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REVIEW

A survey on human resource allocation problem and its applications

Sana Bouajaja[1,2] · **Najoua Dridi**[1]

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Abstract In this paper, we present the existing literature on the human resource allocation problem. We study the main resolution approaches: exact, heuristic and metaheuristics methods proposed to solve the problem. We also examine the different studies from state-of the-art and classify them according to their real life applications in several areas such as production planning applications, maintenance management, hospital systems, project management, etc. Finally, we discuss and analyze the different contributions examined in this field.

Keywords Assignment problem · Human resource · Metaheuristics · Optimization

1 Introduction

The rapidly changing and competitive environment has forced many companies to incorporate the human resource in their central strategy. Aware that human resources can play a decisive role in the success of an organization, managers are seeking more efficient tools to optimize the use and the allocation of their available resources among the different services or systems, with an aim to maximize or to minimize certain functions related to the performance and productivity. The problem arises in a variety of real world settings, and research papers in literature show a continuous interest in human resource allocation problem (HRAP) and cover different practical applications. To illustrate the variety application areas of this problem, several examples of HRAP studies are presented in this paper such as:

✉ Sana Bouajaja
sana_bouajaja@yahoo.fr

1 OASIS Laboratory, National Engineering School of Tunis, University of Tunis El Manar, B.P. 37 Le Belvédère, 1002 Tunis, Tunisia

2 5 Rue Sakiet Sidi Youssef, 7050 Menzel Bourguiba, Tunisia

health services (Kwak and Lee 1997; Trilling et al. 2005; Lanzarone and Matta 2014), production planning (Hopp et al. 2004; Corominas et al. 2006, Eiselt and Marianov 2008), tourism and hotel services (Murakami et al. 2010, 2011), project management (Eskerod 1998; Kang et al. 2011), maintenance management (Bennour et al. 2012), and other applications (assignment of referees to the football matches Scarelli and Narula 2002, military's resource allocation Luoh and Chang 2008), just to name a few.

Despite the considerable amount of research published, in our knowledge, there is no comprehensive review study dedicated to the problem and its applications in various fields, at the same time. Accordingly, we identify that there is a need to summarize the existing literature about the HRAP and classify it according to single and multiple optimization, the solution techniques used and application area.

The great interest in the human factor and the increasing literature on the subject present the main motivation for this survey, in which we show our attention to the theory, resolution methods and applications of the HRAP.

According to the literature, the generic problem resource allocation problem (RAP) is identified as the process of allocating resources among the various projects or business units (Osman et al. 2005; Yin and Wang 2006a, b; Lin and Gen 2007; Chaharsooghi and Meimand Kermani 2008; Jia and Gong 2008). The resource may be a person, asset, material, or capital which can be used to accomplish a goal. This goal is usually driven by specific future financial needs. The best or optimal solution may mean maximizing profits, minimizing costs in terms of money or time, or achieving the best possible quality.

The process of the RAP seeks to find an optimal allocation of a limited amount of resource to a number of tasks, for optimizing their objectives subject to the given resource constraint.

In our case study, among various types of resources, we focus our attention particularly on the human resource, thus the allocation problem is considered very complex due to the human characteristics of persons to assign.

In this work, we look for papers related to the human resource assignment problem, published during the last 20 years, with some contributions from 1955 to 1995. The increasing trend of the number of the sources after 2000 (see Table 1) reflects the recent development of the worker allocation concept and the growth in advances proposed by the scientific community, during recent years.

As shown in Table 1, in total 147 manuscripts were considered in this study, dealing directly or indirectly with the problem and presenting models, resolution

Table 1 Number of references classified according to publication type and year

Publication type	Before 2000	2000–2015	Total
Journals	13	94	107
Proceedings	1	24	25
Ph.D. dissertation	–	3	3
Book	3	7	10
Technical report	1	1	2
Total	18	129	147

approaches in various fields of its application. The reviewed manuscripts consist of journal papers, conference papers, few Ph.D. dissertations and books. Note that a great interest was given to articles published in scientific journals, 89 academic journal papers are considered in this survey. The best sources of journals used in our literature review are presented in Table 2.

It is worthwhile to mention that our reference list cannot be considered as definitive, because of the new continuous publications that appear and can be added to the list.

The HRAP is largely considered in the literature as it appears in several areas. To help the researchers, we provide them with a review of the relevant literature classified into their resolution method and application field.

Our purpose is to identify the most important approaches used, but not to provide the best solutions. We also try to examine papers about HRAP in various fields, since there is no such publication in the literature, grouping critical areas together and detailing them in the same paper. Thus, the current survey can be useful for researchers and give key directions for future work.

This paper is organized as follows: In Sect. 2, we provide the mathematical formulations of the problem (mono-objective and multi-objective), and we present the different criteria and constraints generally considered in the literature. Section 3 is devoted to the resolution methods used for the HRAP. Then, in Sect. 4, real life examples of the HRAP applications are given to show the significant impact of human resource as a source of competitive advantage in many fields. Finally, discussions and conclusions follow in Sect. 5.

2 Problem formulation

In this section, we introduce the mathematical models of the classical HRAP. Then, we present some particular constraints and objectives that lead to specific formulations.

Table 2 List of main journals used

Journal	Articles number	Percentage
European Journal of Operational Research	13	12.15
Computers and Operations Research	9	8.41
Computers and Industrial Engineering	7	6.54
International Journal of production Economics	5	4.67
International Journal of Production research	3	2.80
Operational Research International Journal	2	1.87
Others	68	63.55
Total	107	100

2.1 The classical HRAP

The classical assignment problem is considered as a special case of the Transportation problem, when the number of resources is equal to the number of tasks to assign (Pentico 2007). Therefore, a linear programming formulation is given to the original version of the assignment problem.

As the HRAP problem is a variation of assignment problem, this formulation is still valid for it. In fact, as usually described, the classic problem involves the situations below: assigning tasks (or jobs) to machines or workers that can do them, or assigning workers to machines.

The objective of the problem is to minimize the total cost or maximize the total profit of allocation, because the available resources (human or machines) have not the same abilities to execute the same task and these different efficiencies for performing tasks are expressed in terms of cost, profit, or time involved in executing a given job.

An integer linear programming (IP) formulation, for the classical HRAP, is introduced in Table 4. The mathematical notations used are listed in Table 3.

The formulation model depends on the nature of the problem. If the two sets of workers and jobs have the same dimension, we have a symmetric or balanced assignment problem, otherwise the problem is called asymmetric or unbalanced assignment problem. While the objective of the assignment problem is to optimize one criterion, we are faced with a mono-objective assignment problem, otherwise, multiple-objective functions need to be optimized simultaneously.

