A Systematic Literature Review of the Personnel Assignment Problem

Arash Niknafs, Jörg Denzinger, and Günther Ruhe

***Abstract*—Context: Personnel assignment (PA) is an important problem in industry. In general it is about assigning the right people to the right tasks. Operations research plays a big role in solving such problems.**

Objective: In this paper, we study the personnel assignment problem (PAP) and the proposed solutions to solve it. In addition to that, we aim to identify promising future works from the study results.

Methods: We take a systematic approach towards studying the literature of the PAP. A general systematic review method, which has been recently used by a number of researchers in the field of software engineering, was modified and deployed in this study.

Results: The analysis results reveal potential solution approaches, the trends in application of existing solution methods, and some potential future research areas. The review process is based on our variation of an existing literature review method. This variation is also presented in the paper.

Conclusions: Although a concern in industry, PAP has not been widely studied when compared to other similar fields of research. It has been mainly studied in operations research and in the context of military personnel assignments. It seems that artificial intelligence and machine learning still have a good potential to contribute to this field of research in different applications. Application of PAP in software engineering (SE) is an open area of research. For instance, it looks promising for developer or bug assignments in software development projects.

***Index Terms*— Assignment problem, Personnel assignment problem, Systematic literature review**

I. INTRODUCTION

Fleet management is a broad concept under the umbrella of human resource management (HRM) and it includes ***personnel assignment (PA)***. Personnel assignment problem (PAP) in its simplest form entails the assignment of pre-scheduled tasks to employees. It should be noted that PA is different from determining what types and what number of personnel or equipment should be dispatched –as that goes in the class of fleet composition and fleet size determination problems. In most application areas, PAP is known to be a discrete optimization problem. ***Discrete optimization (DO)*** consists of a set of n variables x_i $(i \leq n)$ with their associated domains D_i of possible values. C is the set of constraints on the values that x_i can take. A solution to the problem is called *valid*, if it satisfies those constraints. It is the application domain knowledge that is used to form those constraints [1]. Finally, there is an objective function f. An optimal solution means the values for the x_i such that all constraints in C are satisfied, and x_i values yield to an optimum value of the objective function.

Many researchers use a more fine-grained categorization of the optimization problems and put the personnel assignment problem under a subcategory of discrete optimization problems called ***Combinatorial Optimization (CO)*** problems.

According to Papadimitriou and Steiglitz [2], in *CO* problems, one looks for an object from a finite -or possibly countable infinite set. That object is usually an integer number, a subset, a permutation, or a graph structure [3].

PAP is a class of the general assignment problem (GAP). In the literature, GAP is defined by using both the scheduling and the knapsack terminology [4]. For a good survey on the solution algorithms for the GAP prior to 1992, refer to the work by Cattrysse and Van Wassenhove [5]. The following definition uses knapsack terminology. From another point of view, the problem can be described as: the optimal assignment of n jobs to m capacitated agents.

Definition 1. ***(General Assignment Problem (GAP))***. Given n items and m knapsacks, the GAP is about finding the optimum assignment of each item to exactly one knapsack, while confining to the capacity limits of any knapsack [4].

Since we will discuss the use of PAP in the context of waste management in the conclusion, we present a definition of PAP that is also an example of PAP application in that context in Definition 2. In the waste collection management, the foremen are responsible for assigning truck operators/drivers to collection areas (sometimes called beats) and trucks.

Definition 2. ***(Personnel assignment problem** in urban waste collection management)**.*** In that context PAP can be defined as the triple:

$$P^{PAP} = (Operators, Beats, Trucks)$$

where, $Operators$ is the group of drivers/operators, $Beats$ is the set of beats, and $Trucks$ represents the set of trucks.

The structure of the rest of this paper is as follows. Section II explains our research methodology. In Section III, an introduction to the PAP and its similar assignment problems (APs) is presented. In Section IV, the studies listed

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in Section III are analyzed and discussed. A few conclusions are drawn in Section V. That is followed by recommendations for potential future works and an introduction to one of our related ongoing research in that section.

