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Product allocation planning with safety compatibility constraints in IoT-based warehouse

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Abstract

One of the most relevant topics in warehouse management system (WMS) is the security issue and concerns the optimal placement allocation of products with respect of product and human safety in a sustainable system. Knowing that differences often exist between virtual view of products placements in centralized WMS and the real situation in the facility due to unplanned movements resulting from human errors or products' misplacements, we propose a reactive and compatibility constraint approach for product storage allocation. Our aim is to reduce the size of floating locations largely used in WMS and to avoid the inherent risks of hazardous accidents which can be generated by incompatibility between products and then to minimize the total logistic costs and to guarantee higher warehousing service levels in a safety monitored environment. This work proposes a multi-agent architecture for product allocation planning with compatibility constraints (PAP/CC), which uses a decision mechanism for product's placement, based on negotiations between agents associated to compatibility tests. This approach represents an improvement key for decentralized management of warehouses in a dynamic and reactive environment. Negotiations mechanisms relying on an Internet of Things (IoT) infrastructure and multi agent systems are defined in order to solve security problem of product allocation operations. Industrial deployment of IoT platform represents an ideal solution for decentralized management and to support collaboration between products and shelves. A simulation case of the proposed interactions mechanisms is provided with the use of NetLogo environment which offers many advantages to control agents and to describe their interactions in a graphical environment.

Keywords: WMS, IoT, Multi-agent, Negociation mechanisms, Simulation, NetLogo.

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1. Introduction

Nowadays, design and operation of warehouses play an important role in the whole supply chain system. For this reason, many researchers have dealt with its problems not only by mathematical modeling but also artificial intelligence modeling and collaborative based negotiations architectures [1]. The crucial goal and key issue for reducing the logistics costs are guaranteeing an effective warehouse management [2]. In this context, the two most important aspects to be considered are inventory management and optimal products allocation. The optimal products allocation during storing operations can bring down the storage costs by reducing inventory levels, while maintaining defined service levels [3].

According to sustainable and safety policies, the risks of major accidents in warehousing operations are challenging due hazardous products handing and storing, as also products' interactions and human interferences. The concept of safety consciousness system was introduced in [4] with the aim of guaranteeing warehouses safety performance and avoiding fatal accidents consequences. An efficient product allocation in the warehouse, in terms of costs and safety, can reduce carrying retrieval and storage times, while balancing different activities in warehouse.

The presented work aims at providing novel solution for smart logistics and security issues in WMS with the use of constraint-based negotiation mechanisms supported by communicating objects approach in an Internet of Things (IoT) background for hazardous industrial context and green environmental issues [5]. This research work is conducted in a joint industry – university research and development program with a chemical industry.

The paper is organized as follows. In Section 2, we detail related challenges and trends in WMS. Section 3 reviews a multi-agent architecture based on IoT infrastructure for product allocation planning with compatibility constraints (PAP/CC) fulfillment in a collaborative warehousing environment and shows why and how it can be adopted for such problem. We propose an improvement of a multi-agent architecture for products' allocation problem in warehouse implementing interactions mechanisms with compatibility constraints, and taking into account human operator agent. In Section 4 simulation of an application case is described using NetLogo platform. Finally, section 5 gives conclusion and prospects of future work.

2. Challenges and trends in Warehouse Management Systems

This section presents a state of the art of different challenges and trends in future WMS. Many researchers have focused their work on different operations running in the warehouses involving Receiving, Storing, Picking and Shipping [6]. Their challenges focus on solving different issues due to the fast changing in customers references, orders received by warehouse companies increasingly exhibit special characteristics related to the huge order size and product variety which sometimes requesting shorter response time or changes after the initial creation and placement of the order. In [7] a distributed, adaptive strategy was proposed aiming to solve the picking and storage location assignment problems. This strategy draw on the product intelligence concept for its implementation in addition to the agent based modeling of the process logic. According to them the product will decide its storage-location assignment based on collaboration and negotiation with shelves and other products. In the next section we will explain products allocation problem, compatibility constraints between products and the importance of an IoT infrastructure for collaborative warehouse PAP/CC fulfilment based on RFID, Wireless Sensors Network (WSN) and multi-agent system.

