Conference Article

A Framework for In-Car Loading Optimization Problem

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Abstract

Speed is a crucial evaluation criterion in the cargo transportation industry. The processes carried out during transfers before cargo reaches the destination unit are vital for timely delivery. Time spent at cargo distribution centers should be minimized, the maximum number of packages should be transported in a single action between transfers, and cargo vehicles should be used as accurately and efficiently as possible. Minimizing unused space inside the vehicles and ensuring that vehicles at cargo transfer centers are arranged correctly and efficiently for faster departures and increased cargo capacity are of great importance. In pursuit of this goal, the present research concentrates on optimizing the loading of vehicle interiors. This investigation proposes a method that determines the optimal dimensions of packages to be loaded within the vehicle, with the intention of maximizing the number of cargo packages while minimizing the interior volume used. A preliminary implementation of the suggested approach has been created. This developed prototype application can assist cargo transportation companies in planning their cargo loading and optimizing the utilization of vehicle interiors. The efficacy of the prototype application was evaluated using a representative vehicle loading dataset, and the results demonstrate its success.

1.   Introduction

The processes carried out between transfer points in the cargo transportation sector are crucial for timely delivery of the package to the end-user and to minimize the cost as much as possible. Vehicles should be used as efficiently as possible, unused spaces inside the vehicles should be minimized, and vehicles at transfer centers should be arranged in a correct and efficient way for faster departures. The cost of cargo transfer should be reduced by transporting the maximum number of packages in a single action.

In previous studies, route optimization problems have been mainly considered in the cargo transportation industry. However, in this project, vehicle interior planning and loading are evaluated as an optimization problem. The aim is to minimize the cost of cargo transfers by transporting the maximum number of packages in a single action. Integrating route and vehicle interior loading optimization products can create a new product that improves the service quality for the cargo transportation industry.

Within the scope of this study, research is being conducted on how optimization can be achieved and how the workflow progresses to enable the optimal loading of vehicles used in the cargo transportation industry. In this context, the objective function, constraints, and variables to be used in the objective function are defined as the subject of optimization, which are the subject of optimization.

In this study, a business process is defined to solve the problem summarized above. A prototype application is developed to demonstrate the defined business process and its success is evaluated using the available dataset. Additionally, a user-friendly interface is designed, where decision variables related to cargo packages (such as size and weight information) can be entered, variable limits can be set, the algorithm to be used for solving the problem can be selected, constraints related to cargo packages can be entered, initial conditions related to the vehicle status can be entered, and a configurable optimization software can be developed to create an innovative product for the cargo transportation sector.

The output of this study is a solution that will improve operational quality, reduce costs, speed up and simplify distribution, and positively impact customer satisfaction for cargo

and logistics companies. The solution presented by this research will pave the way for the initiation of different research projects.

The organizational structure of this paper is as follows: In Section 2, we provide a literature review. In Section 3, we explain the solution proposal we have introduced for the vehicle interior loading optimization problem within the scope of this research. In Section 4, we provide details of the prototype application and demonstrate the application of the proposed solution proposal on a sample dataset. In the final section, we summarize the research and discuss future work.

2. Literature Survey

When examining the existing studies in the literature, it can be observed that researchers have developed algorithms for solving container loading optimization and container assignment problems. In this study, we benefited from the discussion on how to approach the research problem at hand from the following study [1].

Containerization is considered one of the most significant modern innovations. Singh [2] discusses how Malcom McLean's innovative vision led to the creation of shipping containers, which revolutionized international trade and paved the way for inter-modal transportation. Levinson [3] explains that the adoption of shipping containers drastically changed the operational practices of the shipping industry, notably decreasing loading times at ports and minimizing shipping expenses.

Crainic et al. [4], in their study titled" Investigating Container Loading Problems and Its Application in the Logistics Sector," attempted to place packages of various volumes in containers in an optimal way. The aim of this study was to maximize the number of packed products in the loading area optimization. They proposed a three-dimensional bin-packing problem solution using a hybrid genetic algorithm. The results of the study were compared with other solutions in the literature, and their performance was examined.

