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A NOVEL OPTIMIZATION APPROACH FOR ENHANCING EFFICIENCY IN AIRCRAFT MAINTENANCE PLANNING AND SCHEDULING

Summary. The operational side of aircraft maintenance plays a key role in ensuring smooth workflow and the practiced processes' reliability in aircraft maintenance repair and overhaul (MRO). Correct MRO planning effectively reduces downtime and enhances the overall accuracy and dependability of procedures. An optimal schedule of maintenance resources and capacity, which entails using the least amount of ground time and schedule modifications, can be used to ensure that all activities are completed productively and consistently before their deadlines. This paper delves into the creation of an optimization approach that considers the dynamic environment of aircraft maintenance. The approach deals with a constraint programming (CP) model for heavy maintenance resources and capacity scheduling, in which variables such as scheduled maintenance tasks, ground time, workload distribution, and maintenance due dates are bounded by resources and technicians' availability. The proposed CP model showed a strong ability to satisfy different constraints and conditions that were introduced in the artificial industrial environment within a short solving time of 3.12 seconds. Thus, it showed promising results in the case of further developments.

1. INTRODUCTION

Maintenance, repair, and overhaul (MRO) jobs are vital operations in any firm's or company's organizational structure. As a result of these jobs, machinery, equipment, and facilities are guaranteed to run safely, properly, and smoothly.

MRO expenses directly influence operating expenses, which are estimated to account for 10–15% of an airline's operational costs [1]. In the aviation industry, the role of aircraft maintenance is critical. For MRO companies, providing high-quality maintenance services while adhering to the contracted turnaround time (TAT) is essential to guaranteeing the accurate compliance of the agreement and acquiring the customer's satisfaction, which, in turn, leads to further cooperation and more work.

Due to the fast-paced work nature of aircraft MRO, one incorrect decision can disrupt the entire operation and delay the redelivery of the aircraft. Since it is important to be able to compete and stay relevant in the market, the MRO industry needs to adapt to constant improvements, adopt new methodologies and technologies to daily procedures, and keep up with state-of-the-art innovations that are intended to increase the process's efficiency and accuracy.

Currently, the method used for operational planning in most MROs is based on the manual and individual point of view of project or line managers—in other words, a human-based method [2]. Therefore, the mode of planning a check or a project will vary from one operational planner/manager

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to another. This is not ideal because what one person perceives as critical may be seen as mundane by others.

While much existing scheduling software can create flowcharts [3, 4], the process of scheduling tasks and jobs for MRO activities is slightly different. A heavy maintenance check package can contain thousands of tasks including non-routine cards (NRCs). Entering each one manually while establishing dependency relations between them is hefty, time-consuming work. A company might need to hire data inputters to perform just this one task.

In addition to the above, the process of scheduling people and tasks depends solely on a person's opinion and experience, and this viewpoint will differ from one person to another. It would be more efficient and beneficial to the company if there was a system that could set a structure to standardize the planning and scheduling of activities logically. Moreover, while proper planning and scheduling for one aircraft is a manageable job, carrying out the same steps for multiple lines or planes is complex and can be quite challenging. Continuous effective resource allocation, scheduling, and operational flexibility are required to maintain smooth and effective operations. Hence, one can find a significant amount of research aimed at enriching this part of the industry, and although many improvements and developments took place to strengthen decision-making methods, there is still room for more advancements.

The search for new methods for planning and scheduling is not new; it began at the start of the tech era. In 1991, KLM, the Royal Dutch Airlines, used a decision support system for capacity planning [5]. The research formulated the optimization problem as an integer program and solved it with an approximation algorithm based on Lagrangian relaxation. It was redeveloped in 1994 to finish the entire required job using the minimum number of engineers to avoid wasting capacity [6]. Their approach was a stepping stone for all the research in this field. However, much simpler and more accurate and dynamic methodologies exist today. In 2014, researchers developed a non-linear integer programming model. The module was able to perform the dual objectives of minimizing the number of maintenance technicians needed to do the job while also maximizing productivity levels [7]. The study was not related to the aircraft maintenance sector. However, the results were promising, using the same context and objectives, the same idea can be utilized for aircraft MRO companies if the objectives were modified to fit their needs and inquiries.

