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THE USE OF THE GIS SYSTEM IN OPTIMIZING THE COSTS OF INSPECTING TECHNICAL DEVICES

Abstract: Enterprises using cranes, HDS platforms, other handling equipment, or pressure equipment in their activities are subject to registration with the Office of Technical Inspection (UDT), which is obliged to conduct inspection activities on them. Inspections of technical devices are aimed at checking their technical condition. Approximately 1.3 million technical devices are currently subject to UDT supervision in Poland. Annually, UDT inspectors carry out over 1 million tests of technical devices, and the activities carried out by UDT translate into a constant reduction in the accident rate. All this takes place in conditions that require continuous work planning and scheduling. This article aims to present and discuss the use of open-source solutions for planning the work of teams carrying out inspection activities, along with the concept of their use.

Keywords: open data, GIS, FSM, field service management, work scheduling, work dispatching, continuous planning, non-disruptive replanning, real-time planning, overconstrained planning

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Introduction with analysis of the state of the problems

The Office of Technical Inspection (UDT) is a key institution responsible for supervising the safety of technical equipment in Poland. It plays an important role in ensuring compliance with standards and regulations concerning technical infrastructure. As a state legal entity, UDT operates based on several legal acts and, above all, based on the Act of 21 December 2000 on technical inspection (Journal of Laws of 2000, item 122, pos. 1321). This regulation is the legal foundation for the Office of Technical Inspection activities, enabling effective monitoring and assessment of compliance with safety standards.

The history of the Office of Technical Inspection dates back to over a hundred years of Polish technical inspection tradition, which confirms its deep-rooted heritage. Since its inception, UDT has been developing and adapting to dynamic technological and industrial changes. Currently, as one of the pillars of the technical safety system in the country, UDT plays a key role in maintaining high safety standards in various sectors of the economy.

The location of 10 local branches and 22 offices throughout Poland enables UDT to operate effectively at local levels, approaching individual regions' specific needs and challenges. This strategic location of field units and offices allows for a quick response to situations and effective management of technical supervision processes throughout the country.

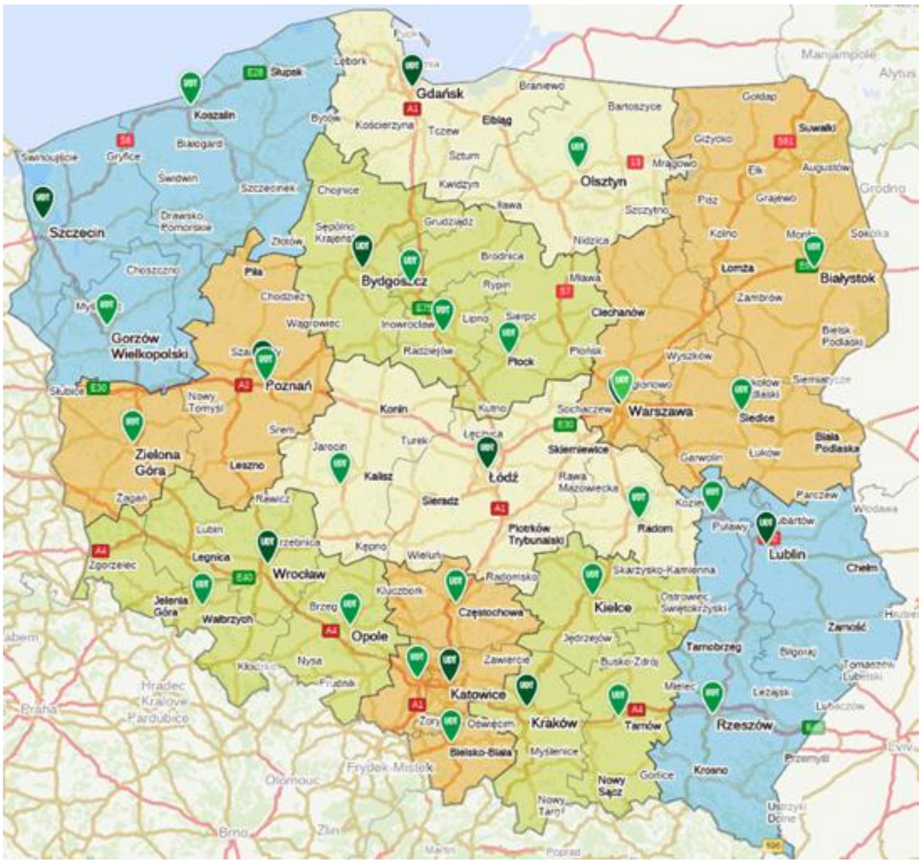

Fig. 1. Map of branches – territorial division

Source: https://www.udt.gov.pl

UDT operates mainly based on the Technical Inspection Act, the legal basis for its activities. It is worth noting, however, that regulations specifying the functioning of this institution can also be found in executive acts related to the Act above. This comprehensive approach allows for effective monitoring and control of areas related to the safety of technical equipment.