The genetic algorithm's stochastic nature, as highlighted by Goldberg [5], increases the likelihood of discovering global solutions, making it an efficient and robust approach to finding optimal solutions. Sarih et al.[6] emphasize the usefulness of genetic algorithms in the context of vehicle loading optimization problems, as they can produce valuable solutions that ensure adequate load distribution and optimal utilization of vehicle capacity. Furthermore, the adaptable nature of genetic algorithms allows them to

effectively handle diverse vehicle types, dimensions, and capacity restrictions, demonstrating their great potential in solving vehicle loading optimization problems.

In a study conducted by Kyungdaw Kang et al. [6], they aimed to optimize the loading arrangement for vehicles and containers using a genetic algorithm-based approach. In this study, the genetic algorithm aimed to optimize the arrangement of loads, weight distribution, and volume utilization to reduce logistics costs and transportation times. This method presents significant potential for increasing operational efficiency and sustainability in the logistics sector [6].

Lim et al. [7]. have developed a new heuristic algorithm, called the polyhedral configuration technique, for three-dimensional bin packing problems. The high performance of the algorithm has been demonstrated by examining experimental results. Liu et al.[8]. have initially used mixed-integer programming for the solution of three-dimensional container loading problems. In addition, Neumann et al.[9] have developed a hybrid approach using a novel packing heuristic strategy and differential evolution algorithm.

Bortfeldt and Gehring [10] propose a hybrid genetic algorithm for the container loading problem with a single container and boxes of different sizes. The resulting storage plans consist of several vertical layers, each containing multiple boxes. Specific genetic operators based on intuition were used to generate offspring. Theproblem was subject to certain constraints, and the proposed method demonstrated good performance in comparative tests [11].

Another study by Boccia et al. [12] aimed to optimize both the routes and loading arrangements for vehicles using a genetic algorithm-based approach. In this study, the genetic algorithm aimed to optimize the arrangement of loads and weight distribution while also optimizing vehicle routes and timings to reduce logistics costs and delivery times. This method provides an effective approach to solving complex transportation problems in the logistics sector.

Wei et al. [13] propose a new multi-objective method based on cluster search to solve the multi-objective three-dimensional container loading problem. This method provides better results compared to the previously proposed Pareto simulated annealing method.

In their study, Bischoff et al. [14] addressed the container loading problem with numerous constraints that arise in many manufacturing fields. They proposed an intuitive algorithm to standardize the packed items within the container. The algorithm

selects expired orders before handling the non-expired ones. Firstly, the algorithm selects an ordered cluster using the simulated annealing algorithm and then places the selected orders into the container using the tree graph search algorithm. The experiments were tested using the BR data tests.

Neumann et al. [9] introduced two novel algorithms based on the ant colony optimization technique to address container loading challenges. With parameters determined through factorial design, these algorithms were assessed using standard problems found in the existing literature and compared to results from other studies. Of the two proposed algorithms, KKS-2 demonstrated superior performance over KKS-1. The effectiveness of these algorithms was found to be comparable to previous research in solving Loh and Nee (LN) test problems, but slightly underperformed when tackling Bischoff and Ratcliff (BR) test problems.

In their work, Can and Sahingoz [15] proposed a genetic algorithm for solving the container loading problem. The algorithm operates in two stages: first, it generates a set of" separating box towers," and second, it arranges these towers to optimize a given criterion. The container loading problem may include various constraints, which the algorithm considers during its operation. To demonstrate its effectiveness, the algorithm was compared against several other methods for the container loading problem in a numerical test. The results of the test show that the presented genetic algorithm outperforms the other procedures.

In their study, Rajaei et al. [16] proposed a parallel genetic algorithm to tackle the container loading problem that involves a single container. Their approach adopts a migration model where multiple distinct subpopulations undergo independent evolutionary processes. Meanwhile, the fittest individuals are exchanged between subpopulations. The effectiveness of the parallel genetic algorithm was established through a comprehensive comparative test, which incorporated recognized benchmark problems and loading techniques introduced by other researchers.

Bortfeldt and Gehring [10] proposed a hybrid genetic algorithm to solve the container loading problem where a single container and boxes of various sizes are involved. The approach creates storage plans comprising multiple vertical layers, each accommodating multiple boxes. The method employs genetic operators based on intuition to generate offspring, while adhering to specific constraints of the problem. Comparative testing verified the effectiveness of the algorithm, exhibiting favorable results.

Tasgetiren and Ozbakır [17] provided information about two-dimensional stock cutting problems with rectangular elements and discussed solution methods. He developed intuitive and meta-heuristic software as a solution method. With this software, examples consisting of rectangular and square pieces with different numbers of pieces were solved, and it was observed that the developed software produced good solutions.