As for personnel scheduling, one can find many examples in the literature, especially in the medical sector, where a shift system is used [8–10]. Of course, the medical sector is quite different than the MRO sector. Still, the same concept can be adopted for MRO activities. For example, freight transportation has incorporated much more advanced techniques utilizing artificial intelligence (AI) to forecast traffic through the use of artificial neural networks (ANNs) [11].

For line and short-term operational planning, much research has been conducted to minimize the TAT and aircraft downtime using AI [12], [13]. In a more recent case study, researchers used a bi-objective model formulated to jointly minimize project duration and state changes and found that this approach was able to minimize the duration of a c-check identify the key milestones and distribute the tasks accordingly [14]. The module was successful, but other capacity constraints need to be implemented.

The literature reviewed above shows that although newer and more advanced approaches exist in other industries and fields, for the MRO sector, there is still room for advancement and development. For maintenance, activities need a complete solution that combines capacity planning, suitable slot allocation for the aircraft, scheduling tasks, and employees.

Even though most MROs now tend to have a long-term plan before any operation based on the contracts and available hangar slots and manpower, disruptions during maintenance operations are very common. These disruptions can emerge as unplanned maintenance tasks NRCs, which can require slot alterations, or capacity and resource adjustments, compromising the accuracy of the initial schedule plan. Manually recreating a new plan with precision while considering all the inputs, variables, and constraints is risky and can lead to major delays not only to the affected aircraft but also to all other lines.

The launching of the data era offered many solutions to the above dilemma. In this paper, a CP approach was used to find the most suitable solution for a small maintenance example. The module was created in a maintenance operational environment to improve the scheduling and planning procedures in such dynamic conditions, focusing only on base maintenance or heavy maintenance. CP is considered a type of AI that is usually used for solving complex and combined problems that are often associated with scheduling, resource allocation, verification, diagnosis, product configuration, and planning [15].

The base structure of the proposed module meets the objectives while satisfying all conditions and constraints. In other words, it finds a feasible solution that satisfies the goal of delivering the aircraft back on time and guarantees customers' satisfaction.

The correct implementation of the module will enable upper management to make more calculated decisions, which will help create a dependable system capable of flexibly adapting to schedule changes to ensure maximum utilization of the company's resources and efficiency.

In this paper, the description of the problem and the MRO environment are explained thoroughly. Then, the software capabilities and working milestones are presented, showing the identification of the activities and project breakdown. Finally, the objective, constraints, and variables of the problems are highlighted, showcasing the results and highlighting the future research steps and the module's capabilities.

2. DESCRIPTION OF MAINTENANCE SCHEDULING REQUIREMENTS

The MRO work environment is very dynamic, as it relies heavily on multiple variables and factors. Thus, it is complicated and challenging to perform correct and accurate planning and scheduling for maintenance activities and resource allocation (e.g. (hangar) spots, infrastructures, tools, consumable materials, parts, and capacities with suitable qualifications and permissions). The variety of aircraft types, the complexity of maintenance duties, limited resources, and severe regulatory requirements contribute to a dynamic and complex environment in which good planning and scheduling are vital for cost-effective and safe operations. Given these limitations, the research objective is to develop and deploy sophisticated optimization algorithms customized to planning and scheduling concerns in aircraft MRO operations.

When a set of work orders or tasks are given to an MRO company to be performed on a specific aircraft, the MRO company will give the customer/operator of the aircraft an estimated time for finishing the maintenance process, and contracts will be signed based on this. This estimated time is the TAT, and it is extremely crucial for the entire maintenance process since airlines strive to keep their planes in the sky as much as possible. One MRO company can have jobs and work on a fleet of aircraft within a single airline or multiple airlines with a variety of checks, such as A-, B-, C-, out-of-phase, and D-checks [16]. Usually, A- and B-checks are done in line maintenance, while C- and D-checks are considered heavy maintenance. However, an MRO company might receive a combination of heavy and line checks. The work to be performed on the aircraft is usually given and grouped by the customer's planning team to form a work package. This package can contain one check or a combination of checks.

