

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/322175801>

RFID IoT-enabled warehouse for safety management using product class based storage and potential fields methods

Article in *International Journal of Embedded Systems* · January 2018

DOI: 10.1504/IJES.2018.10010505

CITATIONS

5

READS

2,196

4 authors:



Sourour Trab

University of Gabès

11 PUBLICATIONS 163 CITATIONS

[SEE PROFILE](#)



Eddy Bajic

University of Lorraine

74 PUBLICATIONS 1,986 CITATIONS

[SEE PROFILE](#)



Ahmed Zouinkhi

National Engineering School of Gabès

111 PUBLICATIONS 602 CITATIONS

[SEE PROFILE](#)



Abdelkrim Mohamed Naceur

University of Gabès

362 PUBLICATIONS 2,161 CITATIONS

[SEE PROFILE](#)

Some of the authors of this publication are also working on these related projects:



object detection and recognition based on deep Learning [View project](#)



Fuzzy control [View project](#)

RFID IoT-enabled warehouse for safety management using product class-based storage and potential fields methods

Sourour Trab*

MACS Research Unit,
National Engineering School of Gabes, Tunisia
Email: sourour.trab@gmail.com
*Corresponding author

Eddy Bajic

CRAN-UMR CNRS 7039,
Université de Lorraine,
Nancy, France
Email: eddy.bajic@univ-lorraine.fr

Ahmed Zouinkhi and Mohamed Naceur Abdelkrim

MACS Research Unit,
National Engineering School of Gabes, Tunisia
Email: ahmed.zouinkhi@enig.rnu.tn
Email: naceur.abdelkrim@enig.rnu.tn

Hassen Chekir

Groupe Chimique Tunisien,
Industrial Zone,
6000 Gabes, Tunisia
Email: chekir.hassen@gct.com.tn

Abstract: Security and risk management in warehouses and logistics is a key factor to achieve a sustainable and safe supply chain. The paper aims at proposing RFID-IoT-enabled warehouse management focused on safety assurance for goods and people leveraging product class-based storage (pCBS), communicating object, RFID and IoT components. Security issues between products, storage locations, transportation equipment, environment and people are handled with the use of potential fields methods associated with smart product management in RFID-IoT warehouse architecture. A dynamic calculation of suitable storage locations is proposed, founded on negotiation mechanisms between products and shelves and their availability and compatibility constraints according to pCBS method. A safe and secure product storage path discovery method is presented using attractive/repulsive potential fields for path minimisation while maximising security level along the way. A multi-agent-based simulation with NetLogo demonstrates the effectiveness of the proposal allowing to achieve safe warehouse management by using smart product reactivity against critical risks.

Keywords: product class-based storage; potential fields methods; communicating object; IoT; RFID; negotiation mechanisms; simulation; NetLogo.

Reference to this paper should be made as follows: Trab, S., Bajic, E., Zouinkhi, A., Abdelkrim, M.N. and Chekir, H. (2018) 'RFID IoT-enabled warehouse for safety management using product class-based storage and potential fields methods', *Int. J. Embedded Systems*, Vol. 10, No. 1, pp.71–88.

Biographical notes: Sourour Trab is a PhD student at the National Engineering School of Gabes (Tunisia) and a member of Modelling, Analysis and Control Systems (MACS) Laboratory. She received her National Engineering degree in Electronic and Microelectronic Systems from the National Engineering School of Sousse (ENISO), Tunisia in 2011. She received her Master degree in Intelligent and Communicating Systems from the National Engineering School of Sousse (ENISO), Tunisia in 2013. Her research activities are focused on communicating object's approach and applications, RFID and IoT concepts and technologies, smart logistics and security issues in warehouses.

Eddy Bajic is a Full Professor in Automation and Industrial Computer Sciences at University of Lorraine, Nancy, France. He received his PhD degree in Automatic Control and Computer Engineering in 1988 and a Research Director degree in 1995. His research activities conducted at the Research Centre for Automatic Control of Nancy (CRAN CNRS UMR 7039) are focused on distributed systems, RFID and smart objects theory and applications, ambient intelligence systems and architectures in manufacturing systems and supply chain. Since 1997, he is expert scientist appointed at European Commission for assessment and evaluation of FP6-FP7-H2020 ICT research projects and program calls in internet of things, RFID and networked enterprises. He gives lectures in automation control, industrial communication networks, ambient systems, RFID and IoT concepts and technologies in France and several foreign universities. He has published about hundred scientific publications in major journals, conferences and books.

Ahmed Zouinkhi is an Associate Professor at the National Engineering School of Gabes (Tunisia) and a member of Modelling, Analysis and Control Systems (MACS) Laboratory. He received his National Engineering degree in Industrial Computing from the National Engineering School of Monastir (ENIM), Tunisia. He received his DEA degree and CESS (certificate high specialised) from the Higher School of Sciences and Techniques of Tunis (ESSTT), Tunisia. He received his PhD degree in Automatic Control from the National Engineering School of Gabes (Tunisia) in 2011 and PhD degree in Computer Engineering from the Nancy University (France). His research activities are focused on distributed systems, smart objects theory and applications, ambient intelligence systems and architectures, RFID, VANET and wireless sensors network concepts and applications in manufacturing and supply chain.

Mohamed Naceur Abdelkrim received his Diploma in Technical Sciences in 1980, Master degree in Control in 1981 from the ENSET School of Tunis (Tunisia), and PhD in Control in 1985 and Doctorate in Sciences Degree (Electrical Engineering) in 2003 from the ENIT School of Tunis. Since 2003, he has been a Professor at the Electrical Engineering Department (Control) of the National Engineering School of Gabes (Tunisia) and he is the Manager of the Modelling, Analysis and Control Systems (MACS) Laboratory.

Hassen Chekir is a Manager Scientific Research in Groupe Chimique Tunisien (GCT) in Gabès. He received his National Engineering degree in Chemical Process from the National Engineering School of Gabès (ENIG), Tunisia in 1983. His main research focus is related to procedures and methods supporting development of chemical industrial product.

This paper is a revised and expanded version of a paper entitled ‘Product allocation planning with safety compatibility constraints in IoT-based warehouse’ presented at The International Conference on Advanced Wireless, Information, and Communication Technologies (AWICT 2015), Sousse, Tunisia, 5–7 October 2015.

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 modelling but also by artificial intelligence methods and collaborative-based negotiations architectures (Vrysagotis and Kontis, 2011). The crucial goal and key issue for reducing the logistics costs is guaranteeing effective warehouse management (Giannikas et al., 2013). In this context, the two most important aspects to be considered are inventory management and optimal product allocation. The optimal product allocation during storing operations can bring down the storage costs by reducing inventory levels, while maintaining defined service levels (Sanei et al., 2011).

According to sustainable and safety policies, the risks of major accidents in warehousing operations are challenging owing to the handling and storing of hazardous products, as well as product to product’ interaction and human exposure. The concept of safety consciousness system was introduced in De Koster et al. (2011) with the aim of

guaranteeing warehouses’ safety performance and avoiding fatal accidents. An efficient product allocation in the warehouse, in terms of costs and safety, can reduce retrieval and storage times, while balancing different activities in warehouse.

The presented work aims at providing a novel solution for smart logistics and security issues in warehouse management system (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 (Trab et al., 2015). This research work is conducted in a joint industry – university research and development program with the chemical industry.

The paper is organised as follows: in Section 2, related challenges and trends in WMS are detailed, Section 3 presents security issues in WMS and Section 4 explains how a product will be considered as a communicating object using RFID and IoT infrastructure. Section 5 presents a multi-agent-based simulation of product class-based storage. Finally, Section 6 gives conclusion and prospects of future work.

2 Challenges and trends in WMS

Many researchers have focused their research works on major operations in warehousing which involve the receiving, storing, picking and shipping stages to facing the challenges on solving critical issues caused by the fast changing in received orders and customers references.

The increase of special characteristics related to huge orders size and products variety along with shorter response-time requests or changes after the initial creation and placement of the order creates disruption in the warehouse managing process (Giannikas et al., 2013).

Distributed and adaptive strategy was proposed to resolve the dynamic picking and storage location assignment problems (Tsamis et al., 2015). Such approach is reinforced by the use of the concept of intelligence embedding on product, in addition with the use of an agent-based modelling framework for the process logic control. The product takes an active role in the decision process for its own storage-location assignment by means of collaboration and negotiation mechanisms, along with scenarios dynamically and automatically played out with the surrounding shelves, resources, other products, and operators. This trend of product empowerment offers tremendous opportunities to tackle the challenging issues in WMS caused by the product allocation problem, high diversity of products, the security/compatibility constraints between products and operators for a safe environment. The IoT approach with its underlying associated technologies (RFID, wireless sensors network – WSN) offers suitable solutions and infrastructures for collaborative warehouse management. For this reason, many researchers have dealt with the use and improvement of WSN (Shang, 2012; Longo et al., 2015; Kostantos et al., 2015) and RFID technologies (Li et al., 2015; Cai et al., 2015) in many domains fields.

2.1 Product allocation problem

The product allocation problem in a warehouse consists of allocating products to different slots of shelves situated in the repository while on one hand minimising the handling costs and on the other hand maximising space utilisation. The basic principle is that the high demand products have to be allocated in the shelf slots closer to the in/out doors in order to reduce the total time for the handling operations (Guerriero et al., 2013). From a general scope, the product allocation problem can be formalised 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 works are focused in solving this WMS problem using centralised and decentralised approaches.

