a multi-agent structure that consists of four agent types: one agent per vehicle and one agent per order to assign orders to vehicles; a fleet manager agent to collect and analyse auction and processing time data of all its vehicles – it distributes the results to its vehicles when needed – and a shipper agent to manage all the orders issued by the shipper.

Dai and Chen (2011) propose a multi-agent framework for carrier collaboration in less than truckload transportation. In this work, each carrier is an autonomous agent with decision-making authority, and the interactions between carriers are performed through multiple auction processes of outsourcing requests. Since each carrier both outsources (sells) and acquires (buys) requests, it acts both as an auctioneer and as a bidder in auction terms.

With regard to the integrated industrial programming of production, component, and manufactured product transportation, existing models are deterministic and static in nature (Chen, 2010), i.e. all relevant parameters are known *a priori*. However, such systems usually operate in dynamic environments, where events are often unpredictable and end up causing emergency changes to previously optimized plans.

## 3. THE PICK-UP PROBLEM IN INTEGRATED AND DYNAMIC ENVIRONMENTS

Transportation plays an important role in integrated and dynamic environments. The lack of components can jeopardize assembly lines, so delays in inbound logistics activities can quickly cause large damages, especially in global supply chains, where the suppliers are located across different cities and countries. On a tactical and operational level, new solutions have been adopted in order to reduce the transportation task related risks.

According to Goel (2008), the lack of timely and reliable information about current vehicle positions and states certainly creates challenges in updating vehicle status, taking into account the dynamic nature of transportation processes as well as new transportation requests arriving on short advance notice. Although fleet telematics is widely recognized as the solution to improve commercial vehicle operations efficiency, it appears that the potential of fleet telematics systems is currently not sufficiently exploited (Goel, 2008).

For agent-based applications and dynamic versions of the VRP, onboard fleet devices – hardware and software – are essential components. In fact, the increased focus on just-in-time logistics, together with the rapid development in telecommunications and computer hardware, has led to increasing interest from the scientific community as well as from potential users on these methods, leading to VRP studies of far more dynamic complexity (Larsen, 2001).

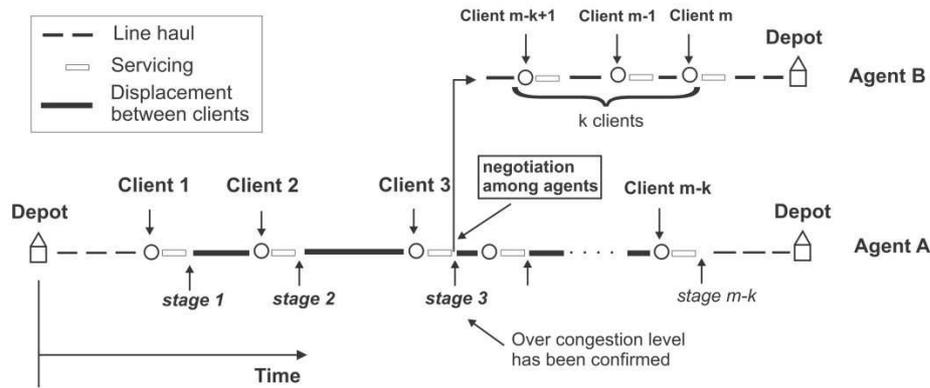


Figure 1. Routing sequence and revision stages (Novaes *et al.*, 2012)

With regard to DVRP, specific methods to identify anomalies in the environment, which are known as fault detection methods, are required. In exceptional traffic situations – with repeated and significant reductions in speed caused by traffic jams, severe accidents, weather conditions, etc. – a stochastic system, acting upon observed data can make decisions autonomously in order to reduce the effects of such phenomena. Thus, after identifying and diagnosing anomalies, the main question becomes how to respond appropriately to such exogenous conditions.

Three types of dynamic events can be highlighted: 1) the first are related to the business itself and are handled by decision makers personally because they require human intervention in order to adjust the planning process (e.g. new pick-up requests, activity priority changes, etc.); 2) random operational events that occur in the process and can be represented by probability distributions (e.g. such as machine breakdown, vehicle breakdown, etc.); and 3) other stochastic situations which could be identified after some observations are made (like traffic jams, weather conditions, etc.). The second and third types of event do not require human intervention, and can be represented by probability distributions and identified by sensors. In this work, we made a proposal where vehicles could deal with traffic jams (an event of the third type).