2.2 Particular constraints and objectives

In Table 4, we have just introduced the main formulation of the classical HRAP version. Although, additional and particular constraints can be studied and lead to

Table 3 Mathematical notations

Indices	
i	Index of job (i = 1,2,…,n)
j	Index of the worker (j = 1,2,…,m)
Parameters	
X	Set of jobs
Y	Set of workers
n	Total number of jobs
m	Total number of workers
c_{ij}	Cost of job i when worker j is assigned
p_{ij}	Profit of job i when worker j is assigned
Decision variables	
$x_{ij} = \begin{cases} 1, & \text{if worker } j \text{ are assigned to job } i \\ 0, & \text{otherwise} \end{cases}$	

Table 4 Symmetric HRAP models

Symmetric HRAP			
Model 1 (mono-objective)		Model 2 (multi-objective)	
$min \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} x_{ij}$	(1.1)	$min \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} x_{ij}$	(2.1)
$\sum_{j=1}^{n} x_{ij} = 1 \quad \forall i \in X$	(1.2)	$max \sum_{i=1}^{n} \sum_{j=1}^{n} p_{ij} x_{ij}$	(2.2)
$\sum_{i=1}^{n} x_{ij} = 1 \quad \forall j \in Y$	(1.3)	$\sum_{i=1}^{n} x_{ij} = 1 \quad \forall j \in Y$	(2.3)
$x_{ij} = 0 \; or \; 1 \quad \forall i \in X, \; j \in Y$	(1.4)	$\sum_{j=1}^{n} x_{ij} = 1 \quad \forall i \in X$	(2.4)
		$x_{ij} = 0 \; or \; 1 \quad \forall i \in X, \; j \in Y$	(2.5)

other versions of the problem with more complicated formulations. For more details, refer to the survey of Pentico (2007). In this article, several variants of the assignment problem from the literature have been described and the correspondent mathematical formulations have been presented and the relevant literatures have been provided, in order to help researchers in developing some variation of the assignment problem.

In Table 5, we present and kept, from the survey of Pentico (2007), just the variations of the assignment problem applicable to the case of human resources. These versions differ from the classic assignment problem, previously presented, by the assumptions adopted or by a particular objective to achieve.

Table 5 may be helpful to introduce special cases that we can face, when studying the HRAP, with particular constraints and objectives. To mention, if the problem version differs from the classical assignment problem with the objectif function, we put "Obj" and "Cst" if the model has additional constraints.

We aim to summarize the work of Pentico and present the different models that have appeared in the literature, classified into three groups as introduced in Pentico (2007):

- Models assigning at most one task per agent (a one-to-one assignment), as in the original version.
- Models assigning multiple agents to a task or assigning multiple tasks to the same agent (a one-to many assignment).
- Multidimensional assignment problems assigning the members of three or more sets, as matching jobs with workers and machines or assigning students and teachers to classes and time slots.

Table 5 can be updated. Some other variants of the HRAP not mentioned in the paper of Pentico (2007) may be added such as Random assignment problem and its applications to resource allocation. The problem, in which benefits are random

Table 5 Different variations of HRAP

Assignment problem variations	Particular objectives and constraints	Mathematical model
Models with at most one task per agent		
The classic assignment problem	Obj and Cst: to find a one-to-one matching between n tasks and n agents, the objective is to minimize the total cost of the assignments	$\min \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}x_{ij}$ $\sum_{i=1}^{n} x_{ij} \leq 1 \quad j = 1,\ldots,n$ $\sum_{j=1}^{n} x_{ij} \leq 1 \quad i = 1,\ldots,n$ $x_{ij} = 0 \; or \; 1$
The classic assignment problem recognizing agent qualification (q_{ij})	Obj: utiliy maximization Cst: there are m agents and n tasks, not every agent is qualified to do every task	$max \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij}$ $\sum_{i=1}^{m} q_{ij}x_{ij} \leq 1 \quad j = 1,\ldots,n$ $\sum_{j=1}^{n} q_{ij}x_{ij} \leq 1 \quad i = 1,\ldots,n$ $x_{ij} = 0 \; or \; 1$
The k-cardinality assignment problem	Cst: there are m agents and n tasks, but only k of the agents and tasks can be assigned, where k is less than both m and n	$min \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij}$ $\sum_{i=1}^{m} x_{ij} \leq 1 \quad j = 1,\ldots,n$ $\sum_{j=1}^{n} x_{ij} \leq 1 \quad i = 1,\ldots,n$ $\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} = k$ $x_{ij} = 0 \; or \; 1$
The bottleneck assignment problem	Obj: to minimize the maximum of assignment costs while the objective of the classic AP is to minimize or maximize the sum of the assignments cost	Minimize $\max_{i,j}\{c_{ij}x_{ij}\}$ or Minimize $\max_{i,j}\{c_{ij} \mid x_{ij} = 1\}$ Subject to the usual constraints for the classical AP
The balanced assignment problem	Obj: to minimize the difference between the maximum and minimum assignment values	Minimize $\max_{i,j}\{c_{ij} \mid x_{ij} = 1\} - \min_{i,j}\{c_{ij} \mid x_{ij} = 1\}$ Subject to the usual constraints for the classical AP.
The minimum deviation assignment problem	Obj: to minimize the difference between the maximum and average assignment costs or equivalently to this formulation	$\min \sum_{i=1}^{m}\sum_{j=1}^{n} \left(\max_{p,q}\{c_{pq}x_{pq}\} - c_{ij}\right)x_{ij}$ Or if m and n differ, Minimize $\min\{m,n\} * (\max_{p,q}\{c_{pq}x_{pq}\}) - \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij}$ Subject to the usual constraints for the classical AP

Table 5 continued

Assignment problem variations	Particular objectives and constraints	Mathematical model
The $\sum_k$-assignment problem	Obj: to find a set of assignments for which the sum of the k largest is minimized	
The semi-assignment problem	Cst: all the agents are unique, some of the tasks are identical or vice versa	$min \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij}$ $\sum_{i=1}^{m} x_{ij} = d_{ij} \quad j = 1,\ldots,n$ $\sum_{j=1}^{n} x_{ij} = 1 \quad i = 1,\ldots,n$ $x_{ij} = 0 \; or \; 1$ With (n < m) and d_j is the number of tasks in group j ($\sum_j d_j = m$)
The categorized assignment problem	Cst: operators may be divided into categories or groups, with sequencing requirements either within each group or between groups Obj: to find a permutation P (an assignment of agents to tasks) for: *Case 1:* operators in the same category work in a particular sequence, but the different categories work in parallel *Case 2:* operators in the same category work simultaneously, but in sequence for the different categories	Case 1: $\min_p \max_k \sum_{j\in S_k} c_{P(j),j}$ Subject to the usual constraints for the classical AP Case 2: $\min_P \sum_{k=1}^{r} \max_{j\in S_k}\{c_{P(j),j}\}$ Subject to the usual constraints for the classical AP
Multi-criteria assignment problems Combining multiple criteria into one Considering multiple criteria sequentially	Obj: to find a solution that recognizes all of the multiple decision criteria	
The fractional assignment problem	Obj: the objective function to be optimized is the ratio of two other objective function expressions	$\min \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}x_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}x_{ij}}$ Subject to the usual constraints for the classical AP d_{ij}: is the time agent i would take to perform task j
The assignment problem with side constraints	Cst: Side constraints that limit the assignment of agents to tasks can be added, such as budgetary limitations, degree of technical training of personnel, the rank of personnel, or time restrictions	$\sum_{i=1}^{n}\sum_{j=1}^{n} r_{ijk}x_{ijk} \leq b_k$ r_{ijk}: amount of resource used if agent i is assigned to task j b_k: amount of resource k available

