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Warehouse Design and Operation using Augmented Reality technology: A Papermaking Industry Case Study

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Abstract

In modern, high competitive markets, efficient warehousing is critical as it accounts for a great part of logistics costs. Companies try to adopt highly adaptive and flexible warehouse design that may support the integration of novel technologies such as Augmented Reality (AR). This paper proposes a framework for warehouse design which minimizes inventory cost while keeping a high degree of service by supporting the integration of an AR warehousing system. The AR system will support the effective management of operations, by providing meaningful information. The proposed methodology is tested and validated in a real-life case study of a papermaking industry.

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Keywords: Warehouse design; Augmented reality; Warehouse simulation; Manufacturing

1 Introduction

Warehouses are a key aspect of modern supply chains and play a vital role in the success, or failure, of businesses today, since they: a) provide storage for raw materials, components, work-in-process, and finished goods b) operate as distribution and order fulfilment centres and c) perform localized and value-added warehousing [1]. For these reasons, warehouses have to be highly adaptive to the production rate so as to reach optimal operation level. Inventory management and control is the key to warehouse design and optimization. The main goal of inventory management and control is to optimize three targets: customer service, inventory costs, and operating costs. Service level must be kept at high levels while inventory and operation costs must be minimized [2].

Warehouse design demands a very methodical and well-structured approach due to warehouse complexity. Warehouse design is highly complex as it is a multi-criteria problem, with interconnected functions and parameters. Warehouse simulation is a commonly used approach to improve its design [3]. Novel digital solutions have been proposed in the literature and also the market that support effective warehouse design, considering different criteria [4] so as to support decision making while offering simulation features that may visualize the functionality of the designed warehouse.

Additionally, novel technologies that shape manufacturing have found fertile ground in different fields [5]. Starting from simpler combinations on laser scanners and barcodes, contemporary warehouses try to integrate new technologies to facilitate managing warehouse available stock and effective product localisation, especially in larger facilities [6]. Utilizing wearables, such as smart watches and head-mounted displays, the operators may easily report product input/ output in the warehouse, while also retrieve the position of a stored product [7]. Using advanced visualization techniques, such as Augmented Reality, the operators may intuitively be guided to find a stored product and easily report stock updates [8].

This paper proposes an adaptive methodology for warehouse design while integrating Augmented Reality. Logistics and statistical analysis has been used and the final is designed according to Economic Order Quantity (EOQ) model, aiming to minimize inventory cost. Additionally, an

Augmented Reality based system to support warehouse management, connecting the operators with a central inventory management platform. To verify the proposed design, it is applied in papermaking industry.

2 State of the art

According to ELA (2004), the capital and operating costs of warehousing in Europe represent about 25% of logistics costs, whilst figures for the USA show that warehousing contributes to about 10% [9]. In spite of warehouse significance in supply chain, there is limited effort in the literature towards that direction [10]. Although, publications show that there is an abundance of information written on analyzing particular aspects of warehouse designing problem, it is the combination of all these aspects that has to be taken into consideration and classified in a strict order so as act as a basis for a successful approach to warehouse design [11].

Warehouse design problems have been early reported in the literature. Oxley [12] presents a comprehensible list of steps which are based on the key features of the previous authors, while also defining the overall system requirements of the supply chain. He emphasizes that the warehouse design should be focused on the storage and handling requirements and that the building should then be designed around these. This basic framework of steps is also enhanced by Rowley [13] with Oxley's contribution.

Simulation models have been applied since the early 1980's through basic simulation packages as presented by Ashayeri, et al. [14]. Most of the research done in simulation field is due to the need for optimal warehouse design and planning, where novel technologies could be early adopted. For example, Automated Guided Vehicle (AGV) transport systems where soon adopted in warehouse applications [15]. Gu et al. provided an extensive overview of warehouse performance analysis models, claiming that simulation models are typically used for evaluating one design alternative, but that they are less suited for design-space exploration [4]. Andriansyah et al. presented a layered warehouse simulation model built from reusable components that considers varying number of storage aisles and workstations in a miniload-workstation order-picking system [16].