In this paper we will investigate an MAS approach in which suppliers deliver parts to an assembling company called Original Equipment Manufacturer (OEM). We consider that a third-party logistics is in charge of performing all inbound activities, including component pick-ups – from different suppliers – and deliveries to OEM facilities. In dealing with dynamic events, a vehicle agent could predict that it would be impossible to accomplish some pick-up tasks during regular work hours and automatically ask for external assistance in seeking other vehicle agents that could complete those particular tasks.

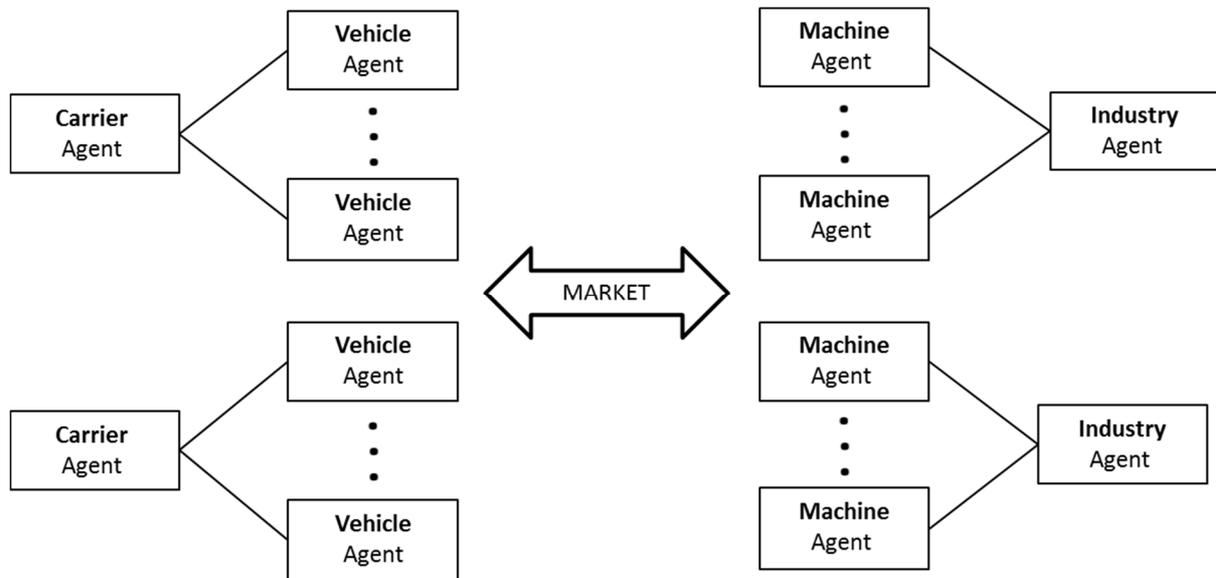
Due to the great degree of variable randomness in a routing process, there may be tasks that are not performed by the time the workday is finished. An auxiliary assistance is then set up with additional self-owned or third party vehicles to perform the remaining tasks. Therefore, pick-ups

that cannot be performed by a regular vehicle are considered planning failures and should be corrected in order to avoid their negative impact on logistics service level agreements.

In a routing process, the time and vehicle speed related data – which can be collected by telematics systems in the vehicle – are critical to determining routing anomalies. Analysis is conducted based on this data, problems are identified, and solutions suggested. Novaes *et al.* (2012) apply a fault detection and diagnosis model to analyse data and estimate the number of pick-ups that will not be performed based on probabilities. In the event of an excessive service demand, the authors suggest that the transportation system (meaning the agents) should send out information to other vehicles operating in the area and to the warehouse asking help to perform the exceeding tasks. If there is no vehicle in the area to meet this demand, the central warehouse may appoint one or more externally owned vehicles (or third party) to perform the backlogged tasks.

Novaes *et al.* (2011) used a DVRP model in which vehicles start and finish their activities in a warehouse. The warehouse serves a specific area where the clients to be visited are located. The logistics operator must collect the components from the suppliers and transport them to the central warehouse. From there they are transferred to long-haul vehicles for delivery to plants in other cities. In the proposed scenario, it is important to evaluate on-time delivery since pick-ups not performed during regular working hours may cause assembly line delays or higher inventory levels. Thus, the number of unperformed tasks during regular working hours is an important control variable and must be kept to a minimum.