Table 5 continued

Assignment problem variations	Particular objectives and constraints	Mathematical model
Models with multiple tasks per agent		
The generalized assignment problem (GAP)	Cst: an agent may be assigned more than one task, while recognizing how much of an agent's capacity to do those tasks each one would use	$\min \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij}x_{ij}$ $\sum_{i=1}^{m} x_{ij} \leq 1 \quad j = 1, \ldots, n,$ $\sum_{j=1}^{n} a_{ij}x_{ij} \leq b_i \quad i = 1, \ldots, m,$ $x_{ij} = 0 \; or \; 1$ a_{ij}: amount of agent is capacity used if that agent is assigned to task j b_i: is the available capacity of agent i
The bottleneck GAP	Obj: to minimize the maximum of the sum of the costs for an agent	
The imbalanced time minimizing assignment problem	Cst: the number of agents (m) is less than the number of tasks (n), thus some agent or agents will have to be assigned to more than one task Obj: to minimize the time by which all the tasks are completed	$\min \max_i \sum_{j=1}^{n} c_{ij}x_{ij}$ $\sum_{i=1}^{m} x_{ij} = 1 \quad j = 1, \ldots, n,$ $\sum_{j=1}^{n} x_{ij} \geq b_i \quad i = 1, \ldots, m,$ $x_{ij} = 0 \; or \; 1$
The β-assignment problem	Cst: not every agent is qualified to do every task, so that, since tasks can only be assigned to qualified agents, an agent may be assigned more than one task	
Multi-dimensional assignment problems		
Multi-dimensional assignment problems	Cst: the problem is one of matching the members of three or more sets	
The three-dimensional bottleneck assignment problem	Obj and Cst: Assigning n workers to do n jobs on n machines with the objective of minimizing the time at which the last job is completed if all the jobs are started simultaneously tijk: is the time that particular worker-job-machine combination would take	$\min \max_{i,j,k} \{t_{ij}x_{ij}\}$ $\sum_{i=1}^{n} \sum_{k=1}^{n} x_{ijk} = 1 \quad i = 1, \ldots, n,$ $\sum_{i=1}^{n} \sum_{k=1}^{n} x_{ijk} = 1 \quad j = 1, \ldots, n,$ $\sum_{i=1}^{n} \sum_{k=1}^{n} x_{ijk} = 1 \quad k = 1, \ldots, n,$ $x_{ijk} = 0 \; or \; 1$
Multi-period assignment problems	Obj: to assign agents to changing tasks or jobs over a time horizon	

variables, is presented in Li et al. (2012) where a new model was proposed. A state-of-the art results about the properties of random assignment problems was discussed in Krokhmal and Pardalos (2009).

A variation of the standard assignment problem with hierarchical ordering constraint, called APHOC, is presented in Toroslu (2003). The problem arises in hierarchical organizations such as Military, where the ranks of personnel to be assigned is presented by a level graph, and the positions to be filled form a forest, in which trees reflect the positions hierarchy. The aim of APHOC is to maximize the sum of the weights, when matching personnel and position sets, while satisfying the ordering constraints.

Later, in Toroslu and Arslanoglu (2007), additional set-restriction constraint was considered with the hierarchical ordering constraints. Therefore, a new multi-objective version of the classic assignment problem called "assignment problem with hierarchical-ordering and set constraints" (AHSC) is introduced. The objective of the AHSC is to determine a perfect matching, minimizing both the set-restriction violations and hierarchical-ordering violations.

We also note that an extensive literature review and surveys exist on assignment problems and deal with the HRAP as an assignment problem, and they can be used to help researchers in this field (Cattrysse and Van Wassenhove 1992; Burkard 2002; Pentico 2007; Öncan 2007; Niknafs et al 2013).

Several studies and academic papers were also found, considering the *competency* factors (De Carolis 2003; Bennour et al. 2012; Boucher et al. 2007), the operator's efficiency (Song et al. 2006; Manavizadeh et al. 2013), the worker preferences, polyvalence and the availability of the human resource (Bennour et al. 2008; Attia et al. 2011) and learning characteristics of workers (Nembhard and Bentefouet 2015) when assigning workers to tasks.

3 Resolution methods

To solve the HRAP problem, different methods of the operational research and the computer science fields are proposed in the literature. To find an optimal solution, exact methods are used, including branch and bound techniques, dynamic programming, linear programming and Hungarian method.

Since the HRAP is known to be a NP-hard combinatorial optimization problem, the existing methods based on mathematical programming techniques are not able to provide exact solutions for the large sized instances of the problem in reasonable time. Thus, heuristic or metaheuristics methods are often chosen to solve real and practical problem instances and obtain a good but not obligatory an optimum solution.

In this section, we provide some used approaches in the state of the art: exact solution procedures (Azimi et al. 2013; Borba and Ritt 2014; Daskalaki et al. 2004; Vilà and Pereira 2014), heuristic algorithms (Bennour et al. 2005; Chaves et al. 2007; Corominas et al. 2006; Moreira et al. 2015) and metaheuristics such as genetic algorithm (Chen et al. 1996; Zhang et al. 2008b; Tan et al. 2009; Zhaodong et al. 2010; Murakami et al. 2011; Younas et al. 2011; Mutlu et al. 2013), tabu search (Dowsland 1998; Alvarez-Valdes et al. 2002; Ammar et al. 2012), simulated annealing (Kirkpatrick and Vecchi 1983; Gunawan and Ng 2011), ant colony optimization (Yin and Wang 2006b; Chaharsooghi and Meimand Kermani 2008; Wang et al. 2012) and finally hybrid optimization techniques where metaheuristics are combined or coupled with heuristics in order to take advantage of the benefits of the different combined approaches (Lee and Lee 2005; Lin and Gen 2007; Abdullah et al. 2007; Lin and Gen 2008; Fikri et al. 2011; Costa Filho et al. 2012; Lukas et al. 2013).

In the following, we will discuss and examine the diverse methods and present the most important relevant literature.

3.1 Exact methods

Exact methods can be useful and provide an optimal solution for a given NP-hard combinatorial optimization problem, with small size instances. In fact, the effort of exact methods increases exponentially with the problem size when we have an NP-hard problem to solve. In the following, we present the most frequently used techniques and quote their most important references.

3.1.1 Hungarian methods

The Hungarian method is a combinatorial optimization algorithm that solves the assignment problem in polynomial time. It was developed and published by Kuhn (1955). The Hungarian algorithm is introduced in several papers with relevant examples to illustrate its application (Kuhn 1955; Xian-ying 2012).

In Xian-ying (2012), this method is used to provide a solution for the teacher's assignment to different courses. The objective is to minimize the preparation time of lessons. In fact, teachers spend different times preparing lessons, because of the different experience, and they are allowed to teach only one course, to be able fully engaged in research.

The Hungarian algorithm was also used in Younas et al. (2011), not for the problem resolution, but it was considered to provide an exact solution of specific cases, which is utilized to compare and evaluate the quality of the results obtained by the proposed genetic algorithm. This work focuses on a specific class of assignment problem, where each task is assigned to a group of collaborating agents working as a team. They assume that each agent has a set of capabilities and each task has a set of requirements. The objective is to assign the agents to the teams so that the gain is maximized. A genetic algorithm was suggested to solve the problem.

3.1.2 Linear and goal programming

As shown previously, the HRAP can be formulated with the techniques of linear programming, which is a powerful tool that can integrate various decision variables into one model to get an optimal solution (Daskalaki et al. 2004; Glaa 2008; Azimi et al. 2013).

The thesis work of (Glaa 2008) has illustrated the use of linear programming for the nursing staff's allocation, considering their profile of competence evolution, in emergency systems of a hospital center. To solve the proposed model, CPLEX was used to provide a solution that helps managers make better decisions to improve the patient handling quality and to control costs.

The research study presented in (Azimi et al. 2013) shows how a linear programming model can be generalized to any human resource problem.

An integer programming formulation was proposed in (Daskalaki et al. 2004) for the timetable of the Engineering Department at the author's university, which was used as a case study. The assignment problem was performed between the set of triplets (course, teacher, a group of students) and the set of pairs (period, day) and it was successfully solved.

