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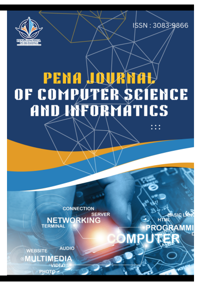

A Review on School Network Problem with Zone Dependent Fixed Cost and Inventory Cost

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ABSTRACT

When it comes to avoiding or contributing to a students' decision to go to school, school distance can play a significant role. Long commutes to and from school can raise the opportunity costs of education and provide safety and security risks, particularly for female students. When compared to other types of location issues (e.g., facility location problem, location, and allocation problem), the school location model is one of the most important research efforts in the location analysis area. The location-allocation problem (LAP) has received a lot of attention in the facility location sector. The Weber issue is well-known for the LAP in continual plane. This article evaluated the problem by taking capacity limits and fixed costs into account, as every centre has a separate setup cost along with a capacity limit to service consumers. Previous research looked at lucrative places by splitting continuous space into a definite number of equal cells and then selecting the best site from a smaller range of potential spots. Inevitably, it can contribute to avoiding suitable places because unproductive regions are still considered when establishing facilities. As a result, transportation expenses might be significantly increased. In addition, alternative school network redesign methods and mathematical programming models do consider school consolidation, deletion, and addition. To optimize cost, the model should consider the development, closure, and amalgamation of a new school. The objective of this research is to develop a multi-start simulated annealing approach specifically tailored for the school network problem with zone-dependent fixed costs and inventory costs. In addition to addressing the allocation problem, this research also incorporates the consideration of zone-dependent fixed costs and inventory costs. Furthermore, inventory costs, incurred when schools are kept in specific zones, are accounted for to provide a comprehensive optimization solution. By developing a multi-start simulated annealing approach for the school network problem with zone-dependent fixed costs and inventory costs, this research aims to provide

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school administrators and policymakers with a valuable decision-making tool. The research also considered in the model to regulate the number of pupils that must be present in a school, allowing the model to mirror the real scenario more precisely. Finally, this research will be able to identify the best techniques for school network redesign issues.

Keywords:
School network problem; simulated annealing approach; zone dependent fixed cost and capacity

1. Introduction

In recent years, the efficient allocation of educational resources has become a critical challenge for policymakers and school administrators. The optimal distribution of schools across different zones can significantly impact educational access, cost-effectiveness, and student outcomes. However, this problem is inherently complex, particularly when considering zone-dependent fixed costs and inventory costs. The objective of this research is to develop a multi-start simulated annealing approach specifically tailored for the school network problem with zone-dependent fixed costs and inventory costs. The proposed algorithm aims to minimize the overall cost associated with school allocation while satisfying various constraints such as zone capacity limitations and the minimum and maximum number of schools per zone. In addition to addressing the allocation problem, this research also incorporates the consideration of zone-dependent fixed costs and inventory costs. The algorithm's objective function is extended to include the costs associated with each zone, which may vary due to differences in infrastructure, transportation, or personnel. Furthermore, inventory costs, incurred when schools are kept in specific zones, are accounted for to provide a comprehensive optimization solution. By developing a multi-start simulated annealing approach for the school network problem with zone-dependent fixed costs and inventory costs, this research aims to provide school administrators and policymakers with a valuable decision-making tool.

Literature Review

2.1 General Issues

Many studies have been performed on facility location problems. These studies began by Weber who noted the effect of industrial location on transportation costs of raw material and final product. Studies on warehouse location were later made more specific in the year 1958 by Baumol and Wolfe. They constructed the model for the warehouse location problem without fixing the installation costs. Consequently, there are deviations in the problem variables which convert it into a problem during transportation. However, the reality revealed fixed costs involved in this location model such as the cost to build a warehouse and the cost of renting warehouse sites. In an extension of the previous study, instead of considering only the transportation costs related to distance, they looked to minimize the total costs of the system by including the fixed and variable costs allied with locating and operating a warehouse. 2.2 Development of Multi-Start Simulated Annealing Approach Simulated Annealing (SA) is a popular optimization algorithm inspired by the annealing process in metallurgy [4]. It has been widely used to solve various optimization problems in different fields. However, SA is known to be sensitive to the initial solution, often getting trapped in local optima. To overcome this limitation, researchers have proposed the use of a multi-start approach with SA, where multiple runs of SA are performed with different initial solutions [33].