A further step has been added to the former publication which has to do with the use of computer simulation. Rouwenhorst et al. stated that a design process runs through a hierarchical framework, identifying strategic, tactical and operational decisions [11]. Rushton et al. (2006) have made a refinement of steps in their earlier edition so as to recognize the importance of flexibility in warehouse design issue [17]. The iterative nature of design process is clarified by the equipment and staffing calculations now being presented after the layout design rather than before, as with most other frameworks. Baker and Canessa explored the current literature on the overall methodology design, validated and refined the general results from the literature with reference to warehouse companies [18]. Accorsi et al. applied an integrated decision-support system for the design and management of a storage system [19]. Mital and Krejci presented a modelling framework and an effective algorithm to design material handling systems and warehouses by the identification of the possible system configurations [20]. Thomas and Meller presented a statistical-based methodology to develop guidelines, used to design a manual and case-picking warehouse [21]. The aforementioned publications make apparent warehouse design follows a structure sequence of interdependent steps.

Nevertheless, there are many differences among the various approaches described above, which steam from the various combinations of design process activities when they are grouped into steps [18]. The past few years, warehouse planning was considered to be a very complex issue due to the absence of the simulation and computing power [3]. In many cases, it was not feasible to experiment on real environment as production rate did not allow to make changes. Nowadays, there are many simulation tools that make warehouse design and planning easier and give to the industry the opportunity to test different scenarios, supporting decision making [22].

A technology that starts to gain ground in industrial applications is Augmented Reality. From knowledge distribution through technical instructions in assembly tasks [23] to remote maintenance support [24], AR is tested in different applications, until it becomes mature enough (both from hardware but also from technical knowledge side) to be fully integrated into manufacturing. Its applicability, as it may be used through various host device, and its mobility has proven to be a great advantage that allows it to be easily used in the production line [25]. Additionally, it has proven to be useful for providing positioning instructions, both in maps navigation but also in large warehouse facilities for inventory management and package retrieval, facilitating the operators to efficiently manage large facilities with changing stocks (such as the case of logistics warehouses) [8].

Based on the aforementioned literature review, it becomes apparent that simulation modelling, in terms of warehouse design, is a one-way selection [26]. This happens due to the fact that simulation models can be extremely valuable, timely and cost-effective means to study the performance characteristics of a proposed warehouse layout. Additionally, novel technologies that may improve inventory management and increase the efficiency of product retrieval in vast warehouses are welcome. Towards that end, this paper suggests a method for warehouse design, considering the integration of mobile devices and Augmented Reality to support product location retrieval by the warehouse operators and efficient inventory management. The developed approach is applied in a papermaking industry for validation.

3 Warehouse design to support Augmented Reality package retrieval

This paper presents an innovative and easy to adapt methodology which can give a reliable solution to the problem of warehouse design and simulation that seems to concern the majority of the industries in our days. This methodology aims to keep a high service level while minimizing the inventory costs.