It should be noted that linear programming focuses on a single goal as profit maximization or cost minimization. Nevertheless, realistic problems do not always have an only criterion goal to achieve. For this reason, the exploitation of multicriteria optimization approaches becomes attractive for the real-world problems resolution, and the goal programming (GP) is one of the most frequently utilized (Lee and Schniederjans 1983; Kwak and Lee 1997; Azaiez and Al Sharif 2005; Xian-ying 2012; Güler et al. 2015). In fact, GP is a variation of linear programming that tries to optimize some objectives simultaneously.

The basic idea is to give a goal or target value to each of the objectives. Then, an achievement function is formulated for each objective, and deviations from this goal are later minimized.

Goal programming has been used successfully in the multicriteria context of the HRAP as in Lee and Schniederjans (1983), and especially in health care systems (Kwak and Lee 1997; Azaiez and Al Sharif 2005).

The advantage of using the GP approach is that, in addition to the standard goal of cost minimization, more criteria are considered in the human resource assignment problem.

The incorporated goals are considered to fulfill the expressed preferences of the human resource to assign, for example, the teaching periods or days of the week or even classrooms in the timetabling problem, or considering the nurses' wishes in health care systems regarding various shifts, in order to maximize their satisfaction and have the best quality of patient care services (Kwak and Lee 1997; Azaiez and Al Sharif 2005).

The different works presented above have shown that goal programming is a promising technique to generate optimal solutions.

3.1.3 Branch and bound

From the different exact methods used to solve combinatorial optimization problems, the branch and bound (B&B) algorithms are considered the most known and the most widely used.

The algorithm consists of an implicit enumeration of all candidate solutions of a search space. The basic tools of the B&B techniques are lower and upper bounds for the objective to optimize, used to eliminate unsuccessful candidates. An iteration of a classic B&B occurs in three steps: selection of the node to process, bound calculation, and branching of the search tree (Paulavičius et al. 2010).

Several references relating to the branch and bound algorithms for the HRAP are available in the literature, as Miralles et al. (2008), Borba and Ritt (2013, 2014) and Vilà and Pereira (2014). All results reported in these papers concern the assembly line worker assignment and balancing problems (ALWABP-2) in Sheltered Work Centers for Disabled, where the objective is to minimize the cycle time by assigning workers to station and tasks to workers, while respecting the precedence constraints between the tasks. The problem will be detailed in the next section.

Miralles et al. (2008) propose a basic B&B approach based on three parameters: search direction, priority rules for selecting nodes from a candidate list and search strategy. In the same paper, a branch and bound based heuristic was presented to solve large instances of the problem, and then the results of the two methods were analyzed.

As mentioned by Borba and Ritt (2013), two main branch and bound strategies are used for solving the ALWABP. A station-oriented strategy: the station k should be filled before considering the next station k + 1, and a task-oriented strategy: a task is assigned to any worker and if the solution becomes infeasible, the node is discarded and the branch and bound continues. In this paper, the second strategy is adopted and the results of the proposed method were compared to the MIP model solution, presented in Miralles et al. (2008) and solved by CPLEX. Computational results show that the method achieved promising results on the benchmark instances from the literature. Later, the same authors introduce a new MIP model for the ALWABP-2 in Borba and Ritt (2013), and propose a task-oriented branch and bound procedure using new reduction rules and lower bounds, obtained by different relaxations of the problem.

Recently, Vila and Pereira (2014) publish in their working paper a station-oriented branch and bound and remember algorithm (BBR) for the ALWABP. This method was inspired by the approach of Sewell and Jacobson (2012), used to solve the simple assembly line balancing problem (SALBP). This work was cited in Borba and Ritt (2014) and the BBR results were compared to those obtained by the B&B method, proposed in this new work of Borba and Ritt. The authors conclude that their resolution method was competitive and complementary to the BBR approach presented by Vilà and Pereira (2014), and they expect that a combination study of both approaches may provide interesting results.

3.2 Heuristic algorithms

When classical methods are not able to find any exact solution or are too slow, heuristic algorithms are used to obtain an approximate solution in a reasonable time. Generally, heuristics are capable to generate results by themselves or combined with optimization algorithms, to enhance their performance in solving real application problems.

In the context of the HRAP, a review of the recent scientific literature shows that many types of heuristics have been developed by several published studies.

Bennour et al. (2005) present their contribution to human resource modeling and assignment in enterprise process using a fast and efficient heuristic binary search algorithm, to satisfy a performance objective of a process and considering the impact of the human competencies on the performance to calculate.

In Corominas et al. (2006), a heuristic method for assigning tasks to multi-functional workers in the service industry was proposed. This assignment has to fulfill that the percentage of working time, dedicated by each worker to each type of task, is near to reference values.

Heuristic methods were also used to solve larger instances of the assembly line worker assignment and balancing problem (ALWABP), due to the NP-hard character of the problem (Chaves et al. 2007; Blum and Miralles 2011; Moreira et al. 2012, 2015; Araújo et al. 2014). A clustering search (CS) heuristic was developed in Chaves et al. (2007). The CS algorithm consists in detecting promising areas of the search space based on clustering. It was simultaneously used in this paper with a search metaheuristic.

Later, Blum and Miralles (2011) have developed a heuristic search algorithm based on beam search (BS) which is a classic tree search method introduced in the context of scheduling, it explores a graph by expanding the most promising node in a limited set.

In most previous studies considering the ALWABP-2, the objective is to minimize the cycle time given a fixed number of workers and stations. More recently in Moreira et al. (2015), a new studied approach is presented and called assembly line worker integration and balancing problem (ALWIBP-1). In this new scenario, the authors have to minimize the number of stations, given the desired cycle time, and using a constructive insertion heuristic (CIH). As input, this heuristic uses a simple assembly line balancing problem type 1 (SALBP-1) solutions (Baybars 1986; Kriengkorakot and Pianthong 2012), and then iteratively adapted to integrate the disabled workers available in the ALWIBP-1. In addition, two post-optimization procedures, based on MIP neighborhoods, were designed to improve the CIH solutions.

Another extension of the ALWABP was illustrated in Araújo et al. (2014). Parallel lines are considered in this paper, and the problem is named parallel assembly line worker assignment and balancing problem (PALWABP). The objective function is to maximize the sum of the throughput rates of each assembly line. To obtain good-quality results in reasonable time, a four-stage heuristic method was adopted. The main idea of this heuristic consists of the generation of worker sets to be assigned in the same line and able to execute all tasks, while respecting the precedence constraints. First, for each worker a set of feasible tasks is generated. Then, based on the task sets already obtained, possible teams of workers that can be assigned together in a line are fixed. Next, according to the production rate of the obtained line, each set of worker is evaluated. Finally, the final solution is obtained by selecting the sets of workers, allowing the slowest cycle time.

3.3 Metaheuristics

To solve complex combinatorial optimization problems, metaheuristics are considered the most practical and efficient methods to provide good solutions, at a reasonable computational time. In this section, we present essential studies that use metaheuristics as simulated annealing (SA), genetic algorithm (GA), tabu search (TS), ant colony optimization (ACO) and particle swarm optimization (PSO) for the HRAP.