Simulated Annealing (SA) is a stochastic optimization algorithm that draws inspiration from the annealing process in metallurgy. It is widely used to solve combinatorial optimization problems where finding the global optimum is challenging. The working principle of SA is based on the analogy of cooling a material to reduce its defects and achieve a more stable configuration. Similarly, SA aims to minimize an objective function by iteratively exploring the search space and gradually reducing the search intensity. The algorithm accepts both improving and worsening solutions during the search, allowing it to escape local optima and find the global optimum [33]. The SA algorithm starts with an initial solution and a temperature parameter, which controls the amount of exploration versus exploitation in the search process. In each iteration, a new candidate solution is generated by perturbing the current solution.

The algorithm then compares the objective function values of the current and candidate solutions. If the candidate solution is better, it is accepted unconditionally. However, if the candidate solution is worse, it is accepted with a certain probability based on a probability distribution derived from the temperature parameter. This probabilistic acceptance enables the algorithm to explore the search space and avoid getting trapped in local optima. The temperature parameter is gradually decreased over time according to a cooling schedule, which determines the rate at which the algorithm transitions from exploration to exploitation. Initially, the temperature is high, allowing a higher probability of accepting worse solutions. As the temperature decreases, the algorithm becomes more selective, favouring only improving solutions. As according to Yu *et al*., [35], simulated annealing is a versatile optimization algorithm that balances exploration and exploitation to find good solutions in complex optimization problems. Its ability to escape local optima makes it a valuable tool, although careful parameter tuning and additional techniques may be necessary to optimize its performance in specific applications. 2.3 School Network or Locate and Allocation of School. Typical combinational problems, such as location-allocation issues, have received extensive investigation.

According to Murray AT [28], it received extensive investigation in a variety of disciplines, including economics, industrial engineering, operations research, regional science, urban planning, geography, computer science, and mathematics. The advancement of computer technology and the enthusiasm of academics from many fields have greatly benefitted location-allocation models. These scholars have offered their unique insights to the analytics of facility placement and facility service regions. Murray AT [28] also states that, in terms of data input and management, visualisation, issue solving, and theoretical advancements, GIS has made significant contributions to location analysis. According to Church RL, Murray AT [10], locating one or more facilities to maximise one or more objectives is the subject of location issues. He also mentioned, an essential subset of location issues, location-allocation issues aim to "place a multiple number of facilities and assign the demands met by those facilities so that the system service is as efficient as feasible". They are based on location theory. It wasn't until Weber's ground-breaking 1909, industrial location book that location theory became formally recognised.

Hakimi [15], who created a formula for selecting one or more facilities on a graph to minimise the sum of the distances or the maximum distances between facilities and points on the graph, is credited with starting most talks regarding location-allocation difficulties. Since the publication of his work, the use of location-allocation models has grown tremendously, and several models have been discovered. The research on location allocation modelling, according to Francis, McGinnis, and White (1983), is divided into four categories based on the discrete vs continuous aspects of the place where facilities are sited. While the facilities for the continuous scenarios can be built everywhere in the region they are intended to service, those for the discrete scenarios can only be erected at a small number of discrete potential locations. These categories include location-allocation issues in discrete networks, continuous spaces, discrete spaces, and mixed spaces.

By offering a framework of classification based on their goal functions, system characteristics, and decision variables, Brandeau and Chiu [7], conducted a review of more than 50 location issues and provided a thorough overview of location problems investigated prior to 1989. To acquire a general summary of the research done in the location and location-allocation domain prior to the 1990s, this publication might be seen as a great place to start. Around the same time, Current *et al*.,

[11] emphasised that location (including location-allocation) difficulties sometimes need the implementation of numerous objectives, making the process of finding solutions more difficult. Their research revealed four primary types of objectives: maximising coverage, lowering trip impedance (such as distance or time), and minimising operational costs. Location-allocation issues are combinational optimization issues, and the solution identifies potential locations for facilities based on the spatial distribution of demand in the local area, with the goal of minimising total cost (travel time, distance, or other impediments), operating cost, or some other overarching objective. According to Church RL, Murray AT [10], it is difficult to solve because it has a very broad solution space, is NP-hard, and cannot be solved in polynomial time by finding the precise optimal solution. They said traditional precise linear programming techniques offered by commercial software such as CPLEX or Lingo are ineffective for large-scale problems. In order to tackle location issues, several heuristic techniques have been developed.

More sophisticated heuristics and metaheuristics were later presented to address the p-median problem, particularly in the recent decade. The extended class of location-allocation problems, in which N additional incapacitated facilities must be located in the plane with regard to M objects, were solved by Bischoff and Dachert [5] using various approaches, and their results were compared. The multi-start, (variable) neighbourhood search, tabu search, simulated annealing, and an evolutionary method were explicitly contrasted. Their numerical findings demonstrate that all approaches perform quite similarly to one another, while the termination criterion may alter computation time and objective quality 2.4 Best Number of Student in Every Class The number of students a teacher oversees in the classroom is known as the class size [19]. Smaller classrooms have been proven to offer higher possibilities of individualised instruction and a healthier learning environment, which has been stressed by many studies.

