Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management
Kuala Lumpur, Malaysia, March 8-10, 2016

Risk issues in facility layout design

Sana Kouki Amri
Laboratoire d'Informatique des Systèmes Industriels, LISI
Institut National des Sciences Appliquées et de Technologie
INSAT, B.P. 676, Centre Urbain Nord, 1080, Tunis, Tunisia
sanakouki@yahoo.fr

Saber Darmoul
Industrial Engineering Department
King Saud University, P.O. Box 800, 11421
Riyadh, Kingdom of Saudi Arabia
sdarmoul@ksu.edu.sa

Sonia Hajri-Gabouj
Laboratoire d'Informatique des Systèmes Industriels, LISI
Institut National des Sciences Appliquées et de Technologie
INSAT, B.P. 676, Centre Urbain Nord, 1080, Tunis, Tunisia
Sonia.gabouj@insat.rnu.tn

Henri Pierreval
LIMOS, UMR – CNRS 6158,
Clermont University, IFMA, CS 20265, F-63175
Clermont-Ferrand, Aubière, France
henri.pierreval@ifma.fr

Abstract— **Dealing with industrial risks is a major issue in the design, management and control of production systems. However, the analysis of why and how risks should be taken into account does not seem to be considered as a global question by researchers, who have mostly focused on specific problems, such as stochasticity or uncertainty. The aim of this article is to point out the importance of risk management and control at a more global level during the design of production systems. More particularly, we discuss opportunities to design facility layout solutions that contribute to avoid, prevent, or reduce certain types of industrial risks taken in the broad sense (flow risks, reliability risks, quality risks, safety risks, environment risks, etc.). We discuss the kinds of risks that such facility layout solutions would allow considering. We address the issue of how to represent risks so that they could be taken into account, and we review existing academic and industrial approaches that are close to this topic. We show that approaching risks with facility layout solutions is a promising research direction that is worth more investigation.**

Keywords— Facility layout design, industrial risk

I. INTRODUCTION

Everyone working with industrial environments is perfectly aware that production systems are subjected to various types of risks that can yield important consequences, typically in terms of safety, costs, performance or customer satisfaction (e.g. delivery time and quality) [1]–[3]. Consequently, at every stage of the design of a production system, the question of how risks can affect the normal operation of the system turns out to be an issue considered as extremely important by most decision makers. Facility layout is known to be an important aspect in the design of these systems and has been addressed in numerous research works [4]–[8]. However, the analysis of why and how risks should be taken into account does not seem to be considered as a global question by researchers, who have mostly focused on specific problems, such as stochasticity or uncertainty (see for example the survey related to layout research by Drira et al [4]).

The aim of this article is to point out the impact of risks at a more global level. In this respect, it is necessary to identify the types of risks that need to be taken into consideration and to be analyzed, as well as the types of consequences that they can have on the system. This can allow improving our understanding of how considerations related to risk can be better taken into account in the definition and the solving of facility layout design problems. Therefore, in section II, we present an overview of industrial risk management. We introduce a classification of industrial risks, describe the risk management process, and address the issue of how to model and represent risks so that they could be identified, analyzed, assessed, and controlled. Section III overviews the main research topics in FLPs. Section IV discusses the kinds of risks that facility layout solutions would allow taking into account through reviews of existing academic and industrial works focused on industrial risk management. This section particularly shows that relatively a few research effort addressed the topic of industrial risk management while addressing FLPs. Finally, we discuss research perspectives and show that approaching some kinds of risks with facility layout solutions is a promising research direction that is worth investigating.

II. INDUSTRIAL RISK MANAGEMENT: AN OVERVIEW

Production systems evolve in a highly competitive, uncertain and changing environment, where it is necessary to make decisions in dynamic conditions to cope with the occurrence of various types of expected as well as unexpected events. The lack of information about such events (nature, likelihood of occurrence and downstream consequences) and inadequate decision making may disturb the pre-established organization and settings of a production system, thus making it deviate

positively or negatively from its expected objectives, behavior, performance and/or quality of service. Expected or unexpected events, uncertainty, disturbances, disruptions, consequences, impacts and many other terms gather to characterize an industrial system faced with situations of risk. Related literature shows that risk definitions are multiple and differ depending on the field of application and the purpose of the study [9], [10]. In order to standardize risk vocabulary, the International Standards Organization suggested the ISO 31000:2009 standard, where a risk is defined as "*the effect of uncertainty on objectives*" [9], [11]. An effect is a positive or a negative deviation from expectations. Objectives are the expression of different goals (e.g. financial, environmental, technical, legal, related to health and safety, etc.) that a production system should reach while satisfying constraints at different levels (project, product, process, department, organization, etc.) and decision horizons (e.g. operational, tactical, strategic). This section introduces a general description of the main types of risks that a production system may be faced with and that are closely related to FLPs (cf. section A), discusses risk models and representations (cf. section B) , and describes general approaches to risk management (cf. section C).

A. Classification of risks

Many authors proposed classifications to the various kinds of risks that can threaten a production system [12]–[14]. We are particularly interested in those risks that are closely related to facility layout problems due to their influence on layout solutions. These risks mainly include supply chain risks, risks related to production resources, and risks related to quality, health, safety, and environment.

1) Supply chain risks

Supply chain risks are related to the management of internal and external flows of parts and products of production organizations. They are related to operational, tactical and strategic problems that can occur between a production system and its suppliers, subcontractors, and/or customers. Examples of such problems include (but are not limited to) fluctuations and uncertainty of demand, uncertainty about routings, processing times and work in progress, untimely deliveries, over costs, and deliveries that do not meet quality, health, safety and/or environmental requirements [15]. Supply chain risk management (SCRM) is the established discipline that proposes tools, methods and frameworks to identify, analyze, assess, and control risks in supply chains [13], [16], [17]. As it will be discussed in more detail in section IV, appropriate facility layout solutions can alleviate some kinds of supply chain risks, especially those related to variability and uncertainty of demand and flows.

2) Risks due to production resources

Risks due to production resources are related to availability and reliability of production equipment, including machines, tools and processes (failures, breakdowns or blockages) and/or human resources (errors; absenteeism) [18]. Several works are interested in studying the relationship between human errors and equipment failures on the one hand, and major risks (fire, explosion, floods, etc.) and occupational health and safety accidents on the other hand [19], [20]. The theory of reliability has emerged as the discipline in maintenance engineering that studies risks of unavailability and unreliability of production equipment [21]. As it will be discussed in more detail in section IV, appropriate facility layout solutions are needed to take into account risks of unavailability of production equipment, reliability requirements (e.g. need to integrate active or passive redundancy), and specifications to ease maintenance operations (e.g. extra lanes or space to facilitate access to equipment, to introduce new equipment, or to move old equipment).

3) Quality risks

Quality risks are defined as "*the susceptibility of a manufacturing establishment to fail to comply with good manufacturing practices, which increases the likelihood of outgoing product quality defects*" [22]. There exists a vast literature on quality management, much of which focuses on identifying and defining constructs associated with Quality Management programs [23] to ensure availability and reliability of raw materials, parts, and/or products and to avoid problems, such as inventory shortfalls, expiry dates, deviations from requirements and specifications, etc. The International Standards Organization (ISO) proposed a standardized Quality Management System (ISO 9001 series) to specify policy, procedures and instructions, in a quality handbook, enabling firms to produce the same quality every time. The standard also focuses on the customers, their demands and satisfaction of their specifications and requirements. As it will be discussed in more detail in section IV, facility layout solutions should cope with some kinds of quality risks, particularly those where manufactured parts and products need some rework (backtracking) to fix some types of defects.

