The role of Industry 4.0 enabling technologies in layout design and management: Current scenario and future developments

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Abstract: In recent years, the design and management of production systems is radically changing with the advent of Industry 4.0 era. Innovations introduced and obtained thanks to the application of Industry 4.0 principles consist in the integration of the so called "nine pillars of technologies" in manufacturing management, leading to the transformation of the conventional factory into a smart factory. More specifically, the introduced innovations involve multiple aspects and areas of the production systems. In this scenario, the aim of this study is to investigate enabling technologies of Industry 4.0, focusing on technologies that have a greater impact on layout design and management. Main characteristics of these technologies will be identified and described according to their application. In order to draw the current scenario, a literature review was performed to answer the research question in a comprehensively way. Results show how simulation, big data and cloud computing are the most used applications. Moreover, we found that the implementation of almost all Industry 4.0 technologies can bring benefits to the layout design, even in sectors other than industrial ones.

Keywords: Industry 4.0, Plant Layout, Management, Manufacturing Systems, Literature Review

1. Introduction

Industry 4.0 denotes the current trend of transformation in manufacturing Industry, also known as the fourth Industrial revolution (Kagermann et al., 2013; Schwab, 2017). Able to revise the approach to the manufacturing, Industry 4.0 involves efforts to "makes use of the latest technological inventions and innovations, particularly in merging operational and information and communication technology" (Gilchrist, 2016, p.186). In a recent literature review (Oztemel and Gursev, 2020), more details have been added to Industry 4.0 definition, defining it as a manufacturing philosophy enabling together latest automation systems and a flexible and effective exchange of data, towards a more innovation in design, process and production. Considering any definitions given, such as a revolution, an approach or philosophy, the assumption that should be highlighted is that Industry 4.0 involves the implementation of new technologies in a broad range of applications in future industries. As it is easy to suppose, many industries have begun to integrate Industry 4.0 in their operations, with the aim to continue in remaining competitive in the market. Such technologies are grouped in the so called "nine pillars" (Alqahtani et al., 2019; Jazdi, 2014; Silvestri et al., 2020) and able to convert a conventional factory into a "smart" factory (Zolotová et al., 2018), characterized by automation and optimized manufacturing processes, technologies are: 1) Industrial Internet of Things (IIoT) and Cyber Physical Systems (CPSs); 2) Big Data; 3) Horizontal and vertical integration of systems; 4) Simulations; 5) Clouds; 6) Augmented Reality; 7) Autonomous Robots; 8) 3D printing; and 9) Cyber Security.

Many of these technologies can be incorporate in the design process of layout design and management, such as Big Data, IIoT, and CPSs. Layout drivers, that include enabling technologies, tools and techniques, manufacturing systems, and supporting factors, have a key role in the layout design (Al-Zubaidi et al., 2021).

For example, Big Data can address the issue of the facility layout problem in manufacturing plants. Big Data allows to efficiently handle the large scale of required data, reducing the production time, improving the accuracy and precision of the manufacturing system by means of the establishment of innovative creative processes (Kumar et al., 2018). In fact, Big Data is the key technology for solving real-world problems, especially when smart factories elaborate a huge amount of heterogeneous data and requiring time-consuming elaborations (Tayal et al., 2020).

Data gathering and manipulation are enabled by IIoT and CPSs, being able to be used for assessing the quality of every machine or production system. For example, it is possible to use IIoT for considering imperfect descriptions of the network layout in respect to the theoretical one. Furthermore, IIoT lets to easily perform post-layout

validation steps when the data gathering is achieved via the IIoT (Savazzi et al., 2014).

Also, CPSs can be employed to improve the factory layout, transportations and ergonomics through simulation and optimization tools. Such implementation can be divided into four main steps, that are: 1) modeling, 2) simulation, 3) presentation, and 3) interaction, enabling a fast teamworking and multidisciplinary problem-solving among technologists, production systems designers, designers and planners (Al-Zubaidi et al., 2021). As result, time and money savings and a faster time-to-market of the product can be achieved (Mladineo et al., 2017).