3.3.1 Simulated annealing

Inspired by the physical process of annealing of solids, simulating annealing (SA) is a local search method, which allows hill-climbing moves to escape from local optimality in the hopes of finding a global optimum. The method was introduced by Kirkpatrick and Vecchi (1983), by analogy between combinatorial optimization problems and the statistical mechanics field. The advantages of SA are its general applicability, flexibility, robustness and ease of implementation (Ugail 2011) and its generally faster execution time, due to the reduced computational effort in avoiding acceptance probability computations and generation of random numbers (Henderson et al. 2003). A disadvantage of the simulating annealing is the difficulty in defining a good cooling scheduling (Coello et al. 2002).

In some studies, simulated annealing was adapted to solve different versions of the HRAP such as in Gunawan and Ng (2011), Odeniyi et al. (2015) and Zhang et al. (2010) dealing with timetabling problem. In Gunawan and Ng (2011), the problem consists of the assignment of teachers to the courses and course sections in order to balance the teachers' load. The results of the SA method are compared to those obtained by tabu search. Zhang et al. (2010) proposes a simulated annealing approach with a new extended neighborhood structure. In fact, instead of swapping two assignments as in a standard simulated annealing, the proposed solution performs a sequence of swaps between pairs of slots. To enhance the efficiency of timetable generation in Nigerian high schools, (Odeniyi et al. 2015) develops a modified simulated annealing algorithm (MSA). To converge in less time, the developed algorithm uses a parabolic exponential temperature decrease function instead of linear exponential temperature decrease function as in the classical simulated annealing. Manavizadeh et al. (2013) use the SA method to solve a mixed model assembly U-line balancing problem and to allocate human resources to each station of the line, considering two types of operators (permanent and temporary) and their skill levels.

3.3.2 Genetic algorithm

Developed by Holland (1975), genetic algorithms (GA) belong to the group of evolutionary algorithms (EA), which use techniques inspired by natural evolution, such as reproduction, crossover and mutation, to generate solutions to optimization problems. Compared to other traditional methods, genetic algorithm has the advantage that it can perform a wide range and large scale optimization problem and it can be easily parallelized (Rojas 1996), then its performance is improved. Due to the move of its individuals in the search space, it cannot be trapped in suboptimal local minimum or maximum, like some other local methods (Rojas 1996). However, sometimes finding the optimal solution is not guaranteed. Another disadvantage of the GA is that it spends a long time to find the best solution because of the great number of fitness functions. In addition, input parameters should be well defined to get good results. From our literature review, we notice that there are numerous examples of the successful application of GA to the HRAP in various fields such as health care systems, (Chen et al. 1996), Assembly Lines in production systems

(Zhang et al. 2008a, b), especially in Sheltered Work Centers for the Disabled (Mutlu et al. 2013) and in manual labor factory (Tan et al. 2009). Chen et al. (1996) have used the GA approach to solve the radiological worker allocation problem, an evolutionary model with restrictive hard constraints was considered to reduce the search space. (Zhang et al. 2008a, b) consider a random key-based genetic algorithm (rkGA) to solve a Multi objective assembly line balancing problem with worker allocation, using advanced genetic operators adapted to the specific chromosome structure and the characteristics of the studied problem. In Zhang et al. (2008a), Pareto dominance relationship was used to solve the problem without using relative preferences of multiple objectives. In Zhang et al. (2008b), an effective fuzzy logic controller (FLC) was adapted to adjust the probabilities of the genetic operators.

An iterative GA is presented in Mutlu et al. (2013). The proposed approach provides the order of performing tasks, then assigns tasks in the selected order to workers and workers to stations using iterated local search.

3.3.3 Ant colony optimization

Introduced in the early 1990s, by Dorigo et al. (1991) as a novel nature-inspired metaheuristic (Dorigo and Blum 2005), the ant colony optimization Algorithm is a technique for finding optimal paths through graphs, based on the behavior of ants, searching for the shortest path from their colony to a source of food (Loiola et al. 2007). First, it was proposed to tackle the well known travelling salesman problem (TSP). This resolution method is based on the communication between the different colony's agents called artificial ants via artificial pheromone tails. In fact, during the construction of solutions to the problem, each ant uses the pheromone trails left by other ants as information reflecting their search experience and be taken into account. Then, good-quality solutions are obtained due to the cooperative interaction between the ants. A detailed presentation of the ACO algorithms can be found in Dorigo and Blum (2005) with its different variants and applications.

The advantage of the ACO algorithm is that it was applied to a wide variety of research problems. Compared to SA and GA, the ant colony optimization algorithms can be adapted to dynamic changes (Mavrovouniotis and Yang 2013). But it is difficult to code and its theoretical analysis is complicated. Another disadvantage of ACO algorithms is that they can fall in local optimal solution since the pheromone is updated based on the current best solution.

The ACO can be applied to different types of problems. A number of researchers have tried to apply it to solve the HRAP, such as in Yin and Wang (2006b), Gutjahr and Rauner (2007), Chaharsooghi and Meimand Kermani (2008), Wang et al. (2012), Mian et al. (2012) and Thepphakorn et al. (2013).

In Yin and Wang (2006b), a nonlinear RAP was optimized using an ACO-based algorithm, this resource can be a worker, he can be assigned to perform tasks. To reduce the search space, adaptive resource bounds updating rule were integrated.

The experimental results show that the proposed method outperforms the genetic algorithm for a set of simulated tests. The same conclusion that the results of the proposed ACO are better than those obtained by using a hybrid genetic algorithm to solve a multiobjectif resource assignment problem, was reached in Chaharsooghi and Meimand Kermani (2008). In this work, a modified version of ant colony optimization was proposed, the learning of ants in updating pheromone rule was increased and the probability calculation was simplified in order to increase the efficiency of the algorithm.

The ACO method was also used to tackle a dynamic regional nurse-scheduling problem in Australia (Gutjahr and Rauner 2007). Compared to a simple greedy approach, the results of the ACO approach show significant improvements.

To solve timetabling course problems in educational institutions, which search the appropriate teachers' assignments, students and classrooms, new variants of ant colony optimization called the best–worst ant system (BWAS) and the best–worst ant colony system (BWACS) were proposed in Thepphakorn et al. (2013), and integrated in an ant colony based timetabling (ANCOT) tool, developed for solving timetabling problems.

3.3.4 Tabu search

Tabu search (TS) is a metaheuristic based on local search, created by Glover (1986), designed to overcome the problem of local optima by the use of memory that keeps the history of the search process and the visited solutions, and known as tabu list. The main idea of this metaheuristic consists on starting from an initial feasible solution, and looks for a new solution in the current solution's neighborhood (Öncan 2007) not necessarily better. The tabu list is a mechanism used to prevent returning to recently visited solutions and avoid cycling, when moving away from local optima through non-improving moves. A new solution in the neighborhood is accepted or rejected according to the tabu list information. One of the advantages of tabu search is the use of a tabu list, exploited as a memory to restrict the search space and guide the search. But, one disadvantage is the difficulty in defining effective memory structures and memory-based strategies (Kuo 2001).

Applications of the tabu search in the literature to various problems, related to the HRAP, in different fields are revealed in Dowsland (1998), Dowsland and Thompson (2000) and Swangnop and Chaovalitwongse (2014) for health care systems, (Alvarez-Valdes et al. 2000, 2002) for a timetabling problem, (Belfares et al. 2007) in military system, and (Ammar et al. 2012) for a production system with parallel machines and multi-skilled workers to assign.

