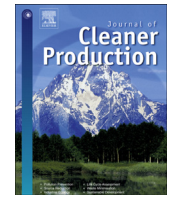
Journal of Cleaner Production 204 (2018) 643–659

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro




# Sustainable robust layout using Big Data approach: A key towards industry 4.0

Ravi Kumar, Surya Prakash Singh*, Kuldeep Lamba

*Department of Management Studies, Indian Institute of Technology Delhi, India*

ARTICLE INFO

*Article history:*
Received 13 September 2017
Received in revised form
26 July 2018
Accepted 30 August 2018
Available online 6 September 2018

*Keywords:*
Big data
Industry 4.0
Sustainability
Layout
Simulated annealing
Principal component analysis

ABSTRACT

A layout design based on large scale (Big) data is more efficient and effective in today's competitive market. Due to variations in product demands, varying product mix, and addition or deletion of products, layout of industry needs to be robust and sustainable. A robust and sustainable industry layout design is capable to handle the variations and is seen as first step towards Industry 4.0 to keep precise and accurate manufacturing of products in given due time. Poor layout design decreases the precision and accuracy in manufacturing of products and increases the production time. To design layout for Industry 4.0, this work proposes an embedded SA based meta-heuristic and principal component analysis (PCA) approach using large scale data to solve sustainable robust stochastic cellular facility layout problem (sustainable-RSCFLP). The data for the problem is collected considering basic 3Vs of Big Data i.e. Volume, Variety, and Velocity. Fourteen different criteria are identified and evaluated by 100 experts to group them based on their Eigen values using PCA. These are Distance, Adjacency, Shape ratio, Flexibility, Maintenance, Accessibility, Hazardous movement, Noise Level, Aesthetic, Safety, WIP and inventory, Space utilization, Capital equipment utilization, and Robustness. These fourteen criteria are clustered in to four factors using PCA approach. These clusters are defined as *Material Handling Distance*, *Maintenance*, *Adjacency*, and *Hazard*. The *material handling distance* comprises of three criteria such as Distance, Capital equipment utilization, and space utilization. In the same way, *Maintenance* comprises of three criteria such as Maintenance, Work in Process and inventory, and Accessibility. Similarly, *Adjacency* comprises of four criteria such as Shape ratio, Robustness, Adjacency, and Flexibility. Finally, *Hazard* comprises of four criteria such as Noise level, Aesthetics, Safety and Hazardous movement. In addition to these four clusters, fifth factor i.e. electrical energy consumption (EEC) is taken separately for each layout alternative to make the proposed layout environmentally sustainable. Thus, the proposed layout considers all pillars of sustainability i.e. EEC (maps environmental sustainability), Maintenance and Hazards (maps social sustainability), and Material Handling (maps economic sustainability) for designing cellular facility layout problem. Further, pool of layouts is generated using embedded SA based meta-heuristic. Each layout is evaluated over each clusters and EEC is calculated for each layout as to make the layout design sustainable. Furthermore layouts are ranked using TOPSIS, IRP, and weighted-IRP qualitative approaches, and a consensus ranking is finally provided to select an efficient sustainable robust layout for Industry 4.0.



## 1. Introduction

Today, the biggest challenge is to protect and improve the environment due to pollution and continuous depletion of resources (Song et al., 2018a, 2018b). The manufacturing plants must be designed safer and less polluting. Now-a-days electrical energy is a vital resource; therefore, it needs to be protected by efficient use of it. In the year 2008, energy consumption in industrial sector was reported as 98 Ej (Exajoule), and is projected to increase up to 44% till 2030 (Vikhorev et al., 2013). O'Driscoll and O'Donnell (2013) also highlighted that some serious efforts must be taken to improve energy production, energy distribution and energy consumption. Moreover, to protect the environment, use of electrical energy must be minimized, since this emits carbon. Bougain et al. (2015)

* Corresponding author.
*E-mail addresses:* ravikumar.iitdu@gmail.com (R. Kumar), surya.singh@gmail.com (S.P. Singh), kuldeep.qror@gmail.com (K. Lamba).

https://doi.org/10.1016/j.jclepro.2018.08.327

highlighted that electrical energy caused up to 15% of the total production cost. Stadlmann et al. (2016) advocated that optimization of energy efficiency and utilization is a major focus of political and social policies which leads to increase in energy cost. They also provided guidelines to construct future facilities. Daut et al. (2017) advocated that major form of energy consumed in a commercial building is electrical energy, and there must be ways to find or forecast EEC. So, to protect the environment, an efficient layout design plays a vital role in minimizing the energy consumption in the form of electrical energy. This paper focuses towards designing a layout which is environmental friendly which uses minimum electrical energy while transporting parts among different machines. Most of the past work related to facility layout design is only based on minimizing material handling distance which is one of the major objective considered in the layout design. However, in this work, while minimizing material handling distance, EEC is also considered which is further minimized to gain environmental savings. So, the final proposed layout is effective and efficient in both saving material handling cost (MHC) as well as saving energy cost represented in the form of EEC.