2.1. Products allocation problem

The products allocation problem consists in allocating products to different slots of shelves situated in the warehouse while minimizing the handling costs and maximizing the space utilization. The basic principle is that the high demand products have to be allocated in the shelves' slots closer to the in/out doors in order to reduce the total time for the handling operations [2]. From a general scope, the product allocation problem can be formalized by considering information about the storage area (layout of the warehouse), the storage shelves and slots (location, number, size, accessibility, availability, dimension, etc...), demand, quantity and time of products supplying. Many research's works are focused in solving this WMS problem using centralized and decentralized approaches.

In the first hand, in order to improve centralized WMS, [8] was addressed to solve warehouse location problem which has been examined in a retail sector case study. An exact method computing the gray relational grade of warehouses was used and the best alternative for warehouse affection will depend on its grade order of greatness. In [2] a mathematical approach for product allocation problem in a warehouse with compatibility constraints was detailed. In [9] was treated the floating stock distribution concept exploiting intermodal transport to deploy inventories in a supply chain in advance of retailer demand. In this way response times are reduced and storage costs can be reduced as well by having products in the pipeline.

In the second hand, in order to improve decentralized and collaborative warehouse management, [6] was used the intelligent product (IP) paradigm in order to respond to different challenges required to a WMS improvement. The IP concept was firstly used in a WMS context in [6] in order to improve the scheduling and control of the storage location assignment and the picking operations. When compared to classical centralized WMS, the IP approach which is fundamentally distributed is considered as more performing when high uncertainty and unpredictable events, changes and disruptions occur. IP approach can lead to a reduction of supply chain operation costs [10] but also implies an increase of complexity directly related to the rising number of managed IPs. The advantages of using intelligent product concept are to ensure informational, communicational and decisional capabilities close to the physical world, thus allowing reducing decision delay and increasing solving efficiency of local dynamic disruptions while avoiding of the inherent risks of centralizing all the information. In [11] a bottom-up approach based on IoT infrastructure was proposed for order fulfilment including picking-packing-shipping phases in a collaborative warehousing environment.

We can remark some limits in the previous works such as the absence of safety and security considerations against risks in those approaches of product allocation.

2.2. Compatibility constraints

The most typical constraints related to product allocation operations referred to shelves and slots capacities, floating location size, trolley capacity, storing time, products compatibility, and product allocation policy… thus a lot of restrictions should occur in real contexts of storage operations. Many research's works are focused in product allocation with compatibility constraints. In [2] the chocolate storage situation was explained by the fact that milk chocolate and dark chocolate products should not be allocated in neighboring slots in order to sustain their quality. This situation occurs also in hazardous industrial warehouses of chemical products [12] or nuclear reactor [13] where incompatibilities between products must be respected. In our work context, chemical product can react violently when they are in contact. Thus they must be stored in separately. The strategy of storage to be adopted consists in avoiding the fact that incompatible products be allocated in neighboring then segregation policies are established [14]. The constraints to be solved in this work referred not only to compatibility between products but also the floating location size minimization. In fact, the floating locations problem is an assignment problem in which one item can be allocated in many positions (floating locations). However, a compatibility test between the item to be allocated and the products situated in neighboring slots of the possible allocation positions represents an optimal solution to reduce the floating location problem.