Additionally, according to Smith and Glass [31], a smaller class size has a favourable impact on instructors' dispositions, individualization, student involvement, quality of education, and student attitudes. Thus, does student get greater knowledge in smaller classes? There is a lot of conflicting information in the literature on schooling. On the other hand, some of the research mentioned in this study discusses how CSR affects kids' conduct, academic success, teachers' employment, pay, and parental convenience. According to Shin (2012), smaller class sizes encouraged black pupils to do better academically in all disciplines and considerably better academically in reading, math, listening, and word recognition abilities among kindergarten through third-grade students.

The impacts of smaller class sizes were calculated by Dynarski *et al.*, [12] for early elementary school through post-secondary education. Early on in school, having lower class sizes enhanced pupils' likelihood of entering college by an additional 2.7 percentage points. The study also showed how larger classes have a negative impact on enrollment rates for black students, kids from low-income households, and students attending high-poverty schools. CSR may be able to reduce racial and socioeconomic disparities in early childhood post-secondary education achievement. Smaller class sizes also boost students' chances of receiving a degree by 1.6 percentage points, particularly in lucrative subjects like STEM, business, and economics.

The vast majority of the 112 peer-reviewed research concluded that smaller classrooms helped close achievement inequalities between pupils. Mathis [26] reviewed the evidence on poor and minority students and found that CSR had beneficial benefits that were twice as strong. Studies on CSR were summarised by Bohrstedt and Stecher [6], Hruz (2000), and Krueger [23].They found that in the first year following a CSR, students in a math class with a student capacity of 15 outperformed those in classrooms with more students. Math lessons showed more benefits and statistically significant outcomes than reading classes. Children from small classes were able to sustain their edge over succeeding years, according to the study, although they did not demonstrate any improvements in their performance. Higher-ability students gained more from a smaller class than their average peers, according to Konstantopoulos' [22] research. 2.5 School Network Problem with Zone-Dependent Fixed Cost and Inventory Cost The school network problem with zone-dependent fixed cost and inventory cost is a complex optimization problem that involves determining the optimal allocation of schools across different zones, considering the associated fixed costs and inventory costs.

This problem arises in the context of managing a school network, where decisions need to be made regarding the placement of schools in various zones to minimize costs while ensuring adequate educational resources. In this problem, the fixed costs are zone dependent, meaning that the cost of establishing a school in each zone varies based on factors such as land prices, construction costs, and administrative expenses. The inventory costs, on the other hand, are related to maintaining educational resources at each school, including textbooks, equipment, and staff. The efficient management of school networks plays a vital role in ensuring quality education and resource optimization. One crucial aspect is the allocation of schools across different zones, considering factors such as fixed costs associated with establishing schools and inventory costs related to maintaining educational resources.

The facility locations are constrained to a set of probable sites on a network, each of which has an assigned opening cost, in the basic plant placement issue (see, for instance, Hakimi [16], Brandeau and Chiu [7], Salhi [29]. Brimberg and Salhi [8], state that it similar to the discrete version, the goal is to find the best balance between the fixed expenses related to building additional facilities and the transportation costs to provide customer service. The research of Aneja and Parlar [3] is the one that is most accurate to this one. The authors tackle an intriguing issue where entering certain locations is prohibited yet traveling through them may or may not be allowed.

The reduction of transportation costs is the study's major concern. In other words, when restricted zones are given a high fixed cost, that research might be viewed as a particular example from research Brimberg and Salhi [8]. Butt and Cavalier [9], Hamacher and Klamroth [17], and Klamroth [21,21] are further publications that consider restricted zones (or obstacles) while putting amenities in the plane. For a variety of zone dependent fixed cost factors, the location of a facility may affect the opening costs. For instance, Brimberg and Salhi [8], the price of land may vary; government incentives in the form of lower taxes may favor certain areas; zoning restrictions will eliminate consideration of other areas (which is the same as assigning a prohibitive opening cost in such areas); or trunking (or haulage) costs to supply goods, services, and labor may factor into account. Eilon *et al*., [13] provide a thorough study of trunking costs. There are several control methods used over time to ensure adequate controls over materials unused or used. These control measures for rating the value of consumption and units of stock include - ABC analysis (Always Better Control), VED analysis (Vital Essential Desirable), FSN analysis (Fast, Slow Moving and Non-Moving), SDE analysis (Scarce, Difficult, Easy) and HML analysis (High, Medium, Low). The location of a facility will likely affect its opening costs.