4) Environmental Risks

Environmental risks correspond to actual or potential threats of adverse effects on living organisms and natural environment by toxic substances, such as effluents, emissions, wastes, resource depletion, etc., arising out of an organization's activities. Many environmental management systems have been developed to manage an organization's environmental programs in a comprehensive, systematic, planned and documented manner. For example, ISO 14000 is a family of standards for Environmental Management Systems (EMS), environmental and EMS auditing, environmental labeling, performance

evaluation and life-cycle assessment. Many authors have developed environmental management approaches, tools and techniques to address specific environmental threats [24]. As it will be discussed in section IV, facility layout design can yield to environmental friendly solutions, reducing for example noise and air pollution.

5) Occupational health and safety (OHS) risks

Occupational health and safety (OHS) risks are related to problems, situations and events that can threaten the safety, health and welfare of whoever might be affected by the workplace environment (suppliers, customers, employees, relatives, etc.). Specific occupational health and safety concerns vary greatly by sector and industry [25]. Several international standards, guidelines, and legislations were developed for occupational health and safety, such as the BS OHSAS 18001 standard, which is the internationally recognized assessment specification for occupational health and safety management systems [26]. It is worth noting that the BS OHSAS 18001 is compatible with the framework of the ISO standards series. ISO 9001 Quality Management Systems, ISO 14001 Environmental Management System, and BS OHSAS 18001/18002 complement each other and form an integrated system [23], [27]. Each component of the system is specific, auditable, and accreditable by a third party after review. Within this integrated framework, many authors have developed OHS risk management tools and models based on historical data and established shop floor procedures and know-how [28]–[30]. Particularly, inherent safety design is one of the disciplines that focus on taking into account OHS risks during the early stages of design of industrial facilities [28], [31], [32].

B. Risk modeling and representation

Several approaches were proposed to model and represent risks in order to allow their analysis and quantitative assessment and enable further decision-making. This section briefly describes the main frameworks that allow modeling, analyzing and assessing risks. For a more extensive and general review of risk modeling and optimization, interested readers can refer to [33].

1) Structural models of risks

Structural models of risks try to establish, find and represent relationships between causes, consequences and impacts of risks. Such models are useful to understand context of occurrence, conditions and scenarios of evolution of risks. Examples of structural representation models stem from works on enterprise risk management [34]–[36] and business process management [37], [38]. They include event and fault tree analysis models [39] and Failure Mode Effect and Criticality Analysis [40].

2) Risk indexes

There have been several theories and attempts to quantify risks. Despite the existence of numerous different risk quantification methods, the most widely accepted one states that risk level or magnitude is equal to rate (or probability) of occurrence multiplied by the impact of the event. The severity of this level is assessed according to an adopted severity scale. The choice of this scale is often subjective, and is based on decision makers' expertise. The Dow Fire and Explosion Index is widely used for risk assessment and safety evaluation [1]. This index determines the realistic maximum loss occurring under the most adverse operating conditions and is applicable to processes where flammable, combustible or reactive material is stored or processed. It is based on historic loss data, the energy potential of the processed materials in the chemical plants and the current application of loss-prevention practices. Several approaches, such as FMEA (Failure Mode and Effect Analysis), DMRA (Decision Matrix Risk Assessment), PRAT (Proportional Risk-Assessment Technique), QADS (Quantitative Assessment of Domino Scenarios), etc., allow mathematical representation and use of risk indexes [28], [41].

3) Risks as stochastic processes

The principle is to analyze risky situations through a combination of probability analysis and graph theory. Each situation is defined by a set of nodes and arcs. The nodes represent the system variables or states and the arcs symbolize the conditional dependencies (cause–effect relationships) among the variables or transition probability among states (for stochastic processes). Then, a conditional probability is associated to each node according to the observation of some variables and the prior knowledge of decision makers. Bayesian networks and Markov chains [42] are among the most famous approaches that deal with this type of risk analysis.

4) Stochastic simulation

Stochastic simulation traces the evolution of variables that can change stochastically (randomly) with certain probabilities. A stochastic model creates a projection based on a set of random values. Outputs are recorded and the projection is repeated with a new set of random values of the variables. These steps are repeated until a sufficient amount of data is gathered. In the end, the distribution of the outputs shows the most probable estimates as well as a frame of

expectations regarding what ranges of values the variables are more or less likely to fall in. Discrete event simulation and Monte Carlo simulation are among the most famous stochastic simulation methods that allow representing and evaluating some kinds of risks [43]–[45].

5) Risks as optimization models

In such models, risks are taken into account within a mathematical optimization framework. Risks are taken into account within one or several objective functions to be optimized, or as constraints to be satisfied [46]–[49]. The objective functions include probabilities of occurrence of events and reflect the impacts of risks (generally in terms of financial impacts, such as costs, penalties, etc.) on the production system. Constraints reflect requirements (e.g. legal, technical, environmental, financial, etc.) that need to be satisfied.

6) Risks as fuzzy numbers

Risk management relies on the assessment of detrimental events (e.g. failures, disruptions) to prioritize them according to one or more severity criteria so that most critical risks are handled first. Fuzzy logic allows dealing with uncertainty and processing risks as fuzzy linguistic terms, fuzzy ratings and fuzzy arithmetic operations [50], [51].

C. Risk management process and approaches

Given the multitude and the diversity of risks threatening a production system, a risk management process should be adopted based on four main steps: identification, analysis, assessment and control.

Risk identification deals with characterizing events and situations that can potentially cause damage to a production system. This step is based on tools (e.g. checklists, what-if scenarios, audits, etc.), methods and approaches to investigate risks in a preventive manner. Several authors developed approaches that include a risk identification step, such as CREA [28], HACCP, HAZOP [52], [53], ARAMIS [54], I-RISK [30], etc.

Risk analysis is the step in which experts try to establish cause and consequence relationships between events and situations that may lead to potential damage. This step can be achieved using tools and methods, such as Root Cause Analysis (RCA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), cause and effect (Ishikawa) diagrams, Failure Modes and Effects Analysis (FMEA), etc., in order to explain risky situations and anticipate all detrimental scenarios.

Risk assessment is related to the evaluation of risks, which includes estimation of likelihood, frequency, gravity, and impact of occurrence of detrimental events and their downstream consequences. Numerous approaches have been proposed to evaluate risks (e.g. [54]–[56]) and domino effects [57].

Risk control includes tools, methods and approaches to anticipate, avoid, eliminate, reduce, mitigate, transfer and/or accept risks. Risk control relies on risk assessment to prioritize risk according to one or more severity criteria so that most critical risks are handled first. Preventive/Proactive control approaches mainly focus on finding ways to anticipate, eliminate, and/or reduce risks before their occurrence. Reactive control approaches mainly focus on monitoring risks during activity execution, detecting and identifying adverse events and scenarios, and finding ways to react to risks by eliminating, and/or reducing them after their occurrence. Hybrid approaches include preventive and reactive control measures [28].