II. Research Methodology

This section presents the research methodology (RM) which we have adopted. We start with the research questions which initiated and guided the process of literature review. Then we explain the way the list of search terms was identified and refined. That is followed by the description of the search strategy [6], [7] and the research inclusion and exclusion criteria –which are based on the ideas from [8] and [9].

The investigated research questions (RQs) are:

- ***RQ1:*** *What are the solution and the validation methods in PAP literature?*
- ***RQ2:*** *How much activity has been there on PAP?*
- ***RQ3:*** *What are some of the limitations of the current research?*
- ***RQ4:*** *What are some of the white spaces (potential future works) in this field of research?*

The phases of our research methodology are shown in Fig. 1. The literature review started with identifying the scope of the research and then preparing a primitive representing set of keywords and terms. This step is represented by the first (and the largest) outer layer in Fig. 1, where the size of a layer implies the relative size of the search space in its corresponding phase.

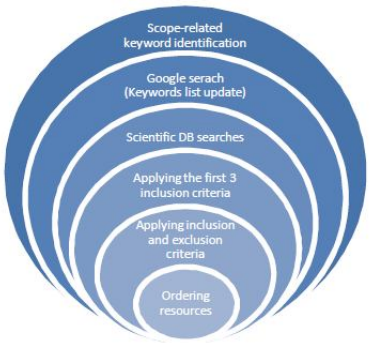

Fig. 1. Phases in our literature review research methodology.

These initial set of keywords, terms and their combinations were used to search for the related work in Google. Although Google search results might not be purely scientific, they are beneficial in the sense that they provide a good insight into the commonly used field-specific terms and keywords. Thus, they help to refine the initial pool of terms and enable better searches to follow in scientific databases. This could be especially advantageous to researchers who are new to a field of research.

The refined set of terms along with their combinations was looked up in the following major online scientific databases (DBs) and search engines: Google Scholar, IEEE Xplore, Scopus, ProQuest, ACM Digital Library, and ScienceDirect.

Table 1 shows the list of the search terms. It should be noted that many decision making problems can be translated as assignment and/or personnel assignment problems. That is why we tried to clearly define and limit the scope of our research by presenting definitions of assignment and personnel assignment problems earlier.

Terms like resource or personnel allocation, selection, restoring and recruiting may seem to be referring to the same problem as PAP. However, the truth is that restoring and allocation deal with scheduling and planning, whereas the assignment problem as define in the literature does not involve scheduling and is merely about finding the right match. As we will discuss in the following section, the definition of PAP does not match the definition of selection and hiring either. Thus the list of terms in the search process is based on the definition of the PAP as is in the literature.

After obtaining the search results, two cycles of inclusion and exclusion processing were performed to filter the search results. The inclusion (or relevance) and exclusion (or irrelevance) criteria are presented in Table 2.

In the first cycle we used the first three inclusion criteria. In the second cycle, the list of resources from the first cycle was narrowed down by applying the rest of inclusion and the exclusion criteria. Resources not meeting any of the inclusion criteria, or meeting one or more of the exclusion criteria were excluded.

Table 1
Refined search terms used to search the resources.

No.	Search term
1	Assignment problem
2	Personnel assignment
3	Optimization
4	Combinatorial optimization
5	Discrete optimization
6	(1 OR 2) AND {system, framework, tool}
7	(1 OR 2) AND {model, technique, approach, algorithm]
8	(1 OR 2) AND {review, analysis, survey}
9	(1 OR 2) AND (3 OR 4 OR 5)
10	(3 OR 4 OR 5) AND (6 OR 7 OR 8)

From another perspective, as shown in Fig. 2, the study selection process goes through four stages: (1) Six databases were searched using the list of terms established in the second largest layer in Fig. 1. The search resulted in approximately 5500 studies. (2) From that pool of studies, 314 were selected by reading the title, abstract and keywords. The studies were sorted in order of relevance by each search engine to make the selection process easier. (3) Duplicate resources were removed (keeping the one with more details). (4) The rest of the inclusion and exclusion criteria were applied, resulting in 34 studies. These studies are listed and briefly explained in the following sections.