In the first hand, in order to improve centralised WMS (Ozcan et al., 2011) has attempted to solve warehouse location problem 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 Guerriero et al. (2013), a mathematical approach for product allocation problem in a warehouse with compatibility constraints was detailed. In Pourakbar et al. (2009), work was done using 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 decentralised and collaborative warehouse management (Giannikas et al., 2013) used the intelligent product (IP) paradigm in order to respond to different challenges required to a WMS improvement. The IP concept was first used in a WMS context in Giannikas et al. (2013) in order to improve the scheduling and control of the storage location assignment and the picking operations. When compared to classical centralised WMS, the IP approach, which is fundamentally distributed, is considered as better performing when high uncertainty and unpredictable events, changes and disruptions occur. IP approach can lead to a reduction of supply chain operation costs (Trentesaux et al., 2013) but also implies an increase of complexity directly related to the rising number of managed IPs. The advantage of using intelligent product concept is to ensure informational, communicational and decisional capabilities close to the physical world. This reduces decision delay and increases solving efficiency of local dynamic disruptions while avoiding the inherent risks of centralising all the information. A bottom-up approach based on IoT infrastructure deployment can leverage system reactivity as was proposed in Reaidy et al. (2015) for order fulfilment, including picking-packing-shipping phases in a collaborative warehousing environment.

Nevertheless, previous works lack safety and security considerations against risks which are not considered during product allocation decision process.

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. Therefore a lot of restrictions should occur in real contexts of storage operations. Many research works are focused on product allocation with compatibility constraints. In Tsamis et al. (2015), the chocolate storage situation was explained by the fact that milk chocolate and dark chocolate products should not be allocated in neighbouring slots in order to sustain their quality. This situation occurs also in hazardous industrial warehouses of chemical products (Zouinkhi et al., 2011) or nuclear reactors (Hasan, 2007) where incompatibilities between products must be respected. In our work context, chemical products can react violently when they are in contact. Thus they must be stored in separately. The strategy of storage to be adopted consists of avoiding the fact that incompatible products be allocated in neighbouring slots then segregation policies are

established (Gaci and Mathieu, 2012). The constraints to be solved in this work referred not only to compatibility between products but also the floating location size minimisation. 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 neighbouring slots of the possible allocation positions represents an optimal solution to reduce the floating location problem.

2.3 *Product class-based storage*

Overall risk issues in a warehouse must consider lots of parameters, such as the nature of products, interactions between products, interaction between people and products, moving with products, products handling and manipulation, and location of products.

The classification of products by methods exploiting multiple criteria will help to optimise incoming factors in the overall equation of performing and assuring security of goods and person.

Class-based storage (CBS) implementation decisions have significant impact on the required storage space and the material handling cost in a warehouse (Muppani and Adil, 2008).

Petersen and Aase (2004) adopted a CBS method to partition stock-keeping units (SKU) into storage classes by demand and randomly assigns storage locations within each storage class area. This study compares the performance implications of CBS to both random and volume-based storage (VBS) for a manual order picking warehouse. They have explored (CBS) by examining the effect of the number of storage classes, pick list size, partition strategy of storage classes, and the storage implementation strategy in the warehouse. The results support previous studies by showing that the performance gap between CBS and VBS decreases as the number of storage classes increases. However, this does not imply that more classes should be used. Results confirmed that a simple two-class system attained nearly 80% of the benefits offered by a volume-based policy, which requires much more time and effort to administer properly. As an effect, the use of the proper partition strategy can result in lower fulfilment times. In addition, the savings of CBS are attainable with either optimal or simple traversal routing. The study also shows that the storage implementation strategy (i.e., the choice of how storage classes are assigned to storage locations) has a major impact on the successful implementation of CBS. The within-aisle strategy outperformed the other storage implementation strategies regardless of the number of storage classes or pick list sizes. The results of this study have important implications for order fulfilment and distribution centre managers. CBS is easier to implement than VBS, because it does not require a complete list of the SKUs ranked by volume and it requires less time to administer than VBS policies do. Instead, SKUs only need to be classified into a few storage classes by their expected demand levels.

Further, this study shows that CBS can be easy to implement using storage implementation and class partition strategies. In addition, the effectiveness of CBS can be realised with the use of traversal routing, the most widely used routing method in warehouses today because of its ease of use and it provides near optimal performance.

When products are combined into fewer classes, a high-activity product (defined by a high pick activity level which often justifies automation of the order picking system with automated material handling systems) occupies a less desirable slot while a premium one might not be available when product arrives (Graves et al., 1977). The opposite might happen when a low-activity product arrives (defined by an automated or sophisticated storage and picking device dedicated to small operations. Mainly for floor storage, stacked pallets, conventional shelving with manual handling). Hence, if the same numbers of storage locations are assigned, the n-class policy will yield a lesser average picking distance as compared to combining products into fewer classes (Francis et al., 1992).

In a different view (Ang et al., 2012) propose a robust optimisation storage assignment model using a predetermined orientation of storage classes with stochastic demands. They claim that this model performs better than existing heuristics for storage allocation.

Stating that risk management in warehouses is a important issue to guarantee security in key sections of the global supply chains, our comprehensive literature and field practices review shows that most of current methods to manage warehouses still do not take into account the risk level classification of SKU.

Cedillo-Campos and Cedillo-Campos (2015) proposed a method named *w@reRISK* to analyse the security risk of SKU stocked in a warehouse. Since risk analysis involves not only factual data, but also perceptions, the hybrid method is based on the ABC classification of SKU by dividing an inventory into three categories – ‘A items’ with very tight control and accurate records, ‘B items’ with less tightly controlled and good records, and ‘C items’ with the simplest controls possible and minimal records. The ABC analysis provides a mechanism for identifying items that will have a significant impact on overall inventory cost, while also providing a mechanism for identifying different categories of stock that will require different management and controls.

The *w@reRISK* method includes a security risk level classification of SKU, pointing out a list of 34 criteria ranking between high risk and low risk, which correspond at a first level to the physical characteristics and use of the SKU (damage to the product, damage to the staff, property damage), and at the second level, the risk directly related to the physical characteristics of the SKU and the potential illegal uses of it (terrorism, material smuggling, human smuggling).

Thanks to its global vision, the method can be used to classify not only SKU, but also any kind of physical items (pallets, containers, etc.) that must be stored or located in a physical space (terminals, logistics platforms, etc.). The

generalist approach of the method provides an important flexibility that can be adapted to the specific needs of the user. Furthermore, due to its logical approach, it is susceptible to become an automated informatics tool to easily reduce warehouses' security breaches.

2.4 Product tracking and monitoring

The first step towards IoT is the collection of information about the physical environment (e.g., temperature, humidity, brightness, etc.) or about objects (e.g., identity, state, energy level). Data acquisition is encompassed by using different sensing technologies attached to sensors, cameras, GPS terminals, while data collection is generally accomplished by short range communications, which could be open source standard solutions (e.g., Bluetooth, ZigBee, Dash7, Wireless M-BUS) as well as proprietary solutions (e.g., Z-Wave, ANT) (Borgia, 2014).

For example, we can imagine a warehouse that has ambient, chilled, and frozen sections, whose customers want to be assured that the goods they receive have been kept within a prescribed temperature range. Temperature sensors can be embedded in cartons or pallets, and can show the temperature of goods by time period for the entire duration of storage and trip to the customer site. No warehouse manager would want to be told or even be blamed that a temperature excursion occurred at his warehouse.

A fundamental role is covered by the RFID technology which allows to identify objects, people or animals, store information about them and transfer it via wireless communication to other electronic devices (Finkenzeller, 2003; Gadh et al., 2010). The RFID system consists of two main components: the tag and the reader. The tag is directly applied to an object and identifies it uniquely through the electronic product code (EPC) while the reader is the element that collects data from the tag and transmits it to the internet world. Passive tags are very affordable, very small and have potentially long life. Their main drawback is that the area in which the tag-reader transmission may take place is very limited from few centimetres with LF/HF waves to few metres with UHF waves. While active tags which are battery power supplied allow to cover greater distances, more complex operations (e.g., they may have sensors installed to monitor the environment), the processing capabilities are still poor and limited to basic sensor calculation.

The last decade has seen the emergence of a currently essential technology for the development of IoT with the wireless sensor network (WSN). WSN is a powerful technology for gathering and processing data in a large variety of domains, from environmental monitoring, industrial manufacturing to intelligent agriculture. Many solutions are available on the market for rapid development and prototyping of efficient solution as Arduino, Waspote, Beagleboard, etc. Traditional WSN consists in a high number of static and resource constrained sensor nodes deployed in an area to sense a certain phenomenon, e.g., temperature, and humidity. Sensors are usually powered by small battery, have a limited lifetime and scarce

computational and memory capabilities. Sensed data is then transmitted wirelessly via multi-hop communications towards one or a small set of sink nodes, which are more powerful devices where the collected information is elaborated. More recently, WSN with mobile elements (MEs) have gained popularity. In this case, MEs move in the network and collect opportunistically data from sensors whenever they happen to be in contact. As consequence, the network density is reduced to form sparse WSNs (i.e., where sensor nodes cannot communicate directly), the energy consumption is distributed more uniformly in the network, and the network life time increases.

IoT infrastructure associates RFID technology with WSN, communicating object paradigm and multi-agent systems (MASs). RFID technology can play an important role in IoT infrastructure as a means of communication and a data provider to supply chain costs (Lim et al., 2013). In Yang and Ye (2014), 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.

Oliveira et al. (2015) present an intelligent model for logistics management based on geofencing algorithms and RFID technology. Geofencing is the process of checking whether an object (product, person, vehicle, asset, etc.) has entered or left a geographical area. This area can be pre-defined (calculation happens in real time on the device itself or on a server), or post-processed (the data is being stored and post-processed on a server). The focus is on dealing with delivery management. The main scientific contribution of safe track is the automatic delivery management. Besides dealing with deliveries without user interaction, it provides a mechanism to detect inconsistencies at real-time. Furthermore, the model monitors detours in planned routes and deals with alarms notifications using mobile devices. In order to provide that features, they employed Geofence concept with two solutions that enable to detect, in real-time, the occurrence of detours in planned routes. They created a component, named SafeDuino (based on an Arduino board) which is a collection of RFID tags and an application that runs in a mobile device, named SafeTrack Mobile, allowing to control loads delivery and pickups. The decision on the occurrence of inconsistencies during the logistics flow is performed through the fusion of context information, obtained from SafeDuino and a mobile device, using radio-frequency technology. The decision on the occurrence of inconsistencies during the logistics flow is performed through the fusion of context information, obtained from a mobile device, and the hardware component SafeDuino. This component is attached at the back door of the truck with an RFID shield, which detects when a cargo passes over the RFID reader. Another feature of the proposed model is that devices can send alarms notification whenever predefined situations occur. These features speed up

decision making, reducing losses and costs for the logistics flow.