In this paper, we consider that certain types of risks can be addressed by facility layout solutions as part of a preventive/proactive approach. Therefore, section IV highlights the need for appropriate tools, methods and approaches to identify, analyze and assess risks from a facility layout point of view, so that a facility layout solution contributes to control some kinds of risks in a preventive manner.

III. FACILITY LAYOUT PROBLEMS

Facility layout problems (FLPs) have received a great attention in research and practice due to their impact on the organization and performance of manufacturing systems [4]–[6], [58]–[60]. FLPs consist in finding assignments of facilities (e.g. machines, cells, warehouses, departments, etc.) to locations in a plant area in such a way that one or more objectives of performance are optimized and one or more constraints are satisfied. There exists a variety of FLPs, depending on several features, including plant morphologies, facilities to be placed, objectives to be optimized, constraints to be satisfied, and the time horizon to be considered. Layout designs allow taking into account several manufacturing system characteristics. Such characteristics include change and variability in product variety and volume, diversity and complexity of facility shapes and dimensions, constraints due to material handling systems, and to pick up and drop off locations. Layout designs also allow coping with existence or absence of flexibilities and requirements related to part/product routing, such as backtracking, bypassing, and existence of redundant manufacturing possibilities or alternative routings. Drira et al. [4] provide a comprehensive description of the different kinds of FLPs, and a recent survey of different solution methodologies. Singh & Sharma [6] provide a review of different modeling and solution approaches of FLPs. Moslemipour et al. [5] provide a recent

review of intelligent approaches to design dynamic and robust layouts in flexible manufacturing systems. In the following, we review different particular features of FLPs.

A. Product features

The layout design generally depends on the product types (continuous flow, such as in chemical industries, or discrete flow, such as in manufacturing industries), product variety and production volumes. In manufacturing industries, Drira et al. [4] distinguish four types of organization, namely fixed product layout, process layout, product layout and cellular layout.

In ***fixed product layout***, the different resources are moved to perform the operations on the product, which has a fixed position, meaning that it does not move within or between production facilities. This type of layout is commonly found in industries that manufacture large size products, such as ships or aircrafts.

Process layout groups facilities with similar functions together (resources of the same type). This organization is often reported to be suited when there is a wide variety of products.

Product layout is used for systems with high production volumes and a low variety of products. Facilities are organized according to the sequence of the successive manufacturing operations.

Cellular layout groups machines into cells to process families of similar parts. Cellular layout problems consist in finding the best arrangement of machines within each cell and in arranging cells on the factory floor.

In continuous flow industries, such as petrochemical industries, Papageorgiou [1] uses the name of ***process plant layout*** and emphasizes that layout is an important part of the design or retrofit of process plants. It involves decisions concerning the spatial allocation of equipment items and the required connections between them. Equipment items are allocated to one floor (single-floor case) or many floors (multi-floor case) considering a number of management or engineering drivers, such as connectivity (piping, pumping), construction (optimization of occupied area and height), and safety (installation of potential protection devices).

B. Plant morphologies

In FLPs, facilities to be placed include circulation lanes/aisles, safety and clearance areas, and production resources, such as departments, production lines, cells, equipment, machines, storage buffers, and material handling systems. Several general plant shapes and dimensions were considered, including regular (generally rectangular) and irregular (generally polygon) morphologies (cf. Figure 1). Lee & Kim [61] suggested four shaping algorithms to modify shapes of departments from an irregular shape (e.g. polygon) to regular (rectangular) shapes. Within the plant shape, the material handling system influences the arrangement of facilities. More particularly, the single row FLP (cf. Figure 1.a.) is defined as an FLP where facilities must be arranged along a straight line (single row) and where products generally circulate in only one direction [62]. Several shapes may be considered from this basic situation, such as straight line, semi-circular or U-shape. The multi-row layout (cf. Figure 1.b.) involves several rows of facilities, where parts can move between facilities from the same row and/or from different rows. The unidirectional loop layout problem (cf. Figure 1.c.) deals with allocating facilities to locations around a closed ring transportation network that usually corresponds to a conveyor system on which parts are transported in only one direction [63]. The open field layout (cf. Figure 1.d.) corresponds to situations where facilities can be placed without the restrictions or constraints that would be induced by such arrangements as single row or loop layout.

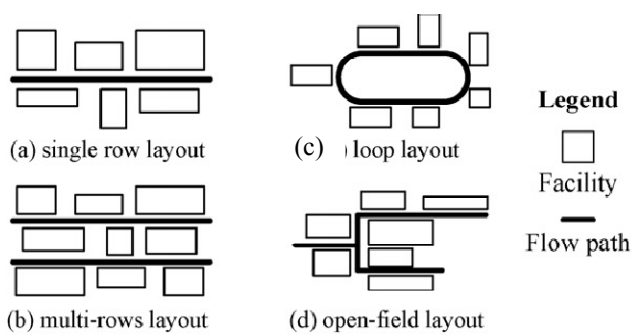

Figure 1. Examples of plant morphologies [4].

C. Backtracking and bypassing

Backtracking and bypassing are two particular movements that can impact the flow of the products in flow-line layouts. Backtracking is the movement of a part, from one facility to another preceding it in the sequence of facilities in the flow-line arrangement. Bypassing occurs when a part skips some facilities during its moving towards the flow line arrangement [4].

D. Time horizon

FLPs differ with respect to the time horizon that is considered for the placement of facilities. ***Static FLPs*** usually refer to single period planning problems, where demand is known or can be forecasted in advance, and where production resources have to be arranged so as to satisfy demand while optimizing one or many objectives. Usually, a relatively long time horizon is considered, on which demand can be assumed stable (no significant fluctuation or change on demand) and no new types of products (requiring new machine capabilities and routings) will be introduced. Such assumptions are generally due to heavy industrial installations that are not modular and with high limitations on flexibility (due to type of energy supply and inter-connection between components for example). Decision makers cannot afford changing their locations as (or when) desired, unless complete system re-engineering is considered.

Dynamic FLPs (DFLP) usually involve multiple planning periods on which some kind of change is considered. Change includes expected fluctuation of demand over time, fluctuation of equipment availability/reliability, and/or introduction of new (or removal of old) product families and/or production resources. The DFLP problem is to find a layout that is robust over multiple periods, or to find a relocation plan (a sequence of layouts) that best fits the expected changes [64]. As it will be discussed in section IV, most references on DFLPs address changes in product flow quantity between facilities.

The reduction of product life cycles and the need to rapidly react to market changes require designing layouts that are more flexible, modular and easily reconfigurable. In ***reconfigurable FLPs***, the changes that occur in a production cycle (e.g. change in products, routings, production volume or commissioning and de-commissioning of resources) are either unexpected or only known slightly ahead of the start of the new production cycle. The production equipment is assumed modular, flexible, relatively lightweight, and with loose inter-connection, which enables its (almost real-time) relocation as (and when) needed to suit the current production environment and requirements [65]–[70].