The aim of this paper is to provide, through a Systematic Literature Review, a comprehensive investigation on technologies enabling the Industry 4.0 that had the greatest impact on the industrial layout, highlighting their peculiar characteristics and main related aspects. While comparable studies have been performed for analyzing the transformation process towards Industry 4.0 technologies in manufacturing enterprises, e.g. in relation to human factors and ergonomics (Reiman et al. 2021), maintenance transformation (Silvestri et al. 2020), barriers for the implementation of the additive manufacturing (Hernandez Korner et al. 2020), and techniques for the use of cyber-physical systems (Dafflon, Moalla, and Ouzrout 2021), to the authors' best knowledge, this is the first review study that defines the state-of-the-art of Industry 4.0 technologies currently applied for the layout design and management.

2. Materials and method

In order to evaluate the interest of the scientific community in the application of Industy 4.0 technologies to the design and management of the layout and in order to investigate the current trends, a Systematic Literature Review (SLR) has been performed. The SLR is a methodical way to identify and assess the existing state of knowledge related to a given question. Because of its high transparency, scientific and replicable character (Tranfield, Denyer, and Smart 2003), it differs from the conventional review for avoiding the risk of bias introduction and lack of a critical analysis (Tranfield, Denyer, and Smart 2003; Briner and Denyer 2012; Kitchenham 2004). A methodological design is required to understand the state of knowing for the given question, as well as, at the same time, for identifying what is not known in the investigated research area (Briner, Denyer, and Rousseau 2009).

In particular, the proposed methodology consists in the following steps: 1) the formulation of the research question; 2) the examination of literature review according to identified key themes; 3) the selection of articles that match with the research criteria; 4) the creation of a database containing the selected documents 5) the analysis of results from the database and their discussion. An overview of the SLR process followed in the present study is shown in Table 1. An overview of the SLR process followed in the present study is shown in Table 2.

This research study aims to address to the following research question:

- *Which are the Industry 4.0 technologies that had the greatest impact on the industrial layout?*

The data were from main electronic databases, including Scopus (scopus.com), IEEE (ieeexplore.ieee.org), Google Scholar (scholar.google.com) and Web of Sciences (WoS). Furthermore, only peer-reviewed journal and conferences have been considered. Databases have been explored through several research strings (Table 1), combining each Industry 4.0 technology and the term "layout" with the Boolean operator <AND>.

Table 1. Research strings considered.

Research Strings
"internet of things" AND "layout"
"simulation" AND "layout"
"additive manufacturing" AND "layout"
"augmented reality" AND "layout"
"cloud" AND "layout"
"big data analytics" AND "safety management"
"advanced manufacturing" AND "layout"
"horizontal e vertical integration" AND "layout"
"cyber security" AND "layout"

In a second step, the selection process of documents was first based on the screening of documents matching the aforementioned research criteria; in detail duplicates and documents that did not correspond to the purpose of the research were removed. Furthermore, In the following two steps, specific selection criteria based on subject areas and document types were applied. The steps followed for the selection process are summarized in Table 2

As mentioned before, selected articles were summarized in a database, that helped authors to characterize and analyze studies according to the purpose of the research.

Table 2. Research steps considered for documents selection.

	Document selection
Step 1	*Formulation of the research question*
Step 2	*the examination of literature review according to identified key themes*
Step 3	*the selection of articles that match with the research criteria*
Step 4	*the creation of a database containing the selected documents*
Step 5	*the analysis of results from the database and their discussion*

3. Literature review outputs

After the first research (Step 1) a total of 502 documents has been found in Scopus database. By analyzing the outputs of Step 1 described in table 2, it was possible to obtain preliminary results to provide a global vision of the research topics in terms of diffusion and interest of the scientific community.

In Figure 1 the temporal distribution of papers is showed and, as it is possible to see, the global trend is growing and there is a significant increase in published documents during 2019 and 2020.