A logistics monitoring platform based on IoT was presented by Zhengxia and Laisheng (2010). The proposal used widespread technologies, such as: EPC, RFID, GPS, GPRS, GSM and WSN. The platform architecture has three layers: data acquisition, data transport and background data processing. The data acquisition layer is in charge of getting information about loads, through EPC and GPS technologies. According to the EPC functions, every load can receive a unique EPC number.

However, the authors developed a static and dynamic EPC model, which reduced the data flow and reused EPC numbers. The data transport layer did the communication between components using GPRS. The background data processing receives and processes the loads information, storing in database. This layer provides information about load history, statistics analysis and products reports. Even more, it alerts that inform when a product expired or if it is delayed.

The entire lifecycle of objects can be tracked too. For example, RFID readers installed along the production plant allow to monitor the production process, while the label can be traced throughout the entire supply chain (e.g., packaging, transportation, warehousing, sale to the customer, disposal). Advanced IoT systems, composed of RFID-equipped items and smart shelves tracking items in real time, may help to reduce material waste, thus lowering costs and improving profit margins for both retailers and manufacturers. Under production and over production may reduce drastically by having a correct estimate of needed items, which can be inferred by analysing data collected by smart shelves. In addition, the real time analysis by sensors allows to identify product deterioration events, which is of vital importance for food and liquids.

Globally, the application of IoT technologies enables advanced transportation systems for people and goods. Fare collection, safer luggage management based on automated tracking and sorting, intelligent screening of passengers, are some examples (Borgia, 2014). Smart industrial management systems, based on IoT technologies, allow to monitor industrial plants, for instance to reduce the number of accidents, especially in case of high-risk plants (e.g., oil plants, gas plants). For example, sensors attached to containers transporting hazardous goods may emit different signals to announce the chemical component contained and the maximum level of that component. In case of critical situations (e.g., being close to the maximum level of a chemical component in a specific geographical area, or incompatibility among chemical components within containers in proximity), sensors may automatically send alarms to control centres that, in turn, manage promptly such dangerous situations.

3 Security issues in WMS

Nowadays safety of goods and people, as well as sustainability are major goals of modern industrial

enterprises. The risk of major accidents is mostly associated with the presence of dangerous substances at such quantities and under such conditions that an uncontrolled handling, mispositioning, release fire or explosion can take place, with potential adverse effects to workers and human health, materials and environment. Handling, storage and disposal of hazardous substances give rise to specific constraints particularly in the warehouse managements systems.

3.1 Risk factors analysis

Many factors can trigger the increasing of accidents in warehouses like significant traffic of materials, forklifts and foot workers in close proximity, work pressure, etc., as it was analysed in Vrysagotis and Kontis (2011) in a survey of 78 Dutch warehouses from 2007 to 2011.

In this study the concept of ‘safety consciousness’ was introduced to guarantee safety performance in warehouses to avoid consequences of harmful accidents by enhancement of individuals’ awareness of safety issues. This awareness works both on a cognitive and a behavioural level.

Guerriero et al. (2013) has demonstrated that major hazardous accidents are related to the intermediate temporary storage and transportation of dangerous substances both in port areas and in marshalling yards. This work has enumerated and analysed a large number of accidents in transport interfaces that are still relevant in current organisations where the cooperation of products, people, resources which sometimes have different and conflicting interests, in the achievement of individual goals with satisfactory level of safety. In 2001, the AZF chemical fertiliser plant in France was blasted by the explosion of several tons of ammonium nitrate, presumably due to a product mispositioning human error which caused the death of more than 21 people. The company was recognised guilty of involuntary homicide and injuries by means of “clumsiness, inattention, negligence, recklessness or breach of duty of security”.

3.2 Products compatibility specification

The compatibility test between chemical products can be computed according to ‘compatibility rules’ (Figure 2) expressed in terms hazard pictograms (Figure 1) based on edition of globally harmonised system of classification and labelling of chemicals (GHS) in accordance to REACH directive for the registration, evaluation, authorisation and restriction of chemicals (Wang et al., 2012).

To identify and manage chemicals products storage in the same neighbourhood disposal Figure 2 illustrates the different possible cases. Three cases are present:

- the + symbol: means that products are allowed to be stored together
- the O symbol: means that products are allowed to be stored together under certain conditions
- the – symbol: means that products should not be stored together.

Figure 1 Chemical products pictogram (see online version for colours)

Symbols	Description	GHS-Symbols	Description
	E Explosive		GHS01 Exploding bomb
	F+ Extremely flammable F Highly flammable		GHS02 Flame
	O Oxidizing		GHS03 Flame over circle
No equivalent			GHS04 Gas cylinder
	C Corrosive		GHS05 Corrosion
	T+ Very toxic T Toxic		GHS06 Skull and crossbones
	Xn Harmful		
	Xi Irritant		
No equivalent			GHS07 Exclamation mark
No direct equivalent			GHS08 Health hazard
	N Dangerous for the environment		GHS09 Environment

Figure 2 Chemical products compatibility rules (see online version for colours)

	+	-	-	+	+	-	-
	-	+	-	○	○	-	-
	-	-	+	+	+	-	-
	+	○	+	+	+	-	-
	+	○	+	+	+	-	-
	-	-	-	-	-	+	-
	-	-	-	-	-	-	+

3.3 Product classification algebra

In most chemical substances warehouses, seven types of products are present: highly flammable, explosive, oxidising, health hazardous, toxic, harmful and corrosive. These products can be classified according to products compatibility rule of Figure 2 with five classes defined as follows. Highly flammable and harmful products as they are compatible can be stored together in class C_1 . These types of products will form a first compatibility class. The second compatibility class C_2 , will cover products with hazardous and toxic effects on health. For remaining products a class will be allocated for each singularity. The corrosive ones in class C_3 , the oxidising products in class C_4 and the explosive types in C_5 . A class may include a set of products with the same hazard pictograms or with different ones but compatible between them.

A mathematical representation of classes and product compatibility is proposed below.

Let C_i be a set of compatible products allowed to be stored in same neighbourhood such that $C_i = \{P_1, P_2, P_3, \dots, P_n\}$ where n is the number of products belonging to the same class.

Let E be the set of products class previously formed. The set E consists of five classes C_i ($i = 1 \dots 5$) where $E = \{C_1, C_2, C_3, C_4, C_5\}$.

For each product class C_i , we associate a set of locations E_{ij} such that $j = 1 \dots n$; n is the number of products suitable locations $P_j \in C_i$.

When taking a product P_i from the class C_i , it must be stored in the set of location associated to the class C_i . Otherwise, if $P_i \in C_i$ then $P_i \notin C_k/k \neq i$ and P_i should not be allocated to $E_{k/j}/k \neq i$.

3.4 Attractive/repulsive potential fields concept

The interaction mechanism between entities using potential field is based on a physical inspiration where entities propagate a force field in the environment in order to attract or repulse others entities.

In our case the entity which will be attracting or repelling by potential fields is the resource carrying a product in the warehouse, this resource can be an automated guided vehicle (AGV) used in the storage operation (Figure 3) on which is mounted a WSN mote device performing the intelligent computation for security management. This vehicle can have both manual and automated control and it can be programmed to do a wide variety of tasks. AGV is considered as a mobile robot that uses vision, magnets, or follows markers or wires in the floor, or lasers for navigation.

Figure 3 AGV and WSN mote device (see online version for colours)

In fact, while the AGV moves a chemical product it forms a composite real entity, as it will be explained in Section 4.2. AGVs are most often used in warehouse applications in order to achieve a specific position goal while avoiding obstacles along their navigation. This position will be considered as an entity emitting an attractive field whereas obstacles will be the investees of repulsive fields entities. The composite entity will move by combining all of the perceived fields (Zbib, 2011). Several studies have worked

on potential field methods (PFM) such as Ferber (1995) and Weyns et al. (2006) who used the potential fields in the context of reactive MASs to determine the behaviour of mobile entities situated in a metric space. Mamei et al. (2006) have used the potential fields for guiding multiple robots deployed in an environment with the ability to guide and coordinate their individual movements. To ensure various interactions between robots, they are equipped with sensors enabling them to acquire information about their environment. If no direct communication medium is available, they coordinate their movements by detecting the movements of other robots.

4 Product as a communicating object using RFID and IoT infrastructure

The communicating object concept can be used as a generic term figuring out many other naming such as intelligent product, connected object, smart object, smart thing, etc. Gutiérrez et al. (2013) analysed the multiple definitions of the smart object, in order to provide a consensus definition satisfying all the software and systems engineering domains. Thus they introduced a new naming of ‘smart thing’ that is to be understood as an umbrella term for which smart product and intelligent product are considered as special forms in different application domains. Other authors as Zaeh et al. (2010), Dhebar (1996), Rijdsdijk (2009), Kiritsis (2011), Liu (2010), López and Ranasinghe (2009), Niskanen (2011) and Zouinkhi et al. (2011) had provided various context-application dependent definitions that can be seized to design and model smart object in multiple research areas such as the IoT, ambient intelligence, robotics and process automation. The use of different naming to handle the communicating object concept is a drawback and somehow a brake to a large adoption and understanding of the underlying paradigm.