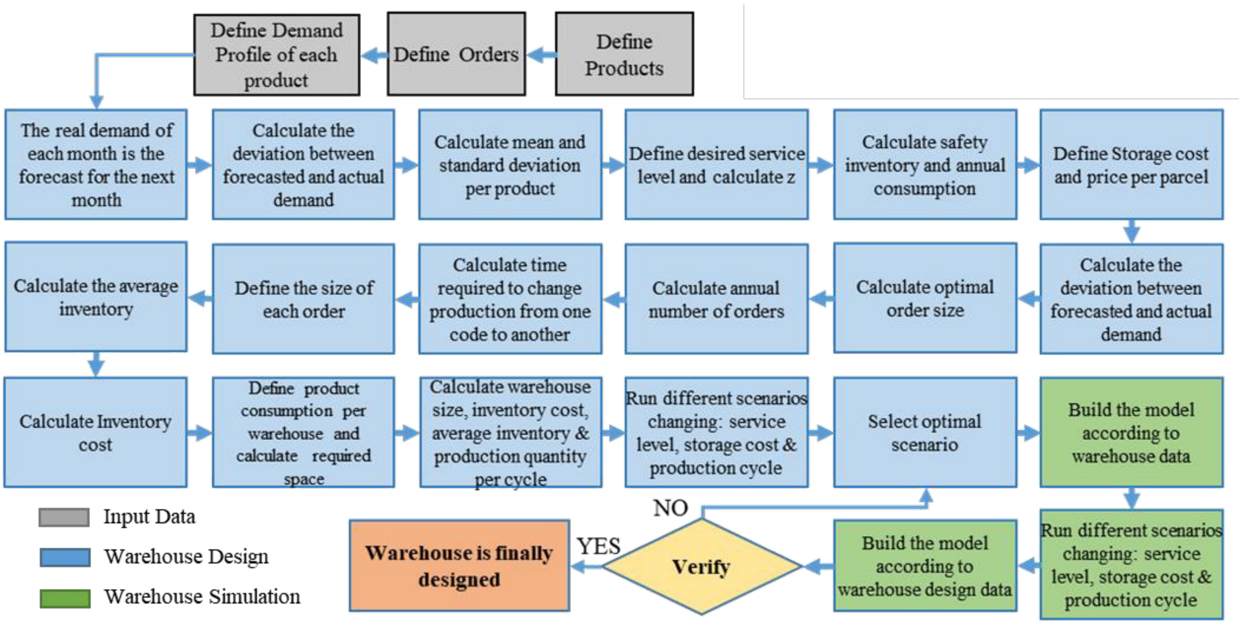

Fig. 1. Workflow of the proposed methodology.

It has to be pointed out a set of assumptions have been made to tackle the obstacles in the following categories: a) demand uncertainty, b) Constant Order Quantity, c) Constant Re-Order Point, d) Suppliers/Production Inconsistency and e) Economic Order Quantity model. The methodology consists of two basic parts with a total number of 23 steps; warehouse design (18 steps) and warehouse simulation (5 steps) as presented in Figure 1.

3.1 Warehouse Design

The design of a well-structured warehouse system concerns a large number of interrelated decisions/ steps which have to be placed in a hierarchical framework. Input data are crucial for reaching a viable verdict on the proper operation. In our methodology, three input data are inserted: products, orders and demand profiles. Then, the proposed methodology is followed to define the warehouse design requirements. The steps of the proposed methodology are listed below (also presented Figure 1 in blue color):

1. Based on the real demand, the forecast for the next month is created
2. its deviation from the real demand is calculated
3. The mean and standard deviation for each product is calculated
4. Define the desired service level and based on that, the z value
5. Calculate safety inventory and the annual consumption
6. Calculate storage cost and parcel price
7. Calculate the deviation between forecasted and actual demand
8. Calculate Economic Order Quantity
9. Define the number of annual orders
10. Calculate time for inventory re-ordering
11. Define the size of order
12. Calculate average inventory
13. Calculate the inventory cost
14. Define product consumption and required warehouse size
15. Calculate final warehouse metrics (size, inventory costs, productivity)
16. Re-run for different values for service level, storage cost and production cycle
17. Define the optimal scenario, which minimizes inventory costs and warehouse size
18. Design the warehouse layout.

3.2 Warehouse simulation

Warehouse simulation is a way of testing different scenarios in real life without any interruption in the production rate. As a result, it gives the opportunity to compare and select the best scenario which will cover warehouse demands. According to warehouse design data, the warehouse model is built. The warehouse model includes: a source for each product, a queue before and after each palletizing station, forklifts according to warehouse capacity which carry pallets to warehouse, the calculated warehouse area where products are stocked, forklifts according to warehouse capacity which carry pallets from warehouse area to each loading area/ exit and a queue to each loading area-exit.