Figure 2 shows the distributions of subject areas for the obtained documents; As expected, Engineering (37.5%) and Computer Science (18.8%) are the most involved research areas.
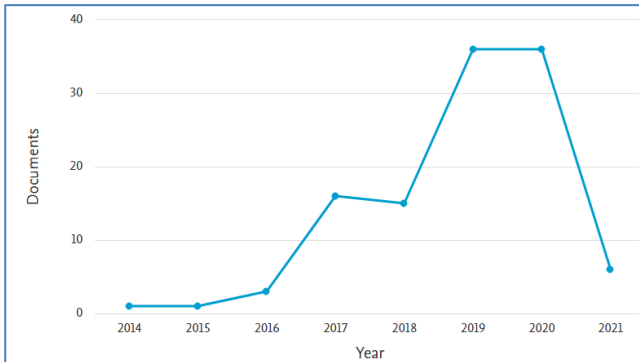
Figure 1. Temporal distribution of documents after Step 1.

After a first analysis, the selection process has been completed, identifying the most significant documents for the research object. As a result, a total of 146 articles and reviews present in literature from 2010 to 2021 has been considered. In table 3 the number of documents for each technology is shown, resulting from the selection process.
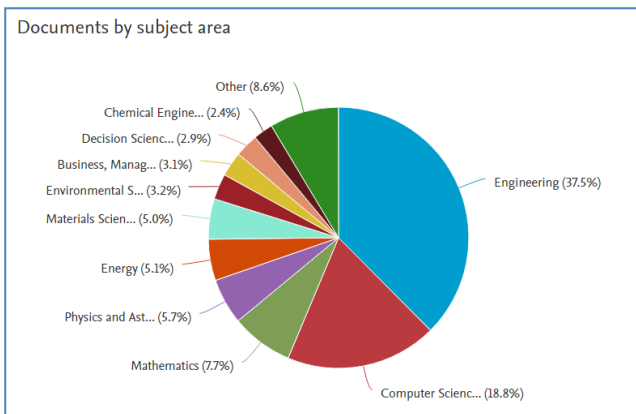

Figure 2. Subject areas distribution of documents after Step 1.

Table 3. Documents considered for each research string and research phase.

Research Strings	Step 1	Step 2	Step 3
"internet of things" AND "layout"	5	3	3
"simulation" AND "layout"	423	151	112
"additive manufacturing" AND "layout"	7	5	5
"augmented reality" AND "layout"	20	14	7
"cloud" AND "layout"	32	12	9
"big data analytics" AND "safety management"	14	9	9
"advanced manufacturing" AND "layout"	1	1	1
"horizontal e vertical integration" AND "layout"	0	0	0
"cyber security" AND "layout"	0	0	0
Total	**502***	**188**	**146**

*334 after screening

In over 76% of the analyzed documents (Appendix A), simulation is used. This is not surprising, considering the widespread diffusion of software such as Witness or Flexim, for production lines modelling (Silvestri et al., 2013). however, it should be emphasized that other technologies, such as cloud computing or big data, are also quite used.

Further information can be gained by analyzing the country of origin of the first author and the Journals where the greatest number of articles has been published.

In Figure 3 countries of origin and thematic areas of the selected documents are showed. China, with 37 articles, is the country with the largest number of documents, followed by USA (18 documents). It is also significant that the countries of origin are a total of 35, reflecting the geographical spread of the research topics.

On the other hand, the analysis of sources shows that the journal with the highest number of documents contains only 4 articles out of 146, the total number of sources is 118 and in only 10 of them more than 1 document is published, resulting therefore 106 peer-reviewed journal and conferences with only one document belonging to the final database (Table 4).

Table 4. Journals of publication.

Journal	n	%
International Journal of Production Research	4	2.7%
IFAC Papersonline	3	2.0%
Simulation Modelling Practice and Theory	3	2.0%
Structural and Multidisciplinary Optimization	3	2.0%
Automation in Construction	2	1.4%
Complexity	2	1.4%
European Journal of Industrial Engineering	2	1.4%
IEEE Transactions on Computer Aided Design of Integrated Circuits and Systems	2	1.4%
International Journal of Security and its Applications	2	1.4%
Journal of Computing in Civil Engineering	2	1.4%
Journal of Construction Engineering and Management	2	1.4%
Journal of Wind Engineering and Industrial Aerodynamics	2	1.4%
Lecture Notes in Electrical Engineering	2	1.4%
Simulation	2	1.4%
OTHERS	106	77.3%

4. Analysis of results: current scenario and trends

In addition to the identification of Industry 4.0 technologies able to play a role in layout design and management, the literature review also allowed to investigate further research themes which include examples of implementation of innovative layout design based on these technologies and related critical aspects.