4.1 IoT reference models

Several EU funded research projects like IoT.est, IoT-A, Icore, BUTLER, RERUM, COMPOSE, EBBITS, IoT6, BETaaS, Mobility First, NEBULA are focusing on architectural concepts. We can mention among them the IoT-A project that inspired many other IoT EU projects that inspired many other IoT EU projects mainly with its architecture reference model (IoT-A ARM). The large number of specific application domains such as smart cities, smart logistics, e-health and smart industries require a certain degree of smartness and inclusive awareness. All those applications are using IoT specific technologies; however, they unfortunately need specific architectures designed for specific use cases, as well as their need inter-operation and inter-system communication. In fact IoT related technologies are characterised by their high level of heterogeneity, which make the IoT landscape extremely fragmented.

IoT-A aims to endorse and reach a best interoperability level at the communication, the service and the information levels, crossing different platforms, but built on a common ground. The IoT-A project believes that achieving these objectives is possible in two steps, firstly by unifying the IoT domain notion (reference model) and secondly, by providing to the IoT developers a common ground work allowing building interoperable IoT system architectures (reference architecture) (IoT-A, 2010–2013). A combination of the reference model with the reference architecture gives birth to the architectural reference model (ARM), which is a set of models, guidelines, best practices, views and perspectives used in order to build wholly interoperable and concrete IoT architectures and systems, and so-called IoT-A ARM. In fact IoT-A ARM is not properly a system architecture, but instead it represents an architecting framework deriving various existing IoT architectures called ‘generic reference architecture’, with two functionality groups: the application and devices functionality group, and the management and security functionality group (Bassi et al., 2013).

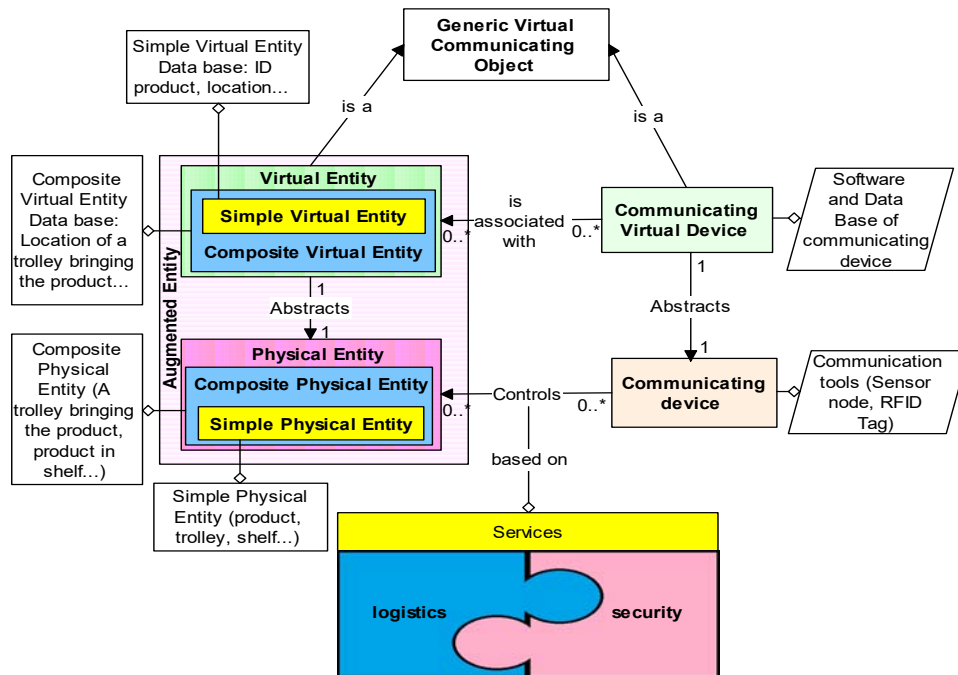
Others IoT projects are focusing on architectures, like E-PRICE (2010–2013) and Nobel (2010–2013), which use a cognitive internet of energy architecture allowing harmonising the energy grid by processing its information via internet for smart grid project. Also, we can denote the smart industry project Iot@Work (2010–2013) which proposed a self managing, resilient networks/middleware and service oriented factory environment architecture. Other projects have treated security with a structural approach like smart city project RERUM and an architecture based on ‘security and privacy by design’ concept by embedding security and privacy mechanisms in the core elements.

We decided to use IoT-ARM conceptual model as a spine for our research work, because of its generic concept and structure. Our contribution to implement and extent the architecture is situated in the IoT business process management and more particularly in the business process modelling, which provides an environment for the IoT-aware business processes modellers that will be serialised and executed in the process-execution functional component. Our business process model involves both logistics and security issues in the context of hazardous and chemical risks for smart logistics and warehousing application. The functional component of the architecture is the communicating object whose model is presented in the following section.

4.2 Product as a communicating object

On the basis of the previous considerations, our research proposal is to upgrade a communication object model with coherence to the IoT-ARM in order to harmonically coordinate smart logistics and warehousing operations of hazardous, chemical and harmful products with respect to logistics optimisation algorithms, and to safety and security of goods, persons and environment.

Figure 4 Communicating object's functional model (see online version for colours)



The terminology to be used in this section is based on the IoT-A conceptual model and the RERUM device extension model as presented in detail respectively in the IoT-A reference model (Bassi et al., 2013). We extend this model with the integration of services related to logistics and security functions and we use these extensions in order to explain our communicating object concepts.

As depicted in Figure 4, our model provides an extended and more detailed view of the generic virtual communicating object constitutive elements presented by the communicating device and the augmented entity. Every unit is a compound of physical and virtual parts. Each component of the augmented entity is subdivided into simple and composite elements. Also, we have to mention that this generic virtual communicating object is inspired from the one given by the IoT-A.

In our work, we started from the RERUM device models illustrating the communicating device, the communicating virtual device and the generic virtual communicating object. Our extensive contribution focused on adding ‘the composite entity’ notion and ‘the smart logistics services’ in the communicating object functional model. In fact as shown in Figure 4, the UML-diagram uses the previously explained notions and indicates the different relationships between those elements, which are as follows:

- The communicating device can control none-or-many physical entities. In the IoT context, a physical entity is linked to a device capable to sense, discover or manipulate its environment. The communicating device can be a sensor node, an RFID tag, an RFID reader. The physical entity can be composite (trolley bringing the product, operator bringing the product...) or simple (trolley, product...). A group of two simple entities gives rise to the composite entity. The idea of

introducing the composite entity into our functional model is due to the fact that it can play a different role than the simple entity one. Then it requires specific security rules (different of those to be used for simple entities) during the different management steps of the logistics cycle.

- The communicating virtual device can be associated with one or several virtual entities. Communicating virtual device represents the database and the software tools of the communicating device.
- Each virtual entity represents one physical entity.
- Each communicating virtual device represents only one communicating device.
- One-or-many communicating device control one-or-many physical entity. This control is based on the smart logistics that enclose two related services, which are the logistics and the security issues.
- One-or-many communicating virtual device can be associated with one virtual entity.

We propose a communicating object model. 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. Baldi et al.

(2012) proposed a comprehensive management platform of modern tobacco logistics based on the IoT technology. 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 (Crainic et al., 2014; Tsamis et al., 2015; Borgia, 2014). Ashton (2009) presented a smart WMS-based IoT which aims to simplify goods inventory and enhance the warehouse automation management level. Yang and Ye (2014) represent a collaborative warehouse platform in 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 MAS for collaborative warehouse management. In this work, negotiations mechanisms based on 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 decentralised management of warehouses and to create collaboration between products and shelves guaranteeing a product class-based storage efficiency.

4.3 Product and resource communicating architecture

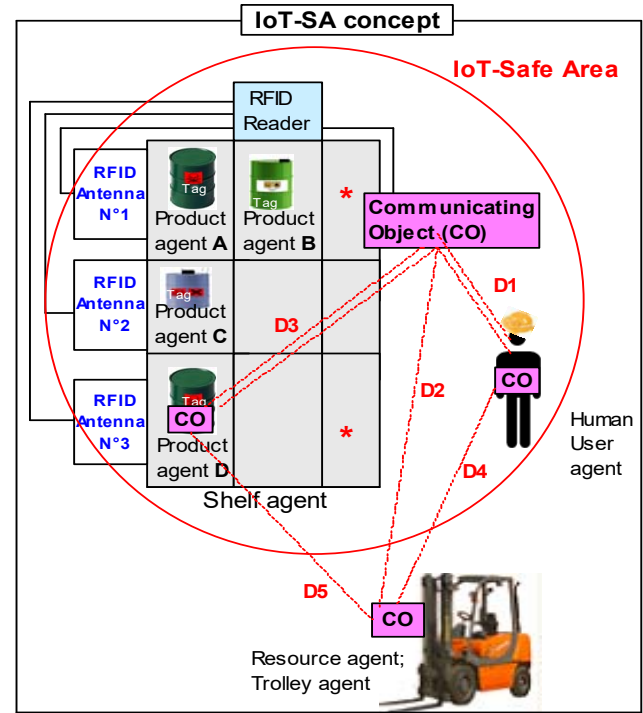
The intelligence involvement on safety in the WMS that we propose is called the ‘IoT-based safe area’ concept (IoT-SA). The IoT-SA concept consists of transforming the warehouse into a set of areas or zones which can be vertical (i.e., shelf) or horizontal (i.e., storage floor zone), among which some can be safely controlled and others not. The safety will be monitored and controlled in the areas where risky interactions can take place between co-actors among products, human users, shelves and transport resource. Figure 5 shows a three layers shelf as a Safe Area bounded by a 3D-perimeter that delimits the edge of a risky interactions zone between communicating objects.

The most critical interactions during products warehousing occur during products movements. Whether there is an arrival of a new order which needs to be stored in suitable locations, or during products picking for shipping preparation. As solutions to this problem we have turned a few places into interaction areas of negotiation ensuring a better performance in security of goods and people. This transformation only concerns some places of the warehouse corresponding to safety critical zones. To cope with this we propose the creation of a set of safety areas named ‘SA’ where smart interactions between all components assure safety and security.