All the above are properly linked and programmed so as to simulate a virtual warehouse environment and operation, while the parameters of each testing scenario are defined. Then, the possible warehouse layouts are defined and run, while their performance is compared and the optimum solution is selected. The result is then verified, comparing the results from the simulation and the design methodology, and if valid, is applied in the warehouse.

3.3 Augmented Reality application for inventory management

Together with the new layout that will be suggested, an application that will support inventory management and warehouse operators' guidance to the position of the product is developed. The application allows the operator to have constant connection with the database of the available stock, record product entries or exits, while also being able to ask for navigation instructions inside the warehouse. The application targets mobile devices, so as to be easy to use in the warehouse, offering increased mobility and enabling access from everywhere to the available stock.

The application hosts a user-friendly interface, which aims to be used by warehouse operators and/or warehouse vehicles drivers. The application offers three functionalities: monitor available stock, manage product (un-)loading and navigation. To visualize current stock, a top-down depiction of the warehouse is used. The operator may select one storing department and see what is stored there. Additionally, a list option is also available. To (un-)load products, QR codes are placed on each pallet of products but also on all the storage shelves, so that the operator may easily scan the QR codes and update the inventory management database for product input and output. Finally, to facilitate the retrieval of products, Augmented Reality navigation instructions are available. The operator provides the product that needs to be retrieved and the application navigates him to it.

4 Case Study and results

This methodology has been applied to a papermaking industry in order to give a solution to warehouse design problem. Targeted industry has to cope with a very high inventory cost which stems from the bad warehouse design and management systems that is currently applied. The developed methodology has been adapted on the warehouse of final products, in close collaboration with experts from the papermaking industry production line.

There are four basic categories of final products which are taken into consideration: 1) kitchen paper 2) rough toilet paper 3) 3-plies toilet paper and 4) 4-plies toilet paper. The demand profile for each product is generated based on actual 8 months demand, as given by the industry. The main targets were to minimize the storage costs while keeping a high service level of about 95% and 98%. Adjusting the proposed methodology to the industrial use case needs, we assumed that the cost of production stems only from the cost of machines' set up. All the methodology has been based on Fixed Order Quantity System with no-constant demand and order time.

4.1 Warehouse Design

Twelve scenarios have been run for 53 final products following real industrial specifications. The scenarios come from the combinations of the possible storage levels (95 or 98%), the storage costs (16, 18 or 20%) and the production cycle duration (1 or 2 months). The selection is based on two basic criteria:

- Minimum inventory cost (first priority)
- Minimum warehouse size (second priority)

Regarding all the above results for twelve scenarios, the one with 95% Service level, 18% storage cost and 1 month production cycle seems to fulfil industry's expectations. The main decision making criteria are highlighted in bold.

Table 1. Results for 1 months, 18% storage cost and 95% Service level

Criterion	Unit	Proposed solution
Safety Inventory	Parcels	30185
Average Inventory	Parcels	55010
Inventory Cost	Euro/ Year	179449
Warehouse Size	M^2	1802
Production Quantity (per month)	Parcels	44983

After selecting the optimum scenario, the CAD of the warehouse layout is created, considering some basic criteria:

a) First-In-First-Out must be served as often as possible so as to limit the possibility for the products to spoil (≥2 columns unless we have access from both sides).
b) The existing space must be used as efficiently as possible.
c) There are two types of pallets: the dimensions of each is either 1,40m*1,40m*0,15m or 1,2m*0,8m*0,15m.
d) Integer number of columns and rows must be used for each code.
e) Stack support must be secured at all times. That means that single columns must not have more than 2 pallets.
f) Warehouse surface must be as small as possible.