Designing a layout is long term decision making and any change in existing layout incurs re-arrangement cost which is very high (Singh and Singh, 2010). Moreover, layout in long run influences the performance of an industry, and impacts to a great extent precision and accuracy of production if the layout design is not capable to handle the fluctuations due to demand variation and product mix. Tompkins et al. (2010) explain that an efficient layout design reduces manufacturing cost by 10–30%. Moreover, it also reduces manufacturing lead time (MLT) (Raman et al., 2009). In today's competitive scenario, every industry strives to become Industry 4.0. Moreover, to cope with rapid change in product mix and product variation, Industry 4.0 plays a vital role. Industry 4.0 focuses on precise and accurate manufacturing by establishing intelligent process (Wang et al., 2016). In this context, design of layout becomes key element in making an Industry 4.0. Therefore, designing a robust layout is essential in this frequently changing environment. However, designing a robust stochastic cellular facility layout (RSCFL) in today's competitive environment is a challenging task due to complexity of layout problem.

The proposed work is of designing layout for Cellular manufacturing systems (CMS). CMS is an extension of group technology (GT) (Luo and Tang, 2009; Liu et al., 2010; and Kumar and Singh, 2017a) and become complex due to increasing competitiveness and market demand. Also, due to high demand and competitiveness, volume and variety of the data generated are also large. Enormous amount of data is generated in manufacturing sector as the use of various sensors and actuators, RFID devices, and digital machines is gaining prominence in production lines, shop floors, and factories (Zhong et al., 2017). CMS based layout reduces material handling, set up time, lead time, and waste and also increases productivity and profitability (Wemmerlov and Johnson, 1997; and Singh and Rajamani, 2012) and best complements to Industry 4.0. Now-a-days, designing a layout based only on material flow among machines, similarity scores, and processing times are not efficient. To design an effective and efficient layout, number of criteria affecting layout should be considered (Tayal and Singh, 2016). Also, there is a need to transform the huge heterogeneous and homogenous data into useful information. In this work, fifteen different criteria are considered which reflect sustainability and Big Data issues. PCA method is used to group fourteen out of these fifteen criteria into factors. EEC is considered a distinct factor to design sustainable layout as electric consumption is considered up to 15% of total production cost (Bougain et al., 2015). For detailed study on Big Data following papers can be referred (Wang et al., 2018; Song et al., 2016).

In this paper, a mathematical model is developed to design RSCFL towards Industry 4.0. Since the cellular facility layout is a bi-quadratic assignment problem (bi-QAP) and a NP-hard problem, an embedded simulated annealing (SA) based meta-heuristic approach is used to solve the model. A pool of layouts is generated, by varying parameters of embedded SA based meta-heuristic. The data for the layout is generated considering 3Vs of Big Data i.e. Volume (number of machines, number of cells, and number of products), Variety (Flexibility, distance, robustness, maintenance, WIP and inventory, shape ratio, capital, space utilization, safety, accessibility, noise level, aesthetics hazardous movement, adjacency, electrical energy consumption), and Velocity (time horizon). In addition, each layout is evaluated using interpretive ranking process (IRP), weighted-IRP, and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Lastly, consensus ranking is provided using integer linear program (ILP). In particular, the paper attempts to realize following objectives:

- Identifying various qualitative attributes affecting the layout of facilities and clustering them using PCA.
- To formulate the problem incorporating sustainability and robustness in the model to make the layout more confirming to changing market environment.
- To incorporate Big Data in the layout design.

Rest of the paper is organized as follows. Section 2 provides the proposed methodology followed by numerical illustration in section 3. Section 4 explains results and conclusions followed by implications and future scopes in section 5.

## 2. Proposed methodology

Here, problem statement and proposed methodology are provided. Problem statement is described in section 2.1 and the proposed methodology is discussed in detail in section 2.2.

### 2.1. Problem statement

Layout design commonly known as facility layout design in cellular manufacturing systems (CMS) is a bi-QAP problem, which is a class of non-polynomial hard (NP-hard) problem. Thus, it becomes a barrier to optimize industry layout using sub-optimal solution. Therefore, the paper proposes an embedded SA based meta-heuristic approach to optimally solve bi-QAP. The layout is optimized considering Big Data approach and the final layout is selected applying MCDM techniques viz. TOPSIS, IRP, Weighted-IRP. The proposed layout obtained through the embedded SA based approach using Big Data and MCDM techniques also captures the sustainability issues. The proposed layout considering Big Data characteristics through 3Vs and sustainability parameters is a robust layout design for Industry 4.0.

### 2.2. Proposed methodology

The proposed approach to design sustainable robust stochastic cellular facility layout (sustainable-RSCFL) is divided into three phases. Phase 1 identifies different factors affecting facility layout based on 3Ps of sustainability i.e. people, planet, and profit, and identified factors are clustered using PCA. Phase 2 generates data using 3Vs of Big Data and also generates pool of layouts using proposed embedded SA based meta-heuristic. Moreover, numeric values for each factor (or cluster) are also computed in this phase. Besides this, EEC parameter considered for sustainability is also computed and considered as fifth factor to design sustainable-RSCFL. The layout design is finalized through MCDM techniques.