Although the maintenance tasks are specified before the aircraft arrives at the facility, many factors can intertwine and directly affect the efficiency of the project's execution. For example, choosing the correct order and the inter-dependencies of tasks can be a key factor in the maintenance process. Also, downtime impact (e.g., a delay in one task, subtask, or an entire project line) can push the schedule back, especially if certain maintenance activities are prerequisites for subsequent operations. Furthermore, resource conflicts either in tools/materials or technicians can force the MRO project to deviate from the agreed maintenance time [17].

It is not the responsibility of the MRO company to decide what to do on the aircraft but rather how to do the required job most efficiently and accurately. This includes the breakdown and understanding of the work package, the establishment of correct and logical precedence relationships between tasks, reaching the end of the inspection phase as fast as possible to initiate the defect rectification phase, planning any new materials according to the findings and recommendations, and finally reaching the redelivery phase [18]. Uncertainties during the execution of a project can emerge from technicians' capacity situations such as holidays, illnesses, training, or overlapping tasks and projects due to delays or any other ad-hocs. They can also arise from unexpected findings that require time to contact the manufacturers and/or order material.

A delay in one line/project will affect other planned projects and aircraft. Thus, dynamic and continuous operational planning is needed to prevent the accumulation of negative effects. Therefore, keeping the agreement and delivering the aircraft back on time are two key elements of competitiveness in the market. The process of delivering the aircraft on time comprises the proper coordination of all resources involved to ensure aircraft punctuality and keep operators waiting as little as possible. At the same time, performing excellent maintenance work to ensure that the aircraft is reliable and airworthy.

However, in an environment characterized by many uncertainties and emergency occurrences, it is quite challenging to accurately forecast the future manually without the help of data-generated modules and algorithms, which is why it is easy to find research on such innovations. In the present paper, the problem is approached by the utilization of CP or constraint optimization. Due to the ability of these modules to find feasible solutions from a large set of candidates [19], they are popularly used in many disciplines, such as the healthcare sector [8] and by water and electricity distribution companies [20], among others.

CP has proven its efficiency in solving optimization problems that are too irregular for mathematical optimization. In our case, this includes allocation, scheduling, and sequencing problems [21].

The process will start by declaring in the programming language that the CP model will be used and then specifying the decision variables while taking only discrete variables into consideration as decision variables.

The next step is defining the constraints and expressions. The constraints must be logical, temporal, and specialized so they can be supported by the CP optimizer engine for CP combinatorial and scheduling models. Constraints in the CP model are propagated at execution time by the CP-solving engine. Constraint propagation is the process of communicating the domain reduction of a decision variable to all the constraints stated over this variable, which can result in more domain reductions. These domain reductions, in turn, are communicated to the appropriate constraints. This process is continued until no more variable domains can be reduced or when a domain becomes empty. When a domain is empty, it means that the model has no solution [21].

The last step is the search for the solution. To find a feasible solution, the optimizer will generate different combinations of values for decision variables through constructive strategies. These strategies are executed and guided toward optimal solutions to converge rapidly.

This CP module can consider large numbers of variables that are required in an MRO work environment as shown in Fig. 1. It needs to consider more than one area of investigation—for example, identifying the activities, tasks' precedence, technicians' allocation, materials' availability, and hangar slot requirements [22].