Table 2
The inclusion (relevance) and exclusion (irrelevance) criteria.

Inclusion criteria	
1	The title includes relevant terms or implies relevance.
2	The resource's abstract or keywords imply relevance.
3	The resource is peer reviewed.
4	The resource (not only its title and abstract) is in English.
5	The resource provides an analysis or describes a problem or a validation of the existing solutions to PA optimization problems.
Exclusion criteria	
6	The resource matches none of the inclusion criteria.
7	The resource is about general social or psychological aspects of the problems.
8	The resource has a more complete version published elsewhere (replacing duplicates with the more detailed versions).

After coming up with a list of studies, we ordered them based on two criteria. The ordering provided us with an easy criterion for choosing, from this large pool of material, the

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very first research to start the reading with. The ordering criteria were: 1- Whether it is a survey/literature review/thesis or not. 2- The number of times the study had been cited elsewhere. Of course at this point, we are passed the selection process, therefore, these criteria do not mean that we eliminate non-survey studies or those studies which have never been cited (or have not been largely cited) elsewhere. They just helped us to find good start points which would inform us (as much as possible) about the history of the research prior to their publication and also give us some kind of direction on what to read next. Literature review papers, surveys, and thesis were the first three in the ordered list. Then the second criterion was used to choose amongst them.

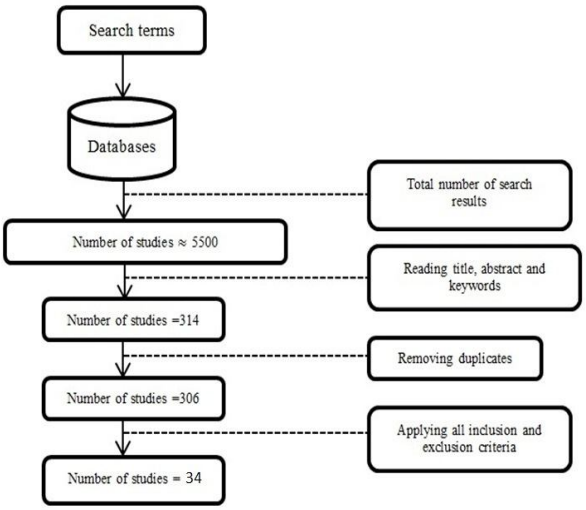

Fig. 2. The number of resources at different stages of the selection process.

III. RESULTS

In this section, we start with the personnel assignment problem and then move on to two classes of GAP that have close similarities with the PAP.

PAP entails the assignment of pre-scheduled tasks to qualified agents. It has a wide area of application such as manufacturing, military, airports, hospitals, and maintenance [10].

PAP has been studied in the operations research (OR) area, as well as management science, engineering management, human resources, and organizational behaviour [10]. Each field of research looks at the problem from its own perspective. For instance, Holness *et al*. [10] study the human aspects of the PAP.

From OR, computer science and mathematical perspectives, finding the optimal solution to a PAP is known to be a ***combinatorial optimization*** and an ***NP-complete*** problem ([11] and [12]).

A. PAP studies

This subsection addresses the first ***RQ1*** that was presented in the beginning of this paper. In particular, Table 3 and Table 4 summarize the answer to ***RQ1***.

In the above mentioned tables, "N/A" is used for those studies that did not propose a solution to the personnel assignment problem but rather discussed a system design or compared different solutions to each other. Some of the studies did not evaluate their proposed solutions and simply presented it as an ongoing work. They are marked in Table 4 by "No evaluation".

Some researchers consider PAP a ***two-sided matching*** problem. The origin of the two-sided matching problem is from college admissions and the matching of marriage [13], where both sides are matched to each other. Another term that might naturally come to mind and be used during primitive searches for PAP studies is ***personnel selection***. It is worth mentioning that personnel assignment differs from personnel selection. In this paper, our focus is on personnel assignment as defined earlier.