Table 3 showed that most important articles related to the topic concern Cloud, Simulation and Big Data.

The information technology industry has considerably benefited from cloud computing, which allows organizations to shed some of their expensive information technology infrastructure and shifts computing costs to more manageable operational expenses. Today's highly competitive global marketplace is refining the way many design and manufacturing companies do business. The force of globalization has connected individuals and organizations all over the world, enabling them to hare data, information, and knowledge in a collective way. Friedman first introduced three major phases of globalization (Friedman 2005): Globalization 1.0, driven by countries and empires; Globalization 2.0, driven by global corporations; and Globalization 3.0, driven by individuals aided by technology. Among the new technologies driven by globalization, cloud computing is one of the major advances in the field of computing. In recent years, the information technology (IT) sector has significantly benefited from cloud computing through (1) on-demand self-services, (2) ubiquitous network access, (3) rapid elasticity, (4) pay-per-use, and (5) location-independent resource pooling (Linthicum 2009). One particular benefit is that cloud computing allows for faster and more flexible development and implementation of IT solutions compared to traditional infrastructures and service models. Even if cloud computing has been adopted in the IT field, it has just emerged on the horizon of other application domains such as product design and manufacturing. As a result, few studies have investigated the potential of cloud computing for the field of product design and manufacturing. A particular need is a well-accepted definition of cloud-based design and manufacturing (CBDM) along with theoretical frameworks and prototypes that can guide the development of CBDM systems. To address resource sharing and optimal allocation, Li et al. (2010) introduced cloud-based manufacturing (CBM), also referred to as cloud manufacturing, based on cloud computing, SOA, and networked manufacturing.

Moreover, in recent few years, Big-data became an important tool for layout design. In particular, an interesting Big-Data study concerns biological industry in China (Yunnan Region). The agricultural population accounts for 59.3% of the total population and the price fluctuations have a significant influence on farmers' incomes.

The selection of crop species, the planting strategy of crops and the arrangement of agricultural plantations according to market price is important to ensure their income. In the study a web crawler program is used to get a large amount of data on the market prices of agricultural products from the Internet. A spatial-time big data analysis model is proposed to optimise layout of the main crops. The study gives suggestions to farmers to plant suitable crops on the right soil at the right time.