Dowsland (1998) deals with nurse restoring problem in a large hospital using TS with strategic oscillation. The aim of the study is to ensure enough nurses are on duty at all times while satisfying individual preferences and requests for days off. In Dowsland and Thompson (2000), the tabu search method was combined with two classical integer programming models Knapsack and networks. Swangnop and Chaovalitwongse (2014) consider a multi-period multi-site assignment problem with joint requirement of multiple resource types. It's characterized by many multi-skill resource types and tasks require joint requirement of more than one resource type to operate. The proposed tabu search algorithm is composed of two steps. First, it allocates resources to site, and then it assigns resources to tasks. Alvarez-Valdes et al. (2000) use a tabu search to assign students to sections at the University of Valencia, Spain. The objective is to ensure satisfactory schedules to students with balanced section enrollments. The process was performed in two phases. In the first phase, the developed algorithm provides a set of timetables for each student. Then, the student's number of each course sections is balanced using the tabu search. Later, the authors consider in (Alvarez-Valdes et al. 2002) the teacher allocation problem, assuming that students are already assigned and using the TS approach. This second work also combines two procedures which allocate teachers to subjects and groups, then assign all of them to timetable periods.

3.3.5 Particle swarm optimization

The particle swarm optimization (PSO) is one of the most recently used metaheuristics to solve the HRAP (Jia and Gong 2008; Fan et al. 2013; Yin and Wang 2006a; Akjiratikarl et al. 2007; Jarboui et al. 2008; Aravindhu and Sathya 2009). It was developed by Kennedy and Eberhart (1995). It is developed from swarm intelligence and based on the research of bird and fish flock movement behavior. The main idea of the PSO, its advantages and shortcomings are presented in Bai (2010).

In Jia and Gong (2008), a multiobjectif PSO (MOPSO) is proposed, to provide a set of Pareto solutions to a multicriteria HRAP. The objective of this work is to assign *m* works to *n* jobs, maximizing the benefit and minimizing the total cost. Recently, the same problem was solved by Fan et al. (2013), using a new method called modified binary particle swarm optimization (mBPSO) algorithm. The results comparing the method solution to ant colony optimization (ACO) and hybrid genetic algorithms (hGA) solutions, already presented in other papers, show that the mBPSO outperforms them (Fan et al. 2013). Yin and Wang (2006a) confirm also in their work, solving a nonlinear RAP with PSO algorithm, that the method used outperforms a genetic algorithm results previously published in the literature.

3.4 Hybridization

Finally, we present some hybridization techniques from the literature used to solve HRAPs. Hybridization is a promising research field, and one of the most successful trends in optimization, and usually gives good results (Talbi 2002; Jourdan et al. 2009). The basic idea is to benefit from the advantages of the classical optimization method combination. This combination is not restricted to different metaheuristics but can integrate for example, exact algorithms with metaheuristics (Blum et al. 2011).

Due to the review of the related literature, we can say that several hybrid algorithms are implemented for the HRAP. Particularly, we notice that hybridization of genetic algorithms (GA) is becoming popular due to their capabilities in handling several real world problems (Grosan and Abraham 2007). In Lee and Lee (2005), Lin and Gen (2007, 2008) and Lukas et al. (2013), a hybrid methodology that utilizes genetic algorithm combined to another optimization method was used for the solution of the HRAP. Results show that the proposed methods are more promising than the GA when used separately.

To solve the assignment problem of students to their examination timetabling, a hybridized tabu search large neighborhood method was developed in Abdullah et al. (2007).

A hybridization of the ACO with the Simplex method was used in Fikri et al. (2011), to obtain a better allocation of tasks to the different members of a multi project staff with changing skills. A hybrid nature inspired intelligent approach, combining ant colony optimization and genetic algorithms was presented in Kyriklidis et al. (2014) to solve human and material resources allocation and leveling problem in project management. A comparative study shows that the hybrid algorithm achieved competitive results compared to individual metaheuristics. The combination of the constraint satisfaction problem with the backtracking search algorithm was proposed in Costa Filho et al. (2012), as a new tool allocation of human resources in a health care system.

4 Applications of HRAP

The HRAP models several real-world problems. The variety of application fields of the HRAP shows the importance given to the human resource allocation in different business areas (see Table 6). The HRAP is considered as subproblem in many real life problems, such as in production systems, health care systems, timetabling problem, tourism and hotel management, project management, maintenance management, and too many others that can't be all enumerated in this section. We give more attention to some of them and present others briefly.

4.1 Production systems applications

From the bibliographical study, many applications of HRAP are found in production management. In fact, to enhance the production efficiency, the allocation of the available human resources should be optimized in manufacturing environments.

Assigning tasks to employees in production management is a difficult challenge. It is mainly due to certain human factors as absenteeism, turnover, poor job performance and employee motivation or lack of job satisfaction.

The difficulty of the HRAP can be also explained by the fact that generally, in production management, the human resource allocation is associated with scheduling problems. Then, to optimize time and the resource assignment simultaneously becomes a hard task.

A bad optimization of the existing worker utilization can have far-reaching consequences for the production rate. For these reasons, many researchers have focused on the above problem and tried to provide better solution that can be applied to real-world cases, we cite (Corominas et al. 2006; Eiselt and Marianov 2008; Tan et al. 2009; Burdett and Kozan 2004), just to name a few. In the two theses (Cheurfa 2005; Hachicha 2012), the problem of human resource allocation in the industrial case was also studied and detailed.

The problem was raised for various configurations of production lines with different layouts, as traditional straight lines, which are recently replaced for more

Table 6 Literature classification according to the field of application

Subject area	References
Production management	Ammar et al. (2012), Attia et al. (2011), Araújo et al. (2012, 2014), Benavides et al. (2014), Bennour et al. (2005, 2008), Blum and Miralles (2011), Boucher et al. (2007), Borba and Ritt (2013, 2014), Burdett and Kozan (2004), Chaves et al. (2007), Chen and Plebani (2008), Cheurfa (2005), Corominas et al. (2006), Costa et al. (2013), Eiselt and Marianov (2008), Haas et al. (2002), Hopp et al. (2004), Manavizadeh et al. (2013), Mayron et al. (2015), Mian et al. (2012), Miralles et al. (2007, 2008), Moreira et al. (2012), Mutlu et al. (2013), Nakade and Ohno (1999), Nakade et al. (2013), Nembhard and Bentefouet (2015), Norman et al. (2002), Sirovetnukul and Chutima (2009, 2010), Song et al. (2006), Tan et al. (2009), Vilà and Pereira (2014), Wang et al. (2012), Zhang et al. (2008a, b)
Health care systems	Azaiez and Al Sharif (2005), Ben Bachouch et al. (2008), Carello and Lanzarone (2014), Chen et al. (1996), Costa and Rivera (2012), De Carolis (2003), Dowsland (1998), Glaa (2008), Gutjahr and Rauner (2007), Kwak and Lee (1997), Lanzarone and Matta (2014), Lust et al. (2012), Rathnayake and Shalinda (2013), Schaus et al. (2009), Trilling et al. (2005), Zheng et al. (2011), Zhu et al. (2013), Dowsland and Thompson (2000), Akjiratikarl et al. (2007) and Swangnop and Chaovalitwongse (2014)
Project management	Acuña and Juristo (2004), Certa et al. (2009), Eskerod (1998), Fikri et al. (2011), Hachicha (2012), Hendriks et al. (1999), Huemann et al. (2007), Kang et al. (2011), Kyriklidis et al. (2014), Selaru (2012), Shahhosseini and Sebt (2011), Wang et al. (2009) and Jarboui et al. (2008)
Maintenance management	Bennour et al. (2012) and Estellon et al. (2009)
Hotel management	Murakami et al. (2010, 2011)
Reviewers assignment	Daş and Göçken (2014), Garg et al. (2010), Goldsmith and Sloan (2007), Hartvigsen et al. (1999), Taylor (2008) and Wang et al. (2008, 2010)
Education systems	Abdullah et al. (2007), Alvarez-Valdes et al. (2002), Daskalaki et al. (2004), Gunawan and Ng (2011), Hertz and Robert (1998), Lee and Schniederjans (1983), Lukas et al. (2013), Thepphakorn et al. (2013), Zhang et al. (2010), Odeniyi et al. (2015), Güler et al. (2015) and Alvarez-Valdes et al. (2000)
Military field	Luoh and Chang (2008)
Sport management	Scarelli and Narula (2002) and Xian-ying (2012)

flexibility by U-shaped lines, parallel workstations or parallel lines and cellular manufacturing systems.

