

Resolving the Recruitment and Selection Problem as NP-Hard Problem

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Abstract

Background/Objectives: As organizations increasingly strive to attract and retain high calibre ICT-compliant staff, recruitment and selection is attracting huge attention. This paper classified the recruitment and selection problem as NP-hard problem and applied metaheuristic algorithm to solve it. **Methods/Statistical Analysis:** This study focused on University of Lagos, Nigeria as case study and applied computational theory in the form of metaheuristic algorithm in a bid to improve on the existing recruitment and selection process. We reviewed literature, gathered requirements, designed a system and statically tested the process-correctness of the proposed system. The operational recruitment and selection data collected and used for statical testing were obtained from secondary materials of the University. **Findings:** We were able to establish that the recruitment and selection problem in University of Lagos, Nigeria is NP-Hard and equally confirmed appropriateness of applying metaheuristic solution rather than exact algorithm to such problem, given its complex and varied nature. In our view, this is an addition to the growing body of knowledge of the metaheuristic community. Also, the research outcome is an addition to the human resource management community knowledge space. Against the backdrop that human resources are germane to the socio-economic transformation of nations coupled with the challenges of obtaining optimal solutions (best-known candidates) from a teeming pool of applicants, human resource experts are excited that a value-addition metaheuristic solution such as ours can reduce their recruitment and selection stress by about 50%. With the right crop of employees, set organizational goals and objectives can be achieved in the most efficient and effective fashion. **Applications/Improvements:** The study outcome is a software architecture that will scale-up the search for optimal solutions (best candidates) from any pool of job applicants in a timely and cost-effective fashion. This best-fit search apparatus will help human resource experts in aligning organization's human resource strategy with its corporate strategy and objectives.

Keywords: NP-Hard, Problem, Recruitment, Resolving, Selection

1. Introduction

The motivation for this work is the need to mitigate the time and cost associated with the recruitment and selection process in an organization while still fulfilling the mandate of attracting and retaining the best minds from a pool of job applicants. This will alleviate the challenges faced by human resource (HR) managers in securing best candidates for delivering on organizational objectives and

strategy. Given its competitive, multi-dimensional, complex, scalable and structured nature, coupled with the fact that it is probable that the search will find best-fits. The outcome of a recruitment and selection process is therefore not an exact solution but a best-known solution as a better recruitment and selection approach may be yet unknown. Hence, the problem is classified as non-deterministic polynomial time hard (NP-Hard). To solve such a fluid and changing problem, analytical and mathematical methods

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have proved to be insufficient. Hence, we used metaheuristic search. Though metaheuristic algorithms are many, we limit the scope of discussion in this article to Tabu Search algorithm. As a metaheuristic search method, it employs local search methods for optimization¹.

There is the propensity for local search methods to become stuck in suboptimal regions otherwise known as plateaus where many job candidates, for example, are equally fit². However, a metaheuristic search like Tabu Search relaxes its basic rule in attempt to improve on the performance of local search. In the first instance, when search is stagnant at strict local minimum at each step, less favourable job candidates can be accepted if no better applicant is available. In addition, prohibitions otherwise known as *tabu* (for taboo) are injected to guide against the search returning to hitherto-visited solutions or job candidates. The solutions visited and the set of rules provided by the user are described and documented using memory structures in the course of implementing Tabu Search. In the event that an applicant has been treated in a given short-term¹ period or has run foul of a rule, such applicant is marked as *tabu* (forbidden) to prevent the metaheuristic tabu algorithm from repeatedly considering that possibility.

Typically, the recruitment and selection process of an organization is highly structured and procedural. This scenario indicates that a hyper procedural-based approach that models and develops software is relevant to various elements of an organization's recruitment and selection process and would yield considerable benefits. Metaheuristics employ ultra procedural model of software development in which procedures call on other procedures in mostly in a recursive manner in a sustained search effort for an optimal solution from a solution space³. The application of metaheuristics for developing recruitment and selection system is promising in view of its complexity, procedural-based orientation, and search for optimal rather than exact solution⁴. In contrast, analytical or exact methods don't have these characteristics because they don't substantially promote systematic procedural optimal approach but a perfectionist approach, which could be problematic for an NP-hard problem⁵.