Manzini and Bindi[18] used a genetic algorithm to solve an application evaluated in the container loading problem. Suitable solution paths that would maximize the loaded goods were investigated, taking loading constraints into account. In the study, using a genetic algorithm, new generations were produced according to the "survival of the fittest" principle, and the best solution was sought by considering the fitness values of the produced generations.

In their study, Peng et al. [19] introduced a simulated annealing algorithm to solve the container loading problem involving a single container and boxes of various sizes. To obtain a feasible solution, they designed a heuristic algorithm that generated a solution from a particular structure. The hybrid algorithm combined basic heuristics with a search of the coding space to approximate an optimal solution. When tested on 700 weakly heterogeneous comparisons, the proposed algorithm outperformed all previous methods.

Bortfeldt [20] aimed to find the optimal positions for placing all boxes inside a container when the size of the container and the number and dimensions of each type of box is known.

The focus of Christofides et al. [21] presentation was on using mathematical models and solution techniques to address container loading problems. Two multi-objective mixed-integer mathematical models were developed for container loading and container selection, along with a mathematical model-based heuristic method. "Weighted sum method" and "Conic scalarization method" were used to solve the developed two-objective mathematical model and the mathematical model-based heuristic method. In addition, a new sorting heuristic and a placement heuristic was proposed for the container loading problem, and a new simulated annealing meta-heuristic was developed. It was observed that better solutions were generated with the developed new meta-heuristic.

In their studies, Jalali Varnamkhasti [22] and Cagan et al. [23] address vehicle loading optimization problems using distinct approaches. Jalali Varnamkhasti [22] provides a comprehensive review of algorithms for multi-dimensional knapsack problems, focusing

on a broader range of algorithms without offering a specific recommendation. Cagan et al. [23] develop a specialized method based on the knapsack algorithm, introducing a three-dimensional bin packing algorithm for vehicle loading problems.

In the literature, various studies [27, 29, 30, 36, 37, 39] focus on modular, service-based software development in different research fields. In this study, we focus on hybrid, modular software design and development for in-car loading optimization in cargo sector.

There are studies that focus on understanding the user behaviors by analyzing user actions in different domains [28, 31, 34, 35, 38]. Also, some studies investigate the software quality [32, 33]. In this study, we leave out the analysis of user-system interaction data and investigation of software quality as future work. We only focus on designing and developing in-car loading optimization system.

This article is an extended version of our previous work [24] on in-vehicle loading optimization systems. Building upon the previous work's findings and methods, this study incorporates new approaches for optimizing vehicle loading beyond what was presented in the earlier work.

3.   Proposed Methodology

This research focuses on the optimization problem of vehicles that travel from multiple points to multiple destinations, such as the cargo sector, rather than just point-to-point transportation. Specifically, the research investigates how to optimize the loading and planning of cargo within vehicles to achieve the most efficient results.

The optimization problem is formulated as follows: a) objective function, b) optimization algorithm, c) decision variables, d) constraints, e) initial conditions, and f) variable boundaries are defined.

The proposed optimization solution function generates solutions for which cargo packages should be loaded onto the vehicle and in what order. The decision variables used in the optimization process may include shape data (rectangular, square, oval, etc.) as well as the volume of the cargo. Constraints, such as the time required for the cargo to arrive, may also be defined for transfers. The proposed solution will also sort cargo packages to be loaded onto the vehicle based on their volume. The interior of the vehicle will be divided into three segments: bottom, middle, and top, and the results will indicate where each package should be placed in the vehicle.

To solve the optimization problem described above, we propose four different approaches using the osqp solver, the knapsack algorithm, linear optimization, and the genetic algorithm. We have developed a framework, as seen in Figure 1 that generates optimization outcomes based on the algorithm selected by the user as shown.