However, the activity of the Office of Technical Inspection is not limited only to the framework defined by the Technical Inspection Act. This institution also acts as a Notified Body No. 1433, under the Act of 30 August 2002 on the conformity assessment system and the Act of 13 April 2016 on conformity assessment and market surveillance systems. In addition, UDT operates based on relevant notifications, which entitle it to perform conformity assessment within the scope of nine EU New Approach Directives and two regulations (Journal of Laws of 2002, item 166, pos. 1360).

UDT also acts as a certification body, operating under the name UDT-CERT. Within this activity area, the institution conducts audits, focusing on the certification of management systems, certification of people's competencies, and certification of products. UDT-CERT is important in ensuring compliance with norms and standards in various fields. Through certification audits of management systems, UDT-CERT confirms that organizations meet specific quality, environment, or safety requirements. At the same time, the certification of individuals is a key tool in confirming professional qualifications and raising the standards of competence of employees. Finally, the product certification process assures that products meet specific norms and standards. Therefore, the activity of UDT-CERT is not only an element protecting against inconsistencies and risks but also supports the improvement of quality, safety, and sustainable development in various sectors of the economy.

Another area in which UDT plays an important role in the Polish market is being a certification body for installers of Renewable Energy Sources (RES) and is responsible for accreditation centers conducting training for these installers (Journal of Laws of 2015, item 478). Regarding certification, UDT confirms that RES installers meet certain standards of competence and qualifications, which is crucial to ensure a high level of performance of works related to renewable energy. At the same time, through the accreditation process of training centers, UDT ensures that the set standards conduct training for RES installers. This means these centers are reliable, provide reliable knowledge, and effectively transfer the necessary skills required in Renewable Energy Sources. This works to raise industry standards while fostering the sustainability of the RES sector by ensuring high standards of installer competence and the quality of training offered by accredited centers. This is an integral part of UDT's commitment to developing and maintaining high standards in renewable energy.

Finally, UDT, as an entity statutorily responsible for the popularization of knowledge in the field of safety of technical equipment at the stage of design, manufacture, and operation, also offers training, which is an initiative aimed at improving the professional qualifications of both manufacturers and users of technical equipment. This area of activity is directly related to the requirements of the Technical Inspection Act, which imposes liability related to the operational safety of technical equipment. As part of these trainings, UDT focuses on providing practical knowledge and skills necessary to effectively and safely use various types of technical devices. For manufacturers, this means raising standards in their production processes by applicable standards and regulations. On the other hand, these trainings are an excellent opportunity for users to understand the principles of safe operation and proper equipment maintenance. Through these training initiatives, UDT not only fulfills its mission related to technical supervision but also actively supports the improvement of competencies in the field of technical safety at various levels of production and use. This, in turn, contributes to a safer and more efficient working environment in technical equipment.

As you can see, such diverse areas of UDT's activity testify to its versatility and ability to adapt to various technical security aspects. As a result, UDT not only complies with the national regulations on technical inspection but also actively participates in the conformity assessment system at the EU level, which confirms its high rank and importance in the context of technical safety in Poland and Europe. One thousand three hundred high-class engineers carry out these tasks.

In the context of dynamic technological development and the increased importance of safety in the work environment and society, the role of UDT is becoming even more crucial. This article takes a closer look at the challenges faced by the Office of Technical Inspection, particularly in field service management (FSM). It also analyses how UDT can effectively deal with these challenges using modern tools, technologies, and proven management practices.