Metaheuristics have gained reputation for offering optimal solution within reasonable time for problems that exhibit traits of NP-hardness, combinatorial optimization or stochastic optimization. Sorensen⁴ argued that metaheuristics algorithm is becoming the main development approach for NP-hard problems or combinatorial

optimization problems such as recruitment and selection. Fortunately, developments in enhancing efficiency of computer algorithms promoted by researchers in the field of advanced computer algorithms now mean that more efficient algorithms with asymptotic gains in terms of processor time and memory space will further reduce the time it takes to solve complex and complicated problems. This has opened opportunities for systematic application of procedures (heuristics) through metaheuristic algorithm.

This article presents report of a study that explains the use of metaheuristic algorithm for the development of a university Recruitment and Selection system. We have taken University of Lagos as case study and implementation of algorithm. The study empirically investigated the claims of NP-hardness of resource planning that some authors have alluded to in the literature⁶. However, few reports have been found in the literature that dwelt on practical application of metaheuristics in industrial settings. Weyland⁷ argued that more practical case studies and industrial experiences are needed by the metaheuristics research community. In addition, frontline international conferences such as the *Metaheuristics International Conference* with focus on metaheuristic applications, have in their calls for papers in recent memory, solicited for more case studies. This work reports on a unique application of metaheuristics in a Nigerian University as part of contribution to the metaheuristic body of knowledge. Our work is significant in the sense that it is rare to find reports of practical application of a sophisticated artificial intelligence concepts such as metaheuristics that emanates from Africa.

The remaining part of this article is made up as follows: Section 2 is the background of study and related work; In Section 3 both the methodology and selected case study are presented; Section 4 outlines results and discussions; Section 5 concludes the paper.

2. Literature

2.1 Metaheuristics

A metaheuristic is an advanced procedure (heuristic) aimed at finding, generating, and selecting a less-advanced procedure also known as partial search algorithm. More often than not, it solves an optimization problem by availing sufficiently good solution specifically in scenarios of insufficient information or constrained computational capacity. Predicating solutions on some critical assumptions about an optimization problem, metaheuristics will

examine the solution set with a view to using same for a variety of problems. Blum and Roli⁸ have identified characteristics of metaheuristics to include approximate and non-deterministic, not problem-specific, guide to search process, focus on near-optimal solutions and handling complex learning processes with simple local search procedures. For optimization problem that involves the search for an optimal solution within a discrete search-space, metaheuristics come in handy. Moreover, it is inadequate to apply exhaustive search or analytical methods⁹ to complex combinatorial problems such as engineering design problems like form-finding and behaviour-finding owing to problem of dimensionality. Tabu search, genetic algorithms, simulated annealing and scatter search are well-known metaheuristics for combinatorial problems. In the literature, the coinage metaheuristics is attributed to Fred Glover¹⁰.

2.2 Recruitment and Selection Problem as NP-Hard Problem: The University of Lagos Case

In recruitment, the focus is on attracting adequate number of individuals with requisite qualifications in a timely fashion to submit applications for jobs in an organization while selection involves making a choice from a group of applicants the best candidate for a given position in an organization¹¹. An organization succeeds on the basis of an effective recruitment strategy. Adopting a systematic and proactive approach will mitigate cost and make efficient the recruitment and selection process. This provides a basis for the use of metaheuristic algorithm that is reputed for its sequencing and selection approach. Effective recruitment and selection as a resource planning strategy will ensure an organisation possesses requisite skills, knowledge and attributes adequate for strategic and operational exigencies on ongoing basis. It also ensures that supply matches demand and enlarge the number of prospective applicants. Other benefits include steady improvement of the selection process, ensuring that a suitable candidate gets the job, and improvement of organisational effectiveness.