E. Objectives of performance

Typical objectives of performance are related to the movement of parts between facilities and to the relocation of facilities. In manufacturing industries, researchers and practitioners often seek to optimize one or several criteria related to the management of flows, such as the material handling flow, the equipment flow and/or the information flow [51]. Management of material handling flows includes concerns about the optimization of the movement of materials and parts through the facility, such as minimizing total material handling cost, total travel times, and/or total travel distances. Management of equipment flows refers to the assessment of requests of proximity, constraints of distance, or requirements of circulation lanes between many facilities, or expectations of future introduction of new manufacturing technologies and equipment into the plant. Management of information flows is related to the nature and frequency of communications between facilities [4].

In process industries, Papageorgiou [1] emphasizes that tradeoffs between connectivity, pumping, construction, financial risk and installation of potential protection devices are necessary. Connectivity costs involve the cost of piping, pumping and other required connections between equipment items. Minimizing construction costs leads to the design of compact plants and involves tradeoffs between the cost of occupied area (land) and height (multifloor plants). Connectivity and land costs increase as the distance between equipment items increases. Financial risk component cost decreases as equipment items are put far apart or by installing extra protection devices. While protection devices are necessary to eliminate accident escalation, their cost should be taken into account.

F. Constraints

Several types of constraints were considered in the literature, some of them are hard constraints that have to be satisfied (due to technical specifications of equipment or safety reasons for example) and some of them are more related to preferences of decision makers.

Area constraints. The total area available for the placement of all facilities (e.g. plant or shop floor area) must be superior or at least equal to the sum of areas dedicated to each single facility. Facilities to be placed on the plant surface may have homogeneous areas (all facility areas have identical shape and dimension), in which case the problem is generally known as equal area FLP. However, if the facilities have heterogeneous areas (facility areas have different shapes and dimensions), the problem is generally known as unequal area FLP [71].

Positioning constraints. In a workshop, some locations have to be dedicated to functional areas, such as poles, pillars, frames, circulation aisles and pathways, to maintain the overall structure of the workshop. Other areas have to be allocated to resources other than machines, such as storage buffers, warehouses, security zones, etc. These areas are closed to the placement of machines, and circulating products cannot overpass them. These restrictions on the positioning of machines are called positioning constraints. The positioning constraints also include the constraint of non-overlapping of machines, their orientation, their lengths, the clearance between them, as well as pick-up and drop-off (P/D) locations from which parts enter and leave facilities.

Proximity constraints. For reasons of good operation, convenience or safety, equipment manufacturers usually recommend distance allowances (minimum and maximum distance) between an equipment and its neighborhood. The distances between the various resources belong to intervals of possible values and are not subject to free choice. These intervals define proximity constraints that should/have to be met.

Budget constraints. The rearrangement costs must not exceed an available budget, usually defined in terms of monetary units.

G. Formulations of FLPs

An FLP can be formulated either as a discrete or as a continuous problem. In the discrete formulation, the plant floor is divided into locations with identical shape and area, like a grid made of rows and columns, where a location is an intersection between a row and a column and which can hold a facility. If facilities have unequal areas, they can occupy more than one location. In the continuous formulation, equipment can be placed anywhere on the surface of the workshop (which is no longer divided into locations), provided that any two equipment do not overlap [72].

H. Mathematical models of FLPs

Different kinds of mathematical models were suggested to model FLPs [4], [6]. Depending on the manner in which the problem is formulated, (discrete or continuous), the formulation can lead to a Quadratic Assignment Problem (QAP) or to Mixed Integer Programming (MIP), which are the most commonly encountered in the literature. In each case, a few authors have argued that the available data may not be known perfectly, and have suggested formulations that take uncertainties into account, including fuzzy formulations [73].

I. Solution approaches

Many solution approaches exist in the literature to solve FLPs. Sangwan [74] highlights three categories of layout approaches: quantitative, qualitative and multi-criteria. Quantitative approaches minimize quantitative objectives, such as the material handling cost. However, models based on quantitative objectives have not been accepted by the researchers to solve the real world problems as the input data required by these models is to be exact. Unfortunately, in real world, this data is uncertain and vague, and a number of non-quantifiable questions remain, which must be considered in making the transition from a pure model to a practical solution. In qualitative approaches, the objective is to maximize the closeness rating between facilities by considering qualitative factors, such as safety, flexibility, noise, dirt, odor, etc. The main problem faced in qualitative approaches is the method of scoring, which is based on pre-assigned numerical values for different closeness ratings but does not consider the flow data. Facility layout problems cannot be solved accurately through intuition alone, and quantitative approaches should not be dismissed in favor of a completely qualitative approaches. This generated the interest of researchers towards multi-criteria approaches, which seek to satisfy multiple objectives, such as the overall integration of all the functions, minimum material movement, smooth workflow, employee satisfaction, safety, flexibility etc. for the better design of layouts. Moslemipour et al. [5] provide a recent review that classifies existing approaches in terms of exact methods, heuristic algorithms, intelligent approaches (including meta-heuristics and artificial intelligence based approaches), and hybrid algorithms.

IV. Integrating Risk Concerns Into Layout Solutions

In this section, we examine how facility layout solutions can help take into account some kinds of industrial risks from an operations management and control perspective.

A. Supply chain risks

Many researchers were interested in studying the impact of variability, uncertainty, impreciseness and vagueness on the quantitative flow data considered for the design of facility layouts. Sangwan [74] notes that the flow data is based on forecasts, which are typically made several years before plant operation. Forecast data includes only estimates about the amount of various types of material flow and cost of moving the various types and size of material, which may not be exact when plant becomes operational. Several authors reviewed applications of fuzzy set theory to deal with variability, uncertainty, impreciseness and vagueness in forecasting [75] and in the subsequent design of facility layout solutions [76], [77]. Kulturel-Konak [73] reviews approaches to uncertainties in facility layout problems. The author distinguishes two approaches to design robust and/or flexible facilities, i.e. designs that do not radically degrade with production changes. The first approach is the dynamic facility layout problem (DFLP), which considers several production periods in an environment where material flow between departments changes over time, and facility layout arrangements are determined for each period by balancing material handling costs with the re-layout costs involved in changing the layout between periods. The biggest difficulty in DFLP has been to estimate future production patterns and condense them into a few discrete scenarios. The second approach is the stochastic FLP in which product mix and demand are assumed to be random variables with known parameters (e.g., expected value, variance, covariance and routing information of products and unit material handling costs). The single period stochastic

FLP is different from DFLP since product demand is stochastic in the former rather than only subject to known changes from period to period as in the latter.

B. Risks due to production resources

Sangwan [74] states that some of the reasons for the fuzziness in flow data in modern manufacturing environments include: functional interrelationships between the factors are not well defined; Equipment breakdowns, rejects, reworks and queuing delays; Flexibility factors generally cannot be measured precisely and modeled mathematically; and general vagueness in defining flexibility. System reconfiguration has appeared as a paradigm that allows changeable functionality and scalable capacity by physically changing the components of the system through adding, removing or modifying machine modules, machines, cells, material handling units and/or complete lines. In the literature, the researchers addressed several types of events and changes that call for reconfiguration:

- **Changes in production volumes.** Such changes are known as a scalability problem. They refer to fluctuation in demand and to variation in product quantities [65]–[70], [78];
- **Changes in functionality.** Such changes are known as a convertibility problem. They refer to modification, upgrade, or introduction of new product or process functionalities or capabilities [79];
- **Changes in requirements.** Such changes refer to modification of customer needs in terms of technical specifications and demands. The problem is then to find configurations that best meet those new requirements [80];

The authors tackled these changes according to different perspectives.