Personnel selection is mainly about recruiting people, whereas, personnel assignment assumes that they are selected/recruited and the tasks to be performed are known and scheduled. All that remains is to assign the personnel to the tasks in a way that the overall job is performed optimally with regards to an objective function. The distinction between these two fields of research was made even clearer in the research works through mutual exclusion of the references in their citations.

Table 3 shows a summary of the PAP research. Some of the research works have taken a graph-based problem modeling and solution approach. That makes sense as the nature of the general (2-dimensional) assignment problem can be easily illustrated using a bipartite graph. Genetic algorithm is also a very popular method in solving PAP.

The reason is the advantages of applying genetic algorithms such as the following [14]: 1- genetic algorithms do not require a comprehensive mathematical understanding of optimization problems; 2- they may incorporate mechanisms that avoid local optimal solution; and 3- they are flexible enough to be incorporated with domain-dependent heuristics and form hybrid algorithms.

In addition to GA and graph-based solution, other techniques have been studies too. For instance, fuzzy logics, multi-criteria decision making (MCDM) methods, neural networks, integer programming and different combinations of these techniques are applied to solve the PAP. In Table 4, the validation methods of the proposed approaches (listed in Table 3) are briefly described.

The general assignment problems are well categorized by Oncan [4] into 11 categories. They are: Bottleneck GAP (BGAP), Nonlinear Capacity Constrained GAP (NCCGAP), Multilevel GAP (MGAP), Elastic GAP (EGAP), Dynamic GAP (DGAP), Stochastic GAP (SGAP), Multi-Resource GAP (MRGAP), Generalized Multi-Assignment Problem, Generalized Quadratic Assignment Problem (GQAP), GAP with Special Ordered Sets of Type II (GAPS2), Bi-objective GAP (BiGAP). Oncan provides a short description and a few example studies for each of these categories. Most of these problems are NP-complete.

In general, Sahni and Gonzalez [15] consider GAP to be an NP-hard problem. Moreover, Fisher and Jaikumar [16] suggest that even finding a feasible solution to GAP is NP-complete. As a result, there are several heuristic solution approaches for GAP. An overview of these heuristic approaches for the GAP can be found in [17–19].

Finally, speaking in particular about the PAP, Toroslu 2003 [11] and Toroslu and Arslanoglu 2007 [12] describes PAP as an NP-complete combinatorial optimization problem.

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TABLE 3
RESEARCH ON PAP.