Despite such a wide range of services, the main area of UDT's activity is technical equipment inspections. The Office of Technical Inspection (UDT) controls many technical devices, including m.in. Machines and devices move people or loads within a limited range. Examples of such devices include overhead cranes, winches, cranes, hoists, freight lifts, escalators, escalators and moving walkways, forklift trucks, cabin and platform circular conveyors, cranes for transporting people or cargo, lifts for moving people for tourist and sports purposes, and many others. The Office of Technical Inspection controls transport-related equipment, including ropeways and mobile platforms in ferry harbors. UDT also inspects pressure equipment that contains liquids or gases at pressures other than atmospheric, as well as non-pressure vessels and tanks with an overpressure of up to 0.5 bar. All this means that UDT cares about the safety and quality of equipment subject to increased pressure and may threaten people and the environment. The Office of Technical Inspection (UDT) conducts tests and inspections of these devices to ensure their safe and effective operation and to protect the health and life of people and the environment. In Poland, over 1.5 million devices are subject to technical inspection, and UDT inspectors perform over a million yearly technical inspections. Performing such a large number of inspections with limited human resources is extremely challenging. This must be done with diligence, time regime, and the use of a minimum number of resources (personnel, equipment – the so-called PDB – measurement and research equipment) and efficient logistics of inspections.

To perform supervisory tasks, each UDT inspector must have the required competencies. To standardize the sets of such skills, they were divided into groups of activities that can be performed. Examples of specializations are presented in Table 1.

Table 1. Selected authorizations

Code	What to do	Full name
ZP	BT, UD, UZ, SK, OZ, OZBT	Portable tanks and acetylene generators
K	BT, UD, UZ, BS, OZ, OK	Boilers and power pipelines
ZS	BT, UD, UZ, BS, OZ	Fixed tanks and pipelines
DZP/DZ	BT, SK	Cranes & Conveyors – Cranes Only
DZP/PK	BT, SK	Cranes & Conveyors – Conveyors Only
DZP-pr	BT, SK, UD, UZ, PEL, OZ	Cranes and conveyors, excluding conveyors for leisure and entertainment purposes
SOUP/ZU	BT, SK	Cranes, mobile platforms, and hoists – cranes only
B	BPR	Process safety
B	Bfs	Functional Safety Equipment
B	CBP	Industrial Cybersecurity
M	ohm	Technical acceptance of metal materials
M	Ots	Technical acceptance of plastic materials
M	ohm	Technical acceptance of metal materials
E	Bts	Electromobility – Technical Research

Source: Own elaboration

Acquiring competence in a given field is long-term and ends with an exam. In the Office of Technical Inspection, this is determined by detailed rules of conduct concerning specialization training, examination, authorization, and maintenance of competencies of the technical personnel of the Office of Technical Inspection. This significantly impacts the availability of engineering staff who can carry out inspection activities.

The inspection process itself is also not a simple matter. As part of it, several activities should be carried out to assess the condition and compliance of the device with specific regulations and standards. These include, for example:

1. Visual Assessment: A visual assessment of the device is carried out, checking for the general condition, damage, signs of wear, looseness, or leaks.
2. Functional testing: Tests are performed to verify that the device works as intended and meets the technical requirements. This may include commissioning, checking operating parameters, and determining the performance or accuracy of measurements.

3. Measurements and tests: Measurements and tests are performed to evaluate the specific technical parameters of the device. These can be electrical measurements, pressure measurements, temperature, noise, or other physical properties.
4. Document control: Technical documentation related to the device, such as operating instructions, certificates, test protocols, and evidence of repairs or upgrades, is checked.
5. Risk identification: Potential hazards associated with using the equipment are analyzed, and countermeasures or recommendations for safe operation are identified.

Another huge obstacle in implementing the inspection process is the dispersion of technical equipment throughout the country. As of 1 January 2023, there are 2477 municipalities in Poland. Our country has no municipality where at least one technical device is not installed. Some of them are devices that do not change their location (e.g., technological pipelines, (Fig. 2)).

Fig. 2. Technological pipelines
Source: udt.gov.pl

Unfortunately, a significant number of devices do not have a fixed location. These are not only devices such as mobile cranes or other cranes mounted on mobile chassis (Fig. 3) but also those that can be easily dismantled and reassembled in another location (Fig. 4)

Fig. 3. Mobile crane
Source: udt.gov.pl

Fig. 4. Tower crane
Source: udt.gov.pl

Constantly rising fuel prices or an increase in the rates per 1 kilometer of vehicle mileage, according to which the employer covers the costs of using private vehicles used by employees for business purposes, increase the costs of conducting statutory activities of the Office of Technical Inspection. This has a direct impact on the operating costs of the business.