Other studies show the use of augmented reality to immersively test the interaction between operator and machine for different layout configurations. In this way it is possible to overcome some important critical issues already in the design phase. Even if most of the Industry 4.0 technologies find application in layout design, the analysis carried out has clearly shown how the technology which can provide the greatest benefits is certainly simulation. The analysis of the documents highlighted the use of commercial software. The first one, called Adaptpack Studio, offers a customized library to assemble virtual models of palletizing cells. The simulation and the real tests performed showed an improvement in the design, development. Adaptpack Studio therefore includes, in a single package, the possibility to program, simulate and generate robot code for four different robot brands. In addition, the application includes specifically the components of a particular company, which allows a very rapid development of new solutions. Another largely used tool is Flexim. In a very relvant research Flexim is used in the analysis of break-even points of ceramic products after simulating the layout of painting robot. In this framework Flexsim software is used to simulate, analyse and optimize the production process of painting for the ceramic factory. The study highlights how the use of robots improve productivity and safety. Flexsim is therefore a simulation software that uses models and simulates in many types of applications, such as healthcare, mining etc. In some studies analyzed, customized software or frameworks dedicated to solving specific problems are developed. An interesting study concerns the design of residential building layout. This framework involves the interaction between a large number of design variables (e.g., different types of apartments with different configurations). The proposed method is based on simulation that applies an evolutionary genetic algorithm (GA), developed to systematically explore the best layout design to maximize the energy efficiency of the building. According to the results of the study, GA seeks to maximise the use of natural energy sources (natural ventilation and sunlight) and to reduce the total energy consumption associated with air conditioning and lighting (30-40%).
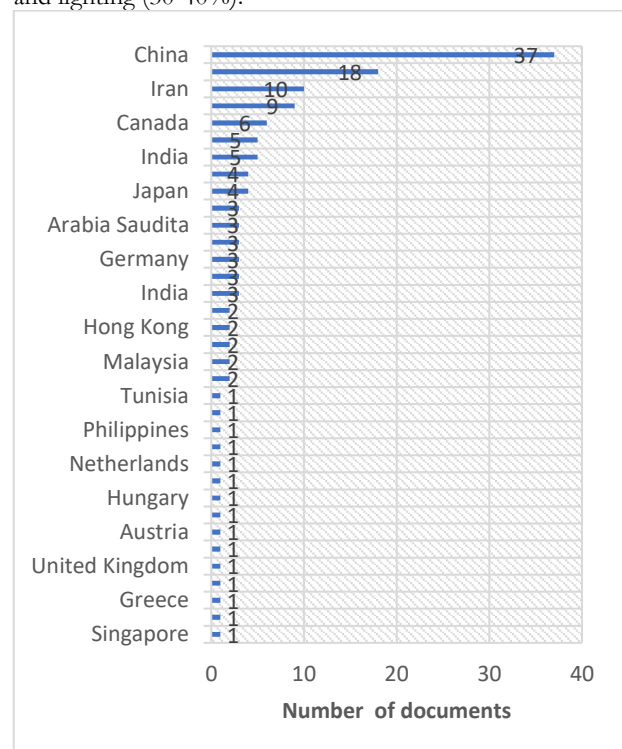

Figure 3 – First author country of origin.

Conclusion

In the present research, a literature review was performed to understand what impacts Industry 4.0 enabling technologies have on layout design and management. For this purpose, 146 papers published between 2010 and 2021 were collected and analyzed. The temporal distribution of articles shows that there was a growing interest in this field, in particular in the last three years.

Many applications were presented to show how Industry 4.0 technologies can benefit layout design. In particular, the most used enabling technologies are Simulation, Clouds and Big data. Simulation use represents over 76% of the analyzed papers, through software which allow to optimize different parameters. About this, in addition to the use of generalist software, which are widespread, in many cases customized IT frameworks or algorithms are developed.
As for Clouds applications, the most important are examples of cloud-based design and manufacturing (CBDM)
Finally, Big data analytics are used above all for layout management and to find improvement solutions as well as for non-manufacturing applications, such as those in the biological industry in China. Future developments of this research consist in the classification of the analyzed studies, according to more specific criteria, in order to implement a quantitative methodology to estimate and measure the impact of technologies.

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Appendix A. Analyzed studies.