- From a **manufacturing system planning perspective**, authors are generally interested in determining a sequence of configurations that best meets change over several periods of time [78], [79].
- From a **system engineering perspective**, authors are interested in finding configurations that best meet some customer requirement specification [80].

As it will be discussed in our conclusion, only a few authors considered **changes in resource reliability and/or availability** and suggested solutions that allow using system flexibility to manage disruptions, disturbances and risks based on a **monitoring and control perspective** and in a reactive manner [81].

C. Quality risks

Quality risks occur when a manufacturing system fails to comply with good manufacturing practices, which increases the likelihood of outgoing product quality defects [22]. This happens due to major challenges, including a maturing workforce, excessive scrap, rework, lack of coordination, poor delivery performance, and a general lack of technical processes and product understanding [82]. In manufacturing industries, equipment breakdowns, rejects, defects, and reworks may require backtracking and bypassing, which impact the flow of the products. Drira et al. [4] highlight several procedures that were presented for dealing with and minimizing backtracking but no procedure was suggested in the literature for addressing bypassing. Elmaraghy et al. [83] emphasize that the ability to predict the probability of errors caused by human involvement can provide the system designer with insights as to the required skill levels, training programs, job design, tasks assignment, work organization as well as options for modifying the system design to achieve better quality results. The authors develop a model to assess the probability of human errors in RMSs, based on tasks characteristics, work environment, as well as worker capabilities using the multi-attribute utility analysis.

D. Environmental risks

In chemical industries, many references focused on determining dispersion models to estimate exposure concentrations and then determine risks (in terms of probabilities) of injuries and death. However, the weather is difficult to model because of parameters, such as atmospheric condition, wind direction and speed, temperature, and humidity, which are stochastic in nature [84]. Deterministic [85] as well as stochastic [2] approaches were suggested to solve the facility layout problem with toxic releases. The stochastic approach considers micrometeorological effects on the toxic dispersion phenomenon (including calculation of random data to get probability distribution of the damage in toxic releases), whereas the deterministic approach is based on the worst-case scenario, formed by a low wind speed, stable atmospheric conditions, and non-terrain obstructions. However, both deterministic and stochastic approaches may suggest large unpractical separation distances between releasing and occupied facilities [86]. Distances between facilities might be reduced if the concentration is decreased, in which case a mitigation system should be used. Mitigation systems are devices used in real process plants to decrease the concentration during toxic dispersions. The selection of a mitigation system strongly depends on the mitigating fluid and the fluid to mitigate. Mitigation systems are also selected based on the type of accident. In [84], the authors optimize facility layouts with toxic releases by incorporating three mitigation systems in the layout model to decrease separation distances between facilities.

E. Occupational health and safety (OHS) risks

From the safety viewpoint, plant layout is largely constrained by the need to maintain minimum safe separation distances between facilities [87]. Solving the plant layout based on risk analysis has initially considered the possibility of explosion accidents where risk is modeled as a function of the distance between the probable explosion point and the affectation points [84]. An old work has presented a graph-based algorithm to produce optimal partitioning to allocate units in different sections where values on edges reflect safety costs [88]. Adequate separation is often done by grouping facilities of similar hazards together. The concept has been extended to include other buildings, such as control rooms, so that a facility refers to the portion of land surrounded by streets where units and people are located [2]. However, space among facilities is limited and will increase the capital costs (more land, piping, etc.) and operating costs as units are separated. If future plant modifications are anticipated, which might impact separation distances, consideration should be given to employing larger initial separation distance and applying protection devices. Therefore, it is essential to determine minimum distances at which costs can be integrated in the plant layout optimization [3]. Current works on FLPs considering OHS risks focus on inherent safety design methodologies [31], and on domino effect reduction [89]–[91].

V. Discussion and Conclusion

This article discussed issues related to the design of facility layout solutions that contribute to avoid, prevent, or reduce certain types of risks taken in the broad sense (reliability, quality, health and safety, demand, environment, etc.). Despite the importance of dealing with industrial risks in the design of production systems, our literature review shows that the analysis of why and how risks should be taken into account does not (yet) seem to be considered as a global question by researchers, who have mostly focused on specific problems, such as stochasticity or uncertainty. We still notice a lack of frameworks and approaches that deal with industrial risks in an integrated and a more generic way while designing facility layout solutions. Integration is related to the risk management process and refers to the necessity to develop approaches that allow both identification, analysis, assessment and design of facility layout solutions that take into account the outcomes of previous steps. Genericity is related to the types of risks and refers to the necessity to develop approaches that allow considering simultaneously several types of risks. Our analysis shows that two main types of risks seem to be well covered in literature, which are risks related to flows of parts and materials (including fluctuation of demand), and risks related to environment, and occupational health and safety. However, other types of risks, such as reliability of resources and quality of products (i.e. in case of reworks) are yet under covered. New approaches should be developed that consider equipment availability and reliability, take into account possible interactions between production resources (e.g. interference, etc.), and evaluate risks in a multi-objective way. Promising research directions are still worth exploring. In the following, we provide two particularly interesting research directions.

A. Dealing with risks of change in design requirements

The design of facility layouts is a complex activity that is primarily aimed at finding efficient layout solutions that satisfy a set of multiple and various requirements, related to various aspects and components of an organization or system, including personnel, operating equipment, storage space, materials-handling equipment, and all other supporting services. Requirements, and the way they are expressed, specified, maintained, updated, and eventually changed highly influence the layout decisions, solution methodologies and quality of solutions [8]. However, during its lifetime, a manufacturing system has to cope with change in requirements. Such adaptation is necessary for example to accommodate introduction of new products and families of products, introduction of new (or retrofitting of old) equipment, evolution of regulations and safety requirements, markets fluctuations, new technologies, etc. Unfortunately, two problems still need investigation: (1) Existing works lack methodologies and tools that allow tracing the evolution of requirements, assessing the risks of change of requirements on layout design, and relating modification of requirements to subsequent required adaptations of corresponding layout solutions. (2) Most of the research effort is directed towards developing facility layout design methodologies and solutions that are specific to some kind of problem. Researchers usually identify inputs and outputs of a particular problem, formulate it in terms of objectives of performance and constraints and suggest a specific algorithm to solve it. Their attention is mainly focused on assessing the performance of their algorithms and on benchmarking them against other approaches. More research effort is needed to design approaches that can adapt algorithms to take variation and change of requirements into account.

B. Dealing with risks of change in system availability/reliability at execution time

Many researchers have developed dynamic and reconfigurable approaches to design facility layout solutions that take change into account. Most of these approaches are preventive and off-line approaches that rely on optimization models to develop a layout that is robust over multiple periods, or to find a relocation plan (a sequence of layouts) that best fits the expected changes. Consequently, changes are mainly related to variation of product flow quantity between facilities, and changes are “expected”, meaning that they are not monitored on-line. There is still a lack of approaches that allow (1) Monitoring and controlling change on-line, based on a reactive manner; (2) Considering other types of change, particularly change in equipment reliability and availability over multiple periods.