For a typical day, applying the model (by simulation) to the static situation, it showed a 0.19% rate of unperformed tasks per day (Novaes *et al.*, 2011) with no more than three back-logs for the same vehicle, representing only 0.004% of the occurrences (an insignificant number of occurrences). However, when there is an exceptional traffic jam, the percentage of unperformed collections rises to 4.3%, with up to 6 unperformed pick-up tasks (Novaes *et al.*, 2011). Based on these results, it can be noted that the



**Figure 2.** Proposed agent structure  
**Source:** adapted from Mes *et al.* (2007)

service quality can be seriously jeopardized under exceptional traffic situations.

In order to identify the outstanding traffic condition occurrences, called hypothesis  $H_1$ , the on board computer performs a sequential probability ratio test (Basseville and Nikiforov, 1993; Novaes *et al.*, 2011). If a normal traffic situation (*hypothesis*) is identified, the pick-up service continues as planned. On the other hand, if the computer detects the  $H_1$  situation after completing a pick-up service (let it be client 3 in the example of Figure 1), by applying the test SPRT (Sequential Probability Ratio Test) the onboard computer will estimate the number of pick-ups that will not be performed –  $k$  collections – and which should be transferred to other agents. In the example shown in Figure 1, the  $k$  the last tasks in the route are transferred to a single vehicle, agent  $B$ . However, the choice of tasks to be transferred and the selection of the auxiliary vehicles to perform them can be set up according to other criteria (Goel, 2008). In this approach different algorithms could be used for the define the price of the bid and to choice the best bid, Aragão Jr (2014), in a similar application, suggest the 2-opt algorithm to define the new cost of a route with the task transferred; using this new cost to compute the bid. In the practice, there are time to process this communication, once the vehicles require a larger time to process the pickups.

The sequential probability ratio test can be understood as a fault detection and diagnosis method applied to service operations (Basseville and Nikiforov, 1993; Isermann, 1997; Simani *et al.*, 2003; Isermann, 2005; Novaes *et al.*, 2012), similar to processes used in automation for monitoring and controlling machine or other equipment operation. In this example, the fault detection and diagnosis model detects a situation of abnormal operation and proposes changes to the initial plan, proactively reacting in advance to improve system performance. This is an extension of concepts developed to deal with mechanical failures, and it is now applied to transportation and logistics problems.

#### 4. PROPOSED APPLICATION

The MAS platform proposed here aims to enable autonomous decisions in DVRP, reducing the number of unperformed tasks as shown in Novaes *et al.* (2011). The agents must ensure autonomous responses to observed dynamic events during the execution of the tasks originally planned, detecting faults (i.e. unperformed pick-up tasks) as earlier as possible in order to avoid undesirable situations. The problem addressed here has the following characteristics:

- tasks are initially planned statically, assuming normal conditions and represented as hypothesis  $H_0$  ;
- the non-feasibility of a task is only identified during the process, i.e. after the pick-up routing has begun;
- the objective is to maximize the number of tasks performed at the least cost;
- the carrier agent can count on an unlimited fleet of third party vehicles, but these vehicles will be used only if proprietary fleet vehicles are not available to meet the additional demand. Such restriction is considered to reduce costs, since using an external vehicle is more expensive than an in-house one;
- vehicle capacity is not considered a constraint since the parts and components in our example present high added-value, low weight, and compatible volume.
- communication between all agents that constitutes the MAS (carriers, vehicles, industries, machines) is assumed to be possible anytime;
- proprietary vehicles should begin and end their routes in the depot, unlike third-party ones;
- route-planning must respect an 8-hour shift (daily working time) mandatory limit.

To specify an appropriate MAS architecture for the problem described above, we propose agents that represent different entities or classes of agents – carrier, vehicle, machine, and industry – each with their own restrictions and interests.

#### 4.1. Classes of agents

In the process of assigning tasks to vehicles, we propose a structure of agents adapted from Mes *et al.* (2007). In their paper, the agents represent fleet, vehicle, job, and shipper while in this application the structure consists of the following classes of agents: carrier, vehicle, machine, and industry as shown in Figure 2.