Year	Title
2021	Mathematical modeling and numerical simulation for determining an optimized oil jet layout for spiral bevel gear lubrication
2021	Solving the layout design problem by simulation-optimization approach–A case study on a sortation conveyor system
2020	Linear layout of multiple flow-direction networks for landscape-evolution simulations
2020	Simulation of layout rearrangement in the grinding/classification process for increasing throughput of industrial gold ore plant
2020	Numerical simulation of thruster-thruster interaction for ROV with vector layout propulsion system
2020	Wind farm layout optimization based on CFD simulations
2020	A simulation-based optimization approach to design optimal layouts for block stacking warehouses
2020	Numerical simulation of nanofluid flow and heat transfer in a microchannel: The effect of changing the injection layout arrangement
2020	Rapid Modeling and Simulation of Integrated Circuit Layout in Both Frequency and Time Domains from the Perspective of Inverse
2020	Numerical Simulation on the Effects of Component Layout Orientation on the Performance of a Neon-Charged Cryogenic Loop Heat Pipe
2020	Synthesis and simulation study of non-restoring cell architecture layout in perpendicular nano-magnetic logic
2020	Implementation and evaluation of a high-presence interior layout simulation system using mixed reality
2020	Evacuation simulation and layout optimization of cruise ship based on cellular automata
2020	Landscape image layout optimization extraction simulation of 3D pastoral complex under big data analysis
2020	Combining metaheuristic search and simulation to deal with capacitated aisles in facility layout
2020	Determination of an Optimal Oil Jet Nozzle Layout for Helical Gear Lubrication: Mathematical Modeling, Numerical Simulation, and Experimental Validation
2019	Multi-agent microscopic simulation based layout design for Lushun Ro-Pax terminal
2019	Detached eddy simulation of flow characteristics around railway embankments and the layout of anemometers
2019	Detached eddy simulation of flow characteristics around railway embankments and the layout of anemometers
2019	Computational Fluid Dynamics Simulation Based Comparison of Different Pipe Layouts in an EATHE System for Cooling Operation
2019	Simulation-based evolutionary optimization for energy-efficient layout plan design of high-rise residential buildings
2019	Layout configuration, maintenance planning and simulation of AGV based robotic assembly systems
2019	A tailored fuzzy simulation integrated with a fuzzy DEA method for a resilient facility layout problem: A case study of a refrigerator injection process
2019	An Augmented Reality approach to factory layout design embedding operation simulation
2019	Simulation based optimization of resource allocation and facility layout for vegetable grafting operations
2019	Numerical simulation of wind-driven rain distribution on building facades under combination layout
2019	A simulation-based approach for plant layout design and production planning

Year	Title
2019	Optimal exit configuration of factory layout for a safer emergency evacuation using crowd simulation model and multi-objective artificial bee colony optimization
2019	Designing the layout of production facilities by using group technology (Simulation on plant jetrike and otoped)
2019	Finite element simulation of RC beams under flexure strengthened with different layouts of externally bonded fiber reinforced polymer (FRP) sheets
2018	3D numerical simulation of a Z gate layout MOSFET for radiation tolerance
2018	Ergonomics and simulation-based approach in improving facility layout
2018	Layout study of strained Ge-based pMOSFETs integrated with S/D GeSn alloy and CESL by using process-oriented stress simulations
2018	Investigation of layout effects in diode-triggered SCRs under very-fast TLP stress through full-size, calibrated 3D TCAD simulation
2018	Tower cranes layout planning using agent-based simulation considering activity conflicts
2018	TFT-LCD module cell layout design using simulation and fuzzy multiple attribute group decision-making approach
2018	Post-layout simulation of an ultra-low-power OTA using DTMOS input differential pair
2018	Using simulation in layout verification of solar module assembly workshop
2018	Evaluation of spatial layout in health care waiting areas based on simulation of droplet movement trace
2018	Integrated simulation-based facility layout and complex production line design under uncertainty
2017	Performance and simulation accuracy evaluation of analog circuits with enclosed layout transistors
2017	Simulation and performance analysis of a novel high-accuracy sheathless microfluidic impedance cytometer with coplanar electrode layout
2017	A high-fidelity three-dimensional simulation method for evaluating passenger flow organization and facility layout at metro stations
2017	Site Layout and Construction Plan Optimization Using an Integrated Genetic Algorithm Simulation Framework
2017	A simplified tool for building layout design based on thermal comfort simulations
2017	Integrated optimal method for cell formation and layout problems based on hybrid SA algorithm with fuzzy simulation
2017	A Monte Carlo simulation approach for quantitatively evaluating keyboard layouts for gesture input
2017	An integrated simulation-based optimization technique for multi-objective dynamic facility layout problem
2017	An ANN-based optimization model for facility layout problem using simulation technique
2017	Genetic Algorithm-Simulation Framework for Decision Making in Construction Site Layout Planning
2016	Simulation, Analysis, and Verification of Substrate Currents for Layout Optimization of Smart Power ICs
2016	Two-way integration of 3D visualization and discrete event simulation for modeling mobile crane movement under dynamically changing site layout
2016	Analysis of Clinic Layouts and Patient-Centered Procedural Innovations Using Discrete-Event Simulation
2016	Simulation of hybrid electric vehicle based on a series drive train layout
2016	Layout effects and optimization of runoff storage and filtration facilities based on SWMM simulation in a demonstration area
2016	Computer-aided design and simulation of strip layout for progressive die planning using Petri nets
2016	Optimizing layouts of initial refueling stations for alternative-fuel vehicles and experiments with agent-based simulations
2016	Using Discrete Event Simulation to evaluate Operating Theater Layout
2016	Research on complex products based on digital layout design and simulation modeling
2016	Simulation and optimization study on layout planning of plant factory based on WITNESS
2015	Simulation and Experimental Evaluation of a Soft Error Tolerant Layout for SRAM 6T Bitcell in 65nm Technology
2015	Simulation of time-of-flight sensors for evaluation of chip layout variants
2015	Architecture plane layout simulation model based on probability optimization genetic algorithm
2015	Hybrid Genetic Algorithm-Simulation Optimization Method for Proactively Planning Layout of Material Yard Laydown
2015	Using discrete event simulation to change from a functional layout to a cellular layout in an auto parts industry [Utilização da simulação de eventos discretos para alterar o leiaute funcional em celular em uma empresa de auto peças]
2015	Lean principles and simulation optimization for emergency department layout design
2015	Optimisation of facility layout design problem with safety and environmental factors by stochastic DEA and simulation approach

