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Review

A survey on multi-floor facility layout problems

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A B S T R A C T

Facility layout problem is a well-known optimization problem which generally deals with the arrangement of the facilities required in an organization. This problem has received much attention during the past decades. However, the researchers have mainly focused on the case where a single floor is available. While, in the competitive world, it is clear that using multi-floor structure layouts are much more efficient and in some cases necessary due to the nature of the functions and activities performed in the firms. Hence, this issue has recently attracted much attention and is becoming increasingly popular. Nevertheless, the lack of a review study on this subject for directing the new research is a great gap that has not been regarded so far. In this paper, first a well-designed framework is presented. Then, all literature references in the field of multi-floor facility problem (MFLP) are gathered, categorized and reviewed thoroughly based on the framework. Accordingly, different applications of MFLP across various industries are discussed; basic features of the problem to capture different situations are identified; the formulation approaches to address the problems and the relevant resolution methodologies are introduced; the majority of the contributions proposed in the literature are analysed from different perspectives. Finally, several issues and research directions are highlighted to be investigated in future work.

Contents

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1. Introduction

Facility layout problem (FLP) is a fundamental problem which seeks to reduce material handling costs, work in process, lead times, utilize existing space more effectively, make plant adaptive to future changes, provide a healthy, convenient and safe environment for employees, and generally increase productivity through determining an efficient arrangement (layout) of the required facilities within the organization (Lim & Noble, 2006; Madhusudanan Pillai, Hunagund, & Krishnan, 2011; See & Wong, 2008). This problem has many applications in real life situations, including layout design for manufacturing systems (e.g. cellular (Mohammadi & Forghani, 2016), flexible (Niroomand, Hadi-Vencheh, Şahin, & Vizvári, 2015), etc.), hospitals, schools and airports (Helber, Böhme, Oucherif, Lagershausen, & Kasper, 2016; Lee & Tseng, 2012; Lin, Liu, Wang, & Liu, 2015), printed circuit board (Raghavan, Yoon, & Srihari, 2014), VLSI (Funke, Hougardy, & Schneider, 2016), semiconductor fabrication (Kim, Yu, & Jang, 2016), logistic systems (Grobelny & Michalski, 2016), chemical processes (Park, Koo, Shin, Lee, & Yoon, 2011), offshore environments (Dan, Shin, & Yoon, 2015), construction projects (Huang & Wong, 2015), warehouses (Derhami, Smith, & Gue, 2016), backboard wiring problems, typewriters, hydraulic turbine design (Singh & Sharma, 2006). However, the main attentions of the research in this area have been focused on the manufacturing applications. It is noteworthy to know that material handling cost constitutes 20–50% of the total operating expenses in manufacturing environments (Francis, McGinnis, & White, 1992; Huang, May, Huang, & Huang, 2010) which can considerably be reduced through designing an efficient layout configuration. Material handling cost is mainly dependent on the amount of material flow and distances between locations of the facilities (See & Wong, 2008). Accordingly, minimizing the material handling cost has been considered as the common objective in the literature. However, there are other criteria for evaluating the efficiency of a layout design, which will be introduced later.

Nowadays, due to the fact that land supply is generally expensive (especially in urban areas), using multi-floor structures in facility layout design (i.e. locating facilities on several floors/layers) plays a critical role in the competitive world (Keivani, Rafienejad, Kaviani, & Afshari, 2010). In addition, a compact building shape provides a better control on the environment, helps to save energy for air conditioning (Goetschalckx & Irohara, 2007), reserves land for future extension (Matsuzaki, Irohara, & Yoshimoto, 1999), makes material handling more convenient and consequently reduces all associated costs (Huang et al., 2010). Even, many facilities such as office and service buildings, warehouses, oil platforms and naval vessels require to accommodate their functions and activities in multi-story structures, due to the nature of their material or process specification (Hahn, Smith, & Zhu, 2010).

In terms of computational complexity, single-floor FLP (SFLP) (and consequently multi-floor FLP (MFLP)) is categorized into NP-complete class (Ahmadi & Akbari Jokar, 2016). This problem has been studied for a long time and has a rich literature. Hereupon, many research efforts have been conducted in the field of SFLP. Among them, a variety of review papers have been published to analyze and summarize the relevant research (Drira, Pierreval, & Hajri-Gabouj, 2007; Kulturel-Konak, 2007; Kundu & Dan, 2012; Kusiak & Heragu, 1987; Liggett, 2000; Meller & Gau, 1996; Singh & Sharma, 2006). In contrast, MFLP is a relatively novel area in the field of FLP and has recently received attention due to its tremendous effect on the efficiency and competitiveness of firms. However, the lack of a review study on this issue for directing the new research is a great gap that has not been regarded so far. Therefore, this paper aims to bridge the gap, through carrying out a comprehensive review and recent survey on the topic for the first time. To do so, first a state-of-the-art framework is designed according to the features and characteristics of the multi-floor facility layout problems. Then, all literature references are gathered, categorized and reviewed thoroughly based on the framework. As a result of this effort, different applications of MFLP across various industries are presented; structural features of the problem which outline different situations are introduced; how to formulate the problems with specific characteristics are discussed; the resolution methods to approach the problems are addressed; and finally the contributions proposed in the literature are elaborately summarized in all associated aspects. In addition to providing this big picture, some fundamental future research directions on the MLFP are underlined. In the way of achieving this goal and in order to provide a better understanding of the related concerns, a brief glance is given on the SFLP in some situations; since most of the extended methods employed in MFLP was firstly introduced for SFLP.

The rest of this paper is structured as follows. In Section 2, multi-floor facility layout problem is introduced in details and the affecting factors are recognized. In Section 3, the structural characteristics of the problem and the formulation approaches are presented. Solution methodologies are discussed in Section 4. Finally, Section 5 provides conclusions and some research directions to be investigated in future research work.

2. Overview of multi-floor facility layout problem

The main difference between single and multi-floor FLP (which has made MFLP more complicated) is that, in multi-floor problem, the departments (facilities) should be imbedded within several floors instead of one floor; and consequently they interact with each other vertically in addition to horizontal direction. Therefore, in an MFLP we are generally faced several main classes of decisions: (1) allocating departments to floors; (2) locating departments within floors; (3) determining the number of required lift facilities; (4) locating lift facilities; (5) assigning the material flows between floors to elevators; (6) specifying details of layout, such as pick-up/drop-off point(s) of departments and aisles structure; and many other related decisions. Evidently, these decisions are interrelated (Goetschalckx & Irohara, 2007). Besides, calculating distances between departments (particularly for the departments located on different floors) is a challenge in MFLP. In order to move from a department to another department located on different floors, movement should be from the flow-originating department to the selected elevator, and after arriving at the desired floor (using the elevator), the destination department should be headed for (Ahmadi & Akbari Jokar, 2016). All these distances should elaborately be calculated.

A distinguishing feature of the MFLP is that the travel time is nonlinear. The travel time between a pair of departments located on different floors is dependent on the distance and includes the travel time related to the three aforementioned movements and also the time spent waiting for the elevator. In manufacturing environments where vertical transporter is often a reciprocating conveyor, the travel time can be approximated as a piecewise linear function, because the waiting time (for the conveyor) is negligible. While, such an assumption may not hold in office environments (Kochhar, 1998).