ID	Year	Ref.	Description
P1	1999	[20]	GA - A PAP under linguistic valuations.
P2	2007	[12]	GA - Multiple objectives based on hierarchical and set constraints.
P3	2010	[21]	Heuristic - A model for assembly production.
P4	2003	[22]	Heuristics (Graphs) - A variation of the standard assignment problem with application in PAP.
P5, P6	2010, 2012	[23], [24]	Particle swarm - Bi-objective PAP (BOPAP).
P7	2008	[25]	MCDM (multi-criteria decision making) AHP - Assignment of military personnel to positions.
P8	2009	[26]	Fuzzy MCDM (ANP & AHP) - Organizing a collaborative cross-functional team.
P9	2012	[27]	GA - Project selection and auditor assignment process in construction projects.
P10	2011	[28]	MCDM + Jonker-Volgenant algorithm - Assigning airline personnel to courses.
P11	1974	[29]	Heuristics - Military PAP.
P12	1965	[30]	Heuristics - A stochastic model.
P13	1973	[31]	Heuristics - PAP under risk of failure.
P14	2009	[32]	Binary integer programming - Two-sided matching PAP.
P15	1988	[33]	N/A - Considerations on the architecture of a decision support system for PA and scheduling within production cell organization.
P16	2011	[34]	Data mining & fuzzy logics - Prediction algorithm for PAP.
P17	2010	[35]	N/A - Discussing a PA system for promoting scientific and technical personnel innovation in China's universities.
P18	1994	[36]	N/A - A model for Navy's PAPs
P19	1992	[37]	N/A - Comparing two methods.
P20	1994	[38]	Heuristics - Assignment of field service technicians.
P21	1992	[39]	Extends the idea of Tabular method [40] - Assignment for serial production lines.
P22	1984	[41]	Multi-attribute, multi-criteria application of goal programming - Reassigning (Air Force) personnel.
P23	1986	[42]	Heuristics - "Balloting labelling and personnel assignment"; It uses partially ordered sets, embedding a partially ordered set into another.
P24	1984	[43]	Heuristics - Given measures of each person's effectiveness, it maximizes the effectiveness.
P25	1984	[44]	Solving a sequence of network flow problems - Making enlisted personnel assignment decisions in military.
P26	1993	[45]	N/A - Describes the problem in a military.
P27	1989	[46]	N/A - The design of a DSS architecture for assigning large numbers of personnel to jobs according to multiple criteria.
P28	2010	[47]	Heuristics - A model to achieve computationally efficient solution of the models for multiple instances of the constituent constrained assignment problem.
P29	2004	[48]	Heuristics - Converting the original problem into a complete bipartite graph (for stable PA)
P30	2006	[49]	Heuristics - Uses the term 'Crew', Driver assignment problem in the military domain.
P31	1981	[50]	Lagrangean relaxation - Assigning student teachers to tutors and schools
P32	2003	[51]	Fuzzy logics and GA – Clothing industry
P33	1995	[52]	Tabu search – Manufacturing industry
P34	2003	[53]	Logic cuts – Manufacturing industry

The following two subsections briefly present multilevel and multi-dimensional assignment problems. The incentive behind their presentations in this paper is that: first, the multilevel assignment problem has been sometimes used to model PAPs; and second, the multilevel assignment problems can somehow be considered as a subcategory of the multi-dimensional assignment problems.

Moreover, the combination of the multi-dimensional assignment problem and PAP in the context of waste collection management, which is a dynamic problem environment, seems like a promising research application idea that we will elaborate on later in this paper.

B. Multilevel general assignment problem

As we mentioned before, multilevel generalized assignment problem (MGAP) has been used in a few studies to model and solve some PAPs.

In general, MGAP consists of assigning n tasks to m agents with a maximum of l efficiency levels. Therefore, it means in a MGAP that models a PAP, personnel can perform tasks at more than one efficiency level. The MGAP was first described in 1979 by Glover *et al*. [54] in the context of large scale task allocation [51]. Agent is a generic term (just like task) in the definition of the multilevel general assignment problems. It refers to whatever that performs the tasks.

To tackle the MGAP, and more specifically ***Multilevel PAP*** where the agents are actually the personnel, a few solutions have been proposed. These solutions are based on GA and fuzzy logics [51], tabu search [52] and logic cuts [53]. These studies are listed in Table 3 with ID numbers 32, 33, and 34.

C. Multi-dimensional assignment problem (MAP)

Multi-dimensional assignment problem (MAP) is a well-known extension of the general assignment problem (GAP). It is usually abbreviated as *s*-AP in the case of *s* dimensions [55]. The dimension of an assignment problem is the number of groups of objects that are to be matched together. If the dimensions of the problem are 3 or more, then the term ***multi-dimensional*** is used to refer to that problem. However, searching the term '*multi-dimensional assignment problem'* in online databases reveals that 3-AP is the most studied MAP. For excellent surveys on MAPs refer to [56], [55], [57–62].

It can be said that MGAP is a subclass of MAPs. It is just that MGAP is limited to three dimensions which are agents, tasks and level of performance, whereas, a MAP can be a problem with any kind and any number of dimensions more than 2.

Studying the MAP revealed great potentials for solving PAPs such as the combination of MAP and PAP which will be discussed later in this paper. This combination creates a combined problem that is even more complex than the single MAP and single PAP. It will be even more complex to solve it if the problem is in a dynamic environment. Then the solution has to integrate features that address that dynamism and uncertainty.