2.3. IoT infrastructure

IoT infrastructure associates RFID technology with WSN, communicating object paradigm and multi-agent systems. RFID technology can play an important role in IoT infrastructure as a means of communication and a data provider to supply chain costs [15]. In [16] a combination between the IoT and cloud computing, using RFID technology was proposed. It aims to achieve automatic product identification and to get the required information about products and warehouse in order to solve many problems, such as product identification and real-time information accessibility. Communicating object paradigm allows connecting different physical world objects (Human user, trolley, shelf and product) to the IoT infrastructure and thus being monitored and potentially controlled. In [5] a communicating object model was proposed. This model fits both the security issues covering object-to-object (O2O), object-to-environment (O2E) and object-to-human (O2H) dependencies, and the smart reactive logistics features aiming to improve the product management within its warehouse. This model was inspired from the IoT European reference model architectures with a specific application focus on logistics and security issues in the context of hazardous and chemical risks. Recently, IoT infrastructure has been proposed in literature to improve the competitiveness and responsiveness of warehouse management. In [17] a comprehensive management platform of modern tobacco logistics based on the IoT technology was proposed. In this work the ambient intelligence paradigm has been associated with RFID technology in order to enhance the warehouse accident handling, warehouse business process, and to perform transparent interactions with products handled throughout the supply chain [18], [19] [20]. In [21] a Smart Warehouse Management System based IoT was presented aiming to simplify goods inventory and enhance the warehouse automation management level. In [11] a collaborative warehouse platform represent a real application for agent-based management in industry where IoT infrastructure provides development of an ideal platform to implement a bottom-up approach based multi-agent system for collaborative warehouse management. In this work, negotiations mechanisms based on Internet of Things (IoT) infrastructure and multi agent systems will be defined in order to solve security problem of product allocation operations. Industrial deployment of IoT platform represents an ideal solution for decentralized management of warehouses and to create collaboration between products and shelves guaranteeing a PAP/CC efficiency.

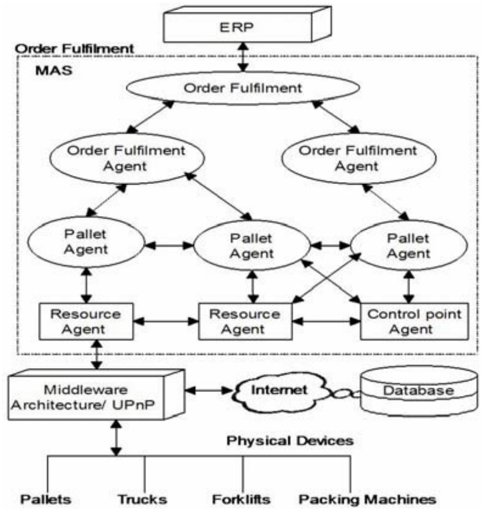
3. Multi-agent architecture based on IoT for PAP/CC

In this section, we aim to explain the scenario based negotiations between products agents and shelves agents for PAP/CC using a multi-agents architecture based on IoT infrastructure in a WMS.

3.1. Multi-agent architecture

In [11] a bottom-up approach based on IoT infrastructure was proposed for order fulfillment including picking-packing-shipping phases in a collaborative warehousing environment. As shown in figure 1 all physical devices (pallets, Trucks, Forklifts and Packing Machines) have their agents' assignments. These agents collaborate with the order fulfillment agents and the control point agent using a "com-eration approach". This approach is based on cooperation and competition between agents in order to reduce the delay penalty cost of order fulfillment. A city hub order fulfillment process using multi-agent system architecture starts processing once an order fulfillment (OF) is released by the Enterprise Resource Planning (ERP) to the city hub (Figure 1). The OF is analyzed by the order fulfillment agent supervisor. Then it creates an order fulfillment agent (OFA) corresponding to the OF. It then generates a set of pallet agents for each OF. PA follows the physical pallet; it negotiates and schedules for it all its next process tasks. Each resource is represented by Resource Agent (RA). Tasks provided by resources are for picking, packaging and shipping. The Control Point Agent (CPA) represents UPnP control point architecture. It is used to control and to communicate general information about devices locations status and their services in the warehouse.