In order to reduce the complexity of the problem, different researchers adopted many assumptions and supposed that one or more of these categories of decisions are fixed in advance and so did not deal with all the decisions simultaneously. Research in this area stem from the work of Moseley (1963) who approached the vertical facility design as a transportation problem. In this problem the departments were located on specific locations in a multi-floor building, according to priority values obtained using the traffic among departments. The model was later inspired to develop new and sophisticated methods. However, since facility layout problem has originated from industrial plants, most of the papers published in the literature have concentrated on industrial environments. This issue is established for both SFLP and MFLP; by this difference that the other applications are more prominent in MFLP in comparison with SFLP. Among them we can refer to multi-deck compartment layout of ships (Lee, Roh, & Jeong, 2005), offshore production systems (Dan et al., 2015; Ha & Lee, 2016; Richardson, Liu, & Mannan, 2015) and particularly the process plant layout (Barbosa-Póvoa, Mateus, & Novais, 2002; Park et al., 2011; Patsiatzis & Papageorgiou, 2002) which is related to the spatial arrangement of equipment items and interconnecting pipework in a chemical plant (Georgiadis, Schilling, Rotstein, & Macchietto, 1999).

In an MFLP we have n facilities (departments) and a land with several floors. These facilities should be imbedded within the floors in a feasible manner (i.e. the facilities must be located entirely inside the floors and not overlap with each other), such that the objective function(s) of the problem is (are) greatly satisfied under the constraints of the problem. Objective function(s) of the problem can be represented quantitatively (Bernardi & Anjos, 2012; Ghadikolaei & Shahanaghi, 2013), qualitatively (Seehof, Evans, Friederichs, & Quigley, 1966) or as a combination of both (Lee et al., 2005; Ramtin, Abolhasanpour, Hojabri, Hemmati, & Jaafari, 2010) which may contain one (Abdinnour-Helm & Hadley, 2000; Bernardi & Anjos, 2012) or several parts with conflicting (Lee et al., 2005; Ramtin et al., 2010) or consistent (Che, Zhang, & Feng, 2016; Ghadikolaei & Shahanaghi, 2013; Hathhorn, Sisikoglu, & Sir, 2013) objectives. A common (part of) objective function which is a distance-based measure (i.e. quantitative) is given as follows, while qualitative objective functions are generally dependent on the closeness rate of facilities:

$$\min \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} f_{ij}(c_{ij}^H d_{ij}^H + c_{ij}^V d_{ij}^V), \tag{1}$$

where f_{ij}, d_{ij}^H and c_{ij}^H denote material flow, horizontal distance and cost per unit horizontal distance between departments i and j, respectively. Also, "V" is the notation of vertical direction. It is notable that thus far, the distances between departments in MFLP have only been modeled as rectilinear distance. Other quantitative cost such as setup cost and waiting cost of elevator(s) (Bozer & Meller, 1992; Hathhorn et al., 2013; Huang et al., 2010; Matsuzaki et al., 1999), building cost (Hathhorn et al., 2013; Patsiatzis & Papageorgiou, 2002), pipeline and pumping costs in chemical plants (Lee, 2015; Park et al., 2011), rearrangement cost of layout in dynamic environments (Afrazeh, Keivani, & Farahani, 2010; Ghadikolaei & Shahanaghi, 2013) and fixed charge of assignment in QAP (quadratic assignment problem) (Kaku, Thompson, & Baybars, 1988) may be incorporated in the objective function.

The cost per unit distance is usually assumed to be constant, while this is not always true especially in the vertical direction. For example, due to the gravity, some conveyors may have less transportation costs in the downward direction than in the upward direction. In addition, different vertical transporters may have various transportation costs (Kochhar, 1998). The cost in vertical direction (c_{ij}^V) is often more than the cost of horizontal direction (c_{ij}^H). The total cost is also influenced by the number and location of lift facilities. These facts indicate that the minimization of total material handling cost is heavily dependent on the vertical transportation cost (Hosseini, Mirzapour, & Wong, 2013; Matsuzaki et al., 1999).

In order to provide a general overview of the research conducted for multi-floor facility layout problems, the factors characterizing the problem are categorized in Fig. 1 as a tree representation. This tree is composed of two main branches (i.e. modelling and resolution approaches). Also, Tables 1 and 2 provide a comprehensive summary of the related papers contributed the literature in each of the branches, respectively. The next two Sections of the paper attempt to clarify the framework and provide more insight about this schematic representation.

3. Problem modelling

In this section, first the structural characteristics of MFLP which may influence the formulation method of the problem are described. Then, different formulation approaches presented in the literature are introduced. Since some specifications of MFLPs, such as dimensions of departments or formulation techniques of departments, are common with SFLPs, we do not deal with these issues in details and refer the readers to related literature.

3.1. Structural characteristics of multi-floor facility layout problems

3.1.1. Static versus dynamic states

Due to the competitive market, the business conditions are quickly changing. As a result, in order to remain in the marketplace, we must adapt ourselves to the changes using dynamic approaches (Balakrishnan & Cheng, 1998). Indeed, changes in production equipment and product mix, variations in customer demand, introducing new products (from which 40% of the company's sales comes (Page, 1991)) and discontinuation of existing products can lead to changes in material flow between departments (Ghadikolaei & Shahanaghi, 2013) and consequently becoming the earlier plan to an insufficient layout design.

The first issue that should be considered to model any facility layout problem is to make a decision whether it is dynamic or static. In the dynamic state, the flow between departments may change over time. Therefore, the planning horizon is divided into some periods (weeks, months, years, etc.) and a layout is specified for each period, by adopting this assumption that the required data are fixed during the intended period (see Fig. 2 for example). On the other hand, in the static state, all data and information would remain fixed over time, and so there is only one layout instead of a sequence of layouts (Balakrishnan & Cheng, 1998; Drira et al., 2007). It is noteworthy that the objective function of dynamic problems should contain the cost related to rearrangement of layouts from one period to another and also the costs incurred due to loss of production time (in addition to the costs of static state) (Kochhar & Heragu, 1999). Although, the latter is usually not taken into account in the problems. Moreover, an additional constraint for the limited budget of rearrangement cost may be imposed to the problem (Baykasoglu, Dereli, & Sabuncu, 2006).

Despite of the importance of employing dynamic approaches, only three papers (Afrazeh et al., 2010; Ghadikolaei & Shahanaghi, 2013; Kochhar & Heragu, 1999) have been published for MFLP in dynamic states so far. Even, these papers are along with many limitations, especially the latter two cases. This fact is due to the high complexity of dynamic MFLP. So, many efforts are required to bridge the gap between theory and practice.

3.1.2. Departments and floors

Departments and floors, which are the main components of any FLP, can be viewed from two aspects of shape and dimension. Shape can be regular (i.e. rectangular) or irregular. Drira et al. (2007) has reviewed this feature of FLPs in details. However, about