The carrier agent collects data from its vehicles, as well as from the tasks assigned to them. It evaluates overall operations performed by proprietary vehicles or third-party vehicles and intervenes in the operations according to its guidelines. The industry agent is in charge of carrying out the production schedule and assigning production tasks to the machine agents. After a machine agent produces an order of components, a transport task is created and assigned to a vehicle agent.

A vehicle agent – as well as the machine agent – performs several tasks. It is up to this agent to manage its work package, making decisions autonomously whenever it detects failures. One of the vehicle agent objectives is to minimize cost while meeting the route restrictions. This line of action contributes to the carrier agent objectives, e.g., it maximizes economic results and fulfils its commitment to maintain the previously agreed service level with customers.

The machine agent aims to produce components and looks for a vehicle agent to perform the transportation task at the lowest possible cost. Thus, vehicle agents and machine agents must negotiate under carrier agent and industry agent supervision, respectively, in order to assign the pick-up tasks to the vehicles. The solution to the global scheduling problem emerges from local scheduling, i.e. one complex overall plan is replaced by many smaller and simpler plans (Mes *et al.*, 2007). This approach reduce one global problem in some smaller ones, so the plan of the agents could not achieve the global optimum, but just local optimums that consider the dynamic events in the operations.

Observing how the agents interact in the MAS, the control structure could be classified in four categories (Mes, 2007; Anosike, 2006), being: centralized – with an agent controlling the others, hierarchical – with some agents controlling others, heterarchical – without control among the agents, and hybrid – combining the control structures. A large number of agents in a heterarchical structure can lead to many messages exchanged within the network since operational conflict solutions could require extensive negotiations (Monostori, 2006). In order to reduce the number of messages travelling on the network, we propose a hierarchical structure for the agents, where the vehicles are subordinated to carrier while the machines are subordinated to industry. Therefore, the tasks to be performed (production or transport tasks) are not represented by agents in this case.

#### 4.2. The negotiation process

The negotiation processes are also called communication protocols or auction protocols. An auction is a protocol that allows agents to indicate their interests in one or more activities, and then uses these indications of interest to determine both activity, and payment allocations among the agents. (Dai and Chen, 2011). In our example, the choice of the agent in charge of performing a task is made

by means of an auction mechanism, as proposed in Wellman *et al.* (2001), Jiang and Tianfield (2006), and Mes *et al.* (2007).

In a MAS, the negotiation mechanism can be divided into three consecutive phases (Jiao *et al.*, 2006): 1) the invitation phase, when a contract managing agent sends a request to the information server to search for potential suppliers; 2) the bidding phase, in which each negotiation agent bargains with the supplier to maximize its benefit, often in an offer exchange mode; and 3) the award phase, characterized by the collection of bids from negotiation agents by the contract manager.

Auctions can be differentiated across many parameters including, but not limited to, those concerning, matching algorithm, price determination algorithm, event timing, bid restrictions, and intermediate price revelation (Wellman *et al.*, 2001). Regarding these parameters, several auction mechanisms have been proposed for agent-based conflict resolution, among them:

- bargaining; this is a one-on-one negotiation protocol in which all trading partners contact each other individually (Mes *et al.*, 2007);
- contract net protocol; where project agents are responsible for scheduling the operations of their interests and the contractor agent makes proposals and defines resource allocation among the planned operations. When planning, the agents should determine transportation and storage resources required to establish operations (Lau *et al.*, 2006);
- sealed-bid auctions; where every bidder submits his bid only once and the best bid is selected; special cases are the first-price sealed-bid auction where the price offered is paid exactly, and the Vickrey auction in which the highest bidder wins but pays the second highest bid price (second-price sealed-bid) (Ausubel and Milgrom, 2006);
- open outcry auctions consist of multiple bidding rounds where all bids are known to each bidder. Some variants are (i) the English auction, where bidders sequentially either raise their bids or withdraw in each round until a single bidder is left, and (ii) the Dutch auction, where the price is reduced step by step starting from a high level until a bidder accepts the price; (iii) the Japanese auction, where the initial price is spread and increased on a regular basis in rounds of negotiation (Mes *et al.*, 2007). The bidder interested in staying active sends a signal every round informing his agreement with the price. Once out of a round, the bidder cannot rejoin the negotiation (Dai and Chen, 2011).