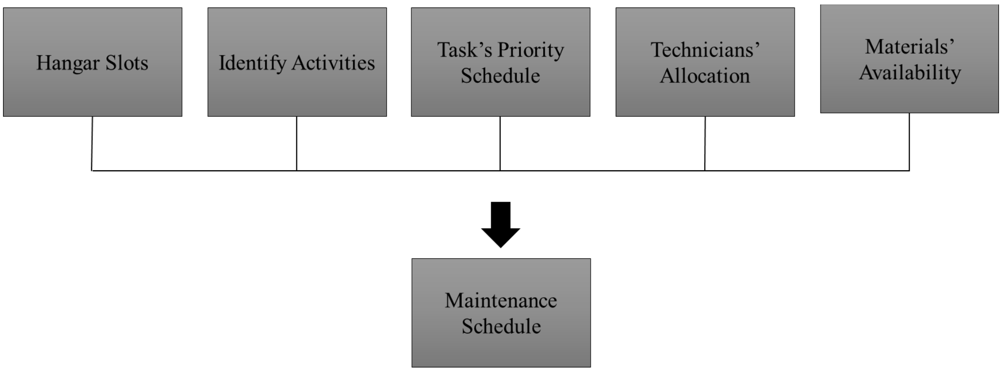

Fig. 1. Different fields that need to be incorporated into the CP module

2.1. Identification of Activities

The received maintenance activities are created under the name of work packages (WPs), such that different aircraft have different WP numbers. Tasks or jobs have been grouped under the maintenance WP. The origin or source of each task is based on the maintenance planning document (MPD) task number, aircraft maintenance manual task number (AMM), service bulletin (SB) number, customer task card (TC), or job order (JO) [23].

One of the main steps is to determine the module's ability to identify the different types of tasks in one work package (WP). The automatic breakdown of aircraft work packages into smaller parts or modules for each aircraft has been performed. The division was based on the type or nature of the tasks. The module first collects all of the tasks of the same nature—for example, special detailed inspection (SDI)—as shown in Fig. 2. This breakdown is gathered from the data collected from the customer's technical documentation and papers.

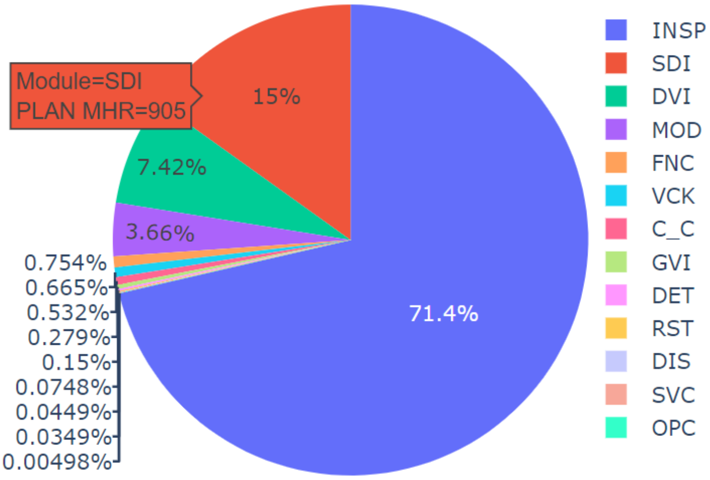

Fig. 2. The automatic breakdown of aircraft work packages

2.2. Tasks' precedence

As one of the main phases of the effective operational procedure is task structuring and prioritizing, it is worth trying to design some logic that the system optimization software should follow. This can only be achieved by creating predecessor activities, indicating which tasks should be completed before which job in a way that complies with both technical and logical conditions.

Based on the literature, structure and predecessor activities lay the foundation for effective planning and preparation [24], thus, paving the way to conclude the execution in an organized and efficient way. These prioritizations or precedent activities can only be defined based on knowledge about the project's activities, durations, and how these activities are connected during maintenance execution [25]. Combining the knowledge obtained from the scientific world with the knowledge obtained from the industry, an outline or a general framework was designed to establish good structure and priority for all activities. In this proposal, the effort was concentrated on finding a methodology that would apply to all aircraft types and different checks, as illustrated in Fig. 3. When the maintenance operation is initiated, it follows the indicated order.

After hangaring and access opening, multiple activities that form the big modules (airframe, engine, avionics, component change, and modifications) and under which subtasks take place in a specific order are initiated in parallel.