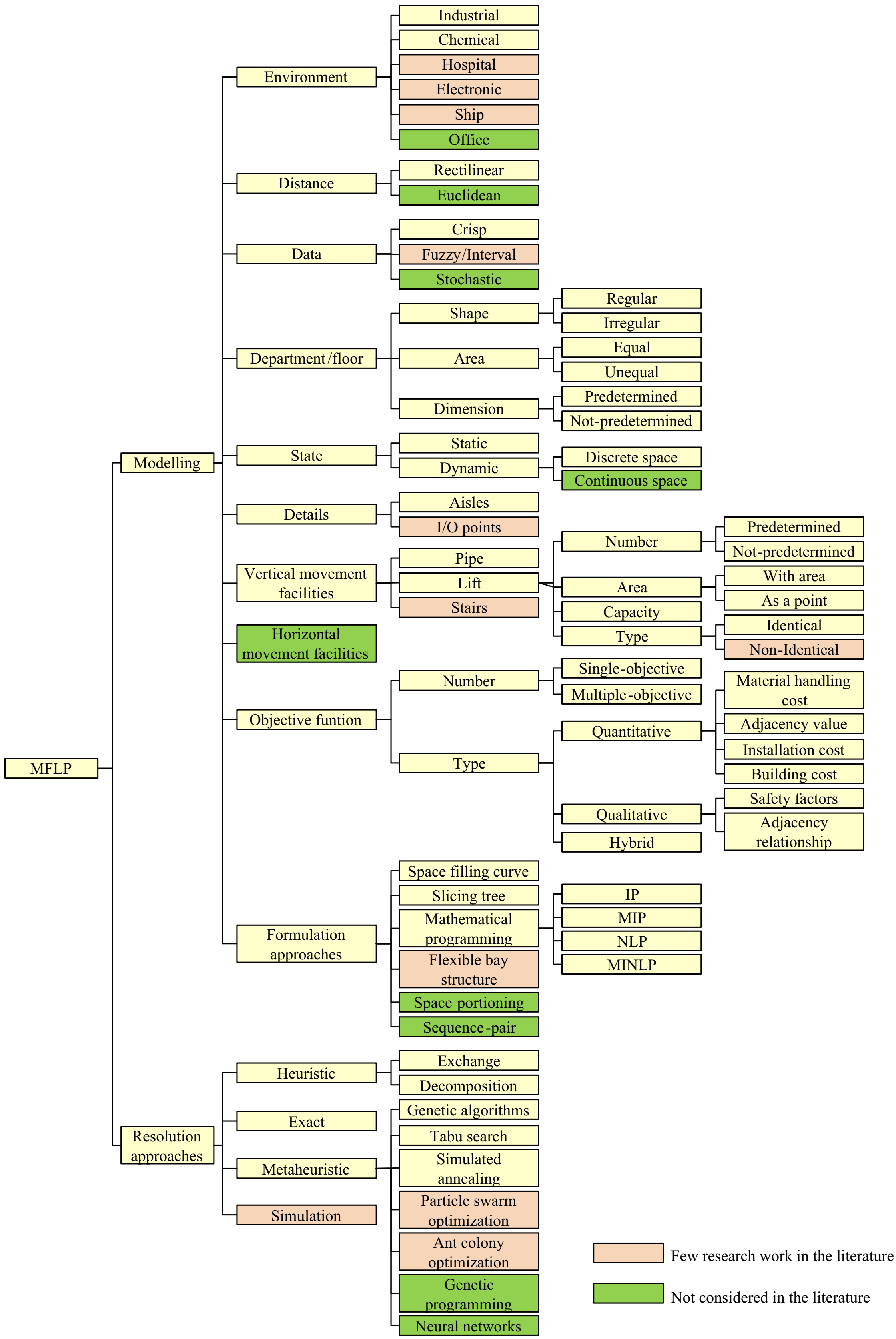

Fig. 1. Tree representation of multi-floor facility layout problem.

the floors another property, i.e. their number, is also involved in addition to shape and dimension.

The number of floors is usually assumed to be predetermined, while Hathhorn et al. (2013) attempted to determine the optimal

Table 1
Summary of formulation approaches of multi-floor facility layout problems in the literature.

References	Year	Static / Dynamic	Departments		Vertical movement facilities					Distances	I/O points	Considerations
			Shape	Dimensions	Type	Numbers	Position	Area	Capacity			
(Che et al. (2016)	2016	S	Irregular							Rectilinear-C to C[c]		Predefined rooms inside the floors
Ahmadi and Akbari Jokar (2016)	2016	S	Rectangular	DV[a]	Elevator	KA[b]	DV			Rectilinear-C to C		Considering various constraints
Izadinia and Eshghi (2016)	2016	S	Rectangular	KA	Elevator	KA	DV	✓		Rectilinear-C to C		- Flow material and location of departments as roust values- Only one (a set of) elevator(s)
Ha and Lee (2016)	2016	S	Rectangular	DV	Piping					Rectilinear-C to C		
Neghabi and Ghassemi (2015)	2015	S	Rectangular	KA	Piping					Rectilinear-C to C		Adjacency in both vertical and horizontal directions
Lee (2015)	2015	S	Rectangular	KA	Piping					Rectilinear-C to C		Safety and maintenance distances
Chraibi et al. (2014)	2014	S	Rectangular	KA	Elevator	KA	KA			Rectilinear-C to C		- For two floors only - Location of corridors
Lee (2014)	2014	S	Cubic	KA	Piping					Rectilinear-C to C		
Izadinia et al. (2014)	2014	S	Rectangular	KA	Elevator	KA	DV	✓		Rectilinear-C to C		- Flow material as roust parameters Only one (a set of) elevator(s)
Hathhorn et al. (2013)	2013	S	Rectangular	DV	Elevator	DV	DV			Rectilinear-C to C		
Ghadikolaei and Shahanaghi (2013)	2013	D	Square	KA	Elevator	KA	KA		✓	Rectilinear-C to C		- Only one (a set of) Elevator(s) - Equal area departments
Hosseini et al. (2013)	2013	S	Rectangular	KA	Elevator	KA	KA			Rectilinear		
Bernardi and Anjos (2012)	2012	S	Rectangular	DV	Elevator	KA	KA			Rectilinear-C to C		
Park et al. (2011)	2011	S	Cubic	KA	Piping					Rectilinear-C to C		
Xiaoning and Weina (2011)	2011	S	Irregular		Elevator	KA	KA			Rectilinear-C to C		
Krishnan and Jaafari (2011)	2011	S	Rectangular	DV	Elevator	DV	DV			Rectilinear-C to C		
Hahn et al. (2010)	2010	S			Stairs	KA	KA		✓	Rectilinear-C to C		
Afrazeh et al. (2010)	2010	D	Square	KA	Elevator	KA	KA			KA		- Only one (a set of) Elevator(s) - Equal area departments
Huang et al. (2010)	2010	S	Irregular		Elevator	DV	DV	✓	✓	Rectilinear-C to C		
Ramtin et al. (2010)	2010	S	Rectangular	DV	Elevator	DV	DV			Rectilinear-C to C		
Kohara et al. (2008)	2008	S	Rectangular	KA						KA		
Goetschalckx and Irohara (2007)	2007	S	Rectangular	KA	Elevator	DV	DV			Rectilinear-C to C		Two types of elevators
Irohara and Goetschalckx (2007)	2007	S	Rectangular	KA	Elevator	DV	DV			Rectilinear-C to C		Two types of elevators
Chang and Lin (2006)	2006	S	Rectangular	KA	Elevator	KA	KA	✓		Rectilinear-O to I (Contour[d])	✓	- Aisles - One door for each department
Hu and Lin (2006)	2006	S	Rectangular	KA	Elevator	KA	KA			Rectilinear-C to C		- Determining the number of floors
Lee et al. (2005)	2005	S	Rectangular	DV	Elevator	KA	KA	✓		Rectilinear-C to C (Contour)		- Aisles and inner walls - For multi-deck compartment
Berntsson and Tang (2004)	2004	S	Rectangular	DV						Is not involved		- Not involving lift facilities - Minimizing land area
Patsiatzis and Papageorgiou (2003)	2003	S	Rectangular	KA	Piping					Rectilinear-C to C		
Patsiatzis and Papageorgiou (2002)	2002	S	Rectangular	KA	Piping					Rectilinear-C to C		
Barbosa-Póvoa et al. (2002)	2002	S	Irregular-3D	KA	Piping					Rectilinear- O to I	✓	- Safety distances between units - Different up and downward costs
Abdinnour-Helm and Hadley (2000)	2000	S	Irregular		Elevator	KA	KA			Rectilinear-C to C		
Matsuzaki et al. (1999)	1999	S	Rectangular	DV	Elevator	DV	DV		✓	Rectilinear-C to C		
Kochhar and Heragu (1999)	1999	D	Irregular		Elevator	KA	KA			Rectilinear-C to C		
Georgiadis et al. (1999)	1999	S	Rectangular	KA	Piping					Rectilinear-C to C		Safety distances between units
Kochhar (1998)	1998	S	Irregular		Elevator	KA	KA			Rectilinear-C to C		
Meller and Bozer (1997)	1997	S	Irregular		Elevator	KA	KA			Rectilinear-C to C		
Jagielski and Gero (1997)	1997	S	Irregular							KA		
Georgiadis et al. (1997)	1997	S	Square	KA	Pippin					Rectilinear-C to C		
Meller and Bozer (1996)	1996	S	Irregular		Elevator	KA	KA			Rectilinear-C to C		
Bozer et al. (1994)	1994	S	Irregular		Elevator	KA	KA			Rectilinear-C to C		
Bozer and Meller (1992)	1992	S	Irregular		Elevator	DV	DV		✓	Rectilinear-C to C		
Suzuki et al. (1991)	1991	S	Rectangular	KA	Piping					KA		Preference of departments' location
Kaku et al. (1988)	1988	S	Rectangular (equal areas)	KA	Elevator	KA	DV	✓		KA		Only one (a set of) Elevator(s)
Johnson (1982)	1982	S	Irregular		Elevator	KA	KA			KA		

