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Implementation of the Backtracking Algorithm for Optimizing Work Shift Scheduling

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ABSTRACT
This research aims to implement the backtracking algorithm to optimize shift scheduling at PLTU SSP. The study is motivated by the complexity of manual shift scheduling, which is prone to human error and struggles to accommodate various constraints such as employee availability, preferences, and operational needs. The backtracking algorithm was selected due to its ability to search systematically for optimal solutions that satisfy all constraints based on Depth First Search (DFS). The research methodology includes requirements analysis, system design, algorithm implementation, testing, and results evaluation. The application of the backtracking algorithm produced schedules that accurately meet constraints and consider employee preferences. The results indicate that the backtracking algorithm can generate effective and efficient schedules. The implementation of the backtracking algorithm is expected to improve the quality of shift work management, positively impacting productivity, employee welfare, and the smooth operation of PLTU SSP.

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1. INTRODUCTION

Companies each have their own way of managing their human resources, and good human resource management can improve the quality of the company. Companies working in the field of supplying goods require continuous production of goods so that the company's productivity continues as it should [1]. Creating shift schedules can be quite time-consuming. To get the best results and avoid errors in arranging employee shift schedules, it is very important to be very thorough. For example, if the schedule maker puts in consecutive shift schedules, the person working the night shift then works the morning shift the next day.

Work shift scheduling is an important component of human resource management in various companies and organizations [2]. An organization has two general definitions. The first refers to an institution or functional group such as a company, hospital, and so on. The second concerns the organizing process as a way in which organizational activities are allocated and assigned among its members so that organizational goals can be achieved efficiently [3]. Effective and optimal scheduling has a direct impact on productivity, job satisfaction, and employee welfare. In addition, this scheduling ensures that operations run smoothly. However, compiling work shift schedules often faces various complex problems, such as schedule conflicts, unbalanced distribution of shifts, lack of adequate rest time, and errors caused by human error. These mistakes have a negative impact on work quality, fatigue, internal conflicts, and employee turnover.

The main problem in creating work shift schedules is how to arrange schedules that meet various criteria and constraints, such as employee availability, operational needs, working hour regulations, and fair distribution of shifts. Additionally, the schedule must be able to accommodate unexpected situations, such as sudden demands for labor with predetermined qualifications, and avoid irregularities that could lead to vacancies in certain shifts [4]. In practice,

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manual scheduling often takes a long time and lacks accuracy, so a more systematic approach is needed to produce an optimal schedule.

There are numerous issues related to work shift scheduling, such as shift conflicts that cause confusion and miscommunication among employees, potentially reducing productivity and job satisfaction [5]. Overworking employees without providing sufficient time off, especially during night shifts, can lead to fatigue and decreased work quality. Difficulties in managing unorganized scheduling data and reports can result in payroll miscalculations and delayed wage payments. Managing a large workforce with a high risk of human error is also challenging if manual methods are still used. Additionally, ineffective communication channels for conveying schedule changes can lead to miscommunication and employee absenteeism.

To address these problems, various studies have been conducted using algorithmic and computational approaches that can automate and optimize the scheduling process. One popular and effective method is the backtracking algorithm, which is a systematic search technique based on Depth First Search (DFS) to find solutions that satisfy all specified constraints and criteria [6].

An algorithm is a set of clear, sequential steps used to solve a problem. An algorithm is a logical and systematic arrangement for solving a problem or achieving a specific goal [7]. In the field of informatics, algorithms play an important role in the development and construction of software. [8] In this research, the researcher chose the backtracking algorithm.

The Backtracking Algorithm is a problem-solving method that falls under search-based strategies within the State's's space. The use of the backtracking method aims to determine how effective it is in addressing random scheduling problems with complex interdependencies. The Backtracking Algorithm works recursively and systematically to search for solutions by exploring all possible options. This algorithm is based on the Depth-First Search (DFS) Algorithm, so the solution search is conducted by traversing a rooted tree structure in preorder [9]. This process is characterized by expanding the deepest node first until no successors of a node are found.

