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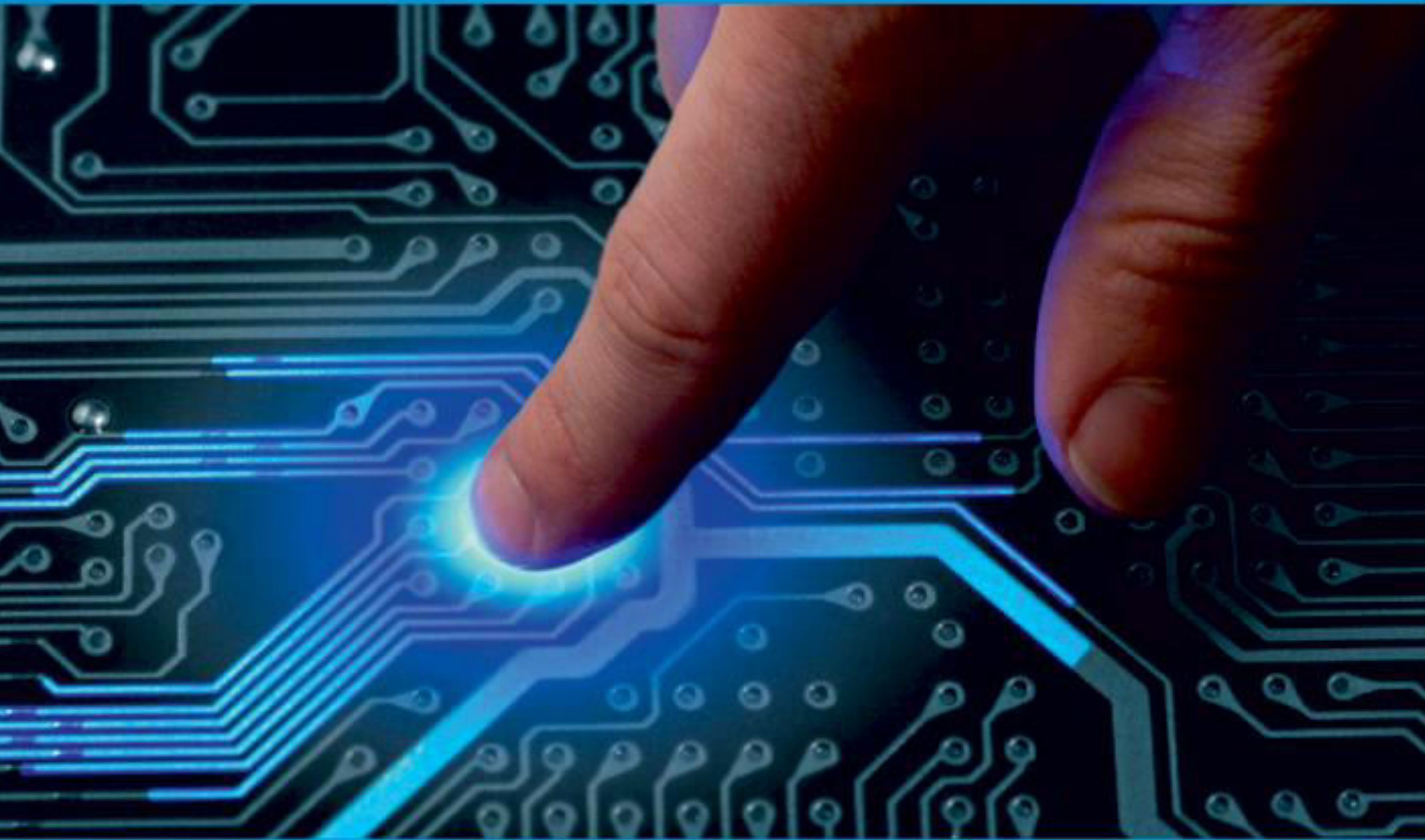

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Rule Based Simulated Annealing Model for The Maintenance of Elevator and Escalator Systems

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ABSTRACT: Maintenance task assignment is substantially a supplement of the task assignment problem. In most of time, it is unbalanced task assignment problem which can be solved by heuristic optimization algorithms. There are many studies related to maintenance task assignment problem in the literature. In this study, a rule based heuristic Simulating Annealing algorithm is proposed to resolve the unbalanced task assignment problem of the maintenance of elevator and escalator systems.

KEYWORDS: Simulated Annealing, Maintenance Task Assignment, Maintenance of Elevators and Escalators

I. INTRODUCTION

In a task assignment problem, it is possible to assign people to jobs, machines or sales regions. The assignment model is actually a specific task whose resources are workers and whose goals are jobs in a way that one person will be assigned to the job and each job will be done by one person. Finally, the problem should be solved in a way that the total assignment cost is minimized.