[a] DV: decision variable.
[b] KA: known in advance.
[c] C to C: center to center.
[d] In contour distances, the distance between any two departments are obtained through aisles.

Table 2
Summary of solution approaches of multi-floor facility layout problems in the literature.

References	Year	Formulation			Resolution	
		Solution space (Continuous or Discrete)	Objective function(s)	Method or model at different stages	Method	# Stages (solver or solution approach)
Che et al. (2016)	2016	D	Min, Min	MINLP	Exact	1 (CPLEX)
Ahmadi and Akbari Jokar (2016)	2016	C	Min	MIP, NLP, NLP	Exact	3 (CPLEX, KNITRO, KNITRO)
Izadinia and Eshghi (2016)	2016	D	Min	MIP	Exact and Metaheuristic	1 (GAMS solver and Ant colony optimization)
Ha and Lee (2016)	2016	D	Min	MIP	Exact	1 (CPLEX)
Neghabi and Ghassemi (2015)	2015	C	Max	MIP	Exact	1 (CPLEX)
Lee (2015)	2015	C	Min	MINLP	Metaheuristic	1 (Particle swarm optimization)
Chraibi et al. (2014)	2014	C	Min, Max	MIP	Exact	1 (CPLEX)
Lee (2014)	2014	C	Min, Min	MINLP	Exact	1 (GAMS solver)
Izadinia et al. (2014)	2014	D	Min	MIP	Exact	1 (GAMS solver)
Hathhorn et al. (2013)	2013	C	Min, Min	MIP	Exact	1 (Gurobi optimization solver)
Ghadikolaei and Shahanaghi (2013)	2013	C	Min	Particular[a]	Exact and Metaheuristic	1 (GAMS solver and Simulated Annealing algorithm)
Hosseini et al. (2013)	2013	C	Min	Particular	Heuristic	1 (SLP method)
Bernardi and Anjos (2012)	2012	C	Min	MIP, NLP	Heuristic	2 (CPLEX, MINOS)
Park et al. (2011)	2011	C	Min, Min	MIP	Exact	1 (CPLEX)
Xiaoning and Weina (2011)	2011	D	Min	SFC	Metaheuristic	2 (Heuristic rules, Simulated annealing)
Krishnan and Jaafari (2011)	2011	C	Min, Max	FBS	Metaheuristic	1 (Memetic algorithm)
Hahn et al. (2010)	2010	C	Min, Min	IP	Exact	1 (CPLEX)
Afrazeh et al. (2010)	2010	D	Min	MIP	Exact	1 (CPLEX)
Huang et al. (2010)	2010	D	Min	SFC	Heuristic	3 (Not mentioned, Threshold accepting algorithm, heuristic algorithm)
Ramtin et al. (2010)	2010	C	Min, Max	MIP	Only formulation	(without solution approach)
Kohara et al. (2008)	2008	D	Min, Min	IP	Exact	1 (Branch and Bound)
Goetschalckx and Irohara (2007)	2007	C	Min	MIP	Exact	1 (CPLEX)
Irohara and Goetschalckx (2007)	2007	C	Min	MIP, MIP	Heuristic	2 (MIP solver; MIP solver)
Chang and Lin (2006)	2006	D	Min	Particular	Heuristic	2 (k-mean algorithm, Genetic algorithm and heuristic rules)
Hu and Lin (2006)	2006	C	Min	FBS	Metaheuristic	1 (Ant colony optimization)
Lee et al. (2005)	2005	C	Min, Max	Particular	Metaheuristic	1 (Genetic algorithm)
Berntsson and Tang (2004)	2004	C	Min	Tree	Metaheuristic	1 (Genetic algorithm)
Patsiatzis and Papageorgiou (2003)	2003	C	Min	MIP	Heuristic	1 (CPLEX)
Patsiatzis and Papageorgiou (2002)	2002	C	Min	MIP	Exact	1 (CPLEX)
Barbosa-Póvoa et al. (2002)	2002	C	Min	MIP	Exact	1 (CPLEX)
Abdinnour-Helm and Hadley (2000)	2000	D	Min	SFC	Heuristic	2 (A heuristic algorithm, Tabu Search algorithm)
Matsuzaki et al. (1999)	1999	C	Min	Tree	Heuristic	1 (Genetic algorithm and heuristic rules)
Kochhar and Heragu (1999)	1999	D	Min	SFC	Metaheuristic	1 (Genetic algorithm)
Georgiadis et al. (1999)	1999	C	Min	MIP		1 (CPLEX)
Kochhar (1998)	1998	D	Min	SFC	Metaheuristic	1 (Genetic algorithm)
Meller and Bozer (1997)	1997	D	Min	SFC	Heuristic	2 (MIP solver, Simulated annealing algorithm)
Jagielski and Gero (1997)	1997	D	Min	SFC	Metaheuristic	1 (Genetic programming)
Georgiadis et al. (1997)	1997	D	Min	MIP	Exact	1 (CPLEX)
Meller and Bozer (1996)	1996	D	Min	SFC	Metaheuristic	1 (Simulated annealing algorithm)
Bozer et al. (1994)	1994	D	Min	SFC	Heuristic	1 (Exchange procedure)
Bozer and Meller (1992)	1992	D	Min	SFC	Heuristic	3 (MIP solver, Simulated Annealing algorithm, Simulated Annealing algorithm)
Suzuki et al. (1991)	1991	D	Min	MIP, IP	Exact	2 (Not mentioned)
Kaku et al. (1988)	1988	D	Min	MIP	Heuristic	3 (k-mean algorithm, MIP solver, Exchange procedure)
Johnson (1982)	1982	D	Min	Particular	Heuristic	1 (Exchange procedure)

[a] The method employed to model the problem is not included in the common formulation approaches.