In the area of U-shaped line, only a limited body of research has been reported (Nakade and Ohno 1999; Chen and Plebani 2008; Sirovetnukul and Chutima 2009, 2010; Manavizadeh et al. 2013; Nakade et al. 2013), to optimize the assignment of workers with different objectives. For example, in Sirovetnukul and Chutima (2010), a U-shaped worker allocation problem is presented and formulated, in order to obtain the optimal allocation of workers and tasks to stations, minimizing deviation of operation times of workers and their walking time simultaneously.

In Nakade and Ohno (1999), the authors have considered an optimization problem of seeking for an allocation of multi-function workers to the line, to minimize the overall cycle time under the minimum number of workers, in a U-shaped production line. While in Nakade et al. (2013), more cases are studied. The same authors deal with two types of U-shaped line balancing problems (UALBP-1) for minimizing cycle time under a given number of permanent/temporary workers, and (UALBP-2) for minimizing the number of temporary workers, when the cycle time is given. A comparative study between straight line and a U-shaped line was presented and the experimental results have shown that the cycle time in a U-shaped line is smaller than that in a straight line for each number tested of temporary workers. Then, a comparison was established between one U-shaped line and two U-shaped lines and it was revealed that the number required of temporary workers in the optimal allocation for two lines is less than for a single line.

In Manavizadeh et al. (2013), there are two types of operators to assign: permanent and temporary. First, a balancing problem was solved, using a simulated annealing algorithm, and the number of the station was defined. Then, based on their skill levels, workers are assigned to the workstations.

Parallel lines and parallel workstations in manufacturing systems are also touched by the HRAP (Araújo et al. 2012, 2014; Costa et al. 2013).

A survey was conducted in Norman et al. (2002) to determine the importance of human issues in cellular manufacturing, where an increased level of technical skills, flexibility of workers and their ability to work in teams, and optimal worker assignment strategies are required to improve the manufacturing efficiency.

In Norman et al. (2002), a worker assignment problem in cellular manufacturing was raised and modeled as a mixed integer programming problem. Human skills are considered in the proposed model, and can be changed and improved by additional training provided to the staff.

Recently, Miralles et al. (2007) have defined a new HRAP, called assembly line worker assignment and balancing problem (ALWABP), which occurs in Sheltered Worker centers for the Disabled (SWDs). This real environment aims not only to get productive benefit but also social benefit of integrating disabled people. The studied problem focuses in the heterogeneity of task times and the presence of incompatibilities (Benavides et al. 2014), and consists of providing a simultaneous solution to a double assignment: tasks to different workers, and these workers to stations. As the ALWABP is so important, many researchers have devoted their time to study different extensions of the problem, and presented new models and approaches in order to provide better solutions (Chaves et al. 2007; Zhang et al. 2008a; Miralles et al. 2007, 2008; Blum and Miralles 2011; Araújo et al. 2012, 2014; Moreira et al. 2012, 2015; Borba and Ritt 2013, 2014; Vilà and Pereira 2014). An analysis of these studies shows that they almost deal with the same problem ALWABP, in the case of SWDs, but differ in the used resolution techniques. They try over time to improve the obtained results, going from exact to approximate solutions.

4.2 Health care systems

Human resources allocation is a major problem in health care systems. In fact, to reduce wait times and the treatment delays, and to provide better quality services to the patients, a rational utilization of the health care personnel becomes a crucial task and one of the important challenges to ensure high efficiency and patient satisfaction.

To overcome the rapidly changing expectations, in this critical health care environment, researchers have focused on this problem, defining new policies and new methods making the best use of its human resources. A review of the literature, related to the discussed area, shows that the HRAP arises as a sub-problem in the management of health care human resources, where resources planning and scheduling problem are raised.

The random events that affect service delivery and give a high variability to the workloads, charged to nurses, is the main difficulty to face, when solving the assignment problem (Lanzarone and Matta 2014). The allocation problem concerns all manpower resources of the health care systems such as admission staff, doctors, training doctors, nurses (Azaiez and Al Sharif 2005; Gutjahr and Rauner 2007; Schaus et al. 2009; Zhu et al. 2013), home health care nurses (Ben Bachouch et al. 2008; Carello and Lanzarone 2014; Lanzarone and Matta 2014), emergency nurses (Glaa 2008; Rathnayake and Shalinda 2013), sanitarian staff, anesthetists (Trilling et al. 2005), Medical workers, radiological workers (Chen et al. 1996), surgeons (Zheng et al. 2011) etc. In these studies, various criteria are considered: minimizing the maximum overtime among the nurses (Lanzarone and Matta 2014), reduction of hospital costs (Costa Filho et al. 2012), minimizing the health state adjusted stay time of the patients (Rathnayake and Shalinda 2013), and minimizing the total payroll costs (Kwak and Lee 1997).

A variety of hard constraints that must be satisfied are taken into account, when solving human health care RAP. Nurses and hospitals preferences, nurse's qualifications and specialization, number and overlapping of shifts, variability in patient demand, unpredictable absenteeism, and personal requests for vacations, and the current applied policies in the health care system (Gutjahr and Rauner 2007), are some of the constraints faced by decision makers in hospitals and health centers.

4.3 Project management

Among various types of resources in project management, human resources are the most important part to ensure the project quality and success and to achieve customer satisfaction.

The optimization of the project human resources allocation is a difficult task of project management, because it is associated with the management of time and involves planning of the available resources. The difficulty of the assignment problem can be also explained by the fact that employees to allocate are scarce (Hendriks et al. 1999; Selaru 2012; Kyriklidis et al. 2014). In fact, there are many tasks to accomplish, but only few resources available (Eskerod 1998) with different knowledge, competencies, diverse skill levels and experience (Haas et al. 2002;

Certa et al. 2009), and have to accomplish tasks in the configuration of work-teams (Huemann et al. 2007). Generally, the application of specialized software for project management, used for day-to-day planning, make the allocation of tasks to resources easier (Selaru 2012). For more details, case studies related to this research field can be found in many references (Eskerod 1998; Hendriks et al. 1999; Acuña and Juristo 2004; Huemann et al. 2007; Wang et al. 2009; Certa et al. 2009; Kang et al. 2011; Shahhosseini and Sebt 2011; Fikri et al. 2011; Selaru 2012).

4.4 Other applications

Previous examples show the importance of the HRAP and its applicability in various areas, but it's not limited to these fields. Other applications can and should be cited, including allocation of maintenance staff to achieve high quality service, responding to the requirements of the production function (Bennour et al. 2012; Estellon et al. 2009), hospitality and tourism industries (hotels, tourist resorts, and restaurants) where human resource is considered as a key issue to increase the satisfaction and the profit (Murakami et al. 2010, 2011). In aircraft systems, optimizing the allocation of the crew members to flights is a difficult task. An airline needs a strategy to cover all required flights (Guo et al. 2005), to model crew satisfaction while minimizing costs.