The layout has been based in real dimensions taken from the existing warehouse storage area and are used for placing inside these limits the existing and the new warehouse layout. The main disadvantage of the existing layout, which is presented in Figure 2, is that bulky storage areas are created for each product, which prevents from FIFO serving and make products reachability a tough issue. Another disadvantage that makes current layout has is that products are not supported so well.
The proposed layout indicates a new way to store the products (Figure 3). This scenario allows FIFO to be served to a greater extend and offers a better reachability for most of products due to the fact that smaller spaces are created. Moreover, following this layout warehouse achieves higher structural support of the piles and increased functionality.

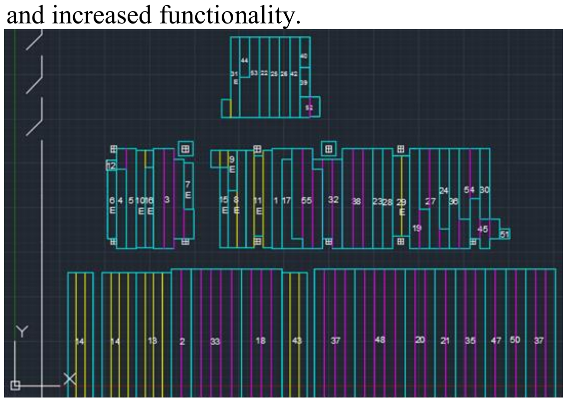

Fig. 2. Existing warehouse layout.

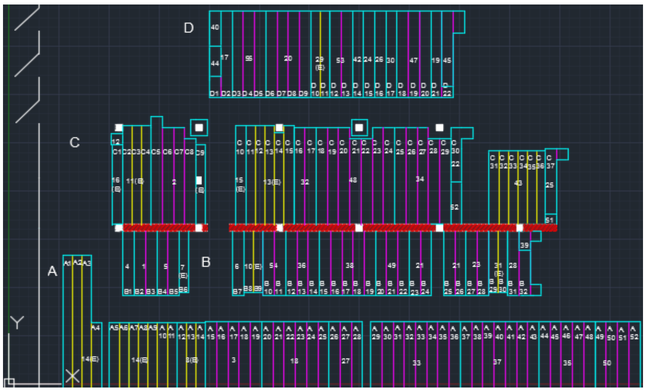

Fig. 3. New warehouse design.

4.2 *Warehouse simulation*

In our case, in order to as to simulate the warehouse operation and verify the proposed design a simulation tool named Enterprise Dynamics® 10 has been used. The two aforementioned design scenarios (existing and proposed) have been inserted in the simulation tool.

The two models have identical modelling resources: i) 53 different products generated from 53 sources, ii) 3 different queues where all products hold before they pass from the palletizing stations, iii) 3 different assemblers which represent the 3 palletizing stations, iv) 2 different kinds of pallets with two different sources, v) 1 queue after each palletizing station where products wait until the forklift comes and dispatches them to the warehouse, vi) 1 forklift for transporting products, vii) The warehouse area where products are stored, viii) 1 queue for each exit where products hold to leave the warehouse and ix) 3 exits. All of them are properly linked and programmed so as to simulate the real industrial environment. The programming language used is 4D-Script. In Figure 4 a 3D screenshot of the simulation model is presented.

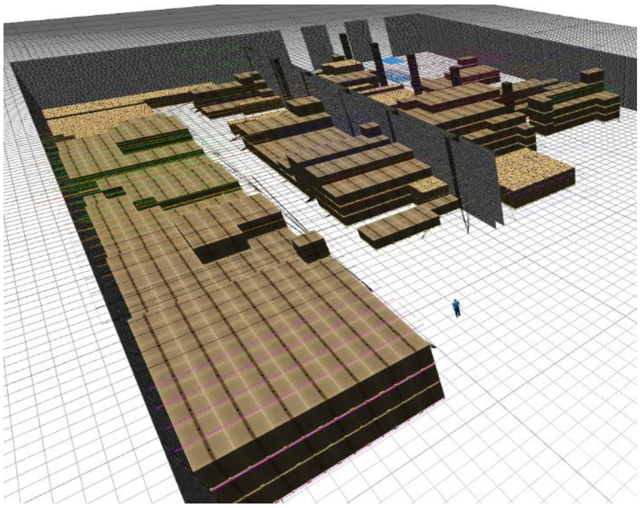

Fig.4. 3D representation of the suggested layout in Enterprise Dynamics.