Year	Title
2015	Research on automatic layout planning and performance analysis system of production line based on simulation
2014	Post-layout simulation time reduction for phase-locked loop frequency synthesizer using system identification techniques
2014	Simulation optimization of facility layout design problem with safety and ergonomics factors
2014	Simulation of Airborne Antenna Array Layout Problems Using Parallel Higher-Order MoM
2014	Analysis on dynamic simulation for ticketing equipments' layout and configuration in the subway station
2014	Layout redesign and material flow analysis at a flexible assembly cell supported by the use of simulation
2014	Layout design and simulation for analog neural network circuit using cmos technology 0, 35 μM
2014	Development of novel electroplating tank layout by computer simulations and verification tests
2014	A simulation-based approach for the optimal design of signalling block layout in railway networks
2014	Application of agent based simulation for evaluating a bus layout design from passengers' perspective
2014	Layout and process optimisation: Using computer-aided design (CAD) and simulation through an integrated systems design tool
2013	Reliability evaluation for different power plant busbar layouts by using sequential Monte Carlo simulation
2013	On the effectiveness of Monte Carlo simulation and heuristic search for solving large-scale block layout problems
2013	Electroquasistatic field simulation for the layout improvement of outdoor insulators using microvaristor material
2013	Evaluating interface layout for visually impaired and mobility-impaired users through simulation
2013	Functional area layout method of underground logistic terminal based on genetic algorithm and automod simulation platform
2013	The production system automatic layout based on simulation
2012	Simulation and optimization of production logistics system layout based on Flexsim
2012	Simulation study of the layout technique for P-hit single-event transient mitigation via the source isolation
2012	SLIDER: Simulation of layout-injected defects for electrical responses
2012	A new optimization via simulation approach for dynamic facility layout problem with budget constraints
2012	A hybrid system for facility layout by integrating simulation and ant colony optimization
2012	From layout directly to simulation: A first-principle-guided circuit simulator of linear complexity and its efficient parallelization
2012	2D FDTD simulation of low loss small angle bend and y branch configurations in a photonic crystal waveguide layout with a Mach-Zehnder device design configuration
2012	Integrating simulation and ant colony optimization to improve the service facility layout in a station
2012	A combined extent fuzzy AHP and simulation method for selecting stacking layout type in marine container terminals
2012	Facility layout using weighted association rule-based data mining algorithms: Evaluation with simulation
2011	Application of a concept development process to evaluate process layout designs using value stream mapping and simulation
2011	An integrated fuzzy simulation-fuzzy data envelopment analysis algorithm for job-shop layout optimization: The case of injection process with ambiguous data
2011	A facility layout problem in a marble factory via simulation
2011	Monte carlo simulation based procedures for solving block layout problems
2010	Full-wave simulation examining layout effect in CMOS RF amplifier design
2010	Application of pedestrian flow simulation to railway station layout design-an approach based on collaboration with customers
2010	Capability-based distributed layout and its simulation based analyses
2010	Generative computer simulation for parallel layout of multi-story row house cluster
2010	A simulation-based approach for risk assessment of facility layout designs under stochastic product demands
2010	Comparing functional and cellular layouts using simulation and Taguchi method