Through this study, not only were users provided with an opportunity to compare the outcomes of various optimization algorithms, but they were also able to do so by utilizing more than one method, building upon the findings of the previous research.
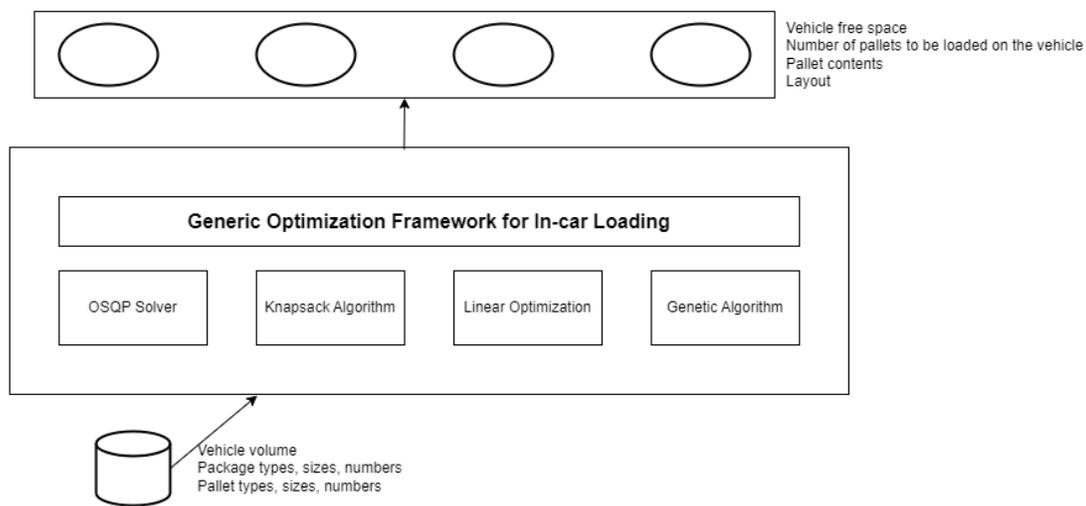

Fig. 1. An Overview of the Proposed In-Car Loading Optimization Framework

3.1   Optimization with OSQP Solver

Objective function and initial conditions:

Initial Condition 1: The volume of the space in the vehicle is to be minimized; therefore, the interior of the vehicle is assumed to be empty before the loading process begins.

Initial Condition 2: Known cargo boxes of predetermined size and volume are loaded onto the vehicle, and no other cargo is added to the vehicle besides these boxes.

Initial Condition 3: The size of the cargo boxes, the number of boxes to be loaded onto the vehicle, and the volume of the vehicle's interior is known before the loading process begins.

Objective Function: Minimization of the optimization function. Decision Variables and Variables for Total Cargo Volume: x1, x2, ..., xN

Optimization Function: Empty Space = Vehicle Volume - (Total Cargo Volume) Total Cargo Volume = w1x1 + ... + wNxN Optimization Function: Empty Space = Vehicle Volume - (w1x1 + ... + w5x5) Variable Boundaries: Vehicle Volume = 5000cm3

3.2 Optimization with Genetic Algorithm

Genetic algorithms are particularly effective for large-scale optimization problems, and the same steps can be followed to solve similar optimization problems with genetic algorithms [25].

Creating an initial population: Each chromosome will be an array that represents the number of packets to be selected from each volume group. The initial population is started with randomly created chromosomes.

Defining a fitness function: The fitness function measures the relationship between the total number of loaded packages and the loaded total volume for each chromosome. It will be used to select chromosomes that have the best fitness values.

Using selection operator: The selection operator selects chromosomes with the best fitness values based on the fitness function.

Using crossover operator: The crossover operator creates new chromosomes by randomly combining genes of the selected chromosomes. This is used to create new generations of chromosomes.

Using mutation operator: The mutation operator changes the value of a gene of a randomly selected chromosome. This is used to add diversity to the population.

Creating new generations: New generations are created using the selection, crossover, and mutation operators.

Defining termination criteria: A specific number of iterations or a fitness value indicates that we have approached the optimal solution and it is set as a termination criterion.

Selecting the best chromosome: The chromosome with the best fitness value in the final population will determine the maximum number of loaded packages and which volume groups have been loaded.

3.3 Optimization with Linear Programming

Defining the objective function: The objective function defines that the number of loaded packages onto the vehicle is to be maximized. This objective function will be used as a target function in the mathematical model.

Maksimize:

$$\sum_{i=1}^{n} x_i$$

n: the number of different volume groups
x_i: number of packages loaded from the i. volume group.

Defining constraints: A mathematical model is created, including the capacity of the vehicle, the volume of each volume group, and the number of packages in each volume group. These constraints ensure that the solution produces valid solutions.

$$\sum_{i=1}^{n} v_i x_i \leq C$$

$$x_i \geq 0$$

v_i: the volume of packages in the i. volume group.
C: the capacity of the vehicle.
x_i: a constraint that ensures the number of packages loaded from each volume group is greater than or equal to zero.