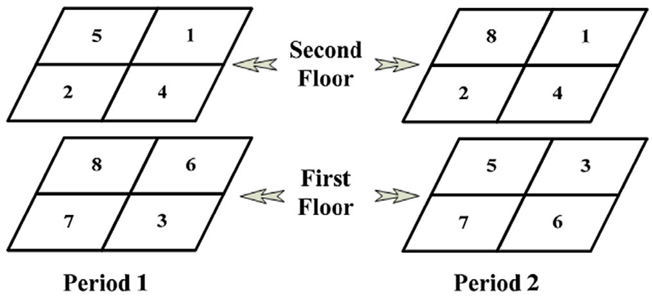

Fig. 2. A dynamic layout plan with two periods (Ghadikolaei & Shahanaghi, 2013).

numbers of floors through introducing the bounds for them. In another work, Patsiatzis and Papageorgiou (2002) find the number of floors and determined the required land area. However, these presented methods were not suitable for relatively large size problems.

It is noteworthy that some researchers in designing multi-floor structures for chemical plants (Barbosa-Póvoa et al., 2002; Lee, 2014; Park et al., 2011) considered the shape of departments in 3D space, i.e. in addition to the length and width, the height dimension is also taken into consideration.

3.1.3. Lift facilities

Departments located on different floors interact with each other through lift facilities. Elevators are the most popular facilities which have been considered for interaction between floors, due to the major focus of academics on manufacturing environments. Besides, chemical and process plant design (Georgiadis, Rotstein, & Macchietto, 1997; Lee, 2014, 2015; Park et al., 2011; Patsiatzis & Papageorgiou, 2002, 2003; Suzuki, Fuchino, Muraki, & Hayakawa, 1991) are seen, where the interaction between departments (units) are established through pipes. Other cases such as for hospitals (Hathhorn et al., 2013), operating theatres (Chraibi, Kharraja, Osman, & Elbeqqali, 2014), multi-deck ship design (Lee et al., 2005) and VLSI design in electronic industries (Berntsson & Tang, 2004) have rarely been studied, even though they are prevalent in real life applications. The elevators are usually considered as a point without occupying any area. However, some researchers, by taking some assumptions like being specified the dimensions of elevators (Lee et al., 2005), being equal the area of elevators with the area of one department (in the problem formulated by QAP approach) (Kaku et al., 1988) and using discrete formulations (Chang & Lin, 2006; Huang et al., 2010), have taken into account the elevators' area.

In decision making for finding the optimal layout design, the number and location of elevators are also involved, which they may be considered as parameters (Abdinnour-Helm & Hadley, 2000; Bernardi & Anjos, 2012; Meller & Bozer, 1997) or decision variables (Hathhorn et al., 2013; Huang et al., 2010; Ramtin et al., 2010). However, in some situations, it is supposed that there is only one elevator (Afrazeh et al., 2010; Ghadikolaei & Shahanaghi, 2013) or a set of elevators (Foulds & Giffin, 1984; Izadinia, Eshghi, & Salmani, 2014; Kaku et al., 1988) which all must be located at a point. Some researchers (Abdelhafiez, Shalaby, & Nayer, 2007; Huang, Chen, & Tsai, 2011) strived to find the optimal location of elevators for a given layout, without considering how the layout is obtained.

Each elevator has a certain capacity from which its exploitation could not exceed. This practical matter is rarely regarded in the formulation of problems (Bozer & Meller, 1992; Ghadikolaei & Shahanaghi, 2013; Huang et al., 2010; Matsuzaki et al., 1999). Hereupon, in the problems with more than one elevator, the load assigned to one (several) of the elevator(s) may be greater than its (their) capacity; as a result, the optimal layout obtained for the formulated problem would not be an optimal solution in practice.

The elevators used in any layout may have various types and they are not necessarily identical. For the first and only time, Irohara and Goetschalckx (2007) defined twos type of elevators called *general* and *dumb waiter.* General elevators are such as those frequently have been considered in the literature, which provide service to all floors. But, dumb waiters are just moving between two given floors. Since the latter type has significantly less installation cost compared to the former, it is enormously appropriate for two floors with heavily interacted departments. So, considering more than one alternative for elevators can result in reducing costs and also increasing the efficiency of layout.

3.2. Formulation approaches

Formulation of facility layout problems, in a general view, can be divided into two categories: *discrete* and *continuous* formulation (see Fig. 3). The solution space of the problem would be limited by employing the first formulation manner; but on the other hand, constructing irregular shapes is possible here. While in continuous formulations, only regular shapes could be achieved. Advantages, disadvantage, and applications of these two methods can be found in Drira et al. (2007), Hungerländer and Rendl (2013), Keller and Buscher (2015), and Saravanan & Kumar (2015).

3.2.1. Discrete formulation

Discrete formulation for FLP originating from QAP simplifies the problem, but the solution space is extremely limited. Due to the complexity of dynamic problems, discrete formulation is the only method which has been employed to model dynamic MFLP.

The procedure to specify the blocks related to each department can be handled through mathematical programming models (Afrazeh et al., 2010; Kaku et al., 1988), which require extremely high computational efforts, or through employing other methods such as *space filling curves* (SFC) (Wang, Hu, & Ku, 2005). See Fig. 4 as an instance for the SFC method in a problem with two floors.

3.2.2. Continuous formulation

Due to the shortcomings of discrete formulations, recent research tends to use continuous approaches. The mathematical programming methods, including integer programming (IP) (Ghadikolaei & Shahanaghi, 2013), mixed integer linear programming (MIP) (Goetschalckx & Irohara, 2007; Hathhorn et al., 2013), nonlinear programming (NLP) (Ahmadi & Akbari Jokar, 2016; Bernardi & Anjos, 2012), and mixed integer nonlinear programming (MINLP) (Lee, 2014, 2015) models and also heuristic

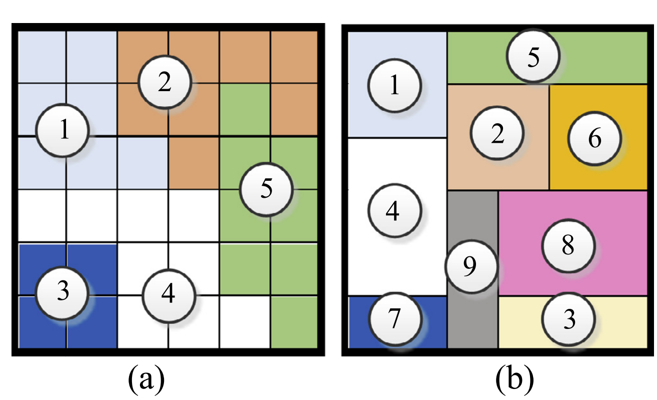

Fig. 3. Layouts obtained using (a) discrete and (b) continuous formulation.

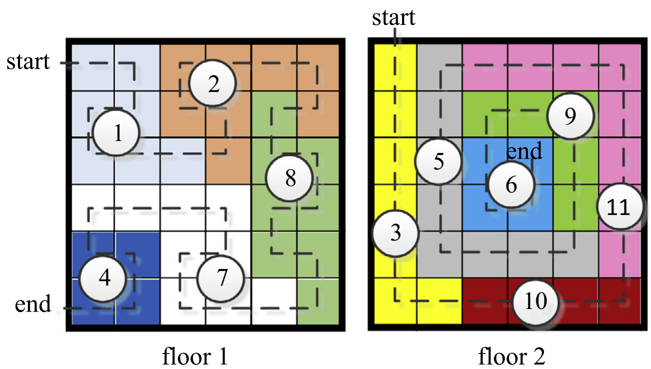

Fig. 4. SFC for a problem with two floors.

methods such as slicing tree (Matsuzaki et al., 1999) and flexible by structure (FBS) (Krishnan & Jaafari, 2011) are the approaches have been employed to formulate MFLP to date. Continuous methods generate regular (rectangular) shaped departments while discrete methods yield irregular shapes.