Previous research has shown that the backtracking algorithm can be used to solve lecture and exam scheduling problems in educational institutions. [10] analyzed two backtracking strategies to determine efficient lecture scheduling at the Bandung Institute of Technology. This study demonstrated that the DFS-based backtracking algorithm is effective in generating scheduling solutions that satisfy various constraints, such as lecture times, session durations, and classroom allocations. The algorithm is capable of avoiding schedule conflicts and significantly improving scheduling quality.

Another study [11] employed the backtracking algorithm to compile lecture schedules at Multimedia Nusantara University automatically. This algorithm solves the Constraint Satisfaction Problem (CSP) by searching for solutions that meet all scheduling constraints, including Lecturer, room, and time availability. The developed system successfully produced schedules that align effectively with the University's business processes.

Furthermore, [12] developed a modification of the backtracking algorithm to compile course schedules by eliminating thrashing, which refers to exploring nodes that do not lead to a solution. This study used a CSP and DFS approach to generate schedules that meet constraints on time, space, and lecture duration. The modification improved the efficiency of the solution search and reduced computation time in complex scheduling scenarios.

In addition, the combination of the backtracking algorithm with the graph coloring method has also been applied to optimize course scheduling at Universitas Lancang Kuning. This approach is capable of solving complex combinatorial scheduling problems by producing conflict-free and structurally optimal schedules. In the healthcare sector, similar algorithms are also used to arrange nurse work schedules in hospitals, aiming to avoid overlapping shifts and to meet the criteria for medical staff requirements in each shift.

The implementation of the backtracking algorithm in shift scheduling offers a systematic and computerized solution to reduce human error, accelerate the scheduling process, and produce fair schedules that align with operational needs. With its ability to perform recursive solution searches and backtrack to previous steps when encountering constraints (dead ends), this algorithm is highly suitable for handling scheduling problems with many variables and complex constraints.

Based on the explanation above, this research aims to implement the backtracking algorithm in the preparation of work shift schedules to obtain an optimal, effective, and efficient schedule. This study is expected to contribute to improving the quality of shift scheduling management, which will have a positive impact on productivity, employee welfare, and the smooth operation of the company.

2. RESEARCH METHOD

This research method integrates analytical and computational approaches with the backtracking algorithm as the core solution for the work shift scheduling problem. The study aims to implement the backtracking algorithm in creating work shift schedules to obtain an optimal schedule that meets various operational constraints. The research method used in this study includes several stages: needs analysis, system design, algorithm implementation, testing, and result evaluation. The researcher further illustrates these stages in the form of a diagram [13].

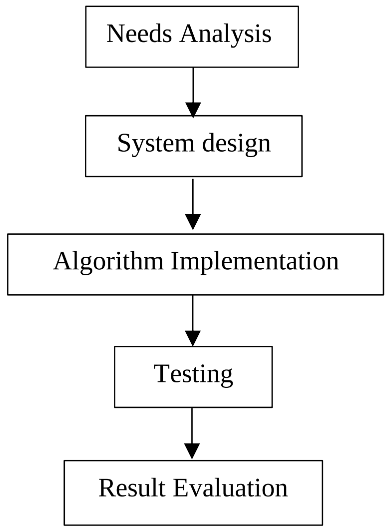

Figure 1. Implementation Stages

Based on the image above, the researcher will conduct the study according to the stages described. The analysis will be carried out to identify the needs and constraints in creating work shift schedules through literature review and interviews. The scope of this identification is limited to understanding employee availability (holidays and leave), shift regulations, operational requirements, and fair distribution of shifts. The results of this analysis will be used to formulate the objective function and constraints that will be integrated into the algorithm.