4.3 *Augmented Reality application for inventory management*

Together with the new layout design, an application that will support inventory management and warehouse operators' guidance to the position of the product is suggested. Its functionalities are presented in Figure 5. The suggested layout facilitates and also necessitates the integration of the developed AR application, as more storage partitions are created so as to smoothen the transition to the new layout for the operators. To digitalise the process of registering input and output of products, QR codes are placed in the warehouse compartments and each pallet or product. With the new QR code-based system, inventory management is simplified and enables constant awareness of the available stock. Using the developed application, the operators can navigate and act more efficiently whenever a request is sent to the warehouse. The application offers three features: view available stock, find a product in the warehouse and report a new entry.

In the first option, the operator or the warehouse manager may monitor the available stock. A top-down layout of the warehouse is presented, where a compartment may be selected to see what is stored in it. The two other functionalities aim to

Fig. 5. Augmented reality-based application for warehouse management support.

support product input and output registration. In the case of new product entry to the warehouse, the operator may scan the QR code on the product and on the storage shelf/ compartment so as to quickly register a new product in the warehouse database.

The last functionality helps to retrieve a specific product in the warehouse. As a new warehouse layout is suggested, and also because the operators tend to change what product is stored in each compartment, an Augmented Reality based guidance is introduced. The operator may provide, through the mobile application, a request to retrieve a product's position from the database and be guided to it. Using device's GPS and the corresponding warehouse compartment's position, as stored in the database, the operator is guided to find it. This application may be used by operators, using either handheld equipment or pallet transfer vehicles.

5 Conclusion

To sum up, warehouse design and planning is an ever-existing challenge in manufacturing that highly affects the efficiency of the warehouse. Many solutions have been proposed in the literature but it still seems to be an open issue for research. The developed methodology presents a step-by-step way to design and plan a warehouse which initiates from inventory control and management and is completed with a warehouse simulation so as to verify warehouse design. Additionally, an Augmented Reality based mobile application is introduced. The application aims to facilitate warehouse management, supporting efficient navigation and product retrieval, which could be extended to logistics warehouse, where there the product stock is constantly changing, thus finding it becomes more difficult for the operators.

For future work, a more throughout analysis of the fluctuating customer demand will be performed, in order to improve the design of the stock levels. Moreover, lost sales cost analysis due to low inventory level and the cost from the unpredictable changing of the production line in order to serve some large orders. Additionally, the developed Augmented Reality application will be extended to other warehouse management use cases.