REFERENCES

[1] L. G. Papageorgiou, "Plant Layout Problems and Optimization," in Encyclopedia of Optimization, C. A. Floudas and P. M. Pardalos, Eds. Springer, 2009, pp. 2979–2987.

[2] R. Vázquez-Román, J.-H. Lee, S. Jung, and M. S. Mannan, "Optimal facility layout under toxic release in process facilities: A stochastic approach," Comput. Chem. Eng., vol. 34, no. 1, pp. 122–133, 2010.

[3] S. Jung, D. Ng, J.-H. Lee, R. Vazquez-Roman, and M. S. Mannan, "An approach for risk reduction (methodology) based on optimizing the facility layout and siting in toxic gas release scenarios," J. Loss Prev. Process Ind., vol. 23, no. 1, pp. 139–148, 2010.

[4] A. Drira, H. Pierreval, and S. Hajri-Gabouj, "Facility layout problems: A survey," Annu. Rev. Control, vol. 31, no. 2, pp. 255–267, Jan. 2007.

[5] G. Moslemipour, T. S. Lee, and D. Rilling, "A review of intelligent approaches for designing dynamic and robust layouts in flexible manufacturing systems," Int. J. Adv. Manuf. Technol., vol. 60, no. 1–4, pp. 11–27, 2012.

[6] S. P. Singh and R. R. K. Sharma, "A review of different approaches to the facility layout problems," Int. J. Adv. Manuf. Technol., vol. 30, no. 5–6, pp. 425–433, Nov. 2005.

[7] M. Solimanpur, P. Vrat, and R. Shankar, "An ant algorithm for the single row layout problem in flexible manufacturing systems," Comput. Oper. Res., vol. 32, no. 3, pp. 583–598, Mar. 2005.

[8] N. Marcoux, D. Riopel, and A. Langevin, "Models and methods for facilities layout design from an applicability to real-world perspective," in Logistics Systems: Design and Optimization, no. 1973, 2005, pp. 123–170.

[9] C. Everett, "A risky business: ISO 31000 and 27005 unwrapped," Comput. Fraud Secur., vol. 2011, no. 2, pp. 5–7, Feb. 2011.

[10] N. Bayar, S. Darmoul, S. Hajri-Gabouj, and H. Pierreval, "Fault detection, diagnosis and recovery using Artificial Immune Systems: A review," Eng. Appl. Artif. Intell., vol. 46, pp. 43–57, Nov. 2015.

[11] I. International Organization for Standardization, "ISO 31000 - Risk management - ISO," 2009. [Online]. Available: http://www.iso.org/iso/home/standards/iso31000.htm. [Accessed: 23-Sep-2015].

[12] S. Darmoul, H. Pierreval, and S. Hajri–Gabouj, "Handling disruptions in manufacturing systems: An immune perspective," Eng. Appl. Artif. Intell., vol. 26, no. 1, pp. 110–121, Jan. 2013.

[13] I. Heckmann, T. Comes, and S. Nickel, "A critical review on supply chain risk – Definition, measure and modeling," Omega, vol. 52, pp. 119–132, 2015.

[14] A. Jain, P. K. Jain, F. T. S. Chan, and S. Singh, "A review on manufacturing flexibility," Int. J. Prod. Res., vol. 51, no. 19, pp. 5946–5970, Oct. 2013.

[15] G. A. Zsidisin, "A grounded definition of supply risk," J. Purch. Supply Manag., vol. 9, no. 5–6, pp. 217–224, Sep. 2003.

[16] P. Singhal, G. Agarwal, and M. L. Mittal, "Supply chain risk management□: review , classification and future research directions," Int. J. Bus. Sci. Appl. Manag., vol. 6, no. 3, pp. 15–42, 2011.

[17] O. Tang and N. S. Musa, "Identifying risk issues and research advancements in supply chain risk management," Int. J. Prod. Econ., vol. 133, no. 1, pp. 25–34, Sep. 2011.

[18] M. Khalaj, A. Makui, and R. Tavakkoli-Moghaddam, "Risk-based reliability assessment under epistemic uncertainty," J. Loss Prev. Process Ind., vol. 25, no. 3, pp. 571–581, May 2012.

[19] Y.-D. Jo and K.-S. Park, "Dynamic management of human error to reduce total risk," J. Loss Prev. Process Ind., vol. 16, no. 4, pp. 313–321, Jul. 2003.

[20] P. . Cacciabue, "Human error risk management for engineering systems: a methodology for design, safety assessment, accident investigation and training," Reliab. Eng. Syst. Saf., vol. 83, no. 2, pp. 229–240, Feb. 2004.

[21] T. Nakagawa, Maintenance Theory of Reliability. Springer-Verlag London, 2005.

[22] J. V. Gray, A. V. Roth, and M. J. Leiblein, "Quality risk in offshore manufacturing: Evidence from the pharmaceutical industry," J. Oper. Manag., vol. 29, no. 7–8, pp. 737–752, Nov. 2011.

[23] T. H. Jørgensen, A. Remmen, and M. D. Mellado, "Integrated management systems – three different levels of integration," J. Clean. Prod., vol. 14, no. 8, pp. 713–722, Jan. 2006.

[24] M. A. Hannan, M. Abdulla Al Mamun, A. Hussain, H. Basri, and R. A. Begum, "A review on technologies and their usage in solid waste monitoring and management systems: Issues and challenges.," Waste Manag., vol. 43, pp. 509–523, Jun. 2015.

[25] V. Nyirendaavwil, Y. Chinniah, and B. Agard, "Identifying Key Factors for an Occupational Health and Safety Risk estimation Tool in Small and Medium-size Enterprises," IFAC-PapersOnLine, vol. 48, no. 3, pp. 541–546, 2015.

[26] L. S. Robson, J. A. Clarke, K. Cullen, A. Bielecky, C. Severin, P. L. Bigelow, E. Irvin, A. Culyer, and Q. Mahood, "The effectiveness of occupational health and safety management system interventions: A systematic review," Saf. Sci., vol. 45, no. 3, pp. 329–353, Mar. 2007.

[27] J. C. De Oliveira Matias and D. A. Coelho, "The integration of the standards systems of quality management, environmental management and occupational health and safety management," Int. J. Prod. Res., vol. 40, no. 15, pp. 3857–3866, Jan. 2002.

[28] P. K. Marhavilas, D. Koulouriotis, and V. Gemeni, "Risk analysis and assessment methodologies in the work sites: On a review, classification and comparative study of the scientific literature of the period 2000–2009," J. Loss Prev. Process Ind., vol. 24, no. 5, pp. 477–523, Sep. 2011.

[29] R. T. L. Ng and M. H. Hassim, "Strategies for assessing and reducing inherent occupational health hazard and risk based on process information," Process Saf. Environ. Prot., vol. 97, pp. 91–101, Sep. 2015.

[30] I. A. Papazoglou, L. J. Bellamy, A. R. Hale, O. N. Aneziris, B. J. M. Ale, J. G. Post, and J. I. H. Oh, "I-Risk: development of an integrated technical and management risk methodology for chemical installations," J. Loss Prev. Process Ind., vol. 16, no. 6, pp. 575–591, Nov. 2003.