2010	Simulation analysis of site design and layout planning to mitigate thermal environment of riverside residential development
2010	Evaluation of the Virtual cell layout through simulation and design of experiments with regard to queue time
2010	A Monte Carlo simulation based heuristic procedure for solving dynamic line layout problems for facilities using conventional material handling devices
2010	Monte Carlo simulation methods for dynamic line layout problems with nonlinear movement costs
2010	Simulation study of coordinating layout change and quality improvement for adapting job shop manufacturing to CONWIP control
2020	Clouds of Oriented Gradients for 3D Detection of Objects, Surfaces, and Indoor Scene Layouts
2020	KASLR-MT: Kernel Address Space Layout Randomization for Multi-Tenant cloud systems
2020	A data layout method suitable for workflow in a cloud computing environment with speech applications
2019	A novel projection algorithm for production layout extraction from point clouds
2019	Layout design optimisation with point cloud object modelling for multi-robot industrial working cell
2019	Web-based visualization of 3D factory layout from hybrid modeling of CAD and point cloud on virtual globe DTX solution
2017	Layout optimization of a robotic cell for foundry application by CAD based point cloud modeling - A case study
2016	ayout optimization of continuum structures considering the probabilistic and fuzzy directional uncertainty of applied loads based on the cloud model
2014	Wireless cloud networks for the factory of things: Connectivity modeling and layout design
2020	SSVEP Stimulus Layout Effect on Accuracy of Brain-Computer Interfaces in Augmented Reality Glasses
2020	Applying mobile augmented reality (AR) to teach interior design students in layout plans: Evaluation of learning effectiveness based on the ARCS model of learning motivation theory
2019	Exploring the performance of an augmented reality application for construction layout tasks
2019	An Augmented Reality approach to factory layout design embedding operation simulation
2019	Effect of varying task attributes on augmented reality aided point layout
2016	Application of virtual/augmented reality in steelmaking plants layout planning and logistics
2014	Preliminary evaluation of input devices for furniture layout systems employing augmented reality
2020	Integrated frame work for identifying sustainable manufacturing layouts based on big data, machine learning, meta-heuristic and data envelopment analysis
2020	Landscape image layout optimization extraction simulation of 3D pastoral complex under big data analysis
2020	Optimization Model of Traffic Sensor Layout considering Traffic Big Data
2019	Big data analysis applied in agricultural planting layout optimization
2019	FTLADS: Object-Logging Based Fault-Tolerant Big Data Transfer System Using Layout Aware Data Scheduling
2018	Sustainable robust layout using Big Data approach: A key towards industry 4.0
2018	An effective system layout planning method for railway logistics centre in the background of big data
2021	Optimal layout of ellipses and its application for additive manufacturing
2020	Topology optimization of support structure layout in metal-based additive manufacturing accounting for thermal deformations
2020	Space-time topology optimization for additive manufacturing: Concurrent optimization of structural layout and fabrication sequence
2018	Additive manufacturing functionally graded titanium structures with selective closed cell layout and controlled morphology
2018	Combined optimization of part topology, support structure layout and build orientation for additive manufacturing
2013	Simulation-based visual layout planning in advanced manufacturing
2020	Stochastic EMI Noise Model of PCB Layout for Circuit-Level Analysis of System in IoT Applications
2020	Intelligent smart city parking facility layout optimization based on intelligent IoT analysis
2020	Optimization of distributed cloud computing data center layout for ubiquitous power internet of things [面向泛在电力物联网的分布式云数据中心优化选址]