Maintenance task assignment is substantially a supplement of the task assignment problem in which there are two types of the task assignment: balanced task assignment (n persons, n tasks), unbalanced task assignment (m persons, n tasks, where n>m). Balanced task assignment problem may be resolved by the linear modes while unbalanced task assignment problem is a problem with multiple constraints of objective function optimization, that may not be resolved by linear models because of its complexity but by heuristic models.

In this study, a rule based heuristic Simulating Annealing algorithm is proposed to resolve the unbalanced task assignment problem of the maintenance of elevator and escalator systems. This method can optimize the maintenance of multiple elevators and escalators at different locations based on some predefined rules.

II. RELATED WORK

There are many studies related to maintenance task assignment problem in the literature. The maintenance task may refer to operational aircraft maintenance, maritime vehicle maintenance, railway track maintenance, wind tribune maintenance, manufacturing maintenance, lift maintenance etc.

In [1] authors proposed a methodology supporting decision making in order to suspend maintenance actions affecting the consignment of the aircrafts, with high flying unit operability and low maintenance cost. In their proposed model, a range of established maintenance plan alternatives were evaluated based on economical and operational constraints at the flying unit level of operator. Also, they carried out many experiments to validate the model.

Li et al proposed a dynamic maintenance task assignment framework based on expert knowledge in which the essential part of the model is selecting domain experts for the tasks with respect to expert knowledge by using the theory of discrete stress–strength interference. Experts' performances were reviewed and the task corresponding to the most appropriate domain expert at diverse periods were assigned by the collaborative maintenance platform [2].

In another study, a rule based expert system was proposed for the technician's assignment in order to handle computer system troubles instead of help desk experts. It was indicated that the system carried out results better than the experts [3].

In [4] authors presented a service logistics and maintenance literature classification for the maritime sector. Also, they investigated the feasibility and the deficiency of existing studies in maritime sector. Their study showed that all of the resources of maintenance such as maintenance engineers, service tools, spare parts and infrastructure had to be considered to service levels in maintenance service.

The other study reviewed the literature in decision making models for maintenance planning of railway tracks. Furthermore, it was observed that stochastic degradation modelling, multiple decision-supporting levels, and more detailed objective functions took place in the current studies increasingly [5].

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In [6] author proposed a model for wind farm operation and maintenance based on wind gust and wind speed data. Their model aimed at finding the most efficient execution order and the optimal intervention time for maintenance tasks by minimizing revenue loses. They applied clustering with respect to wind speed and wind turbine working zone for initial safe working rules. Moreover, they were able to predict the revenue loss for each maintenance plan

Another study proposed a decision support model to identify and assign catenary system (railway overhead electrical lines) maintenance tasks using integer programming and heuristic methods with minimizing objective function of maintenance cost and labor cost. They indicated that their model decreased the total cost compared to the classical system [7].

In [8] authors submitted a multi-agent approach for the dynamic scheduling of maintenance task for a production system of petroleum industry by using the SARSA reinforcement learning algorithm to allow the agents in order to learn the best behaviours for their different roles without losing any performance. Also, they included a simulation model to show the experiments results by using an Algerian petroleum refinery data.

Authorsare proposed a real-time scheduling policy of the corrective maintenance to decrease the cost of energy and the overall maintenance for a probabilistic serial production line in terms of an online task allocation problem. Moreover, they compared their policy with other heuristic policies to evaluate the effectiveness of the model [9].

In [10] authors are offered a selective maintenance problem model in order to collectively optimize the decisions of maintenance and assignment in a system with multiple objectives. The goal of their model was to minimize the total cost of maintenance and labor for a maintenance scheduling guaranteeing a determined reliability threshold. They carried out a heuristic method originated from the genetic algorithm as a solution technique.

Authors are presented a review of multi criteria models in order to resolve the problems of maintenance optimization, having increased applications and recent advances. After analyzing a total of 150 publications corresponding to maintenance applications, they indicated that there were two types of important maintenance problem: strategy selection and interval optimization. Moreover, they declared that Multi Attribute Decision Making methods were appropriate for the problems of strategy selection while Multi-Objective Evolutionary Algorithms were suitable for the problems of interval optimization [11].

In [12] authors are reviewed the literature of the electricity transmission lines maintenance scheduling, which was important to reduce breakdowns and avoid expensive production shutdowns. They implied some attributes such as fuel management, network considerations and data uncertainty for both regulated and deregulated electricity power systems. Also, they indicated that heuristic techniques such as genetic algorithm, particle swarm optimization and Simulated annealing were widely used in the transmission lines maintenance problems due to the NP-hardness of that.