To operationalize decentralized transportation using collaborative agents, the entities involved – carrier agent, vehicle agents, machine agents, and industry agents – must negotiate among themselves. A problem to be considered in this case is related to distributed computing, where agents exchange information about their status using messages. In this context, managing the negotiation process is a relatively complex activity.

#### 4.3. Algorithm for tasks auction

The Vickrey auction was considered appropriate to this scenario because this mechanism presents some benefits according to Ausubel and Milgrom (2006) and Mes *et*

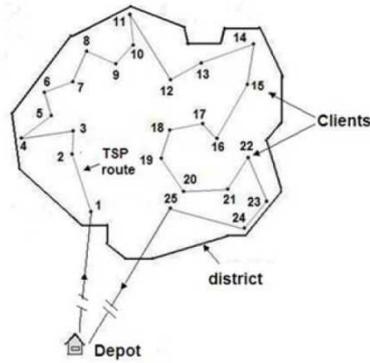


Figure 3. Preliminary Route and clients to be served (Novaes *et al.*, 2011)

*al.* (2007). It is fast, requires relatively little information, and eases route re-planning in response to operational changes. These characteristics contribute to accomplish the auctions rapidly, during the operation planned. Another advantage of the Vickrey auction is that bidders are encouraged not to overstate the value of his proposal, as the winning bidder can never affect the price paid, so there is no incentive for any bidder to misrepresent his value.

We assumed that the Vickrey auctions take place at fixed and pre-defined intervals set by the carrier agent. For example, if at a particular pick-up stop the onboard system identifies a task to be transferred, three different ways of defining which task must be transferred are used (Novaes *et al.*, 2011; Goel, 2008). The first and simplest consists of selecting the last planned task. In the second alternative, the vehicle agent will examine all unperformed tasks so far, selecting those that, if transferred, could contribute more to improving its own operational and economic performance. For instance, in Figure 3, a VRP type routing is shown with 25 pick-ups. At the 14th stop, the onboard system found a traffic condition of type  $H_1$  and determined that one of the tasks in the sequence  $\{15, 16, \dots, 25\}$  should be transferred to another vehicle agent. Then, the vehicle agent starts to examine which one of the 11 remaining tasks should be transferred. By examining task 16, it notes that there are prospective gains due to two types of reduction: (a) reduced mileage, and (b) reduced down time when visiting client 16, which should be transferred from the route of the regular vehicle agent. The gain is the difference between the cost generated by the remaining basic routing sequence, and the new routing that excludes the selected task. Therefore, by analyzing every single task on sequence  $\{15, 16, \dots, 25\}$  the system will select the tasks to be transferred that will mostly reduce cost. The third form of selecting the task to be transferred is an extension of the previous form. After some attempts to transfer a task from the routing, such as task 16, the VRP algorithm is once again applied to the other activities, resetting the routing sequence but considering all the other remaining tasks except number 16. Finally, the task that most reduces mileage in the regular VRP sequence is chosen.

The optimal solution for selecting the task to be transferred is the result of a combinational problem. Thus, the approach used to choose tasks will depend on the accuracy desired and available computing time. In cases which more than one task needed to be transferred, the computing process is similar. The process carried out by the agents receiving tasks is reversed and analogous to the task insertion process (Goel, 2008).

After selecting the tasks to be transferred, a price determination algorithm is applied. A Vickrey auction is used in order to evaluate vehicle agent proposals and to select the most appropriate one, as proposed by Mes *et al.* (2007). According to Mes *et al.* (2007), the auctioneer agent, which organizes and inspects the auction, sets a reference value  $V_i^{(ref)}$  to the bids of a corresponding auction round regarding the allocation of task  $i$  ( $i = 1, 2, \dots, m$ ), where  $m$  is the number of regular tasks to be performed in the routing process. For this purpose, the carrier agent takes into account the marginal transportation cost needed to perform it. After each round of the auction, the auctioneer agent determines a maximum value  $V_i^{(max)} > V_i^{(ref)}$  for the bids, for each task  $i$ . If there are no bids in a round, their values are out of the range imposed by the carrier agent and a higher  $V_i^{(max)}$  would be established. An auction is not always positively completed for a particular task because there may be no offers, or their values may be out of the range imposed by the carrier agent. Whenever this occurs, there will be other auctions for the same task, in a total of  $n$  auctions. In the last round of an auction, the auctioneer agent will accept any offer in order to ensure that the pick-up is effectively performed. Thus, let  $p_i^{(\vartheta)}$  be the value of an offer for task  $i$ , in auction number  $\vartheta = 1, 2, \dots, n$ . For  $\vartheta = 1$ , offers with  $p_i^{(1)} \leq V_i^{(ref)}$  will be accepted and for  $\vartheta = n$ , any offer will be accepted.