In the structured logic, the program issues the order to perform tasks as follows: checks tasks (CHK), detailed inspection (DET), special detailed inspections (SDI), visual checks (VCK), general visual inspections (GVI), defect rectification phase (DEF), discard tasks like the discard of filters and o rings (DIS), servicing tasks such as oil replenishments (SVC), lubrication (LUB), functional checks (FNC), and operational checks (OPC). As for the component change module (CC), we only have either change or restoration tasks (RST). The subtasks are ordered in a way that ensures that in case of any findings or non-routine occurrences, there is enough time to be mitigated. It is well known that it is more probable to find a faulty item or corroded part after a check or inspection rather than in the case of a simple discard/replacement or lubrication task.

The faster it is to reach the end of inspection or the inspection complete phase (IC), the more likely it is that the entire package will be finished on time. This is because the logistics department will have enough time to order the needed materials that are required after the raised NRCs; it will also give the engineering department enough time to handle the manufacturers' contacts and finish the defect rectification (DEF) in time. Hence, the aircraft can be delivered on time.

The inspection phases up to the IC is the most critical milestone in the entire work package flowchart. Once that phase has ended, the rest of the work is very clear. All the engineering and logistic support is finished, and it is up to the technicians to carry out the final rectification works and servicing allowing for the final stages of operational checks to be carried out.

Once all of the big modules and their related subtasks are finished, the access-panels close phase is launched. After that, pre-flight and final inspections take place following regulations [26], and the aircraft is then ready to be delivered to the operators.

2.3. Resources allocation (Technicians, slots, materials)

The practice of assigning and arranging resources, such as individuals, time and place slots, and supplies, to various tasks or activities efficiently and effectively is referred to as resource allocation. It creates a typical problem in many sectors and disciplines where effective resource allocation is critical for accomplishing corporate goals [27]. When allocating technicians and mechanics, their skills and qualifications should be taken into consideration [28].

Also, the availability of tools and materials [29] should be considered, as well as free hangar spots or slots [30]. At this stage of our investigation, there is no slot allocation or checking for materials' availability. These parameters will be integrated into the research in the future.

3. OBJECTIVES AND CONSTRAINTS PARAMETERS

During the MRO workflow and the execution of the long-term plan that was already decided by the assigned contracts, disruptions and the need to reschedule everything (resources, slots, tasks, etc) will eventually take place, no matter how good the original plan was. The reason for these changes as explained in the previous chapter is due to the dynamic and unpredictable findings and errors that might occur during the inspection phase. Hence, re-adapting to the new parameters will be needed at some point.

Usually, it is up to the line manager (LM) to manually reorganize the technicians and the planning department to deal with hangar slot reassignments. However, due to the complex and demanding nature of these tasks, accurately fulfilling the requirements of this work is quite challenging and can lead to inefficient and even poor decision-making tactics, especially during the high season, and many disruptions/problems. Thus, the implementation of a planning and scheduling module can offer required and quick support to aid decision-makers in making more informed and accurate decisions.

The framework allows the LM or the planner scheduler to input the real up-to-date data and problematic tasks, if any, making it easy to visualize all possible scenarios and solutions.

For creating such a framework, it was necessary to define the objective, inputs, variables, and constraints for the CP module to make sure it functioned as intended.

3.1. Inputs of the CP module

In the optimization example, a virtual or artificial environment was created. The environment consists of six aircraft (A/Cs), the maintenance process starts on the same date, and each A/C has a different number of manhours left as shown in Table 1.