One of the objectives of the human resource (HR) sector of the University of Lagos is to have a core of ICT-Compliant staff with appropriate values and work ethics. To this end, a number of activities have been initiated to attract and retain highly qualified, experienced and competent staff in core functions¹². We

closely and carefully monitored recruitment and selection process in University of Lagos and observed that particular care has been taken to ensure that the process is open, flexible, current, dynamic and creative, capable of increasing effectiveness and efficiency, as well as gender-sensitive.

Using this well-thought out process, the vacancies shown in Table 1 were filled in years 2014 and 2015.

The real-life operational data above shows a systematic declining trend in numbers from ground-zero (number of candidates that applied for a post) to final stage (number of candidates employed) and confirmed that recruitment and selection search space continued to shrink as the search lasted. Based on this statistical psychology coupled with the interview responses of human resource managers in the university, the researchers concluded that a typical recruitment and selection process is a marathon, methodological and painstaking exercise aimed at securing the best-known minds for available vacancies in an apparent attempt to optimize the attainment of the university's objectives and strategy. The research equally revealed that human resource managers don't claim to have secured perfect or exact solutions (employees) at the end of a recruitment and selection exercise but rather would admit that they got the best-knowns under the prevailing circumstances. All these are hallmarks of an NP-Hard problem which is better resolved as stochastic or metaheuristic optimization problem to obtain optimal or high-quality solutions in reasonable time³.

2.3 Related Work

Gusdorf¹³ researched recruitment and selection and produced for undergraduate students a learning model made up of two parts. He reiterated that organizations have a number of options as initial step in a recruitment and selection process that is based on signals from human resource planning suggesting the exigency of additional labour. Therefore, careful human resource planning has to predict accurately future personnel needs and take into cognizance the total growth potentials of the organization. After due consideration and elimination of alternatives, recruitment and selection planning will start. Despite shedding light on costs and essence of a recruitment and selection programme, the author failed to classify the problem as an NP-hard problem let alone offering a computational solution to such problem. This is the main motivation for our work.

Table 1. Select vacancies filled in years 2014 and 2015

Year	Post	No. of persons needed	No. of Candidates that applied	No. of Candidates shortlisted	No. of candidates interviewed	No. of candidates employed
2014	Technologist II	45	758	667	125	45
	Assistant Registrar (Litigation)	1	21	6	3	1
	Assistant Registrar (Solicitor)	2	16	5	3	2
	Senior Systems Analyst	3	28	12	7	3
	Systems Analyst I	2	48	25	11	2
	Systems Analyst II	3	76	62	8	3
2015	Fireman II	2	40	18	8	2

Source: University of Lagos Registry (Human Resource Management Department)

¹⁴Outlined staff recruitment and selection policy and procedure of the Anglian Ruskin University. It graphically presented the process using flowchart in an apparent attempt to enhance understanding. To deliver on its mandate, the university focuses on recruiting and retaining the best and brightest. To highlight the dynamism of the policy and procedure, the work specified that in view of changes in legislation and employment practice, the procedure can be reviewed time and again by the University authorities at their discretion. Clearly, the work provided insight on recruitment and selection process in a university which is highly valued in the context of our work. However, our work is in the context of a local university - University of Lagos. In addition, it did not highlight the role of computation in easing recruitment and selection concerns, a departure from our current efforts focus on computation algorithm for aiding the process.

¹⁵Developed a guide to help organizations review existing approach to recruitment and selection. The article noted that in seeking to get the most from employees, a key factor is to ensure that only those who have the potential to make the greatest contribution are recruited. It outlined principal elements of recruitment and selection, each having a contribution to make in helping to find the most suitable candidates for any

given post. Despite highlighting and enunciating these elements, it did not classify the problem as NP-hard. Neither did it offer any computational insight for solving the problem.