As auctions take place, the carrier agent tends to broaden the range of acceptable values for the offers. A function that appropriately expresses such expansion of the range of offer values is as follows (Mes *et al.*, 2007):

$$p_i^{(\vartheta)} \leq V_i^{(ref)} + \left( \frac{V_i^{(max)} - V_i^{(ref)}}{(n-2)^k} \right) (\vartheta-1)^k, \text{ with } \vartheta = 1, \dots, n-1$$

$$\text{and } k \geq 1 \quad (1)$$

For  $k = 1$  the interpolation is linear, and for  $k > 1$  there is a polynomial interpolation. So for  $\vartheta = 1$ , we have  $p_i^{(1)} \leq V_i^{(ref)}$  and for  $\vartheta = n-1$  we have  $p_i^{(n-1)} \leq V_i^{(max)}$ , thus broadening the range of acceptable values for  $p_i^{(\vartheta)}$  as new auctions occur. It is noteworthy that all proposals that meet restriction (1) will be accepted in a Vickrey auction, the best proposal will be selected, and the final price will be the one corresponding to the offer ranked second.

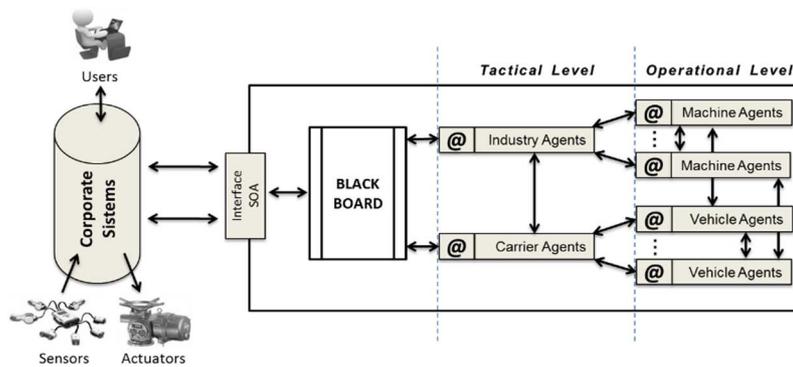


Figure 4. Platform architecture for system planning and operation

4.4. Proposed architecture for the MAS

Communication among agents would use a standard web pattern that allows for system integration. According to the World Wide Web Consortium (W3C), the organization World Wide Web standardization, “a web service is a software system designed to support interoperable machine-to-machine interaction over a network” (W3C, 2010).

According to the W3C (2010), the software architecture of a program or computing system is the structure (or structures) of the system that includes software components, the externally visible properties of those components, the relationships among them and the constraints on their use. Service-Oriented Architecture (SOA) consists of a set of components which can be invoked, and whose interface descriptions can be published and discovered. The Simple Object Access Protocol (SOAP), provided by the W3C, is a commonly used protocol for this type of communication.

Using SOA allows for decoupling system communication from the external environment in a flexible and reliable manner. The software applied to fault detection and problem diagnosis normally used in operations require high processing time. Thus, in order to reduce processing time and avoid operational interruptions, these systems should operate asynchronously. Asynchronous processing allows that the results of improvement algorithms be sent to the agents at right time. Thus, the execution of the algorithms would happen: 1) at predetermined time intervals, defined by users or, 2) when an abnormal condition is identified by the system. These algorithms can be implemented as programs developed in languages such as C ++, FORTRAN, etc.