Author is focused on the maintenance of geographically distributed assets like railway switches and off-shore wind farms. He presented a genetic algorithm-based solution for these type of maintenance problems [13].

Tan et al solved the lift scheduling optimization problem amongst multiple offshore platforms with transport vessels by using three heuristic algorithms, that is, particle swarm optimization, genetic algorithm and firefly algorithm. They proved that their model improved the efficiency of lift scheduling in multiple topsides takedown [14].

III. SIMULATED ANNEALING

The Simulated Annealing Algorithm (SA) is a heuristic and probabilistic optimization technique inspired by the annealing process of metals designed in order to approach a determined function global optimum. SA is based on heating solids followed by slow cooling [15]. At each epoch inside the SA, if a lower cost than the actual feature vector is acquired by using the objective function, the SA assigns the neighbour of the prevailing solution to the feature vector. In order to search for the global optimum and avoid local optimum, a neighbour delivering a higher cost in the objective function can also be assigned to the feature vector with a pre-determined probability [16]. A simple Simulated Annealing algorithm is given in Fig.1 below.

- Let $s = s_0$
- For $k = 0$ through k_{max} (exclusive):
  - $T \leftarrow$ temperature($1 - (k+1)/k_{max}$)
  - Pick a random neighbour, $s_{new} \leftarrow$ neighbour(s)
  - If $P(E(s), E(s_{new}), T) \geq$ random(0, 1):
    - $s \leftarrow s_{new}$
- Output: the final state s

Fig.1. Simulated AnnealingAlgorithm

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IV. Application and Experiments

Simulated Annealing, one of the heuristic algorithms, was used when assigning tasks for the maintenance and repair of elevators and escalators. The objective function required for the algorithm was created using the rules required for task assignment, as seen in Fig.2 below.

```
def objective_function(_df_jobs, _df_teams, _df_off_days):
    costs = {
        CostType.Priority: 0,
        CostType.Skill: 0,
        CostType.Shift: 0,
        CostType.DailyWork: 0,
        CostType.MonthlyWork: 0,
        CostType.OffDay: 0
    }
```

Fig.2. Objective Function

The variables used in the objective function are as follows:

CostType.Priority: Failure takes more priority than maintenance

CostType.Skill: Tasks of certain difficulty levels should be assigned equally to qualified employees.CostType.Shift: The next shift of the personnel on night duty should be during the day.

CostType.DailyWork: Total work cannot exceed 11 hours per day

CostType.MonthlyWork: Total work cannot exceed 270 hours per monthCostType.OffDay: Personnel are not appointed on days off.

```
_cost = objective_function(df_jobs, df_teams, df_off_days)
# Make circular shifts
df_jobs_new = df_jobs.copy(deep=True)
df_teams_new = df_teams.copy(deep=True)
rnd_col = random.choice(df_teams_new.columns)
df_teams_new[rnd_col] = np.roll(df_teams_new[rnd_col], 1)
rnd_index = random.choice(df_jobs_new.index.values)
df_jobs.loc[rnd_index, :] = np.roll(df_jobs.loc[rnd_index, :], 1, axis=0)
_cost_new = objective_function(df_jobs_new, df_teams_new, df_off_days)
rand1 = np.random.rand()
form = 1 / (np.exp(_cost_new - _cost) / T0)
# print(f'rand1: {rand1:.2f}\tform: {form:.2f}\tT0: {T0:.2f}')

if _cost_new >= _cost:
    df_jobs = df_jobs_new
    df_teams = df_teams_new

    # st.subheader('JOBS')
    # st.dataframe(df_jobs)
    # st.subheader('TEAMS')
    # st.dataframe(df_teams)
elif rand1 >= form:
    df_jobs = df_jobs_new
    df_teams = df_teams_new
```

Fig.3. Python Code of Simulating Annealing

The objective function value was tried to be maximized on the basis of giving positive points when the rules were followed and negative points when the rules were violated, and the relevant Python code is given in Fig.3.

V. Conclusion

The maintenance of elevator and escalator systems is an unbalanced task assignment problem whose objective function with multiple constraints, that may not be solved by linear models because of its complexity but by heuristic optimization algorithms. To solve this problem, we used a rule based simulating annealing algorithm whose objective function consisting of constraints given as rules. The objective function was used as a maximization function in way that the maximum number of rules were tried to be followed.

As a future study, the other heuristic optimization algorithms can be used for the same problem comparatively.

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BIOGRAPHY

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