[31] S. Rathnayaka, F. Khan, and P. Amyotte, "Risk-based process plant design considering inherent safety," Saf. Sci., vol. 70, pp. 438–464, Dec. 2014.

[32] A. Tugnoli, F. Khan, P. Amyotte, and V. Cozzani, "Safety assessment in plant layout design using indexing approach: implementing inherent safety perspective. Part 2-Domino Hazard Index and case study.," J. Hazard. Mater., vol. 160, no. 1, pp. 110–21, Dec. 2008.

[33] P. Krokhmal, M. Zabarankin, and S. Uryasev, "Modeling and optimization of risk," Surv. Oper. Res. Manag. Sci., vol. 16, no. 2, pp. 49–66, 2011.

[34] S. Mathrani and A. Mathrani, "Utilizing enterprise systems for managing enterprise risks," Comput. Ind., vol. 64, no. 4, pp. 476–483, May 2013.

[35] D. Wu, D. L. Olson, and A. Dolgui, "Decision making in enterprise risk management: A review and introduction to special issue," Omega, vol. 57, pp. 1–4, May 2015.

[36] P. Bromiley, M. McShane, A. Nair, and E. Rustambekov, "Enterprise Risk Management: Review, Critique, and Research Directions," Long Range Plann., vol. 48, no. 4, pp. 265–276, Aug. 2014.

[37] R. Conforti, M. La Rosa, G. Fortino, A. H. M. ter Hofstede, J. Recker, and M. Adams, "Real-time risk monitoring in business processes: A sensor-based approach," J. Syst. Softw., vol. 86, no. 11, pp. 2939–2965, Nov. 2013.

[38] R. Conforti, M. de Leoni, M. La Rosa, W. M. P. van der Aalst, and A. H. M. ter Hofstede, "A recommendation system for predicting risks across multiple business process instances," Decis. Support Syst., vol. 69, pp. 1–19, Jan. 2015.

[39] E. Ruijters and M. Stoelinga, "Fault tree analysis: A survey of the state-of-the-art in modeling, analysis and tools," Comput. Sci. Rev., vol. 15–16, pp. 29–62, Feb. 2015.

[40] S. Bassetto, A. Siadat, and M. Tollenaere, "The management of process control deployment using interactions in risks analyses," J. Loss Prev. Process Ind., vol. 24, no. 4, pp. 458–465, Jul. 2011.

[41] P. Willquist and M. Törner, "Identifying and analysing hazards in manufacturing industry—a review of selected methods and development of a framework for method applicability," Int. J. Ind. Ergon., vol. 32, no. 3, pp. 165–180, Sep. 2003.

[42] P. Weber, G. Medina-Oliva, C. Simon, and B. Iung, "Overview on Bayesian networks applications for dependability, risk analysis and maintenance areas," Eng. Appl. Artif. Intell., vol. 25, no. 4, pp. 671–682, Jun. 2012.

[43] M. Jahangirian, T. Eldabi, A. Naseer, L. K. Stergioulas, and T. Young, "Simulation in manufacturing and business: A review," Eur. J. Oper. Res., vol. 203, no. 1, pp. 1–13, May 2010.

[44] D. Mourtzis, M. Doukas, and D. Bernidaki, "Simulation in Manufacturing: Review and Challenges," Procedia CIRP, vol. 25, pp. 213–229, 2014.

[45] A. Negahban and J. S. Smith, "Simulation for manufacturing system design and operation: Literature review and analysis," J. Manuf. Syst., vol. 33, no. 2, pp. 241–261, Apr. 2014.

[46] E. J. Bernechea and V. J. Arnaldos, "Design optimization of hazardous substance storage facilities to minimize project risk," Saf. Sci., vol. 51, no. 1, pp. 49–62, Jan. 2013.

[47] E. J. Bernechea and V. J. Arnaldos, "Optimizing the design of storage facilities through the application of ISD and QRA," Process Saf. Environ. Prot., vol. 92, no. 6, pp. 598–615, Nov. 2014.

[48] H. Medina, J. Arnaldos, and J. Casal, "Process design optimization and risk analysis," J. Loss Prev. Process Ind., vol. 22, no. 5, pp. 566–573, Sep. 2009.

[49] J. W. Lee and J. Ko, "Optimization for Allocating the Explosive Facilities in Order to Minimize the Domino Effect Using Nonlinear Programming," Korean J. Chem. Eng., vol. 22, no. 5, pp. 649–656, 2005.

[50] Y.-M. Wang, K.-S. Chin, G. K. K. Poon, and J.-B. Yang, "Risk evaluation in failure mode and effects analysis using fuzzy weighted geometric mean," Expert Syst. Appl., vol. 36, no. 2, pp. 1195–1207, Mar. 2009.

[51] F. Dweiri and F. A. Meier, "Application of fuzzy decision-making in facilities layout planning," Int. J. Prod. Res., vol. 34, no. 11, pp. 3207–3225, Nov. 1996.

[52] J. Dunjó, V. Fthenakis, J. a Vílchez, and J. Arnaldos, "Hazard and operability (HAZOP) analysis. A literature review.," J. Hazard. Mater., vol. 173, no. 1–3, pp. 19–32, Jan. 2010.

[53] N. Bayar, S. Darmoul, S. Hajri-gabouj, and H. Pierreval, "An Immune based Ontology Implementation of Hazard and Operability Analysis in Production Systems," Appl. Mech. Mater., vol. 575, pp. 884–894, 2014.

[54] O. Salvi and B. Debray, "A global view on ARAMIS, a risk assessment methodology for industries in the framework of the SEVESO II directive.," J. Hazard. Mater., vol. 130, no. 3, pp. 187–99, Mar. 2006.

[55] K. K. Krishnan, I. Jithavech, and H. Liao, "Mitigation of risk in facility layout design for single and multi-period problems," Int. J. Prod. Res., vol. 47, no. 21, pp. 5911–5940, Nov. 2009.

[56] I. Jithavech and K. K. Krishnan, "A simulation-based approach for risk assessment of facility layout designs under stochastic product demands," Int. J. Adv. Manuf. Technol., vol. 49, no. 1–4, pp. 27–40, Oct. 2009.

[57] A. Necci, V. Cozzani, G. Spadoni, and F. Khan, "Assessment of domino effect: State of the art and research Needs," Reliab. Eng. Syst. Saf., vol. 143, pp. 3–18, Jun. 2015.

[58] A. Kusiak and S. Heragu, "The Facility Layout Problem," Eur. J. Oper. Res., pp. 229 – 251, 1987.

[59] R. D. Meller and K. Gau, "The Facility Layout Problem□: Recent and Emerging Trends and Perspectives," J. Manuf. Syst., vol. 15, no. 5, pp. 351–366, 1996.

[60] T. A. Lacksonen and E. E. Enscore, "Quadratic assignment algorithms for the dynamic layout problem," Int. J. Prod. Res., vol. 31, no. 3, pp. 503–517, Mar. 1993.

[61] G.-C. Lee and Y.-D. Kim, "Algorithms for adjusting shapes of departments in block layouts on the grid-based plane," Omega, vol. 28, no. 1, pp. 111–122, Feb. 2000.