A corporate system is a software used by companies to manage its operations, which must receive data from system users, web services, and sensors. This data is previously processed to be used by users, or recorded in a black board structure (Figure 4). The agents that manage the subsystems are in charge of monitoring the operations of their entities, always checking if the planned activities are running on time as well as detecting and diagnosing anomalies in such operations. In order to make decisions and act on ongoing operations, these agents not only consider the status of each task, but they must also take into account expectations in terms of system performance. The information used by agents is gathered from corporate databases, which are updated by means of continuous communication between the agents and the central database, in order to enable integrated system performance analysis.

In our MAS architecture proposal, agents are involved in the tactical and operational tasks (Figure 4). The agents in charge of making tactical decisions – industry and carrier – would negotiate to create an initial schedule. In turn, the agents that act at the operational level – agents, machine, and vehicle – should react autonomously to dynamic events, doing changes on the initial planning in order to keep the viability of the operations with satisfactory results. The agents interact with each other in order to achieve their own objectives.

An example of a decision making process for an integrated production-transportation system, taking into account the categories of agents proposed – carrier, vehicle, machine, and industry – is shown in Figure 5.

In this example, the pick-up activity is performed by one vehicle that leaves the warehouse with its scheduled

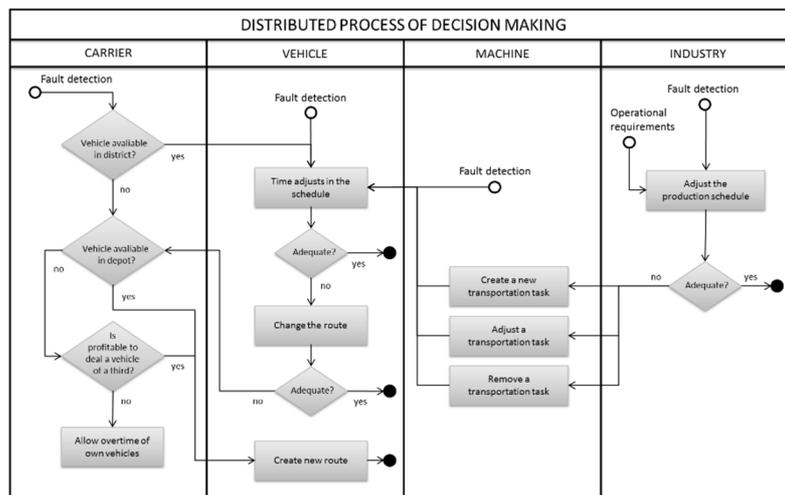


Figure 5. Distributed process of decision making by agents in a production-transportation integrated problem

tasks and follows the route assigned to it by a vehicle routing problem (VRP) algorithm. Under a static approach, when the activities cycle exceeds regular working hours, the vehicle will return to the warehouse without performing the agreed tasks, which will be fulfilled next day. In some situations, service overload can result in more than one-day backlogs. Delays will certainly result in penalties since there is a service level agreement between the contractor and the third party. Under a dynamic approach, services previously planned to a particular vehicle could be transferred to another one in a specified time window in order to avoid unperformed tasks at the end of a workday. Average travel speed is a parameter used to represent traffic variations, since it is assumed that the time spent on the stops the OEM clients is not affected by traffic conditions.

## 5. CONCLUSIONS

The use of autonomous agents is suitable for collaborative decision making in many situations, especially when integrated production and transportation activity management is necessary. Planning and performing pick-up activities of parts and components from different suppliers to an OEM has an effect on inbound logistics performance, and consequently on production activities. These activities should be managed in a way that allows for dynamic adjustments in transportation and production programming. The platform based on agents, as proposed here, addresses this problem suggesting that agents manage vehicle routing activities autonomously in a dynamic and integrated environment.

In order to define the structure of the MAS platform, several aspects were considered: management level, control structure, negotiation mechanism, architecture integration, use of web services, use of human intervention, maturity level (i.e., how complete and validated an application is), among others. Four classes of agents were proposed which were organized under a hierarchical structure in order to reduce the number of messages exchanged between the agents. Collaborative decision making by the agents allows them to interact and adjust the routing problem's initially optimal schedule. The Vickrey conflict negotiation mechanism seemed suitable because it requires little information and eases route re-planning in response to operational changes.

The conceptual MAS structure to the dynamic vehicle routing problem presented and discussed here could be useful in releasing people from decision-making concerning operational activities, since the MAS can incorporate intelligent and autonomous behaviour in a dynamic environment.

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