The main objective of inventory cost management is to strike a balance between the competing economic interests of not holding too many goods. resulting in a need to lock up money and pay for storage, spoilage, theft, and obsolescence. To avoid the expense of not satisfying such a necessity, the urge to make commodities or goods accessible when and where necessary (quality and quantity-wise) becomes vital. Adeyemi and Salami [2]. Inventory has a long history of serving as a shield against uncertainty. However, in recent years, the drawbacks of keeping inventory have come into greater focus, particularly in relation to the potential harm this may do to the responsiveness of the supply chain. Additionally, growing globalization has a tendency to result in longer supply lead times, which, according to traditional inventory control theory, requires more inventory to maintain the same level of service [34]. The school network problem entails determining the optimal allocation of schools across different zones to minimize the overall cost. The cost comprises two components: zone-dependent fixed costs associated with establishing schools in each zone and inventory costs related to maintaining educational resources at each school. The objective is to find the allocation that minimizes the total cost while ensuring adequate educational resources are available to serve the students' needs.

2.6 Development of Multi-Start Simulated Annealing Approach for A School Network Problem with Zone-Dependent Fixed Cost And Inventory Cost

The multi-start simulated annealing approach provides a powerful framework for optimizing the allocation of schools in a network, considering zone-dependent fixed costs and inventory costs [1]. By exploring multiple initial allocations and utilizing simulated annealing for neighbourhood exploration, the approach enables the discovery of allocations that minimize the overall cost while ensuring efficient resource allocation. This approach can aid educational authorities in making informed decisions regarding school network management, facilitating cost optimization and improved educational outcomes. By applying the multi-start simulated annealing approach to the school network problem with zone dependent fixed cost and inventory cost, educational authorities can make informed decisions regarding the placement of schools in different zones. The approach enables the identification of allocations that minimize overall costs while ensuring efficient resource allocation and adequate educational resources in each zone. This optimization framework can contribute to improved resource management, cost optimization, and enhanced educational outcomes within the school network.

2.7 A Review of Some Studies on Multi-Start Simulated Annealing Approach

Table 1
A Review of some studies on multi-start simulated annealing approach

Researcher	Date	Model	Methods/Procedure
Vincent and Lin [32]	-206 best solutions out of the 360 benchmark instances -The proposed MSA algorithm was coded in C programming language and experiments were conducted on a PC. -2013-2014	-multi start simulated annealing (MSA)	-The objective function value for each parameter combination is record compute the RER (relative error rate). -Comprehensive computational experiments -traditional single-start simulated annealing -Pseudo-code of the proposed MSA algorithm
Lin and Vincent [24]	-team orienteering problem with time windows and mandatory visits (TOPTW-MV) -computational study based on 168 TOPTWMV benchmark - 2017	multi-start simulated annealing (MSA)	-MSA procedure - MILP model of TOPTW-MV -A mathematical programming model of TOPTW-MV is formulated
Venkateswaran *et al.*, [33]	Multipurpose system - Multi-Objective Combinatorial Optimization Population - Multi-Start Simulated	parallel simulated annealing	-Multi-Objective Combinatorial Optimization Population. -Hyper-horistics

	Annealing Algorithm First - 2022		
Mockus, and Pupeikienė, [27]	High-school timetabling - Timetabling algorithms using the web-based software. - 2010-2012	Multi-start and Simulated Annealing	web-based implementation - efficiency of algorithms depends on subjective parameters -multi-start algorithm -Bayes approach
Maschio, and Schiozer [25]	A new method for history matching - Finding good matched models while preserving the diversity of solutions	Simulated annealing (SA)	-Iterative Discrete Latin Hypercube (IDLHC) with multi-start Simulated Annealing methods

3. Conclusion

The literature review highlights the general idea of developing a multi-start simulated annealing approach for the school network problem with zone-dependent fixed costs and inventory costs. The existing body of research demonstrates the efficacy of simulated annealing in solving combinatorial optimization problems, while multi-start approaches enhance its performance by exploring diverse regions of the solution space. Incorporating zone-dependent fixed costs and inventory costs within the objective function enables a comprehensive optimization solution for school network allocation. By addressing the research gap identified in the literature, this study aims to contribute to the field of school network optimization by proposing a novel algorithm that combines multi-start simulated annealing with zone-dependent cost considerations. The subsequent sections of this paper will delve into the methodology and implementation of the proposed approach, further advancing our understanding of efficient school resource allocation in the context of real-world constraints and cost factors.

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