We have already discussed about the complexity of solutions to PAP. The following is a brief on the complexity of solutions to MAPs.

Grundel and Pardalos [56] state that the MAP is NP-hard. Moreover, Kuhn [63] mentions that while an AP (with only 2 dimensions) may be solved in the polynomial time, *s*-AP (i.e. *s*-dimensional AP) for every $s \geq 3$ is NP-hard [64] and inapproximable [65].

In another study, Gilbert and Hofstra [57] prove that unlike the two-dimensional linear problem, the general class of problems of dimension three or higher are NP-hard,

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though polynomial methods have been developed in some special cases.

TABLE 4
THE VALIDATION APPROACHES TAKEN IN PAP RESEARCH.

ID	The validation approaches
P1	A small example.
P2	Random test cases + comparison with other methods.
P3	Case study (automobile air conditioning assembly line).
P4	Randomly generated test cases + comparison with other methods.
P5	Use composite scores of twelve candidates and six positions (12x6) as in [26] + comparison with other methods.
P6	Same as P4.
P7	Experiment with 30 graduate students with 2–10 years of work experience + compared with practice.
P8	An application example (in a case company in Taiwan) along with two additional examples + comparison with other methods.
P9	Case of the Kaohsiung Government + comparison with other methods.
P10	Randomly generated data is used to analyze the model.
P11	An illustrative example.
P12	A small illustrative example to elaborate on algorithm's steps.
P13	Uses a small example.
P14	A numerical example (for a Corporation in industry).
P15	N/A
P16	Experiment (Assignment of English teaching personnel).
P17	N/A
P18	A case study in industry. The method is compared with practice.
P19	Illustrative example using randomly generated data + comparison with other methods
P20	Real-world case study + compared with practice.
P21	Experiments (examples in a production line).
P22	Case study in military (Air Force).
P23	Case study.
P24	An illustrative small example plus an example from airplane industry for pilot assignment.
P25	A problem in industry. But the instances of the problem are generated using a random problem parameter generator.
P26	N/A
P27	No evaluation.
P28	Case study in military (Navy).
P29	No evaluation.
P30	Experiment on both real-world data (obtained from a military organization) and randomly generated data + comparison with other methods.
P31	7 randomly generated problems and 1 practical problem.
P32	Case study in clothing industry.
P33	Randomly generated instances of the problem.
P34	Randomly generated instances of the problem.

IV. DISCUSSION

In response to ***RQ2***, the analysis of the studies shows that, though of being perceived as challenging in industry, PAP has not been widely studied (when compared to other similar fields of research). Fig. 3 shows the number of studies on PAP per year. It all started in 1960s but there was a gap until mid-70s. Generally speaking, it was not well received until 2009.

The increasing attention to the PAP is also noticeable in the diagram on the right-hand side of Fig. 3, where the horizontal axis shows the year and the vertical axis shows the techniques applied. Note that (on the vertical axis in Fig. 3), the review studies, discussion papers, and those papers that solely described a problem in a context are put under N/A category.

This diagram also shows that the techniques are getting more and more diverse when compared to the early years of PAP research. At that time most solutions were mainly heuristics. Nevertheless, over years, the popularity of heuristics has not declined at all. For more details on the techniques and their validity refer to Table 3 and Table 4, respectively.

It is very interesting that the most common publication venues for the PAP research are journals. 29 studies (out of the 34) were published in scientific journals. Journal of Computers & Industrial Engineering and the European Journal of Operational Research each with three PAP studies have the highest number of relevant publications. In addition to the journal papers, there are two theses and three conference papers amongst the published studies.

The left side of Fig. 3 depicts the mapping of studies on PAP (as listed in Table 3) with regards to their type of validation. Simulations are by far the most widely used method of validating the proposed solutions. That is followed by experiments and case studies. There are some studies that use the same random problem generator. Nevertheless, there is no common standard dataset to use for comparisons between different proposed techniques. That is due to the fact that such problems require application-specific solutions and thus comparing them with the same dataset does not seem fair.