An area in which savings can be sought is the optimization of the costs of travel of UDT inspectors to the locations where the devices that are the subject of the inspection are installed. Such optimization cannot be a one-time search for savings but a long-term strategy.

In the next part of the article, the concept of using the GIS class system and optimization algorithms will be presented to optimize the costs of conducting inspections of technical equipment while applying the limitations existing in this area. The results will be presented in the form of the architecture of the potential solution. Tools will be presented, thanks to which it will be possible to implement the concept.

Material and methods

Geographic Information Systems (GIS) offer tools and features that can be effectively used to optimize the inspection process for technical equipment. The following are some of how GIS can help reduce costs:

- Inspection Route Planning: Using spatial data in GIS enables inspector route planning quickly, easily, and efficiently. By analyzing data on the location of technical equipment, terrain conditions, and priorities related to the need for inspections, it is possible to create optimal inspection routes, minimizing travel

and time costs. This approach saves time and costs associated with the movement of inspectors.
- Inspection scheduling: GIS also allows you to schedule inspections efficiently. Data on the timing of recent inspections, maintenance cycles, and other factors can be incorporated into creating optimal inspection plans, minimizing costs, and ensuring equipment continuity (Palmer, 2019).

While route planning itself is not a new issue and algorithms for creating optimal routes are known, in the case of an issue such as optimal inspection planning, it is necessary to take into account additional constraints resulting from the availability of resources (people, equipment) and the competencies that must be possessed to perform inspection activities effectively.

To effectively use the Geographic Information System (GIS) to optimize the cost of inspecting technical equipment, you can use various tools, both software and geospatial data.

The key solutions are, of course, the GIS software itself (e.g., ArcGIS, QGIS, or Google Earth Engine), spatial databases, or spatial data itself (e.g., OpenStreetMap (OSM), data from state systems). Of course, you can use languages such as Python with GIS libraries (Geopandas, Shapely) or R with GIS packages (sf, leaflet). However, route planning tools such as Route4Me or OptaPlanner are the kind of tools that can be easily used to optimize route planning and that can be adapted to the specific inspection requirements of technical equipment.

OptaPlanner is an open-source operational optimization software used to solve planning and scheduling problems. First of all, it is:
- Optimization Engine: OptaPlanner is an extensive optimization engine that can solve various optimization problems such as route planning, task scheduling, lesson planning, resource allocation, etc.
- NP-hard problem solver: It is structured to deal with computationally difficult problems (NP-hard), which means there is no fast algorithm to solve them, but OptaPlanner tries to find the best possible solution.
- Programming Interface: Provides a programming interface that allows software developers to implement and adapt optimization algorithms to a specific problem.
- Multi-language support: OptaPlanner supports multiple programming languages such as Java, .NET, Python, etc.

It is important to remember that OptaPlanner is not a ready-for-everything application. It provides an optimization engine but is not a ready-to-use system that can be fully configured without any programming knowledge. Its use requires some programming knowledge. It is also not a data analysis platform: Although it can analyze data in the context of solving an optimization problem, it is not oriented towards data analysis in a general way, like data analysis tools, for example. It is also not a data storage tool or database. OptaPlanner operates on data provided by the user. Finally, it's not a data visualization system either. While it can provide some output data in a form that can be visualized, it's not a tool for visualizing data in general. Dedicated data visualization tools are usually used for this purpose.

Nevertheless, OptaPlanner is a powerful optimization tool that provides an engine for solving optimization problems, but its full use requires programming work and adaptation to the specific problem domain. One of the key advantages of OptaPlanner is its ability to deal with all sorts of limitations and preferences. It can be customized for a specific domain by specifying optimization rules and criteria. Thus, it can be used to solve a variety of problems.