¹⁶Focused on NP-hardness based on his work on theoretical Computer Science. The work revealed that most real-life problems like recruitment and selection problem cannot be solved quickly using mathematical or analytical methods. Put in another fashion, they cannot be solved in polynomial time using exact algorithms due to their multidimensional nature and the fact that only an optimal solution can be found as other clever ways of solving same problem may yet not be known. Hence, appreciable or exponential time is needed underscoring the non-deterministic polynomial time hardness of the problem (NP-hard problem). The work however fell short of classifying human resource planning as an NP-hard problem just as it did not mention that metaheuristic optimization could be applied to aid the recruitment and selection process.

In a nutshell, our work, in the first instance, classified recruitment and selection as an NP-hard problem and then applied metaheuristic algorithm (search algorithm) for resolving it by designing a recruitment and selection system.

3. Method - The University of Lagos Recruitment and Selection Case

In order to identify the requirements for the recruitment and selection system and find out the current trend in the application of metaheuristics in the field of resource planning, with special focus on human resource planning, relevant literature was reviewed, interviews were conducted and several observations made about the human resource management practices of the University of Lagos. We then modelled the proposed metaheuristic system using semantic network, automata theory¹⁷ and Unified Modelling Language¹⁸. Thereafter, the software representations (requirements document, design and algorithms) were statically tested to verify that errors would be almost non-existent when proposed system is implemented.

Possible outcome of the study and likely threats to results obtained were equally evaluated. Finally, the researchers considered that a system aimed at optimizing the outcome of recruitment and selection should itself be an optimized system for achieving the overall goal of improved system in all ramifications. We therefore performed asymptotic analysis of the efficiency of the metaheuristic algorithm in terms of speed and memory utilisation.

3.1 Computational Expression of the Recruitment and Selection Problem

With the aid of the objective-methodology mapping shown in Table 1 above, the researchers focused on the application of computational theory using semantic network and automaton to respectively explain the body of knowledge and transitioning in the recruitment and selection process of University of Lagos. We then applied Tabu Search to the recruitment and selection procedures to actualize the proposed metaheuristic system¹.

The semantic network for a real-life job advert emanating from University of Lagos is shown in Figure 1. This advert appeared in national newspapers in compliance with Federal legislation/regulation that vacancies in Federal institutions be advertised in national daily newspapers to achieve the objective of nation-wide publicity.

Request to and response from the Recruitment and Selection system is represented in Figure 3. Using directed graph, the diagram shows a finite state machine with elements $(Q, \Sigma, Z, \delta, q_0, F)$. The element Q refers to vertices (finite set of states) while Σ is a defined set of input symbols (designators). The finite set of output symbols (designators) is represented as Z , the transition from one state to another is represented by δ , the initial (start) state is q_0 , and the accepting (final) state is F ¹⁹.



Figure 1. Semantic Network for a real-life job advert by University of Lagos (Advert Source: Daily Trust Newspaper Wednesday, November 30, 2011 page 55)

Table 2. Objective-methodology Mapping

SN	Objective	Methodology
1.	To reduce the time and cost associated with recruitment and selection process in University of Lagos	Requirements engineering, design and implementation of a metaheuristic system using Tabu Search
2.	To ensure that the proposed metaheuristic algorithm itself is an optimized system for overall improved performance.	Asymptotic analysis of efficiency of metaheuristic algorithm in terms of CPU speed and memory space

In the mathematical function $\omega: \Sigma \times Q \rightarrow Z$, ω is the output function that maps ordered pairs of states and input symbols into output symbols.

Figure 2 shows the state transition of the recruitment and selection process as a finite automata^{20,21}. Its states are the eight elements of recruitment and selection: placing job vacancy, performing job analysis, launching initiatives to attract candidates, screening of candidates, interviewing of candidates, selection and appointment of candidates, employee induction, orientation and training, and evaluation of employee¹⁵.