Solving the model: The mathematical model is solved using a linear programming solver. The solver produces the best solution that maximizes the objective function and satisfies the constraints.

Analyzing the results: The solver produces results that determine the maximum number of loaded packages onto the vehicle and which volume groups have been loaded.

4. Prototype Application of Proposed Methodology

We implemented the optimization problem solution using various algorithms, including the knapsack, genetic, and linear optimization algorithms, as well as the OSQP library. The results from each approach are presented below, and a comparison between them will be discussed in another section.

The sample dataset details are as follows:
The capacity of the vehicle is 10,0003.
There are four different categories of cargo package sizes, with volumes of 80, 50, 30, 20 cm3.

The number of cargo packages in each volume category is known, and they are distributed as follows: 121 packages of 80 cm3, 130 packages of 50 cm3, 150 packages of 30 cm3, and 120 packages of 20 cm3.

The aim of the optimization problem is to determine the best combination of cargo packages to load onto the vehicle, maximizing the utilized volume without exceeding the vehicle's capacity. Each algorithm has its own strengths and weaknesses, so it is essential to analyze the results and compare their performance in solving this particular optimization problem.

The OSQP solver [26] is a powerful tool for solving quadratic programming problems, including the knapsack problem. It is highly efficient and can handle largescale problems with many constraints and variables. However, it may not be the easiest algorithm to implement and may require some expertise to use effectively. The knapsack algorithm is relatively simple to implement and can produce good solutions quickly. However, it may not be able to handle more complex problems with many variables or constraints. It is highly flexible and can handle a wide range of problems. However, it is slow because it may require a larger number of iterations to converge to a good solution and may be computationally expensive for larger problems. It is highly efficient and can handle large-scale problems with many constraints and variables. However, it may not be the easiest algorithm to implement and may require some expertise to use effectively.

Overall, for relatively simple problems with a small number of variables and constraints, the knapsack algorithm may be the most efficient and effective solution. For larger, more complex problems, the OSQP solver, genetic algorithm, or linear programming may be more appropriate.

Table 1. Volume and Count Table

Volume	Count

80	121
50	130
30	150
20	120

Table 2. Result of OSQP Solver

Volume	Count
80	55
50	55
30	54
20	54

Packet Count	Filled Space	Empty Space
218	9850	150

Table 3. Result of Knapsack Algorithm

Volume	Count
80	0
50	62
30	150
20	120

Packet Count	Filled Space	Empty Space
332	10000	0

Table 4. Result of Linear Algorithm

Volume	Count
80	0
50	62
30	150
20	120

Packet Count	Filled Space	Empty Space
332	10000	0

Table 5. Result of Genetic Algorithm

Volume	Count
80	58
50	72

30	14
20	67

Packet Count	Filled Space	Empty Space
211	10000	0

5.   Conclusion and Future Work

In this study, a methodology was proposed for the solution of the vehicle interior optimization problem to enable more efficient cargo loading in the cargo sector and a prototype application was developed. Multiple methods were used to solve the vehicle interior optimization problem, and the result of the method that found the most optimum values was returned to the user. These different methods and algorithms used in the optimization process were also evaluated comparatively. The proposed methodology was tested on sample data sets, and successful results were obtained. These results can help companies in the cargo sector manage their operations more effectively and can contribute to the development of more advanced vehicle interior optimization solutions to increase operational efficiency in the cargo sector. Future studies based on this work could include the following: developing and testing customized optimization methods for different vehicle types, developing more effective optimization solutions using artificial intelligence and machine learning algorithms, and researching the broader applicability of the proposed methodology by conducting tests on larger and more complex datasets.

6.   Acknowledgements

References

[1] A Step by Step Guide for Choosing Project Topics and Writing Research Papers in ICT Related Disciplines, Communications in Computer and Information Science, Volume 1350 Page 727-744 the Publication year 2021 (pp. 727-744). Springer International Publishing.

[2] Singh, L. (2019) "The Metal Box That Transformed Global Trade: The Innovative Vision of Malcom McLean behind the Container Revolution," Legacy: Vol. 19 : Iss. 1 , Article 4. Available at: https://opensiuc.lib.siu.edu/legacy/vol19/iss1/4

[3] Levinson, M. (2016). The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger. Princeton University Press.