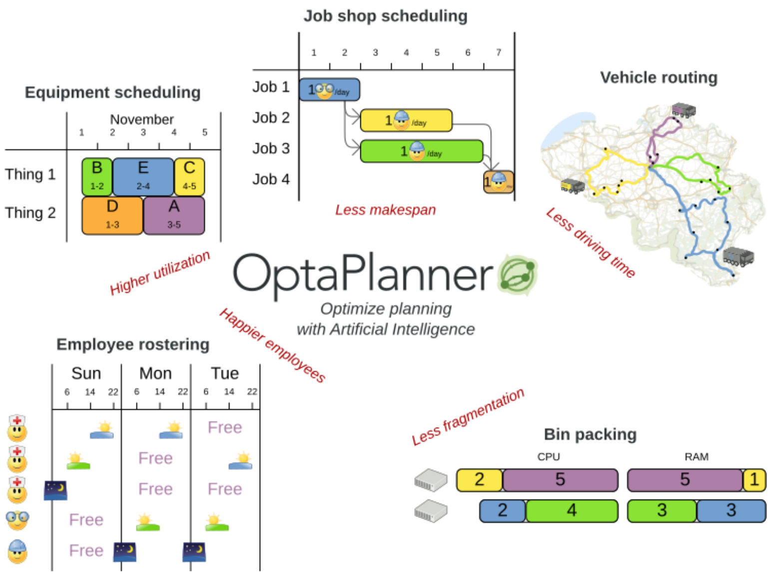

Fig. 5. OptaPlanner – application areas
Source: https://www.optaplanner.org

In optimizing the costs of inspection of technical devices, we limit ourselves to two areas of optimization: task assigning and vehicle routing.

The data for feeding the optimization engine has been prepared to be directly used in the optimization engines provided by OptaPlanner.

In the case of the data for the algorithm for optimal assignment of tasks, information on the competencies of inspectors (Lichtarski, 2011) and their absences (holidays, illnesses) was used as input. In this set, the limitations are the sets of competencies and the availability of people.

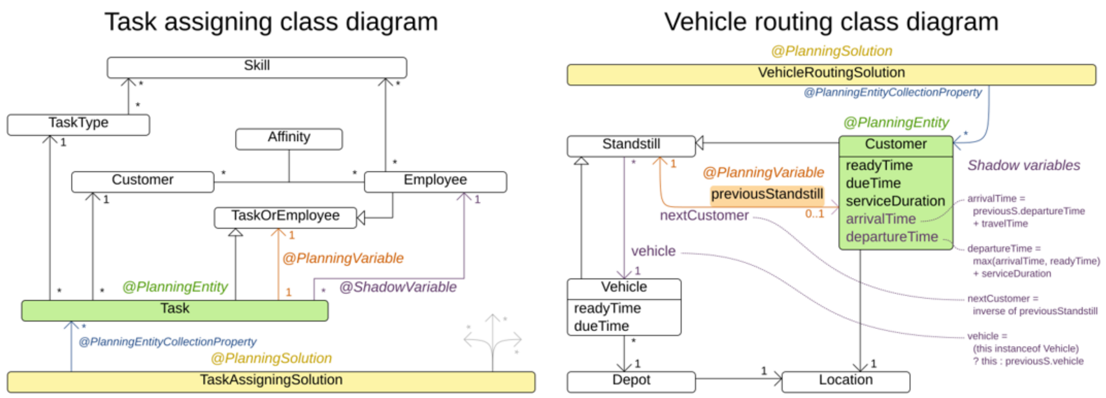

Fig. 6. OptaPlanner – application areas
Source: https://www.optaplanner.org

To feed the data into the structures of the Vehicle Routing Problem (VRP) algorithm, data on technical equipment under supervision and inspection plans resulting in large part from tables specifying the dates of periodic and ad hoc control inspections for individual types of equipment were used. The table (Table 2) presents selected items specifying the dates of periodic and ad hoc check-ups for material handling equipment (UTB).

Table 2. Forms of UTB technical supervision and dates of periodic and ad hoc control inspections – selected items

No.	**Material handling device**	**Form of technical supervision**	**Date of the examination**	
			Periodic	**Ad hoc control**
1	2	3	4	5
1	UTB is made in whole or in part in an explosion-proof version	full	every year	-
…	…	…	…	…
5	General-purpose hoists and winches with mechanical drive	limited	-	every two years
…	…	…	…	…
13	Hand-driven cranes of all mechanisms with a lifting capacity of more than 2000 kg	limited	-	every three years
…	…	…	…	…
21	Stationary mobile platforms	limited	-	every two years
22	Mobile loading platforms	limited	-	every three years

Source: Regulation of the Minister of Entrepreneurship and Technology of 30 October 2018 on the technical conditions of technical supervision in the field of operation, repair, and modernization of material handling equipment (Journal of Laws of 2002, item 2176)

In the case of route optimization, the basic algorithm is CVRP – i.e., an extension of the VRP problem that considers the load capacity of vehicles. This is an extension of the VRP problem, which is designed so that the amount of goods that need to be delivered to the customer using the available fleet is additionally considered. In our case, this will be used to include in the algorithm the equipment (quantity, weight) that should be available to inspect the technical device at the customer's site.