[62] H. Hosseini-Nasab and L. Emami, "A Hybrid Clonal Selection for the Single Row Facility Layout Problem with Unequal Dimensions," iBusiness, vol. 04, no. 03, pp. 216–221, 2012.

[63] R. M. Satheesh Kumar, P. Asokan, and S. Kumanan, "An artificial immune system-based algorithm to solve linear and loop layout problems in flexible manufacturing systems," Int. J. Prod. Dev., vol. 10, no. 1/2/3, p. 165, 2010.

[64] J. Balakrishnan and C. H. Cheng, "Dynamic layout algorithms: a state-of-the-art survey," Omega, vol. 26, no. 4, pp. 507–521, Aug. 1998.

[65] G. Meng, S. S. Heragu, and H. Zijm, "Reconfigurable layout problem," Int. J. Prod. Res., vol. 42, no. 22, pp. 4709–4729, Nov. 2004.

[66] S. Heragu, G. Meng, W. H. M. Zijm, and J. C. W. Van Ommeren, "Design and analysis of reconfigurable layout systems," Enschede, The Netherlands, 2001.

[67] M. R. Abdi, "Layout configuration selection for reconfigurable manufacturing systems using the fuzzy AHP," Int. J. Manuf. Technol. Manag., vol. 17, no. 1/2, pp. 149 – 165, 2009.

[68] M. M. Azevedo, J. A. Crispim, and J. P. de Sousa, "Flexible and Reconfigurable Layouts in Complex Manufacturing Systems," in Advances in Production Management Systems. Competitive Manufacturing for Innovative Products and Services. IFIP Advances in Information and Communication Technology, vol. 397, C. Emmanouilidis, M. Taisch, and D. Kiritsis, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2013, pp. 484–493.

[69] H. a. El Maraghy, "Flexible and reconfigurable manufacturing systems paradigms," Flex. Serv. Manuf. J., vol. 17, pp. 261–276, 2006.

[70] J. S. Kochhar and S. S. Heragu, "Facility layout design in a changing environment," Int. J. Prod. Res., vol. 37, no. 11, pp. 2429–2446, Jul. 1999.

[71] M. J. Wang, M. H. Hu, and M. H. Ku, "A solution to the unequal area facilities layout problem by genetic algorithm," Comput. Ind., vol. 56, no. 2, pp. 207–220, 2005.

[72] B. H. Ulutaş and S. Kulturel-Konak, "An artificial immune system based algorithm to solve unequal area facility layout problem," Expert Syst. Appl., vol. 39, no. 5, pp. 5384–5395, Apr. 2012.

[73] S. Kulturel-Konak, "Approaches to uncertainties in facility layout problems: Perspectives at the beginning of the 21st Century," J. Intell. Manuf., vol. 18, no. 2, pp. 273–284, Jul. 2007.

[74] K. S. Sangwan, "Fuzziness in Materials Flow and Plant Layout," in Production Engineering and Management under Fuzziness, C. Kahraman and M. Yavuz, Eds. Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg, 2010, p. 565.

[75] C. Kahraman, M. Yavuz, and İ. Kaya, "Fuzzy and Grey Forecasting Techniques and Their Applications in Production Systems," in Production Engineering and Management under Fuzziness, C. Kahraman and M. Yavuz, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2010, pp. 1–24.

[76] B. K. Wong and V. S. Lai, "A survey of the application of fuzzy set theory in production and operations management: 1998–2009," Int. J. Prod. Econ., vol. 129, no. 1, pp. 157–168, Jan. 2011.

[77] A. L. Guiffrida and R. Nagi, "Fuzzy Set Theory Applications in Production Management Research□: A Literature Survey," J. Intell. Manuf., vol. 9, pp. 39–56, 1998.

[78] A. Bryan, S. J. Hu, and Y. Koren, "Assembly System Reconfiguration Planning," J. Manuf. Sci. Eng., vol. 135, no. August 2013, p. 041005, 2013.

[79] M. Landherr and E. Westkämper, "Integrated product and assembly configuration using systematic modularization and flexible integration," Procedia CIRP, vol. 17, pp. 260–265, 2014.

[80] S. Cavin and N. Lohse, "Multi-Level Skill-Based Allocation Methodology for Evolvable Assembly Systems," in 12th IEEE International Conference on Industrial Informatics, 2014, pp. 532–537.

[81] M. Fanli, T. Dalong, and W. Yuechao, "Modeling of Common Organizational Structure for Reconfigurable Assembly System," in 2006 6th World Congress on Intelligent Control and Automation, 2006, vol. 2, pp. 6738–6743.

[82] G. T. S. Ho, H. C. W. Lau, N. S. H. Chung, and W. H. Ip, "Fuzzy Measurement in Quality Management Systems," in Production Engineering and Management under Fuzziness, C. Kahraman and M. Yavuz, Eds. Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg, 2010, pp. 515–536.

[83] W. H. Elmaraghy, O. A. Nada, and H. A. Elmaraghy, "Quality prediction for reconfigurable manufacturing systems via human error modelling," Int. J. Comput. Integr. Manuf., vol. 21, no. 5, pp. 584–598, Jul. 2008.

[84] C. Díaz-Ovalle, R. Vázquez-Román, J. de Lira-Flores, and M. S. Mannan, "A model to optimize facility layouts with toxic releases and mitigation systems," Comput. Chem. Eng., vol. 56, pp. 218–227, 2013.

[85] C. Díaz-Ovalle, R. Vázquez-Román, and M. Sam Mannan, "An approach to solve the facility layout problem based on the worst-case scenario," J. Loss Prev. Process Ind., vol. 23, no. 3, pp. 385–392, May 2010.

[86] C. O. Diaz, R. Vázquez-Román, S. Jung, and M. S. Mannan, "A comparison of deterministic and stochastic approaches to solve the facility layout problem with toxic releases," Comput. Aided Chem. Eng., vol. 26, pp. 93–98, 2009.

[87] K. Park, J. Koo, D. Shin, C. J. Lee, and E. S. Yoon, "Optimal multi-floor plant layout with consideration of safety distance based on mathematical programming and modified consequence analysis," Korean J. Chem. Eng., vol. 28, no. 4, pp. 1009–1018, 2011.

[88] S. Jayakumar and G. V. Reklaitis, "Chemical plant layout via graph partitioning-1. Single level," Comput. Chem. Eng., vol. 18, no. 5, pp. 441–458, May 1994.

[89] A. López-Molina, R. Vázquez-Román, M. S. Mannan, and M. G. Félix-Flores, "An approach for domino effect reduction based on optimal layouts," J. Loss Prev. Process Ind., vol. 26, no. 5, pp. 887–894, 2013.

[90] J. de Lira-Flores, R. Vázquez-Román, A. López-Molina, and M. S. Mannan, "A MINLP approach for layout designs based on the domino hazard index," J. Loss Prev. Process Ind., vol. 30, pp. 219–227, 2014.

[91] N. Khakzad and G. Reniers, "Risk-based design of process plants with regard to domino effects and land use planning," J. Hazard. Mater., vol. 299, pp. 289–297, Dec. 2015.