Military team allocation is also considered in Luoh and Chang (2008), Korkmaz et al. (2008) and Belfares et al. (2007). In Scarelli and Narula (2002), the assignment of referees to football fixtures in an Italian championship is presented as an illustrative example, for a multicriteria assignment problem. Many attributes involved at different levels, such as the compatibility of each referee for every match, make the problem difficult to solve.

HRAP becomes an important concern for conference organizers (Goldsmith and Sloan 2007; Taylor 2008), research funding agencies (Das and Göçken 2014) and academic journal editors in charge of assigning submitted manuscripts to reviewers. This problem, known as reviewer assignment problem (RAP), can be classified as a HRAP (Wang et al. 2008). The concerned people, faced to a large number of papers and reviewers, various subject areas among the papers and different types of expertise among the reviewers (Hartvigsen et al. 1999), have to optimize a number of criteria ensuring fairness among reviewers-papers (Garg et al. 2010). A good assignment helps to ensure program's quality and enhance the development of publication and the learning outcomes. A literature study on the reviewer assignment problem can be found in Wang et al. (2008, 2010).

Finally, HRAP in educational systems is mentioned. In this field of application, human resource assignment is considered as a sub-problem of the course scheduling problem. In fact, in timetabling problem, teachers are assigned to courses, then courses are assigned to time slots, and finally time slots are assigned to classrooms (Hertz and Robert 1998). In the literature, various timetabling problems have been studied according to the type of constraints and the type of institution implicated (school, university) (Abdullah et al. 2007; Alvarez-Valdes et al. 2002; Daskalaki et al. 2004; Gunawan and Ng 2011; Hertz and Robert 1998; Lukas et al. 2013; Thepphakorn et al. 2013; Zhang et al. 2010). The research on the timetabling problem has shown a strong relation between the human resource allocation and the performance and success of students.

From this section, it can be seen that HRAP is raised in different business fields, proving that the importance of human resource allocation has been recognized in many disciplines.

5 Summary and conclusion

In this paper, we have examined some aspects of the HRAP concerning its mathematical models, resolution methods and its applications. This study reveals that the human allocation is an important and difficult task since finding a solution for such problem is NP-hard. Numerous publications were produced to cover theoretical and experimental studies of the problem in several application areas. Our work seeks to highlight the increasing interest in HRAP, in the last 20 years. In this section, we aim to point out the research trends in this period.

Among the 147 publications presented in previous sections, 82 % deals directly with the HRAP. To show the interest granted to this problem the 20 last years, 121 sources cited in the reference list (articles, conferences, books,…), that address the issue directly with techniques, algorithms or theoretical developments discussions, are classified according to their date of publication. Table 7, which covers the recent years, presents the number of publications in each 5-year period, since 1995–2000 to 2010–2015. It is clearly visible that recently, there has been a growing interest in the allocation of human resources, in the literature. In fact, human resources are recognized today as sources of competitive advantage, hence more attention is paid to their optimization.

In Sect. 2, the general theory of the HRAP was presented, then its mono-objective and multi-objective mathematical models were studied. In Table 8, we classify the different publications, dealing with direct applications of HRAP, according to the number of the objective functions to be optimized: mono-objective or multi-objective optimization problem. We note that the most cited papers (72 %) focus on mono-objective human resources assignment problem, while only 28 % of the references consider multi-objective optimization problems. Although, the majority of the real-world problems are multidisciplinary in nature and require the satisfaction of several criteria at the same time.

In Sect. 3, various optimization techniques, exact methods, heuristics, meta-heuristics and hybrid methods to solve the given problem were discussed. Table 9

Table 7 HRAP publications over the last 20 years

Publications year	1995–2015 (20 years)	1995–1999	2000–2004	2005–2009	2010–2015
Number of publications	121	8	13	47	53
Percentage (%)	100	6.61	10.74	38.84	43.80

Table 8 Nonobjective and multiobjective HRAP publications

	Monobjectif	Multiobjectif
Number of publications	77	30
Percentage (%)	71.96	28.04

Table 9 HRAP solving techniques

Resolution method	Exact methods	Heuristics	Metaheuristics	Hybrid methods
Number of publications	20	34	41	12
Percentage (%)	18.69	31.78	38.32	11.21

summarizes these HRAP solving techniques. It is shown that nearly 70 % of publications use heuristics and metaheuristics as resolution method, while only 18 % are dedicated to exact methods and the remaining ones are based on hybridized techniques. Metaheuristics are widely used for the HRAP, the choice is justified by the NP-hard property of the considered problem.

To identify the most popular metaheuristics used for HRAP, the different references using these techniques were classified in Table 10, according to the resolution method adopted. The results illustrate an expanding diversity of the methods applied to the problem: genetic algorithm (GA), tabu search (TS), ant colony optimization (ACO), particle swarm optimization (PSO) and simulated annealing (SA), are the most frequently used techniques. This table shows the diversity of methods applied to the problem and demonstrates that hybrid algorithms are commonly used, because they are powerful methods for solving NP-hard problems, since they combine the beneficial characteristics of two or more algorithms. Then, GA and TS are the mostly used among the independent methods. But still more effort needed, applying for example, artificial intelligence techniques as artificial Neural Networks can be a promising method and contributing to solve the problem.

The HRAP was recognized in several business fields, in recent years. Many real-world applications of HRAP are considered in the related literature, we have provided references to most of them that have appeared over the past 20 years, but they can't be all enumerated in this survey. Therefore, we have tried to focus on

Table 10 Metaheuristic methods for HRAP solving

Metaheuristic	ACO	TS	GA	SA	PSO	HA
Number of publications	8	9	16	3	5	12
Percentage (%)	15.09	16.98	30.19	5.66	9.43	22.64

Table 11 Publications classification according to the application area

Application area	Production management	Health care systems	Project management	Education systems	Reviewers assignment	Other applications
Number of publications	39	20	13	12	7	16
Percentage	36.45	18.69	12.15	11.21	6.54	14.95

those that we think are the most important to highlight. A classification of the HRAP publication according to their application area is highlighted in Table 11. It is clear that production scheduling is largely concerned with the HRAP. The HRAP is a very important issue in this field, since an optimal assignment of operators is needed to better perform their work and thus to improve the production efficiency, then in health care system where human resource is still the most important element in the success or failure of the offered services.

Our review of the existing literature allows us to observe that the HRAP was joined to scheduling and restoring problems in several practical cases of various fields. It is also interesting to note that a significant number of studies have considered the human resources allocation and the operations assignment simultaneously, this leads to increase the complexity of the problem, as in the assembly line worker assignment and balancing problem (ALWABP).

Finally, it is worth to mention that some limitations can be noted, in the most cited papers dealing with the personnel allocation problem, such as the lack of human factors consideration in the assignment. In fact, it is widely ignored that, in real life situations, several factors may influence the resolution of the problem. Among the characteristics that are neglected and can be considered for further research, we include personnel's motivation, absenteeism, health, fatigue, stress, skill level, experience, personality characteristics and attitude…Several factors may increase the complexity of the problem. Therefore, there is much work to do to solve real-world problems. Bearing in mind human factors, during the assignment, can be an interesting direction for future work in HRAP.

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