The lack of dynamic and reactive information to ensure prevention against risks threatening goods and people within warehouses has led us to develop a decentralised, dynamic and interactive protocol, for the picking and storage phases in order to ensure the security of goods and

people. Picking and storage phases are considered as the most critical phases in the storage cycle.

Figure 5 ‘IoT-based safe area’ concept (see online version for colours)



The criticalness of those phases is due to the permanent movements of products, trolleys and people during the warehouse operations; a human user bringing the product while using or not a trolley in order to storing it in the appropriate shelf location, or also products picked from their shelves for shipment preparation.

So we intend to develop a safe control of interactions of all warehouse components in order to manage the IoT-SA using the communicating object concept. It needs to create a set of communicating objects collaborating together within the warehouse while ensuring security of goods and peoples. The products that are present in the warehouse, the human users, the shelves, the trolleys, the safety equipment (such as the security helmet, safety glasses, safety gloves) will all be equipped with embedded communicating entities allowing to turn them into communicating objects in an IoT approach. This transformation of warehouse's equipment into communicating objects will be ensured on the first hand by attaching RFID tags to all the previously cited warehouse actors and on the second hand by use of WSN technologies with adding a sensor node in both shelf and trolley in order to create a local decision making system ensuring a faster alert signaling a risky or ultimately an emergency situation. The physical entities, which will be controlled by RFID tags, will have a virtual representation in the base station involving all information required for guaranteeing its intelligence and creating its associated agent.

5 Multi-agent-based simulation of product class-based storage

The negotiations between products and shelves for product-based class storage will be implemented by use of a multi-agents system (MAS) approach designed to represent an RFID and IoT infrastructure in a WMS.

5.1 MAS approach

MASs have been developed in the context of distributed artificial intelligence and consist of a set of distributed cooperating agents each of which acts autonomously. It provides a novel approach to complex problems in a distributed manner where decisions should be based on processing of information from various sources of diverse nature (Woolridge and Jennings, 1995).

MAS approach was used in several research works to solve WMS problems. Reaidy et al. (2015) proposed an IoT infrastructure for collaborative warehouse order fulfilment based on MAS. It integrates a bottom-up approach with decision support mechanisms such as self-organisation and negotiation protocols between agents based on 'com-peration' concept, which involves both competition and cooperation. This approach improved the reactions capabilities of decentralised WMS in dynamic conditions. By using agent-based modelling, a statistical study was proposed by Shqair et al. (2014) allowing estimating the effects of different warehouse parameters on the distance travelled in the facility.

In fact, each agent can communicate with all other agents in a MAS, in order to share results or to request information about shelves' availabilities, products' compatibilities, etc. The communication between agents can take two different forms: the negotiation, which is the result of the competition between agents and the planning, which comes from the cooperation between agents. In our case, both cooperation and negotiation are used to solve the product allocation planning with using of potential fields.

5.2 WMS agents modelling with NetLogo

A simulation of the negotiations mechanisms in a warehouse is performed using NetLogo software. NetLogo is a convenient platform for modelling and simulating multi-agent architecture where agents are functioning in parallel (Sallez et al., 2004). It is mostly used for simulating social and natural phenomena and is particularly suitable for modelling complex systems and analysing the connection between the behaviour of basic entities and the macro-level patterns that emerge from their interactions (Vidal et al., 2004).

Four entities are available in all NetLogo agent simulation:

- Observer: A central agent, responsible for simulation initialisation and control.
- Patches: Components of a user-defined static grid (2D or 3D world), inhabited by turtles. Patches are useful to describing environment behaviour.
- Turtle: Agent that 'lives' and interacts in the world formed by patches. Turtles are organised in breeds, that are user-defined groups sharing some characteristics, such as shape, but most importantly they share specific user-defined variables that hold the agents state.
- Links agent: Agent that connects two turtles in order to represent usually a spatial/logical relationship between them. The definition of turtle specific variables allows them to carry their own state and facilitates the encoding of complex behaviour. Agents' behaviour is specified using NetLogo programming language that supports a rich set of functions called reporters, and procedures. The language includes a large variety of primitives for graphical animation and calculation acting on turtles' motion and environment inspection.

Table 1 shows the warehouse agents projection of different entities, their real physical entities present in the real warehouse environment and their NetLogo associations.

Table 1 WMS agents modelling with NetLogo

<i>Real physical entities</i>	<i>Agent entities</i>	<i>NetLogo</i>
Product	Product agent	Turtle
Automated guided vehicle	Resource agent	Turtle
Appropriate storage zone	Storage zone agent	Patche
Not appropriate storage zone	Obstacle agent	Patche

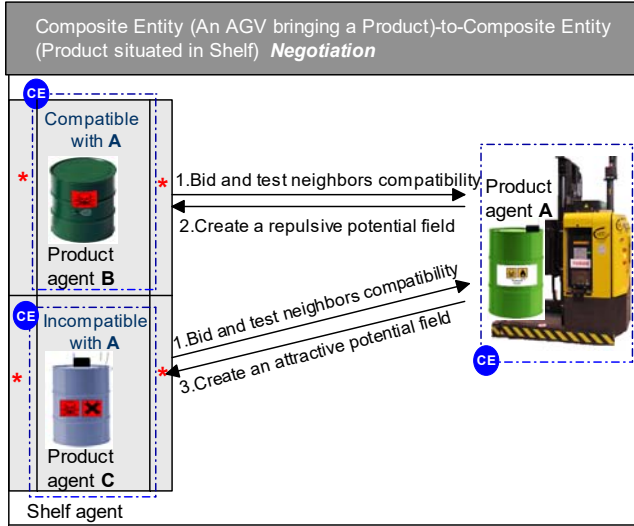
Firstly we describe the product agent (i.e., a turtle in NetLogo) which is representative of a chemical product in the real world. It will be stored in the appropriate location on shelves. Then the resource agent (a turtle in NetLogo), commonly the AGV in the warehouse that will ensure the product transportation to the appropriate storage zone in an automatic way. Finally the appropriate storage zone will be represented by a storage zone agent (i.e., patches in NetLogo), while the not-appropriate ones will be played by obstacle agents.

5.3 MAS negotiations mechanisms for class-based storage achievement

This research study is generic enough to fulfil many industrial applications cases in WMSs 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 project. In order to explain negotiations mechanisms we will take the case of negotiations mechanisms concerning hazardous chemical products in order to determine product allocation, as illustrated in Figure 6. In fact while storing operation is

running, negotiations will occur between two composite entities (CE): a product-based CE which aggregates product and resource (i.e., an AGV carrying the chemical product) and a shelf-based CE which aggregates product and storage places (i.e., chemical product located in the shelf). The negotiations between CE concern the risk compatibility checking between products assigned to one of the empty slots marked by (*) with the neighbouring products on the shelf.

Figure 6 Negotiations mechanisms messaging between composite entities (see online version for colours)



When the compatibility check is good an attractive potential field (APF) is created in empty slots and the product can be placed in that shelf. Otherwise a repulsive potential field (RPF) is created in the empty slots. The compatibility test between chemical products can be computed according to 'compatibility rules' represented by a matrix previously depicted in Figure 2 which is commonly used in chemical industries. Other compatibility calculation methods could be considered for other application domains without disturbing the global approach.

5.4 Attractive/repulsive potential fields concept

PFM have been investigated during the past years for obstacle avoidance research aims and they have gained increased popularity among researchers in the field of robotic and mobile elements. The idea of imaginary forces acting on a robot has been suggested. In these approaches obstacles exert repulsive forces onto the robot, while the target applies an attractive force to the robot. The sum of all forces known as the resultant force determines the subsequent direction and speed of travel (Koren and Borenstein, 1991).

We apply PFM to control the movement of a product toward its allocated storage placement. For appropriate storage zone we establish an attractive potential field and for the inappropriate ones a repulsive potential field. The path to be crossed by a product toward the nearest and available storage zone will be controlled by the resulting

potential field summing repulsive and attractive effects. The not-appropriate storage zones reflect the neighbouring incompatible products and the already occupied storage zones.

We define the attractive potential field U_a on a logarithmic basis between a product to store and a storage location as follows:

$$U_a = -V \cdot \ln(\|x - x_f\|)$$

where V is a gain parameter for the attraction effect.

For the not appropriate storage zone E_{kj} where $k \neq i$ we establish a repulsive potential field U_r . In fact for the appropriate storage zone E_{ij} belonging to the class C_i an attractive potential field can be considered as a repulsive one of not appropriate storage location for other classes C_j such as $j \neq i$.

The repulsive potential field U_r is given by:

$$U_r = V_0 \cdot \ln(\|x - x_f\|)$$

where V_0 is a gain parameter representing the intensity of repulsion.

The resulting potential field V_p is the sum of all attractive and repulsive potential fields, calculated as follows:

$$V_p = \sum_{i=1}^n U_{ai} + \sum_{i=1}^m U_{ri}$$

where n designates the appropriate allocation number and m represents the not-appropriate allocation place number.

To further explain the class-based storage approach, which aims to allocate all classes of products to the appropriate storage zone, we consider a product $P_1 \in C_1$, and we assign an attractive potential field to the appropriate storage zone. Then P_1 can be allocated in the places E_{1j} , with $j = 1 \dots n$ while moving away from the busy and incompatible locations.

Let us consider another product $P_2 \in C_2$, we associate to each emplacement with an attractive potential field.

If we considered another product P_2 which can be allocated to the places E_{2j} , with $j = 1 \dots n$, this product should move away from the busy and incompatible locations.

Similarly for all others products classes, a product $P_i \in C_i$ can be allocated to the places E_{ij} , $j = 1 \dots n$. In this case we should assign an attractive potential field to appropriate locations and repulsive ones to the not appropriate storage zones.