Results and discussion

The presented concept has been pre-validated using OptaPlanner and Java implementation. Below are selected code snippets that present important aspects of the implementation.

```
@Override
public Constraint[] defineConstraints(ConstraintFactory constraintFactory) {
    return new Constraint[] {
            noMissingSkills(constraintFactory),
            minimizeMakespan(constraintFactory),
            criticalPriorityBasedTaskEndTime(constraintFactory),
            majorPriorityTaskEndTime(constraintFactory),
            minorPriorityTaskEndTime(constraintFactory)
    };
}

private UniConstraintStream<Task> getTaskWithPriority(ConstraintFactory constraintFactory, Priority priority) {
    return constraintFactory.forEach(Task.class)
            .filter(task -> task.getPriority() == priority);
}

private Constraint noMissingSkills(ConstraintFactory constraintFactory) {
    return constraintFactory.forEach(Task.class)
            .filter(task -> task.getMissingSkillCount() > 0)
            .penalize( constraintName: "No missing skills",
                    BendableScore.ofHard(BENDABLE_SCORE_HARD_LEVELS_SIZE, BENDABLE_SCORE_SOFT_LEVELS_SIZE,
                     hardLevel: 0,  hardScore: 1),
                    Task::getMissingSkillCount);
}
```

Fig. 6. Implementation – constraints for job scheduling
Source: Own elaboration

It was also possible to use Python and optimize with the help of the OptaPy package – an OptaPlanner-based AI constraint solver for Python to optimize the vehicle routing problem.

Even on quite small volumes of data, the manufacturer's information that using OptaPy in Python is much slower than using OptaPlanner in Java or Kotlin has been confirmed. It is worth noting that the implementation work and tests covered only the integration aspect while constituting a validation process to assess the quality of the data provided. This focused on the harmonization of system components, including the integration of new elements into existing infrastructure. At the same time, the tests were aimed at verifying the correctness and consistency of the data provided, including their structure and compliance with specific standards and requirements of OptaPlanner. This process only guarantees the system's functionality and consistency with data quality.

Thus, the possibility of using the tool in the automation and optimization of the costs of technical equipment inspections was confirmed. Our research findings provide insight into the potential of OptaPlanner as a tool to support optimization decisions in technical equipment inspection management.

Conclusions

In today's fast-paced business environment, organizations seek to remain competitive, manage resources efficiently, minimize operating costs, and provide excellent service quality. In organizations such as the Office of Technical Inspection, one of the key areas in which these goals can be achieved is optimizing the costs of conducting inspections of technical equipment. Tools such as OptaPlanner solve several problems encountered in organizations that must manage the services and resources offered in the field, commonly referred to as Field Service Management (FSM). This article analyzes the potential of OptaPlanner software in optimizing the costs of technical equipment inspections. Selected aspects related to problem definition, modeling, implementation, and experimentation are presented, showing how this tool can significantly reduce operating costs and improve the efficiency of inspection processes.

The introduction to the topic included identifying the challenges of managing the cost management of technical equipment inspections in today's business environment. The article focuses on specific elements of the optimization process, including defining the problem, modeling it in the context of technical device inspections, adapting the OptaPlanner tool to specific needs, and conducting practical experiments.

In further work, it is worth considering an algorithm that optimizes routes, considering the time intervals in which it is possible to inspect the technical equipment at the customer's site. – the so-called Vehicle Routing Problem with Time Windows (VRPTW). The algorithm that solves the VRPTW problem and minimizes the cost of all routes must find solutions without exceeding time windows. The substantial challenges inherent in the practical functioning of the optimizer can, in part, stem from the sheer magnitude of data, thereby giving rise to an expansive realm of potential solutions. This is particularly evident in instances where the data volume reaches so significant proportions, such as the management of 1.5 million devices, the execution of 1 million inspections, and the involvement of 1300 inspectors. Consequently, it becomes imperative to undertake a comprehensive evaluation of the optimizer's efficacy within the context of real-world conditions. This evaluation should encompass a meticulous scrutiny of its performance across diverse scales and scenarios, ensuring a nuanced understanding of its capabilities and limitations.

Acknowledgments

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