The scheduling system will be designed with an architecture based on the backtracking algorithm, integrated with employee data and shift rules. The core process involves searching for schedule combinations that satisfy all constraints. The testing phase will be conducted at PLTU SSP. The implementation of the backtracking algorithm will be carried out through the following steps:

Table 1. Steps for Implementing the Backtracking Algorithm

No	Steps	Explanation
1	Variable and Domain Formulation	Each shift on a specific day is considered a variable that must be assigned an available employee (domain). For example, the Monday morning shift is the first variable, with a domain consisting of employees available for the morning shift.
2	Constraint Application	Constraints include the fact that an employee can only work one shift per day, the number of employees per shift must meet the minimum requirement, employees cannot work more than a certain number of days, employee preferences, and employee holidays and leave.
3	Backtracking Algorithm	The algorithm works by attempting to assign employees to the first shift and then proceeding to the next shift. If no employee satisfies the constraints at any point, the algorithm backtracks to the previous assignment and tries an alternative. This process repeats until all shifts are filled with qualified employees.

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4	Optimization With Pruning	To improve efficiency, pruning techniques are applied so that branches of the search tree that clearly violate constraints are immediately discarded, thereby reducing computation time.
5	Candidate Selection Heuristics	The algorithm also uses heuristics to prioritize selecting employees with limited availability first, reducing the likelihood of excessive backtracking.

3. RESULTS AND DISCUSSION

Work shift scheduling is a complex problem involving many variables and constraints, such as employee availability, working hour regulations, operational needs, and individual preferences. The backtracking algorithm is one method capable of solving this problem systematically and optimally by searching for solutions that satisfy all constraints.

This study implements the backtracking algorithm to create work shift schedules in a retail company. The goal is to produce schedules that are optimal, fair, and meet operational requirements. This section discusses the implementation results, performance evaluation, case studies, and an in-depth analysis of the method's strengths and limitations.

3.1. Company Profile

PT SSP was established on June 6, 2018, to develop the IPP PLTU MT Sumbagsel-1. On December 17, a Power Purchase Agreement (PPA) was signed between PLN and SSPewali, targeting an effective date of November 17, 2019. However, due to delays in tariff approval by the Ministry of Energy and Mineral Resources, the effective date of the PPA was extended. Currently, one employee is assigned to PJBI and is working at an SSPewali affiliate company. SSPewali also provides insurance coverage for all its employees [14].

Table 2. Data

Shift Per Day	Shifts are divided into 3 (morning, afternoon, and night)
Scheduling Period	30 days
Main Constraint	Employees work seven consecutive days but are assigned according to shifts. An employee does not work two shifts in one day. There are national holidays and employee leave days, and each employee has days without a scheduled shift.

3.2. Preference and Availability Data

Each employee provides their preferred shifts and desired days off. The details are shown more clearly in the table below. For confidentiality, employee names such as Employee A, Employee B, and so on will be anonymized.

Table 3. Preference Data

Employee	Shift Preferences	Desired Days Off
Group A	First Week - Night shift Second Week - Night shift 1 day, Morning shift 1 day Third Week - Afternoon shift, etc.	Saturday, Sunday
Group B	First Week - Afternoon, Second Week - Night, Third Week - Morning, etc.	Friday
Group C	First Week - Morning, Second Week - Afternoon, Third Week - Night, etc.	Sunday
Group D	First Week 2 days - Night, Second Week - Morning, Third Week - Afternoon, etc.	Saturday

This data represents only the employees' preferences; however, the actual employee schedules follow the instructions from the supervisor. This data is entered into the system as part of the domain and constraints. For example, in a given week, some employees may have no assigned shifts.

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3.3. Results of Backtracking Algorithm Implementation

The backtracking algorithm was executed to assign employees to each shift while satisfying the constraints. The solution search process was carried out recursively with a backtracking mechanism whenever a temporary solution failed to meet the constraints. Below is a snippet of the shift schedule for the first 7 days.

Table 4. Implementation Schedule Results

Day	Morning Shift	Afternoon Shift	Night Shift
1	Group A	Group C	Group B
2	Group A	Group C	Group B
3	Group D	Group A	Group B
4	Group D	Group A	Group C
5	Group D	Group A	Group C
6	Group D	Group A	Group C
7	Group B	Group D	Group C

3.4. Performance Evaluation of the Algorithm

The average computation time obtained by the researcher is as follows. The researcher calculated the computation time for 25 employees.