In Figure 3, the automaton is re-fashioned as a symbol manipulator where

- S1 = Terminal states (Job Vacancy and Employee Evaluation)
- S2 = Transition states (other elements of Recruitment and Selection process)
- 0 = Inter-element transition
- 1 = Intra-element transition

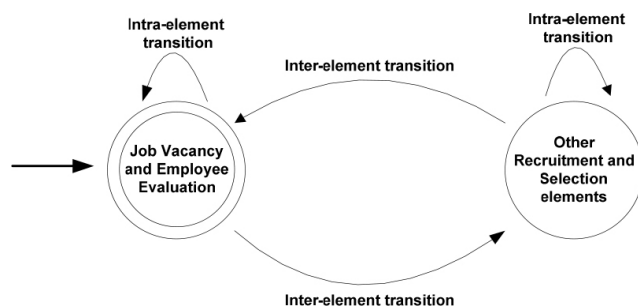


Figure 2. Automaton for the recruitment and selection process. In Figure 3, the automaton is re-fashioned as a symbol manipulator

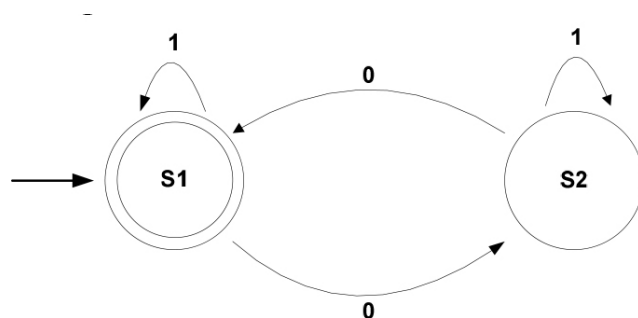


Figure 3. Recruitment and selection automaton as a symbol manipulator

3.2 Architectural Requirements

The architectural requirements for the proposed system are outlined in Table 3 while Figure 5 is the use case diagram, showing actions to be executed by users.

The use cases for the proposed system are therefore Add Recruitment and Selection Element Information, Access Recruitment and Selection Element Information, Edit Recruitment and Selection Element Information, and finally, Delete Recruitment and Selection Element Information.

3.3 Architectural Design

To model the solution, we used UML tools like Use Case Diagram and Deployment Diagram. However, for space constraint, we present only the metaheuristic algorithm using Tabu Search in the form of a pseudo-code as follows:

```

s ← s0
sBest Candidate ← s
vacancy Tabu List ← null
while (not vacancy Search Stopping Condition())
    vacancy Candidate List ← null
    for (vacancy Candidate in search Neighborhood)
        if (not contains Tabu Elements (vacancy Candidate,
        vacancy Tabu List))
            vacancy Candidate List ← vacancy Candidate List
            + vacancy Candidate
        end
    end
    vacancy Candidate ← Locate Best Vacancy Candidate
    (vacancy Candidate List)
    s ← vacancy Candidate
    if (fitness (vacancy Candidate) > fitness (sBest
    Vacancy))
        vacancy Tabu List ← feature Differences (vacancy
        Candidate, sBest Vacancy)
        sBest Vacancy ← vacancy Candidate
        while (size(vacancy Tabu List) > max Vacancy
        Tabu List Size)
            Expire Features (vacancy Tabu List)
            s ← vacancy TabuList First Elements
        end
    end
end
return (sBest Vacancy)

```

Table 3. Cross-cutting functional requirements

R01	Add Recruitment and Selection element information	The system shall allow authorized users to add Recruitment and Selection element information to the database
R02	Access Recruitment and Selection element information	The system shall allow authorized users to access Recruitment and Selection element information from the database
	To ensure that the proposed metaheuristic algorithm itself is an optimized system for overall improved performance.	Asymptotic analysis of efficiency of metaheuristic algorithm in terms of CPU speed and memory space
R03	Edit Recruitment and Selection element information	The system shall allow authorized users to edit Recruitment and Selection element information on the database
R04	Delete Recruitment and Selection element information	The system shall allow authorized users to delete Recruitment and Selection element information from the database