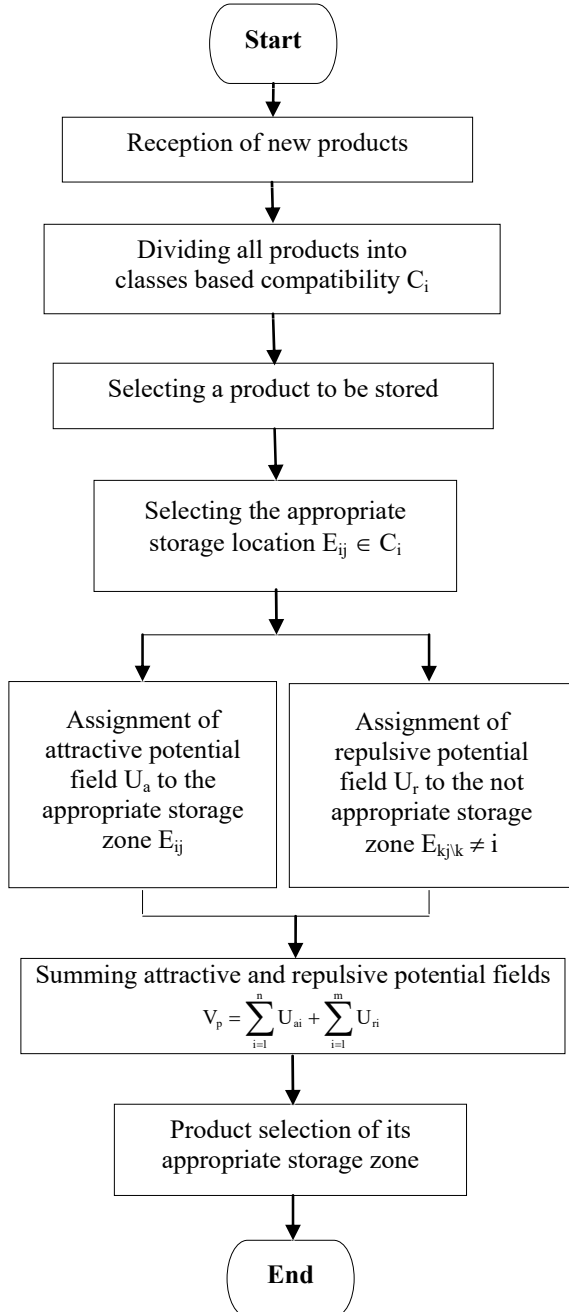
5.5 Product class-based storage principle

Let us describe the different steps followed to validate our work and to approve the product class-based storage steps according to the study done in the previous section. The storage determination method will be driven in two steps; the first one is to allow the product to select its appropriate storage zone, which is explained by the algorithm given in Figure 7. The second step is to allow the product to

determine its minimum path to reach the selected location. The appropriate algorithm is detailed in Figure 8.

The algorithm in Figure 7 summarises the steps followed to select the appropriate storage location of a product after dividing all products into classes. This location should be the nearest to the product, designed to store the class of products to which it belongs and available.

Figure 7 Algorithm of selection of the appropriate storage zone by a product



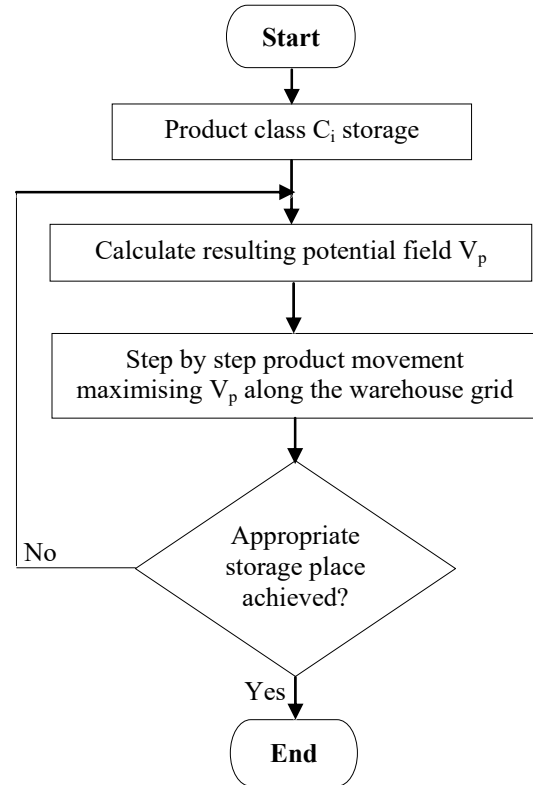
According to this algorithm, the first step is the reception of a new product stock in the warehouse. The second step is the classification of products into classes according to compatibility C_i . The third step aims at selecting a product to be stored. The selection of the appropriate storage location $E_{ij} \in C_i$ will be done in the fourth step. Fifthly, an

attractive potential field U_a will be assigned to the appropriate storage zone E_{ij} and repulsive potential fields U_r will be assigned to the not-appropriate storage zones $E_{kj\k \neq i}$. In final step, all attractive and repulsive potential fields will be summed and the product will select its appropriate storage zone.

After selecting its final destination the product will move toward it while minimising the path route and maximising the security level by means of compatibility checking as described in Figure 8. In fact all products of a same class C_i will move toward their suitable storage locations sequentially while calculating the resulting potential field V_p at each movement step.

In NetLogo simulation environment, the products' movement steps can be according to X or Y individually or interpolated way X/Y. If the appropriate storage zone is reached and the product is well allocated, the algorithm stops otherwise the previous steps are repeated until achievement of the product storage.

Figure 8 Algorithm of determination by a product of the minimum path to the selected location place

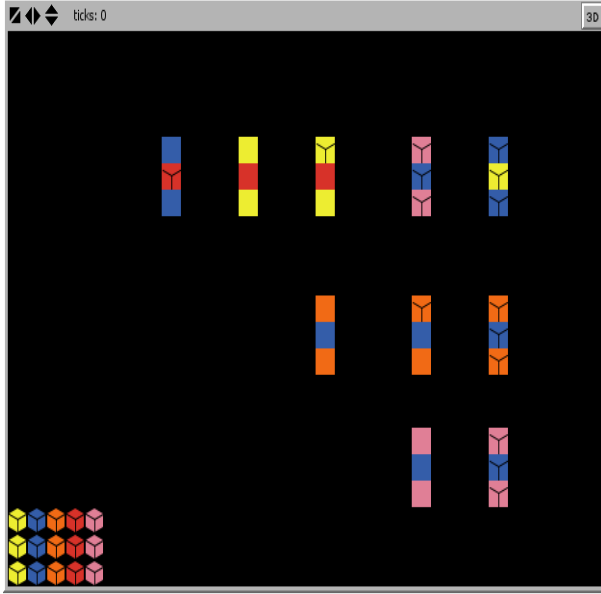


5.6 Product class-based storage Simulation

According to Section 3.3 our warehouse system contains five classes of compatibility, which can be presented in NetLogo environment by five colours (a colour for each product class C_i and the same colour for their appropriate storage locations E_{ij}). On the following Figure 9 representing the NetLogo simulation layout, we use the yellow colour for C_1 , blue for C_2 , orange for C_3 , red for C_4 and finally pink for C_5 .

The boxes in the lower left corner of Figure 9 are the received demand of new product storage. The coloured squared shapes in the simulation space represent the shelves of the warehouse.

Figure 9 NetLogo simulation layout for product class-based storage method (see online version for colours)



The shelves can include storage zones that are either appropriate, occupied or not-appropriate. The first product class C_1 has five possible storage locations (E_{11} , E_{12} , E_{13} , E_{14} , E_{15}). They are all figured by yellow patches, with three available locations (uniform yellow square) and two occupied ones (yellow square with three crossed black lines at the centre). For the second class five slots are occupied and five others are still free. For the third one three locations are still available for storage and three are not-appropriate due to their occupation by a same class of products. The fourth class of products can occupy two storage locations without approaching from the occupied ones. The final compatibility class has only two available emplacements and the four others are occupied.

Figure 10 shows a storage scenario of the first product of C_1 . The product reached its appropriate and nearest available location while running computation based on the algorithms explained in Figures 7 and 8. We remark that the yellow line represents the path followed by the product toward its suitable location which is the nearest one from its departure position. The suitable location is selected after computing the resultant potential field V_p according to the algorithm given in Figure 7. Then while product moves to this nearest available location it calculates the potential field resulting at each displacement using the algorithm of Figure 8.

Figure 11 shows the different positions X_{cor} and Y_{cor} (coordinates in the NetLogo grid space) crossed by the product $P_1 \in C_1$ during its allocation fulfilment. These curves show the variation of coordinates X_{cor} and Y_{cor} in function of the time. Red curve is for X_{cor} the green one represents Y_{cor} .