3.2.2.1. Mathematical programming approaches. In mathematical programming based methods, the dimensions and/or position of the departments are represented by variables. The main advantage of employing mathematical programming methods to model the problem is that it is easy to incorporate different aspects and constraints of the problem; including fixed location departments, rectangular and non-rectangular floors, floors with different areas, fixed shape departments, limitations to locations of elevators and departments (due to technical constraints), area of elevators, and so on (Ahmadi & Akbari Jokar, 2016). Therefore, the methods based on mathematical programming can perfectly reflect the real-life situations and so outperforms the other methods from the managerial perspectives.

3.2.2.2. Slicing tree method. Slicing tree method was first proposed in Tam (1992) for SFLP and was employed frequently in the literature (Scholz, Petrick, & Domschke, 2009; Wu & Appleton, 2002). Matsuzaki et al. (1999) extended this procedure to MFLP by introducing a new type of nodes (called D) representing the floors in the tree (see Fig. 5).

3.2.2.3. Flexible bay structure method. The FBS method (Kulturel-Konak, 2012) which generally divides the plant site into row or column bays with varying width (see Fig. 6), for the first and only time, was deployed by Krishnan and Jaafari (2011) for MFLP, in which the presented model is limited to only two floors. ALDEP method (Seehof et al., 1966) is also based on bay structure (but not exactly the same as FBS). This method was originally offered for SFLP, however it is implicitly declared that ALDEP is applicable for MFLP up to three floors.

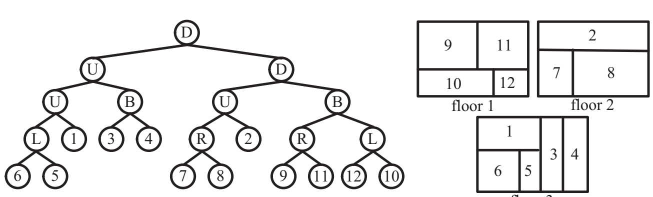

Fig. 5. Slicing tree and structure of a MFLP (Matsuzaki et al., 1999).

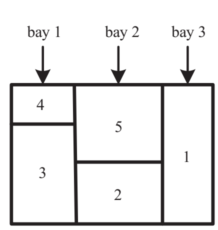

Fig. 6. A layout based on FBS structure.

4. Solution methodologies

The proposed methods for solving the models of MFLP can be categorized into two main categories: *single stage* and *multiple stages* methods, which are discussed in the following. The methods are generally based on exact, heuristic, metaheuristic or simulation approaches. The formulation framework employed to present the problem influences the selection of the resolution approach. The exact methods perfectly search the solution space of the models and therefore the optimality of the final solution may be guaranteed; while the others do not consider the whole solution space and so may fall into local solutions. In spite of this fact, the exact methods are not necessarily of practical value. Because, as Liu (2004) states, they can only deal with very small size problems (less than 10 facilities), while real-life cases include a large number of facilities (e.g. 30–40 departments). Due to the computational complexity of the FLP, any increase in size of the problem leads to a considerable increase in the computational time. However, as will be explained in the following, some researchers (Ahmadi & Akbari Jokar, 2016; Bernardi & Anjos, 2012) have decomposed the problem into some simpler problems and dealt with each one using an exact approach to benefit from the power of the exact methods.

4.1. Single stage methods

In the single stage techniques, all decisions are taken at one phase, including the assignment of departments to floors, determining the number of elevators, specifying the location and dimensions of departments, etc.

For the first time in single stage techniques, Cinar (1975) proposed CRAFT-3D heuristic methods as an extension to the original CRAFT algorithm (Armour & Buffa, 1963; Buffa, Armour, & Vollmann, 1964) which was already presented for SFLP. CRAFT-3D uses an improvement procedure (based on the exchange of departments) to find the solutions with the minimum horizontal as well as vertical material handling costs. To do that, only the departments which have equal areas or are adjacent could be considered for exchange. Similar to CRAFT-3D, another exchange based method named SPACECRSFT (Johnson, 1982) was developed by extending CRAFT, with the difference that SPACECRAFT could incorporate nonlinear cost parameters by providing an allowance for waiting times in vertical interchanges. Splitting departments through the floors was the shortcoming of SPACECRAFT. A comparison between these two methods may be found in Jacobs (1984). Bozer, Meller, and Erlebacher (1994) overcome this drawback via formulating the problem with SFC and allowing the area of departments to vary in a given range. This new method was named MULTIPLE. The last three methods was steepest descent, i.e. they applied the exchange with the greatest improvement cost. As a result, their final solution heavily depended on the initial solution. In order to remove the effect of initial solution and prevent from falling into local optimal solutions, Meller and Bozer (1996) developed a simulated annealing (SA) algorithm for adjusting the sequence of departments on SFC in MULTIPLE method. This new method was called SABLE. Patsiatzis and Papageorgiou (2003) provided two solution procedures (based on iterative scheme and decomposition) comprising a master problem and a sub-problem. The master problem determined the number of floors, assigned the departments to the floors and also found a lower bound for the main problem through an MIP model. The detailed layout of each floor and the upper bound on the main problem was obtained in the sub-problem, which was an MIP model. The master problem and sub-problem were iteratively solved, until the difference of upper bound and lower bound of the problem met a given tolerance. This procedure seems to be located in the category of two stage methods. But, as the master problem and the sub-problem mutually interact with each other, the whole framework can be considered as a single stage method.

SLP (Muther & Mogensen, 1973) is an old improvement technique to enhance an existing layout based on the material flow analysis and closeness rating (Liu & Chen, 2008). Recently, this procedure has been applied to MFLP by Hosseini, Wong, Mirzapour, and Ahmadi (2014) to improve the layout of a card and packet production company (with two floors) suffering from the high total travelling distance, cross-traffic and cost. Three layout alternatives were generated and the best one was selected based on quantitative criteria. Following that, Hosseini et al. (2013) employed a simulation approach to assess the effectiveness of different alternatives obtained from applying the SLP method on the problem.[1]

MULTI-HOPE (Kochhar, 1998) method was developed by extending a method named HOPE (Kochhar, Foster, & Heragu, 1998) which was for SFLP. MULTI-HOPE generates an initial solution with SFC and numbers the blocks of the departments in the solution in order to employ a genetic algorithm (GA) to search the optimal solution of the problem. Also, in order to eliminate the effect of curve type in SFC on the optimal solution, various curves are adopted in generating the initial population of GA. Following that, Kochhar and Heragu (1999) extended MULTI-HOPE to dynamic states and offered DHOPE method. The tree representation of MFLP for the first was presented in MUSE method (Matsuzaki et al., 1999), in which SA algorithm was employed to find the near-optimal solutions of the problem. In addition, GA was used (at each iteration of inner loop of SA algorithm) to specify the numbers and locations of elevator(s), after dividing the land into square blocks. Next, a heuristic scheme assigned the flow between departments on different floors to selected elevators, according to their capacities. The VLSI design problem in Berntsson and Tang (2004) was approached by tree representation method, then GA was used to obtain the solutions of the problem. This model did not deal with lift facilities, due to the nature of the problem. Jagielski and Gero (1997), for the only time, applied genetic programming to solve the problem modeled by SFC method. Splitting departments across the floors was the disadvantage of the framework.