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References

[1] Frazelle E. Supply Chain Strategy: The Logistics of Supply Chain Management, 2002 McGraw-Hill, New York
[2] Wild T. Best Practice in Inventory Management, 2002, 2nd edition.
[3] Mourtzis D, Doukas M, Bernidaki D. Simulation in manufacturing: Review and challenges. Procedia CIRP. 2014 Jan 1;25:213-29.
[4] Gu J, Goetschalckx M, McGinnis LF. Research on warehouse design and performance evaluation: A comprehensive review. European Journal of Operational Research. 2010 Jun 16;203(3):539-49.
[5] Mourtzis D, Doukas M. The Evolution of Manufacturing Systems: From Craftsmanship to the. Handbook of Research on Design and Management of Lean Production Systems. 2014 Jan 31:1.
[6] Novák V, Krajčovič M. Warehouse Management System. TRANSCOM. 2011;23.
[7] Donnawitz, D. Industry 4.0 is transforming the warehouse sector, Perle, 2016. Available online: https://www.perle.com/articles/industry-4.0-is-transforming-the-warehouse-sector-40140747.shtml
[8] Fraga-Lamas P, Fernández-Caramés TM, Blanco-Novoa Ó, Vilar-Montesinos MA. A Review on Industrial Augmented Reality Systems for the Industry 4.0 Shipyard. IEEE Access. 2018;6:13358-75.
[9] Establish Inc./ Herbert W. Davis & Co. Logistic Cost and Service, CSCMP Global Conference; 2010.
[10] Kostrzewski M. Simulation method in research on material-flow in a warehouse. Logistics and Transport. 2014;21.
[11] Rouwenhorst B, Reuter B, Stockrahm V, van Houtum GJ, Mantel RJ, Zijm WH. Warehouse design and control: Framework and literature review. European Journal of Operational Research. 2000;122(3):515-33.
[12] Oxley B. Avoiding inferior design. Storage Handling and Distribution, 1994; 38(2): 28-30
[13] Rowley J. The principles of warehouse design. The Institute of Logistics & Transport, Corby. 2000.
[14] Gelders L, Ashayeri J, Van Looy P. A Simulation Package for Automated Warehouses. Material Flow. 1983;1(3).
[15] Hibino H, Fukuda Y, Fujii S, Kojima F, Mitsuyuki K, Yura Y. The development of an object-oriented simulation system based on the thought process of the manufacturing system design. International journal of production economics. 1999 Apr 20;60:343-51.
[16] Andriansyah R, De Koning WW, Jordan RM, Etman LF, Rooda JE. A process algebra based simulation model of a miniload-workstation order picking system. Computers in Industry. 2011 Apr 1;62(3):292-300.
[17] Rushton A, Croucher P, Baker P. The handbook of logistics and distribution management: Understanding the supply chain. Kogan Page Publishers; 2014 Jan 3.
[18] Baker P, Canessa M. Warehouse design: A structured approach. European Journal of Operational Research. 2009 Mar 1;193(2):425-36.
[19] Accorsi R, Manzini R, Maranesi F. A decision-support system for the design and management of warehousing systems. Computers in Industry. 2014;65(1):175-86.
[20] Mittal A, Krejci CC. A hybrid simulation model of inbound logistics operations in regional food supply systems. In Winter Simulation Conference (WSC), 2015:1549-1560
[21] Thomas LM, Meller RD. Developing design guidelines for a case-picking warehouse. International Journal of Production Economics. 2015 Dec 1;170:741-62.
[22] Mourtzis D, Papakostas N, Mavrikios D, Makris S, Alexopoulos K. The role of simulation in digital manufacturing: applications and outlook. International journal of computer integrated manufacturing. 2015 Jan 2;28(1):3-24.
[23] Rentzos L, Papanastasiou S, Papakostas N, Chryssolouris G. Augmented reality for human-based assembly: using product and process semantics. IFAC Proceedings Volumes. 2013 Jan 1;46(15):98-101
[24] Mourtzis D, Vlachou A, Zogopoulos V. Cloud-based augmented reality remote maintenance through shop-floor monitoring: a product-service system approach. Journal of Manufacturing Science and Engineering. 2017;139(6):061011.
[25] Mourtzis D, Vlachou E, Zogopoulos V, Fotini X. Integrated production and maintenance scheduling through machine monitoring and augmented reality: An Industry 4.0 approach. InIFIP International Conference on Advances in Production Management Systems 2017 Sep 3 (pp. 354-362). Springer, Cham.
[26] Efthymiou K, Sipsas K, Mourtzis D, Chryssolouris G. On knowledge reuse for manufacturing systems design and planning: A semantic technology approach. CIRP Journal of Manufacturing Science and Technology. 2015 Jan 1;8:1-1