We can remark some limits in the bottom-up approach architecture, with firstly the absence of a human user agent and a shelf agent despite their major roles in warehousing operations. In the previously explained architecture the Forklifts is driven by a human user then the interaction and negotiations with his agent should take place in the proposed architecture and in the delay penalty cost calculations steps. Secondly, as shown in figure 1 there is a set of arrows indicating the presence of collaborations between resources and pallets but in the proposed sequence diagram in [11] we noticed that all messages and negotiations are dedicated to resource-resource or pallet-pallet. Finally, we denote the lack of safety control on products, resources and human during WMS operations. Based on this architecture of collaboration between agents and with the objective to overcome its limitations we propose a safety based interactions mechanisms between agents in a WMS as shown in figure 2. The multi-agent architecture propose in figure 2 was proposed for PAP/CC fulfilment based IoT infrastructure in a collaborative warehousing environment using negotiations mechanisms. All physical devices (products, shelves, trolleys and human user) have their agents' assignments. These agents collaborate with the product allocation fulfilment agent and the control point agent using negotiations mechanisms. A product allocation fulfilment process using multi-agent system architecture starts processing once a product allocation fulfilment is released by the enterprise for PAP/CC. The product allocation fulfilment is analyzed by its agent supervisor which generates a set of shelf agent for each product allocation agent designating the available slots in shelves. Shelf agent will negotiate with product agent to be allocated and the neighbours of the available slot in shelf about products compatibility. Each resource is represented by trolley agent ensuring all picking tasks fulfilment. The control point agent represents UPnP control point architecture and the local decision making agent for the decentralized WMS architecture. The next section will be deduced to provide a scenario based negotiations between products agents for PAP-CC in a WMS.



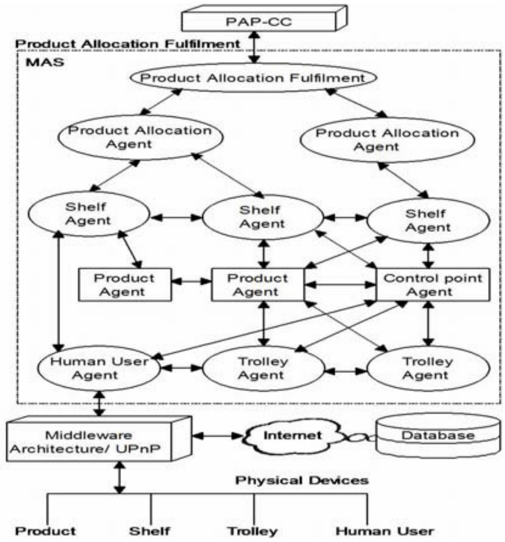


Fig1. Multi-agent architecture for order fulfillment process [11] Fig2. Multi-agent architecture for PAP/CC

3.2. Negotiations mechanisms for PAP/CC achievement

This research study is generic enough to fulfil many industrial applications cases in warehouse management when compatibility constraints between products are critically required. We will develop our proposal on a chemical industry warehouse application case in the framework of an industry–university research and development program. Then to explain negotiations mechanisms we will take the case of chemical products negotiations mechanisms for PAP/CC which are illustrated in figure 3. In fact while storing operation negotiations will be between products and a composite entity (CE) based shelf (i.e. chemical product situated in the shelf). In fact this case concerns the verification of the compatibility between the product assigned to one of the empty slots marked by (*) with the product to be his neighbour on the shelf according to the base station allocation.

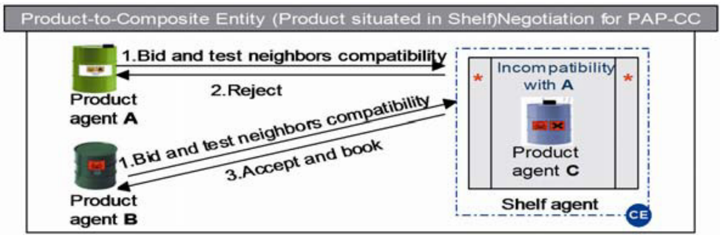


Fig3. Negotiations mechanisms for PAP/CC.