The established bay structure for the problem considered in Lee et al. (2005) (due to the predefined aisles) provided the basis for encoding the solution of the problem by the chromosomes with five segments and solving the problem using GA. Because of existing more than one path between any two departments through the aisles, the shortest path between them was determined by dijkstra's algorithm. For the first and only time, Krishnan and Jaafari (2011) defined the FBS formulation of MFLP with chromosomes having three segments, two of which indicated the sequence of departments in the first and the second floors respectively (as regards the problem cope with only two floors) and the third showed the number and location of elevators by binary variables (see Fig. 7). Then, a memetic algorithm (MA) was designed to solve the formulated problem. The QAP formulation of dynamic problem in Ghadikolaei and Shahanaghi (2013) was encoded as a sequence of departments in different periods, for employing the SA algorithm to find the near-optimal solution of the problem. Here, new solutions are generated via exchanging two departments in one of the periods, e.g. in Fig. 2, the new solution of [(5,**7**,2,4,8,6,1,3),(8,1,2,4,5,3,7,6)] could be obtained from exchanging departments 1 and 7 in solution [(5,1,2,4,8,6,7,3),(8,1,2,4,5,3,7,6)].

Most of the researchers (Afrazeh et al., 2010; Barbosa-Póvoa et al., 2002; Georgiadis et al., 1997, 1999; Goetschalckx & Irohara, 2007; Hahn et al., 2010; Hathhorn et al., 2013; Izadinia et al., 2014; Kohara, Yamamoto, & Suzuki, 2008; Lee, 2014; Neghabi & Ghassemi, 2015; Park et al., 2011; Patsiatzis & Papageorgiou, 2002) have deployed exact methods to solve their developed mathematical models. In this respect, CPLEX solver has frequently been used, since the models commonly included integer variables associated with the floor of departments. In this regard, several heuristic algorithms have been proposed (Georgiadis et al., 1997; Kohara et al., 2008) for the purpose of eliminating symmetrical layouts and degenerating solutions, and consequently to narrow the solution space. In addition, with the aim of further reduction of computational efforts in large-scale problems, Georgiadis et al. (1997) examined the pre-allocation of specific departments and aggregated similar departments into a group.

4.2. Multiple stage methods

Due to the further complexity of MFLP compared to SFLP, most of the researchers recently have decomposed the main problem into two or three sub-problems. By considering the main difference between MFLP and SFLP, i.e. the existence of more than one floor, this idea arises that first (in one stage) the departments are assigned to the floors and then (in next stages) the layout of the floors and other details are determined. While this approach conveniences the overall solution procedure, but it may follows significant consequences. Indeed, since the initial stage are the basis for the next stage(s), any error or inaccuracy in modeling or solving the initial stage would influence the other(s) (Jayakumar & Reklaitis, 1996).

4.2.1. First stage: assigning departments to floors

The first method for assignment of departments to floors was a mathematical programming model with a quadratic objective function (Liggett & Mitchell, 1981) which required heuristic procedures to solve large size problems. Therefore, Bozer and Meller (1992) linearized this model and obtained an MIP model, called FAF (Floor Assignment Formulation). FAF model has commonly been used in the literature for the mentioned purpose (Abdinnour-Helm & Hadley, 2000; Ahmadi & Akbari Jokar, 2016; Bernardi & Anjos, 2012; Meller & Bozer, 1997). Also, Irohara and Goetschalckx (2007) modeled the first stage as a generalized assignment problem (GAP) and developed an MIP model for the intended purpose. Besides, another MIP model was presented in Suzuki et al. (1991).

K-mean algorithm is another technique that has been employed for the first stage. This technique groups the departments into the desired number of clusters, in such a way that the similarity within and between the clusters are maximized and minimized, respectively. Here, the number of clusters is equal to the number of floors. Hence, the departments with high interaction flow will be placed in a group and the interaction between different floors would be minimized. After clustering the departments in Kaku et al. (1988), each one was assigned to a floor by solving a QAP. On the other hand, Chang and Lin (2006) first selected the reference

[1] It is notable that the publication date of Hosseini et al. (2013) is before Hosseini et al. (2014), while the first is the extension of the second. It seems that Hosseini et al. (2014) has been submitted before Hosseini et al. (2013), but has been published later.

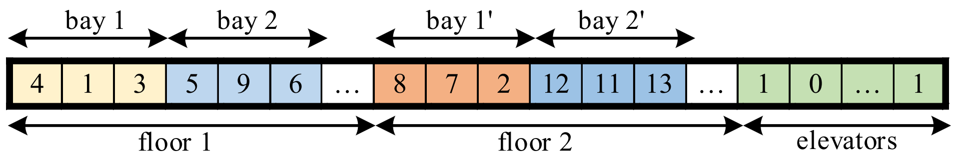

Fig. 7. Representation of chromosome in Krishnan and Jaafari (2011).

department of each cluster (floor) an then assigned the remaining departments to the clusters. Also, Foulds and Giffin (1984) partitioned the departments into a number of sets by deploying a partitioning algorithm which uses the similar concept of k-mean algorithm. Then, the sets were assigned to the floors by considering inter-floor travel times. In another work, Abdinnour-Helm and Hadley (2000) utilized the concept of graph portioning to create a model for the first stage and then deployed GRASP algorithm (Feo & Resende, 1995) to obtain its solution. Of course, they proposed this method only for large size problem requiring more computational effort (because of its heuristic nature) and for small size problems, FAF method was adopted.

A heuristic technique was presented by Neghabat (1974), in which a sequence of departments was partitioned into several groups, such that each group contained as many departments as could fit on a single floor. Then, each of the groups were allocated to a floor by employing an algorithm associated with the one-dimensional facility layout problem. Also, BLOCPLAN software (Donaghey & Pire, 1990) assigns departments to the floors with an adjacency-based heuristic method. This technique uses the area of departments and a user-specified factor and performs based on the maximal difference between the actual and the ideal area of each floor. All departments located on the same floor are considered to be adjacent, while those are on the different floors are seen as non-adjacent departments; indeed no importance is given to horizontal and vertical distance between departments. BLOCPLAN software also allows the users to manually assign departments to floors.

4.2.2. Second (and third) stage(s): determining the layout and other related details

At this point (i.e. after the first stage), the floors associated with all departments are known. Hereinafter, different methods consist of one or two more stages in order to find the final layout of departments.

The heuristic method ALDEP (Seehof et al., 1966) may be viewed as the first method formally dealt with MFLPs. This method was originally presented for SFLP, which handle the problems up to three floors. But, it is not clear how it assigns the departments to the floors. However, it uses heuristic rules based on a sweep method (similar to FBS) to find a good layout for all floors independently. Ignoring the inter-floor interactions and splitting departments across floors are the major shortcomings of ALDEP. Bozer and Meller (1992) proposed SABASS method to obtain the layouts of all floors simultaneously in the second stage, by relaxing the details of elevators and using the same procedure as SABLE method. Then, at the third stage, called LLAP, a method similar to the second stage method and based on the SA algorithm was proposed for determining the details of elevators. SABLE method was modified by Meller and Bozer (1997) and STAGE method was introduced, in which the floor of departments did not exchange. Also, Meller and Bozer (1997), in order to demonstrate that the exchange of departments through floors does not promote the procedure of improving solutions, represented FLEX method in which the departments were allowed to be exchanged among the floors. Several heuristic schemes were deployed in Donaghey and Pire (1990) and Neghabat (1974) and by which the layouts of all floors were independently obtained, without considering any lift facilities. Ignoring the individual interactions between departments located on different floors was the main drawback of these techniques. Foulds and Giffin (1984) utilized maximal planar adjacency graph (through adopting tetrahedron approach) to represent the relative location of the departments on each floor. Then, the final layouts of the floors were constructed from the adjacency graph. Splitting the departments across different floors was the main disadvantage of this method.