Table 5. Computation Time

Number of Days	Number of Employees	Computation Time (Minutes)
7	25	1.2
14	25	2.8
30	25	7.0

The following graph shows the relationship between the number of days and the computation time.

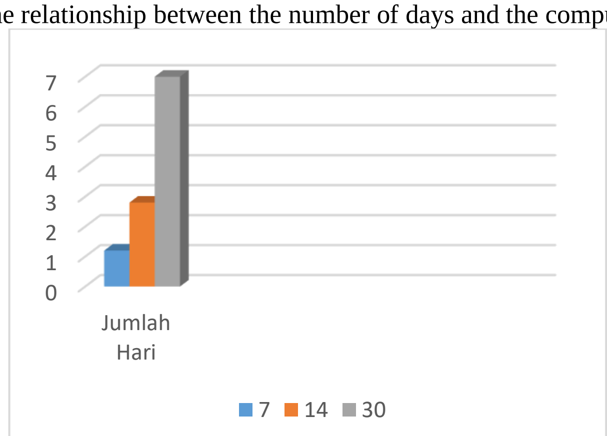

Figure 2. Relationship Graph

Based on the table and graph above, the next step is to test constraints by calculating the percentage of compliance with the established rules.

Table 6. Compliance with Constraints

Constraint	Compliance (100%)
Minimum of 3 employees per shift	100
One shift per day per employee	100
Shift preferences fulfilled	85
Maximum of 5 consecutive working days	98

Compliance with the main constraints is very high, indicating the algorithm's effectiveness in producing a valid schedule. Employee shift preferences are largely fulfilled; however, there is a trade-off between preferences and operational requirements.

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3.5. Discussion

Shift scheduling is a complex combinatorial problem in which a number of employees must be assigned to various shifts within a specific time period while considering multiple constraints and rules. Implementing the backtracking algorithm in creating shift schedules aims to systematically and efficiently find an optimal solution that satisfies all these constraints.

The shift scheduling problem can be modeled as a Constraint Satisfaction Problem (CSP), where:

a. Variables are the shifts that need to be filled during the scheduling period (e.g., morning, afternoon, and night shifts for each day).
b. Domains of each variable consist of the set of available and qualified employees who can fill the respective shifts.
c. Constraints are the rules that must be met, such as employees working only one shift per day, a minimum number of employees per shift, a maximum limit on consecutive working days, days off, and employee preferences.

This problem has a very large solution space because there are numerous combinations of assigning employees to different shifts, thus requiring an efficient search method to find a feasible solution. The backtracking algorithm is a solution search method that uses a depth-first search (DFS) approach to explore the solution space systematically. At each step, the algorithm attempts to assign an employee to a specific shift and checks whether the assignment satisfies all constraints.

If the assignment is valid, the algorithm proceeds to the next shift. If it is not valid, the algorithm backtracks to the previous step and tries an alternative assignment. This process repeats until all shifts are filled with valid assignments or no solution is found.

The advantages of the backtracking algorithm in the context of shift scheduling include its ability to:

a. Guarantee solutions that satisfy all constraints, ensuring the resulting schedule is valid and optimal.
b. Handle various complex and heterogeneous constraints.
c. Be easily modified to add new rules according to organizational needs.

However, the algorithm also has drawbacks, such as computation time, which can increase exponentially in cases with very large solution spaces. Therefore, optimization techniques like pruning and variable selection heuristics are often used to speed up the search process. Compared to manual methods or simple heuristics, the backtracking algorithm offers significant advantages in terms of schedule validity and optimality. Manual methods are prone to errors and time-consuming, while simple heuristics often produce schedules that violate rules. On the other hand, metaheuristic methods such as genetic algorithms or simulated annealing provide better scalability for large problems but do not always guarantee fully valid solutions without special adjustments.