If the compatibility test is good the product can be placed in the shelf otherwise if the two products are not compatible the shelf must signal an alert to express its product's rejection. The compatibility test between chemical products can be computed according to 'compatibility rules' expressed in terms hazard pictograms (Figure 4) based on edition of Globally Harmonized System of Classification and Labelling of Chemicals (GHS) in accordance to REACH directive for the Registration, Evaluation, Authorization and Restriction of Chemicals [24].

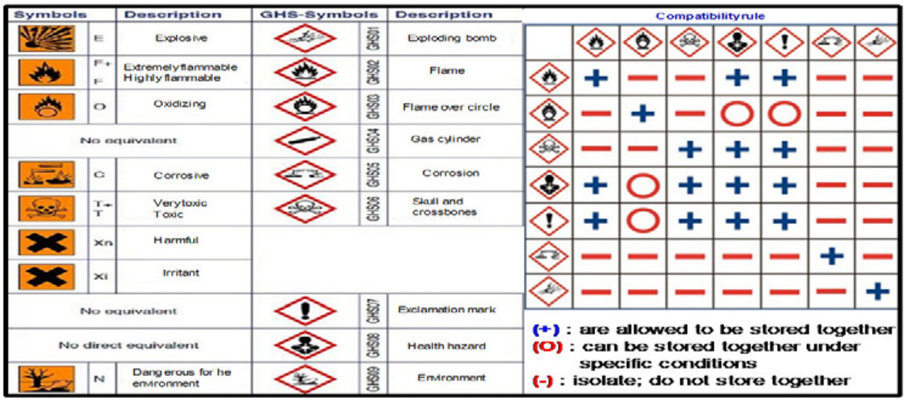


Fig4. Chemical products pictogram and compatibility rules.

4. NetLogo platform and the negotiations mechanisms scenario

A simulation of the negotiations mechanisms was performed using NetLogo Software which is a convenient platform for modeling and simulating multi-agent architecture where agents are functioning in parallel [22]. It's mostly used for simulating social and natural phenomena and particularly suitable for modeling complex systems and analyzing the connection between the behavior of basic entities and the macro-level patterns that emerge from their interactions [23].

4.1. Simulation and modeling with NetLogo

A NetLogo simulation model principally involves two basic elements: a two-dimensional grid that models the environment ("patches") and a set of agents ("turtles") with their own attributes and a set of procedures they can perform. The turtles represent trolley agent, the human person agent or the boxes which are chemical products.

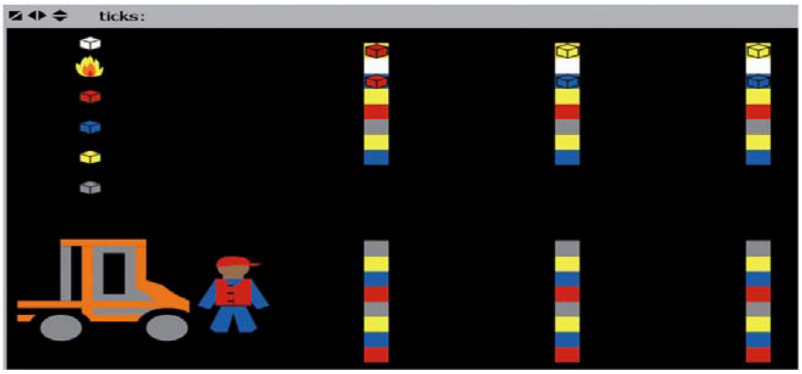


Fig5. Schematic view of the warehouse elements: products, human user, trolley (turtles) and shelves (patches).