Since the area of departments was equal in the problem of Kaku et al. (1988), a QAP was solved for each of the floors to establish their layouts. Indeed, by having k floors, $k+1$ QAP problem should be solved (which one of them was related to the first stage). Afterwards, the exchanges between the departments located on different floors was checked for further improvement of the solution. Also, Suzuki et al. (1991) used the concept of QAP, by dividing the land into several modules, and developed an IP model to assign the modules to the departments.

The metaheuristic TS (tabu search) algorithm was utilized by Abdinnour-Helm and Hadley (2000) for solving the SFC formulation of the problem at the second stage. They applied shift moves (i.e. moving a single department) and pairwise exchanges for generating new neighborhood solutions (see Fig. 8). Also, a heuristic method (similar to a method in single row FLP (Heragu & Kusiak, 1988)) was offered to find a good initial solution for TS algorithm. In another study by Huang et al. (2010), the near-optimal sequence of departments on SFC formulation was obtained by employing TA (threshold accepting) algorithm. Then, a heuristic algorithm was represented to determine the number and also the location of elevators and consequently the final layout of the floors. GA (genetic algorithm) was equipped with some heuristic rules by Chang and Lin (2006) to obtain the final layout.

Other researchers preferred to deal with the other stages through exactly solving the mathematical programming models such as MIP (Irohara & Goetschalckx, 2007) and NLP (Ahmadi & Akbari Jokar, 2016; Bernardi & Anjos, 2012). In this respect, they approximated the departments as circles in order to find initial solutions for their models. These methods generally have better

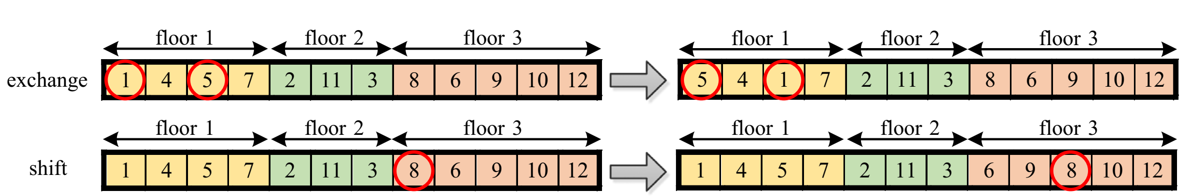

Fig. 8. An example of shift move and pairwise exchange of departments.

performance compared to the previous methods, especially the method presented in Ahmadi and Akbari Jokar (2016) which greatly outperformed the others.

5. Conclusions and future research directions

A comprehensive survey associated with multi-floor facility layout problems along with modeling and resolution approaches is presented in this paper. For this study, all of the related papers in the literature are collected and analyzed from different aspects. Because of the increasing importance of designing multi-floor structure facilities over the time and also the little attention have been dedicated to this issue in the past, more research is required. Several directions and trends which seem worthwhile to be followed in the future research are suggested here:

- First of all, since the FLP was originated in industrial environment, the research has still mainly focused on this area. This fact also holds for MFLP. Hence, allotting the efforts to benefit other areas such as markets, ships, hospitals and administrative organizations would be valuable. The related problems of these situations may have their own special considerations. For example, operating theatre facility layout (OTLP) has different objectives (e.g. reducing the length of healthcare processes and operating costs, increasing the effectiveness and satisfaction of personnel and also patient, etc.) in comparison to manufacturing systems which aims to reduce material handling costs.
- Even, designing a layout for a manufacturing environment strongly depends on the type of manufacturing system. Lack of attention to this key characteristic may lead to a layout which does not meet the requirements. The manufacturing system also affects the decisions related to the flow of materials and products. Recently, three research work (Khaksar-Haghani, Kia, Mahdavi, Javadian, & Kazemi, 2011; Khaksar-Haghani, Kia, Mahdavi, & Kazemi, 2013; Kia, Khaksar-Haghani, Javadian, & Tavakkoli-Moghaddam, 2014) have been published in this respect, by taking into account cellular manufacturing system. However, paying attention to this matter in the future work will be worthwhile.
- Due to the complexity of MFLP, the existing papers adopted many restrictive assumptions. Most of the published work has dealt only with determining of a block layout for departments. While a plan can be implemented when incorporates all aspects of the design such as I/O points of departments, aisles structure, capacities and limitations of carrying and moving facilities, existing technical restrictions (e.g. fixed barriers, irregular shaped green land, etc.). Also, considering several types of transportation modes in both vertical and horizontal direction can enhance the developed model. Particularly in horizontal direction which has not been involved in MFLP.
- Involving the above considerations can impose uncertainty on the problem. For example, clients of a hospital may use the stairs or lift in order to travel between different floors. Due to the behavioral characteristics of the clients, the choice between these two alternatives is random in nature. Therefore, considering the capacities of stairs and lift will influence the related decisions. Also, in the real-life situations, more data needed to model a problem is not definite and known in advance (e.g. interaction flows, required area of facilities, etc.). In such cases, employing the uncertainty approaches such as stochastic, fuzzy or robust methods can be useful. In this respect, only two studies have recently been conducted in this matter in Izadinia and Eshghi (2016) and Izadinia et al. (2014).
- In the competitive world, market demand is constantly changing. Changes in the characteristics related to products and market may change the condition and situation of a facility. Adopting dynamic methodologies can somewhat handle these issues. However, there are numerous research gaps in dynamic MFLP (especially in continuous spaces, which even holds for SFLP). In order to design a dynamic layout, we require to be known about the future changes, but it is generally not established. Therefore, utilizing the uncertainty approaches would enhance the designed layouts in capturing the real conditions.
- Most of the real-world problems include many objectives, which may not be expressed in terms of cost. While, the majority of the work published in the literature has considered only a single objective function to merely capture costs. Hence, investigating on multi-objective approaches are suggested as research direction.
- There are some interesting formulation approaches such as sequence-pair method and space portioning method (which uses the location matrix representation) in the literature of FLP which have not now been applied to the MFLP. The readers may respectively refer to Kim and Goetschalckx (2005) and Irohara and Yamada (2005) to read more about these methods.
- The MFLPs are more complicated than the SFLP to be solved. Therefore, further research is required to investigate on the finding of high-quality solutions for the large-scale problems. In this regard, employing the powerful modern metaheuristic algorithms, such as ant colony optimization (ACO) and particle swarm optimization (PSO), which demonstrated their robust performance for SFLPs (refer to the reported results in Kulturel-Konak and Konak (2011a, 2011b)) may be beneficial. As a good alternative, applying the genetic programming, due to its tree structure, to the slicing tree method is suggested. Indeed, the genetic programming is very suited to the aforementioned method. While, it is rarely seen in the literature. The readers are referred to Kundu and Dan (2012), in order to overview the application of metaheuristic methods in facility layout problems.
- Also, deploying expert systems in order to utilize the human expert's knowledge in designing a sophisticated plan is suggested. The expert systems can be used in a hybrid structure with other methods of facility layout design.
- As a final point, more future research direction can be identified using the tree representation provided in Fig. 1. Also, in this figure some issues which have not been investigated in the literature (such as Euclidean distance) and have received less attention (e.g. I/O points) are explicitly highlighted. In addition, many of the gaps have implicitly introduced throughout the context.

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