[4] Crainic, T. G., Perboli, G., Tadei, R. (2008). Extreme Point-Based Heuristics for Three-Dimensional Bin Packing. INFORMS Journal on Computing, 20(3), 368-384.

[5] Goldberg, D. E. (1989). Genetic Algorithms in Search, Optimization, and Machine Learning. Addison-Wesley.

[6] Kyungdaw K., Ilkyeong M., Hongfeng W. Genetic A hybrid genetic algorithm with a new packing strategy for the three-dimensional bin packing problem. Applied Mathematics and Computation Volume 219, Issue 3, 2012, Pages 1287-1299.

[7] Lim, A., Rodrigues, B, Wang, Y.: A multi-faced buildup algorithm for threedimensional packing problems. Omega , 31,471–481 (2003)

[8] Liu, S., Shang, X., Cheng, C., Zhao, H., Shen, D., Wang, F.: Heuristic algorithm for the container loading problem with multiple constraints. Computers and Industrial Engineering. 108, 149-164 (2017).

[9] Neumann, F., Sudholt, D., Witt, C. (2009). Computational complexity of ant colony optimization and its hybridization with local search. In F. Rothlauf, J. Heuristics, T. D. Runarsson (Eds.), Design of Intelligent Systems Based on Fuzzy Logic, Neural Networks and Nature-Inspired Optimization (pp. 237-256). Springer, Berlin, Heidelberg. Studies in Computational Intelligence, vol 248.

[10] Gehring, H., Bortfeldt, A., 2002. A Parallel Genetic Algorithm for Solving the Container Loading Problem. International Transactions in Operational Research 9, 497-511.

[11] C. Gomez Santillan, L. Cruz Reyes, V. Landero Najera, A. Alvim, P. Melin, M. Quiroz, and J. Ruiz Vanoye. Heuristic Algorithms: An application to the Truck Loading Problem. In L. G. Martinez, S. Sanchez, J. Rodriguez (Eds.), Logistics Management and Optimization through Hybrid Artificial Intelligence Systems (pp. 153-170). IGI Global.

[12] Boccia, M., Crainic, T. G., Sforza, A., Sterle, C. (2010). A metaheuristic for a two-echelon location-routing problem. In Optimization Letters (Vol. 4, No. 1, pp. 1-12). Springer.

[13] Wei, J., Zhang, J. (2021). A pareto-based variable neighborhood search for the 3D container loading problem. European Journal of Operational Research, 295(3), 1095-1108.

[14] Bischoff, E. E., Ratcliff, M. S. W., 1995. Issues in the development of approaches to container loading. Omega 23(4), 377-390.

[15] Can, O. and Sahingoz, O.K.," Solving container loading problem with simulated annealing algorithm," 2014 IEEE 15th International Symposium on Computational Intelligence and Informatics (CINTI), Budapest, 2014, pp. 391-396, doi: 10.1109/CINTI.2014.7027749.

[16] Rajaei, M., Moslehi, G., Reisi-Nafchi, M. (2022). The split heterogeneous vehicle routing problem with three-dimensional loading constraints on a large scale. European Journal of Operational Research, 299(2), 706-721.

[17] Tasgetiren, M. F., Ozbakır, L. (2016). "Iki boyutlu dikdortgen sekilli stok kesme problemi icin yeni bir hibrit algoritma" Selcuk University Journal of Engineering, ˙ Architecture and Technology, 30(1), 1-10.

[18] Manzini, R., Bindi, F. (2009). Strategic design and operational management optimization of a multi-stage physical distribution system. Transportation Research Part E: Logistics and Transportation Review, 45(6), 915-936.

[19] Peng, Yu and Zhang, Defu and Chin, Francis Y.L., 2009. A Hybrid Simulated Annealing Algorithm for Container Loading Problem. Proceedings of the First ACM/SIGEVO Summit on Genetic and Evolutionary Computation,919–928.

[20] Bortfeldt, A. (2012). A hybrid algorithm for the capacitated vehicle routing problem with three-dimensional loading constraints. Computers and Operations Research, 39(9), 2248-2257.

[21] Christofides, N., Whitlock, C., 1977. An Algorithm for Two-Dimensional Cutting Problems. Operations Research 25(1), 30-44.