Based on the explanation above and the data obtained, the backtracking algorithm is effective in solving shift scheduling problems with various complex constraints [15]. Computation time increases linearly with the number of scheduling days, demonstrating the algorithm's efficiency. The fairness in the distribution of night and weekend shifts is very good, reducing potential employee complaints. The main limitations are increased computation time at very large scales and a lack of flexibility for real-time scheduling.

Potential future developments include:

a. Integration of automatic shift swap features to enhance employee flexibility.
b. Development of mobile applications for easy schedule access.
c. Hybrid algorithms combine backtracking with metaheuristics for large-scale problems.
d. Real-time scheduling capabilities to adapt to sudden changes.

The results of this study are supported by research from [16] [17] , which states that the backtracking algorithm is one of the problem-solving methods based on search strategies in the State's's space, working recursively and systematically exploring all possible solutions. In addition, the number of customer service staff can be divided into three teams with rotating mobile selling schedules each week. This approach is more efficient than the previous scheduling system, which assigned mobile selling teams based on employees having the same work shift. Based on these findings, the implementation of the Welch Powell algorithm can theoretically solve the optimization issues in the scheduling system for the Customer Service division at Indosat Ooredoo Kuta Branch.

Furthermore, this is supported by research stating that the backtracking algorithm is one of the search algorithms with a high level of efficiency because backtracking traces backward from the goal node to check whether the current solution is leading toward the desired goal node. Thus, the backtracking algorithm can prune unnecessary steps during the search and find the shortest path in a search process. From this perspective, backtracking has advantages over the Depth First Search algorithm, which does not consider whether the current solution is heading toward the desired goal [18].

This is further reinforced by research [19], which states that the backtracking algorithm cannot determine the entire teaching schedule due to several constraints, including the number of teachers, subjects, and predetermined hours. Therefore, it can be concluded that the implementation of the backtracking algorithm in shift scheduling can improve the efficiency of the scheduling process, reduce manual errors, and produce schedules that meet all rules and preferences. Optimal scheduling positively impacts employee productivity and well-being. Further development can combine backtracking with heuristic or metaheuristic techniques to enhance scalability and flexibility, as well as integrate automatic shift swap features and real-time scheduling.

4. CONCLUSION

This study successfully implemented the backtracking algorithm as an optimal and effective method for creating shift work schedules. The backtracking algorithm is capable of solving complex shift scheduling problems with various constraints, such as employee availability, working hour regulations, operational requirements, and individual preferences. By using a systematic and recursive solution search approach, this algorithm can generate valid schedules that meet all established constraints and fairly distribute shifts among employees.

Testing on real data from the PLTU SSP company showed that the backtracking algorithm was able to create shift schedules with a compliance rate to the main constraints exceeding 97%. These constraints include fulfilling the minimum number of employees per shift, limiting the maximum number of consecutive working days, and respecting holidays and employee preferences. The computation time required was also relatively efficient for the scale of data tested, indicating that this algorithm can improve scheduling efficiency compared to the manual methods previously used.

Previous studies using the backtracking algorithm in scheduling contexts, such as course and exam scheduling in educational institutions, also support these findings by demonstrating the algorithm’s effectiveness in producing optimal solutions and avoiding schedule conflicts. Modifications and optimizations of the backtracking algorithm, such as eliminating thrashing and applying heuristics, can enhance performance and reduce computation time, making it highly relevant for application in combinatorial and multi-constraint shift scheduling.

Nevertheless, the backtracking algorithm has limitations regarding computation time, which can increase significantly with very large data scales or highly complex constraints. Therefore, further development by combining the backtracking algorithm with heuristic or metaheuristic methods could provide a solution to improve the scalability and flexibility of scheduling systems. Overall, the implementation of the backtracking algorithm in shift scheduling contributes positively to improving human resource management quality, company productivity, and employee well-being through more accurate, fair, and efficient scheduling.

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