3.4 Architectural Verification and Validation

The validation phase aims at increasing confidence that the Recruitment and Selection architecture is fit for purpose²². The techniques for validating this architecture are static and dynamic verification and validation²³ using manual testing or prototyping. Since the cost of fixing is lower before building, both measures aim at improving the design prior to implementation by identifying possible errors. We used manual testing for this work. In verifying and validating the Recruitment and Selection system for requirements compliance and correctness of process, each software representation was evaluated. The software representations include requirements specification, system design and pseudo code. The ultimate goal was to ensure that in the build-up process, user requirements were treated in all software representations as well ascertain that the software product fulfilled operational needs and emergent properties.

4. Results and Discussion

In the first instance, the study examined and classified the recruitment and selection problem of the University of Lagos as NP-Hard. Thereafter, we proffered a metaheuristic solution and performed asymptotic analysis of the efficiency of the metaheuristic algorithm in terms of speed and memory utilisation. Finally, we evaluated possible threats to our findings. The followings are elaborations of findings.

4.1 Confirming Recruitment and Selection as NP-Hard Problem

A meticulous examination of the standard operating procedures and operational statistics of the University of Lagos human resource sector confirmed that the recruitment and selection problem is both an NP-hard problem as well as a stochastic optimization problem since sometimes, it is a game of chance²⁴. The researchers did not stop at classifying the problem. Since studies have shown that problems of this nature are best solved using procedure-based approach, we proffered a Tabu Search solution - a variant of metaheuristic algorithm. When subjected to static testing, the solution proved adequate in the context of obtaining optimal solution. The asymptotic analysis indicated that the algorithm has linear run-time since its speed and memory space utilization are a function of the number of job applicants. This, in our opinion, is an efficient algorithm - though it can be improved upon.

4.2 Evaluation Threats

There are indications that an expanded evaluation of the various components of the Recruitment and Selection system could unveil news insights. In any case, the data used in this empirical study are real-life operational data. Moreover, the subjects interviewed are employees of University of Lagos who possess practical knowledge of the existing human resource management practices of the institution. This provided them a good platform to contribute objectively to the outcome of the study. Thus, a serious consideration can be given to their views. Moreover, just

a fraction of data from the large pool of recruitment and selection operational data of the university since its inception in the early 1960s were used for the study, which in a sense could constrain the statistical relevance of the outcome. Nonetheless, the study outcome shows that the recruitment and selection problem is NP-hard and can be resolved using metaheuristic algorithm²⁵. In our view, this is a good result since at this juncture in the project, the key goal is to have a first impression of the possibility of using metaheuristic approach to solve the recruitment and selection problem. Hence, despite using small amount of data, there is adequate evidence to infer that recruitment and selection is an NP-hard problem that can be tackled using metaheuristic algorithm. We can thus generalize that the proposed metaheuristic Recruitment and Selection system is effective.

5. Conclusion

Against the backdrop that sources of innovation for sustainable national transformation are derived from codification of theoretical knowledge rather than from muscular power, a carefully orchestrated and coordinated human resource management strategy that secures best minds is commendable. Using University of Lagos as case study and for industrial experience, this work classified the recruitment and selection problem as NP-hard problem, citing the reasonable time it takes to select the best-known job candidates from the pool of applicants and the fact that there may be a better recruitment and selection process that is yet unknown - hence the process is subject to constant review. We then designed a metaheuristic algorithm with a view to facilitating the recruitment and selection process by providing timely and quality information from the human resource database for decision making at every stage. In the ultimate analysis, our findings are as an addition to the growing knowledge space of the metaheuristic research community. This is particularly significant when one considers that rarely does such empirical study using a sophisticated computational technique such as metaheuristic search originate from Africa.

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