[22] Varnamkhasti, M.J., Overview of the Algorithms for Solving the Multidimensional Knapsack Problems. Advanced Studies in Biology 4(1), 37–47 (2012)

[23] Cagan, J., Shimada, K., Yin, S., (2002). A survey of computational approaches to three-dimensional layout problems. Computer-Aided Design Volume 34, Issue 8, July 2002, Pages 597-611.

[24] Ozen, Y., Memis, Y., Yalcin, D., Aktas, M. S. "Kargoculuk Sektorune Yonelik Arac Ici Yukleme Optimizasyon Sistemi". Orclever Proceedings of Research and Development,1(1), 130- 141, 2022.

[25] Bajpai, P., Kumar, M., "Genetic Algorithm – an Approach to Solve Global Optimization Problems", Indian Journal of Computer Science and Engineering1(3) ,199–206

[26] OSQP: OSQP Document. University Of Oxford. https://osqp.org/docs (2022). Accessed 14 Apr 2023

[27] Tufek, A. et al., "Provenance Collection Platform for the Weather Research and Forecasting Model," 2018 14th International Conference on Semantics, Knowledge and Grids (SKG), Guangzhou, China, 2018, pp. 17-24, doi: 10.1109/SKG.2018.00009.

[28] Baloglu, A., Aktas, M. S., BlogMiner: Web blog mining application for classification of movie reviews, 2010 Fifth International Conference on Internet and Web Applications and Services, 2010.

[29] Aktas, M.S., Fox, G.C., Pierce, M., Managing dynamic metadata as context, The 2005 Istanbul International Computational Science and Engineering Conference (ICCSE2005), Istanbul, Turkey, 2005.

[30]   Aktas, M.S., et al. "Information services for dynamically assembled semantic grids", The First International Conference on Semantics Knowledge and Grid (SKG 2005) Beijing China, 2005.

[31]   Uygun, Y. et al., On the Large-scale Graph Data Processing for User Interface Testing in Big Data Science Projects, 2020 IEEE International Conference on Big Data (Big Data), Atlanta, GA, USA, 2020, pp. 2049-2056, doi: 10.1109/BigData50022.2020.9378153.

[32]   Sahinoglu, M. et al., Mobile Application Verification: A Systematic Mapping Study. In: , et al. Computational Science and Its Applications – ICCSA 2015. ICCSA 2015. Lecture Notes in Computer Science(), vol 9159. Springer, Cham. https://doi.org/10.1007/978-3-319-21413-9 11

[33]   Kapdan, M. et al., On the Structural Code Clone Detection Problem: A Survey and Software Metric Based Approach. In: , et al. Computational Science and Its Applications – ICCSA 2014. ICCSA 2014. Lecture Notes in Computer Science, vol 8583. Springer, Cham. https://doi.org/10.1007/978-3-319-09156-3 35

[34]   Olmezogullari, E.; Aktas, M. S., Pattern2Vec: Representation of clickstream data sequences for learning user navigational behavior. Concurrency and Computation: Practice and Experience 34 (9), 2022; 34(9):e6546. https://doi.org/10.1002/cpe.6546.

[35]   Olmezogullari E. et al., Representation of Click-Stream Data Sequences for Learning User Navigational Behavior by Using Embeddings, 2020 IEEE International Conference on Big Data (Big Data), Atlanta, GA, USA, 2020, pp. 3173-3179, doi: 10.1109/BigData50022.2020.9378437.

[36]   Aktas, M.S. et al., "Information services for grid/web service oriented architecture (soa) based geospatial applications", The First International Conference on Semantics Knowledge and Grid (SKG 2005) Beijing China, 2005.

[37]   Dundar, B. et al., A Big Data Processing Framework for Self-Healing Internet of Things Applications," 2016 12th International Conference on Semantics, Knowledge and Grids (SKG), Beijing, China, 2016, pp. 62-68, doi: 10.1109/SKG.2016.017.

[38]   Baeth, M.J. et al., Detecting Misinformation in Social Networks Using Provenance Data, 2017 13th International Conference on Semantics, Knowledge and Grids (SKG), Beijing, China, 2017, pp. 85-89, doi: 10.1109/SKG.2017.00022.

[39]   Aktas, M. et al., Implementing geographical information system grid services to support computational geophysics in a service-oriented environment. NASA Earth-Sun System Technology Conference, University of Maryland, Adelphi, Maryland, 2005.