As shown in figure 5 the patches describe the slots of shelves and are represented by colored squares where each colour spots the adequate place for the product having the same colour (for example the blue square is the best allocation of the blue box product). The environment interactions and the neighbors' discovery can be satisfactorily described due to the behavioral rules which can be defined for the turtles and the ability of patches to detect specific turtles. In our case the turtles which will participate in the simulated negotiation scenario are the products to be allocated to the appropriate place in a shelf (available slots in shelves) and they will be shown as patches where there is no product.

4.2. NetLogo interface and interactions mechanisms scenario

In this section we consider incompatibility between products (white and red products are incompatible and should not be stored in the same neighborhoods).

To illustrate our proposed negotiation mechanism with compatibility constraint let's consider that due to unplanned movements resulting from human errors or products' misplacements there are two misplaced products figured by a red product in blue slot and a red product in a yellow location as shown in figure 5. By using the neighbors' discovery capability available in NetLogo, the slots (patches) can easily detect the products surrounding them and though detect any incompatible product in the vicinity and by the way any misplaced product on their own location.

After receiving a demand of new product storage (white box in upper left corner of figure 5), the PAP/CC agent computes three floating locations depicted in white squares. Then the simulation program implements the negotiation scenario between shelves (patches) and the incoming white product to determine the appropriate locations according to the product's compatibility constraint and then find two slots over three (ticked white boxes √) that fulfill the constraint. The cross-marked (X) white box is not relevant for placement because an incompatible product is in its proximity as shown in figure 6. This demonstrates the reactivity of the proposed negotiation mechanism for a safe storage guarantee and against products' misplacement.

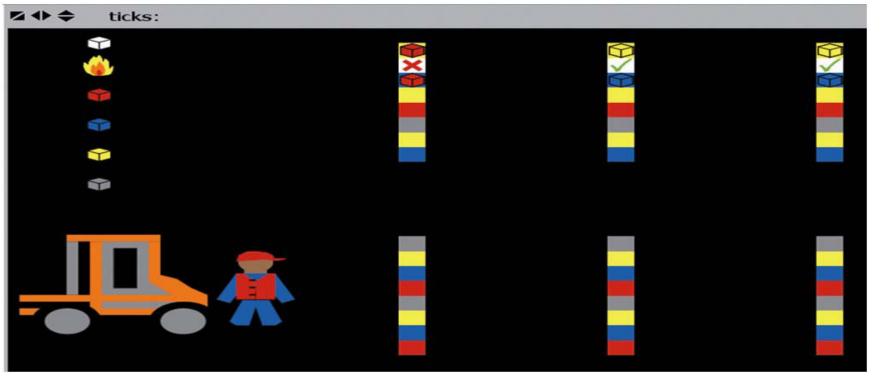


Fig6. Schematic view of product allocation negotiation scenario using shelves neighbours discovery.

5. Conclusion and prospects

In this work, a Products Allocation Planning with compatibility constraints (PAP/CC) was proposed to solve the problem of storing of hazardous products and constraint dependant products in warehouses by using negotiations mechanisms based on Internet of Things (IoT) infrastructure and multi agent systems. This approach provides a better reactivity to unplanned products movements due to human errors or products' misplacements that are often unknown from the centralized warehouse management system. Industrial deployment of IoT platform represents an ideal solution to implement our proposal for decentralized management of warehouses and to create collaboration between products and shelves. The compatibility constraints monitoring will guarantee a PAP/CC efficiency and will reduce the size of floating locations computed by the centralized Warehouse Management System.

We have modeled and simulated our negotiations mechanisms on the NetLogo platform which offers many advantages for user friendly and fast prototyping. A simple and efficient scripting language allows entities to be controlled and their interactions with the environment to be described.

Future works will integrate the extension of compatibility constraints to resources (trolleys) and human operator in order to optimize the resources use and products placement in a safety awareness environment for people and materials. The technical implementation in a Tunisian Chemical Group will be made by use of RFID, communicating object and wireless sensors network in an IoT system.

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