Fig. 4 shows the number of papers per validation type. In this paper, by validation we mean a way of evaluating performance or accuracy or proving feasibility of a proposed solution to PAP. Only 2 of the studies were not validated. For some other studies, validation made no sense because the study didn't propose a solution and was merely reviewing, describing, formulating or analyzing something. In other words, validation, as we refer to it in this paper, was *N/A* to those studies.

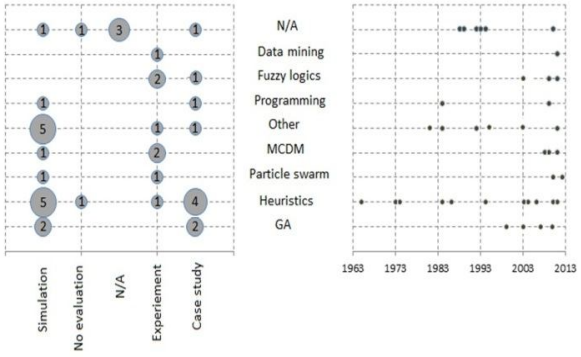

Fig. 3. Mapping of studies with respect to the solution technique, year of publication, and validation type.

Fig. 4 also shows that most of the studies have conducted validation in industry. It shows that, overall, case studies and simulations have been more popular. Looking at Table 4, it becomes clear that most of these case studies are in military context (e.g. Air Force, and Navy). This fact and the application-specific nature of solutions to the assignment optimization problems suggest that there is still a great potential for future research on PAP in other contexts.

Evaluating solutions to PAP are expensive and time-consuming because the systems that are developed to solve such problems are usually knowledge systems. The single phase of knowledge elicitation for building a knowledge system requires a great deal of time and effort. That might be one reason why almost 50% of the validation methods are simulations.

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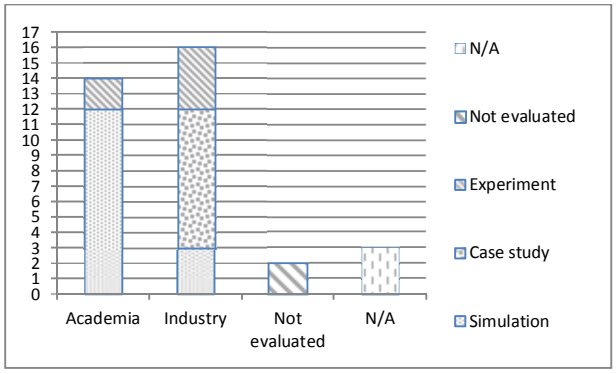

Fig. 4. Validation approaches in PAP research.

V. CONCLUSION AND FUTURE WORK

In industry, efficiency has become a serious challenge for all businesses. Even if a business is performing well and does not seem to need to make savings through efficiency, competition in the marketplace pushes it to do so. PAP is one of the areas where middle level management can contribute to the efficiency in a business.

In this research, we modified and used a well-known systematic literature review method. The modification is presented in Section II. Using that method, the history of the research on personnel assignment problem is studied.

First, the general concept of assignment problem is presented and then its subcategory of personnel assignment problem is studied. In general, PAP is concerned with the optimal assignment of a group of qualified personnel to a group of prescheduled tasks.

As we mentioned before, the resemblance between PAP and MAP led us to studying MAP as well. That revealed potentials in using MAP. MAP can be customized and used to model and solve different PAPs in the real world.