Figure 10 Storage operation of the product $P_1 \in C_1$ (see online version for colours)

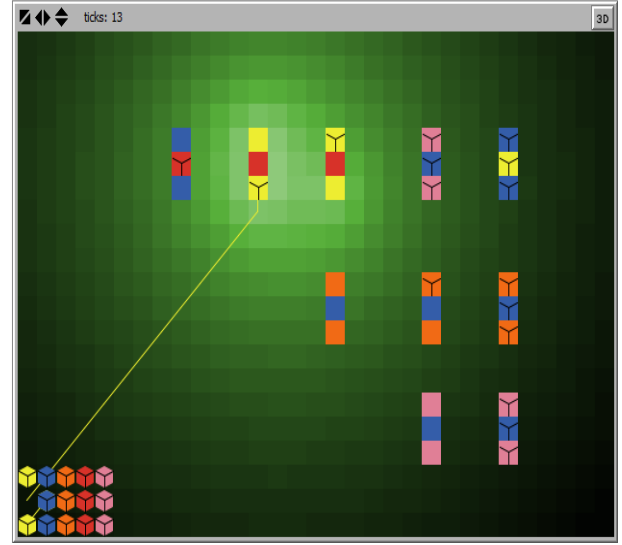
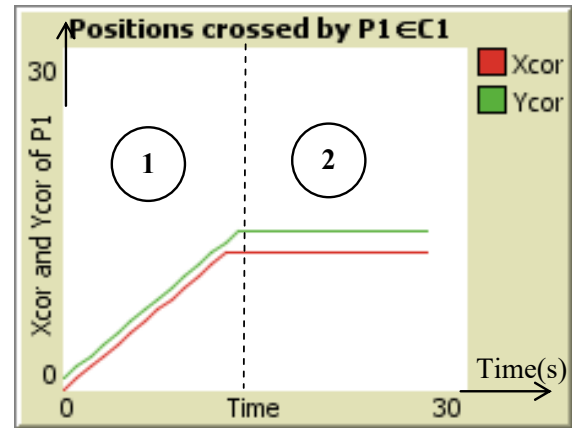


Figure 11 Coordinates X_{cor} and Y_{cor} of product movement $P_1 \in C_1$ to reach its destination safely (see online version for colours)



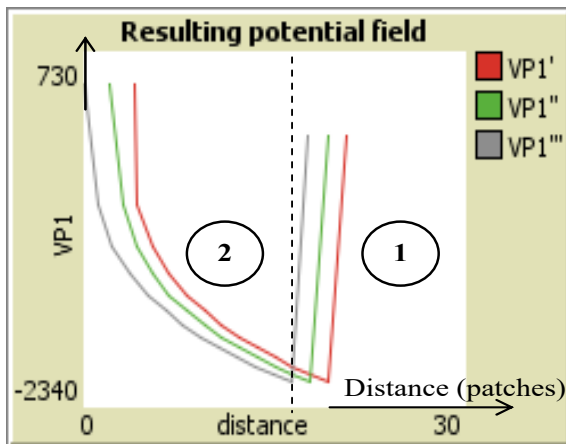
The curve in Figure 11 comprises two regions. Region #1 shows the product storage phase. It indicates that the coordinates X_{cor} and Y_{cor} change along the time until reaching its destination in duration of 14 s. Region #2 represents the fact that the product has reached its selected storage location where $X_{cor} = 12$; $Y_{cor} = 14$ and remain constants.

Let us analyse the resulting potential field variation as function of the distance given by $distance = \sqrt{x_{cor}^2 + y_{cor}^2}$, while product moves towards its storage location. Figure 12 shows the resulting potential fields variation of $P_1 \in C_1$. V'_{p1} is the attraction effect of the first free storage location, V''_{p1} is relative to the attraction effect of the second free storage location, and V'''_{p1} the attraction effect of the third free storage location. It must be read from right to left direction which corresponds to the decreasing of distance between product and target places during the movement.

The three curves of Figure 12 represent the potential field variation in function of the distance that separates the departure position of P_1 and the three suitable storage

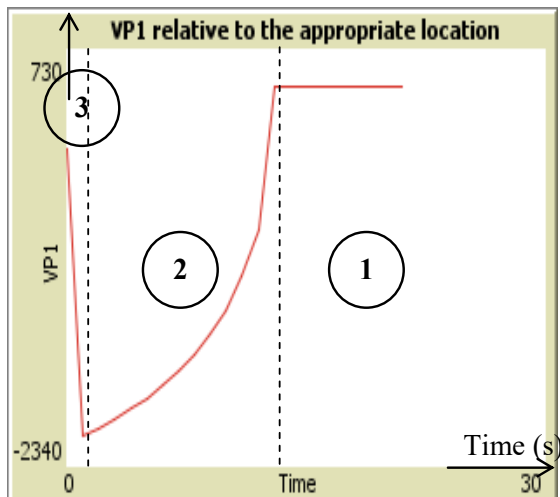
locations. Each curve relies on two regions. In region #1 we can observe a decreased value of V_{p1}' , V_{p1}'' and V_{p1}''' from 700 to $-2,340$. The same higher value is computed for three available emplacements for different distances from the departure location in the warehouse. Then we can deduce that the red curve is relative to the nearest available emplacement. In the second region both V_{p1} value increase from $-2,340$ to 730 which indicates that the product is close to its final position. The more the distance decreases the more the resulting potential field attraction effect increases. The red curve V_{p1}' represents the most attractive potential field relative to the nearest storage placement.

Figure 12 Resulting potential fields V_{p1}' , V_{p1}'' and V_{p1}''' variation in function of the distance (see online version for colours)



Now let us analyse the variation of the resulting potential field V_{p1} as a function of time as shown in Figure 13. The figure must be read from left to right direction which corresponds to the time line of the product movement. V_{p1} is the required field to lead the product to its appropriate location. The curve shows three different phases. In region #1, the resulting potential field V_p decreases from an initial value of around 700 to a negative value of about $-2,340$.

Figure 13 Resulting potential field V_{p1} variation in function of the time (see online version for colours)



The highest value of the resulting potential field V_{p1} in the first phase explains the potential field calculated initially to select the appropriate storage location before departure of the product. V_{p1} is the result of algorithm of selection of the appropriate storage zone (see Figure 7). Then the quick increase at the beginning of region #2 is due to the first movement step of the product where it begins executing the algorithm of path calculation (see Figure 8).

For region #2, the potential field gradually increases from $-2,340$ to 730 within 15 seconds, which reflects the product movement in the warehouse according to the steps of the path calculation algorithm. Indeed, the more the product approaches its destination the more the attractive potential field increases.

Region #3 represents the product arrival at its convenient location with a stabilised potential field V_{p1} at a constant value of about 730 which is the potential field value remaining at the destination place. So at this point the product is safely well stored in its appropriate emplacement.

By running the same scenario with the other classes of products, the method ensures the storage of all the new arrived ones, by applying algorithm of selection of the appropriate storage zone and algorithm of path calculation, for each product of each class.

The overall simulation sketch is shown in Figure 14. The results were obtained with the first product $P_1 \in C_1$. We remark that each product occupies its final position with respect to compatibility classes. It moves in the warehouse towards its destination while staying away from risky and inappropriate or occupied storage slots. Concerning the three products in pink, red and blue in the lower left corner of Figure 14 they still stay in the receiving area because there are no more free slots available to continue the storage process. The safety storage process is terminated.

Figure 14 Product class-based storage overall simulation (see online version for colours)



6 Conclusions and prospects

In this paper we presented a product class-based storage approach for safety warehouse using potential fields in IoT approach is proposed. This approach provides a better reactivity to allocate incompatible products in the appropriate storage zones in the warehouse, assuring security and safety of goods and people. Industrial deployment of RFID and IoT platform represents an ideal solution to implement our proposal for management of warehouses and to create collaboration between products and shelves. The product compatibility constraints monitoring will guarantee a product class-based storage efficiency and will reduce the time of storage with the minimisation of storage path followed by each product while determining its appropriate storage path.

The modelling and simulation of the proposed product class-based storage approach is performed on an agent-based simulation platform NetLogo which offers many advantages as a graphical user friendly interface and allows 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 optimisation of the path length crossed by the product to reach its appropriate storage location using optimisation techniques, and interactions between staff and products. A technical implementation in the Tunisian Chemical Group will be conducted with the use of RFID, communicating object and WSN.

References

- Ang, M., Lim, Y-F. and Sim, M. (2012) 'Robust storage assignment in unit-load warehouses', *Management Science*, Vol. 58, No. 11, pp.2114–2130.
- Ashton, K. (2009) 'That 'internet of things' thing', *In the Real World, Things Matter More than Ideas* [online] <http://www.rfidjournal.com/articles/view?4986> (accessed 22 March 2015).
- Baldi, M-M., Crainic, T-G., Perboli, G. and Tadei, R. (2012) 'The generalized bin packing problem', *Transportation Research Part E: Logistics and Transportation Review*, Vol. 48, No. 6, pp.1205–1220.
- Bassi, A., Bauer, M., Fiedler, M., Kramp, T., Kranenburg, R., Lange, S. and Meissner, S. (2013) *Enabling Things to Talk*, Springer, Heidelberg.
- Borgia, E. (2014) 'The internet of things vision: key features, applications and open issues', *Computer Communications*, Vol. 54, pp.1–31.
- Cai, Q., Zhan, Y. and Yang, J. (2015) 'RFID authentication protocol design methodology', *Int. J. Embedded Systems*, Vol. 7, No. 2, pp.91–103.
- Cedillo-Campos, M-G. and Cedillo-Campos, H-O. (2015) 'w@reRISK method: security risk level classification of stock keeping units in a warehouse', *Safety Science*, Vol. 79, pp.358–368.
- Crainic, T-G., Gobbato, L., Perboli, G., Rei, W., Watson, J-P. and David, L-W. (2014) 'Bin packing problems with uncertainty on item characteristics: an application to capacity planning in logistics', *Procedia – Social and Behavioral Sciences*, Vol. 111, pp.654–662.
- De Koster, R., Stam, D. and Balk B-M. (2011) 'Accidents happen: the influence of safety-specific transformational leadership, safety consciousness, and hazard reducing systems on warehouse accidents', *Journal of Operations Management*, Vol. 29, Nos. 7–8, pp.753–765.
- Dhebar, A. (1996) 'Information technology and product policy: smart products, M2M', *Management Journal*, Vol. 14, No. 5, pp.477–485.
- Ding, W. (2013) 'Study of smart warehouse management system based on the IoT', *Intelligence Computation and Evolutionary Computation*, pp.203–207, Springer, Berlin, Heidelberg.
- E-PRICE (2010–2013) *Price-based Control of Electrical Power Systems*, EU FP7 Project [online] <http://www.e-price-project.eu/> (accessed 1 March 2015).
- Finkenzeller, K. (2003) *RFID Handbook: Fundamentals and Applications in Contactless Smart Cards, Radio Frequency Identification and Near-Field Communication*, John Wiley & Sons, Inc., New York, NY, USA.
- Francis, R-L., McGinnis, L-F. and White, J-A. (1992) *Facility Layout and Location: An Analytical Approach*, 2nd ed., Prentice Hall International, Englewood Cliffs, NJ, USA.
- Gaci, O. and Mathieu, H. (2012) 'A dynamic risk management in chemical substances warehouses by an interaction network approach. New frontiers in graph theory', in D. Yagang Zhang (Ed.): pp.451–468, ISBN: 978-953-51-0115-4, InTech.
- Gadh, R., Roussos, G-K., Michael, G-Q., Huang, B-S., Prabhu, C-C. and Chu, P. (2010) 'RFID – a unique radio innovation for the 21st century', *Proceedings of the IEEE*, Vol. 98, No. 9, pp.1546–1549.
- Giannikas, V., Lu, W., McFarlane, D. and Hyde, J. (2013) 'Product intelligence in warehouse management: a case study', *Lecture Notes in Computer Science*, Springer, Vol. 8062, pp.224–235.
- Graves, S.C., Hausman, W.H. and Schwarz, L-B. (1977) 'Storage-retrieval interleaving in automatic warehousing systems', *Management Science*, Vol. 23, No. 9, pp.935–945.
- Guerriero, F., Musmanno, R., Pisacane, O. and Rende, F. (2013) 'A mathematical model for the multi-levels product allocation problem in a warehouse with compatibility constraints', *Mathematical Modelling*, Vol. 37, No. 6, pp.4385–4398.
- Gutiérrez, C., Garbajosa, J., Diaz, J. and Yagüe, A. (2013) 'Providing a consensus definition for the term "smart product"', *20th IEEE International Conference and Workshops on the Engineering of Computer Based Systems (ECBS)*, 22–24 April, Scottsdale, Arizona.
- Hasan, S-E. (2007) 'International practice in high-level nuclear waste management. Concepts and applications in environmental geochemistry', in D. Sarkar, R. Datta and R. Hannigan (Eds.): pp.57–77, Elsevier.
- IERC Cluster Book (2012) *The Internet of Things-New Horizons* [online] <http://www.internet-of-things-research.eu> (accessed 1 April 2016).

- IoT@Work (2010–2013) *Internet of Things at Work*, EU FP7 Project [online] <https://www.iot-at-work.eu/> (accessed 2 April 2016).
- IoT-A (2010–2013) EU FP7 Project [online] <http://www.iot-a.eu>.
- Kiritsis, D. (2011) 'Closed-loop PLM for intelligent products in the era of the internet of things', *Computer-Aided Design*, Vol. 43 No. 5, pp.479–501.
- Koren, Y. and Borenstein, J. (1991) 'Potential field methods and their inherent limitations for mobile robot navigation', *IEEE Conference on Robotics and Automation*, Sacramento, California, 7–12 April, pp.1398–1404.
- Kostantos, K., Kyriazis, D. and Themistocleous, M. (2015) 'Real-time event management in cloud environments', *Int. J. High Performance Computing and Networking*, Vol. 8, No. 3, pp.212–221.
- Li, Q., Zhu, G. and Miao, L. (2015) 'Developing operation layer of logistics information system based on EPCIS', *Int. J. Embedded Systems*, Vol. 7, No. 2, pp.115–122.
- Lim, M-K., Bahr, W. and Leung, S. (2013) 'RFID in the warehouse: a literature analysis (1995–2010) of its applications, benefits, challenges and future trends', *International Journal of Production Economy*, Vol. 145, No. 1, pp.409–430.
- Liu, Y. (2010) 'The research about information interaction design based on the usability of intelligent product', *International Conference on Networking and Digital Society*, 30–31 May, Wenzhou, China.
- Longo, F., Bruneo, D., Villari, M., Puliafito, A., Salant, E. and Wolfsthal, Y. (2015) 'Towards the future internet: the reservoir, vision cloud, and cloud wave experiences', *Int. J. High Performance Computing and Networking*, Vol. 8, No. 3, pp.235–247.
- López, T. and Ranasinghe, D. (2009) 'Taxonomy, technology and applications of smart objects', *Information Systems Frontiers*, Vol. 13, No. 2, pp.281–300.
- Manzini, R., Accorsi, R., Gamberi, M. and Penazzi, S. (2015) 'Modeling class based storage assignment over life cycle picking patterns', *International Journal of Production Economics*, Vol. 170, pp.790–800.
- Muppani, V-R. and Adil, G-K. (2008) 'A branch and bound algorithm for class based storage location assignment', *European Journal of Operational Research*, Vol. 189, No. 2, pp.492–507.
- Niskanen, I. (2011) 'Towards the future smart products systems design', *Pervasive Computing and Communications Workshops*, 21–25 March, Seattle, Washington.
- Nobel (2010–2013) *Neighborhood Oriented Brokerage Electricity and Monitoring System*, EU FP7 Project [online] <http://www.ict-nobel.eu/> (accessed 20 April 2015).
- Oliveira, R-R., Ismael, M-G. Cardoso Jorge, L-V-B., Cristiano, A-D-C., Mario, P-P. (2015) 'An intelligent model for logistics management based on geofencing algorithms and RFID technology', *Expert Systems with Applications*, Vol. 42, Nos. 15–16, pp.6082–6097.
- Ozcan, T., Celebi, N. and Esnaf, S. (2011) 'Comparative analysis of multi-criteria decision making methodologies and implementation of a warehouse location selection problem', *Expert Systems with Applications*, Vol. 38, No. 8, pp.9773–9779.
- Petersen, C-G., and Aase, G-R. (2004) 'Improving order-picking performance through the implementation of class-based storage', *International Journal of Physical Distribution & Logistics Management*, Vol. 34, No. 7, pp.534–544.
- Pourakbar, M., Sleptchenko, A., Dekker, R. (2009) 'The floating stock policies in fast moving consumer goods supply chains', *Transportation Research Part E*, Vol. 45, No. 1, pp.39–49.
- Ready, P-J., Gunasekaran, A. and Spalanzani, A. (2015) 'Bottom-up approach based on internet of things for order fulfilment in a collaborative warehousing environment', *International Journal of Production Economics*, January, Vol. 159, pp.29–40.
- RERUM (2013–2016) EU FP7 Project, *Reliable, Resilient and Secure IoT for Smart City Applications* [online] <https://ict-rerum.eu/> (accessed 15 April 2015).
- Rijsdijk, S. (2009) 'How today's consumers perceive tomorrow's smart products', *Journal of Product Innovation*, Vol. 26, No. 1, pp.24–42.
- Sallez, Y., Berger, T. and Tahon, C. (2004) 'Simulating intelligent routing in flexible manufacturing systems using NetLogo', *IEEE International Conference on Industrial Technology (ICIT)*, Hammamet, Tunisia, 8–10 December.
- Sanei, O., Nasiri, V., Marjani, M-R. and Moattar Hussein, S-M. (2011) 'A heuristic algorithm for the warehouse space assignment problem considering operational constraints: with application in a case study', *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Kuala Lumpur, Malaysia, 22–24 January.
- Shang, Y. (2012) 'Fast distributed consensus seeking in large-scale sensor networks via shortcuts', *Int. J. Computational Science and Engineering*, Vol. 7, No. 2, pp.121–124.
- Shqair, M., Altarazi, S. and Al-Shihabi, S. (2014) 'A statistical study employing agent-based modeling to estimate the effects of different warehouse parameters on the distance traveled in warehouses', *Simulation Modelling Practice and Theory*, Vol. 49, pp.122–135.
- Trab, S., Bajic, E., Zouinkhi, A., Abdelkrim, M-N., Chekir, H. and HadjLtaief, R. (2015) 'Product allocation planning with safety compatibility constraints in IoT-based warehouse', *The International Conference on Advanced Wireless, Information, and Communication Technologies, AWICT*, 5–7 October, Sousse, Tunisia.
- Trentesaux, D., Grabot, B. and Sallez, Y. (2013) 'Intelligent products: a spinal column to handle information exchanges in supply chains', *Advances in Production Management Systems, Sustainable Production and Service Supply Chains IFIP: Advances in Information and Communication Technology*, Vol. 415, pp.452–459.
- Tsamis, N., Giannikas, V., McFarlane, D., Lu, W. and Strachan, J. (2015) 'Adaptive storage location assignment for warehouses using intelligent products', *Service Orientation in Holonic and Multi-agent Manufacturing: Studies in Computational Intelligence*, Vol. 594, pp.271–279.
- Vidal, J-M., Buhler, P. and Goradia, H. (2004) 'The past and future of multi agent systems', in *Proceeding AAMAS workshop on Teaching Multi-agent Systems*, New-York, USA, 19–23 July.
- Vrysagotis, V. and Kontis, A-P. (2011) 'Warehouse layout problems: types of problems and solution algorithms', *Journal of Computations and Modelling*, Vol. 1, No. 1, pp.131–152.

- Woolridge, M. and Jennings, N-R. (1995) ‘Intelligent agents: theory and practice’, *Knowledge Engineering Review*, Vol. 10, No. 2, pp.115–152.
- Yang, L. and Ye M. (2014) ‘The design and development of intelligent warehouse management system based on .NET and internet of things’, *International Conference on Logistics Engineering, Management and Computer Science*, 24–26 May, Shenyang, China.
- Zaeh, M-F., Reinhart, G., Ostgathe, M., Geiger, F. and Lau, C. (2010) ‘A holistic approach for the cognitive control of production systems’, *Advanced Engineering Informatics*, Vol. 24, No. 3, pp.300–307.
- Zhengxia, W. and Laisheng, X. (2010) ‘Modern logistics monitoring platform based on the internet of things’, in *International Conference on Intelligent Computation Technology and Automation, ICICTA*, Vol. 2, pp.726–731.
- Zouinkhi, A., Bajic, E., Rondeau, E. and Ben Gayed, M. (2011) ‘Ambient intelligence: awareness context application in industrial storage’, *Wireless Sensor Network*, Vol. 3, No. 3, pp.135–146.