In total, 34 studies were selected through a customized process of term identification, search and selection. The studies were analyzed in more details in Section III and Section IV. The principle findings for the ***RQ3*** (from this systematic review of the PAPs) are:

- Most of the studies on PAP have been in military context.
- Heuristics are the widely taken approach to solving PAP. That is followed by GA and MCDM methods. That indicates the focus of the studies on a limited set of mainly popular techniques.
- There has been a small increase in the number of research on PAP in recent years. Yet, compared to other similar field of research, PAP has not been widely studied.
- Out of the 31 studies, to which evaluation was applicable, 29 were evaluated. That is a very good rate. However, one should note that the application-specific nature of most of these solutions (whether heuristics or not) does not allow to apply them to other problems.
- The results show that the PAP is receiving more and more attention and the diversity of the methods that are being applied to the problem is expanding, consequently. Although data mining, GA and particle swarm have been applied, artificial intelligence and machine learning techniques seem to have yet a lot to contribute.
- Dynamic environment is a key challenge in the real world applications. However, it has not yet been studied in PAPs. Our literature review of the PAP and MAP show that the dynamic environment of the problem has not been widely studied. A recent study on dynamic optimization problems as well as a search in the website at http://www.dynamic-optimization.org/ indicated the novelty of applying optimization methods for dynamic environments to the personnel assignment problems.
- Multi-dimensionality is another aspect that can be integrated but, so far, has been studied only in just some research, yet from a slightly different perspective (under the title of multilevel PAP). There are many PAPs in the real world that are multi-dimensional (e.g. the assignment of personnel to tools and then to tasks or the assignment).
- Development of publicly available and standard databases for the sake of comparison between proposed solutions seems promising. It would enable a better means of evaluation and advancement in this field of research.
- Personnel selection/hiring and scheduling have received more attention than personnel assignment in industry. This might be due to the fact that timing and scheduling have been greater concerns with the managers. That might be the result of a sole focus on doing things right (in old management styles) rather than doing the right things (in the new age management).

From our research results, and in response to ***RQ4***, we came up with a few ideas for future works in the field of PAP. Those ideas are mainly about the integration of robust optimization and MAP solution methods into the PAP solutions. Two diverse application areas, namely software engineering project management and urban solid waste management, were also identified for potential application of PAP. The former can benefit from PAP in the assignment of developers to tasks and activities, whereas the latter can benefit in assignment of collection truck operators to trucks and to the neighbourhoods.

Studying the PAP from a MAP perspective also seems promising. Although personnel assignments based on MGAP take PAP one step closer to reality, it still lacks some aspects of the real world. Those aspects can be integrated into PAP through a combination with MAP. For example, the assignment might have more than two dimensions. It could be that the personnel had to be assigned to the right tools (e.g. trucks in the case of waste collection) and the right task (e.g. the collection area). Therefore something like the tool, for instance, adds a third dimension to the original PAP. This yields to the idea of 3-PAP (or 3-dimensional PAP).

Another issue worth studying is change. Change has been always a challenging issue for the managers because different entities in organization (e.g. personnel) show resistance in face of change. Nevertheless, change is unavoidable. It may not only be unavoidable but also, in some cases such as businesses in dynamic environments, it might be regularly observed. Thus, many businesses prefer to find a relatively stable personnel assignment. In other

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words, they seek an assignment that is robust in face of slight changes. This brings up the idea of robust PAP. There has been one research (cf. [48]) on stable PAP; yet a lot can be done in this area in the future. Robust optimization is one well studied area in operations research that has potentials for contribution to PAP.

Thirty years ago, in order to be able to compete with rivals in an industry, management was more concerned with efficiency in the use of organizational resources [66]. That efficiency was mainly defined as optimization of the costs and/or quality (i.e. doing the job right). However, nowadays, they are moving from a bit away from "doing the job right" towards "doing the right job". Part of "doing the right job" is put as the employee contentment [66]. It is now believed that employee contentment is what management has to take into account in order to increase efficiency and be able to remain competitive. In spite of the rich literature of *job/personnel satisfaction* in management studies, this concept has not been directly addressed in PAP research.

Finally, a robust search-based solution to a 3-dimensional PAP seems a promising idea as it is a closer thought to what goes on in practice in many businesses. Our future work is to study the feasibility and application of this combination in the context of urban solid waste management.

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