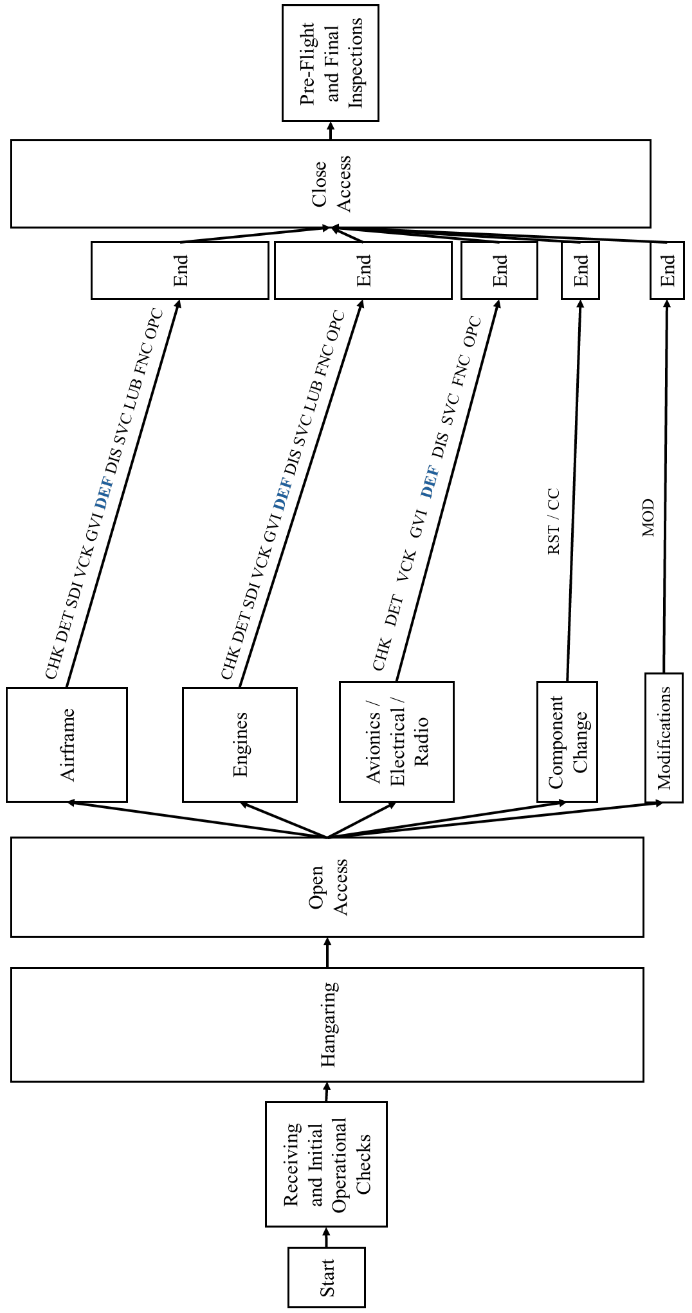

Fig. 3. Structure proposal for maintenance operations

Table 1

Start date and end date for each aircraft work package and the sum of man-hours left for each aircraft

Aircraft	Start date	End date	Man-Hours
A0	29-Apr-23	28-May-23	350
A1	29-Apr-23	24-May-23	300
A2	29-Apr-23	17-May-23	220
A3	29-Apr-23	19-May-23	250
A4	29-Apr-23	17-May-23	225
A5	29-Apr-23	22-May-23	280

These man-hours represent the time needed to complete the different WPs that are required to be done. The tasks of the WPs are shown in Table 2. In the example, the tasks were grouped based on the type of task, and, in this way, as already mentioned, each WP was divided into smaller phases or modules based on the type of tasks required. This will allow the line manager to have some flexibility between tasks and more freedom to move tasks in case of an emergency, material delay, or major findings/problems. The above maintenance checks need to be broken down into sub-tasks and then distributed to the technicians (six employees) in a way that ensures the TAT is met and the contracted downtime is respected.

3.2. Objective of the CP module

To maximize the performance of the planning and scheduling of the tasks while keeping time in mind, a skill measurement factor or worker key performance indicator (KPI) was introduced for each worker from 0 (minimum score) to 9 (maximum score) based on their skills, experience, and history of performing a certain task.

The main goal is to minimize downtime, ensuring that the MRO facility will finish the check on time by making sure that every technician is used effectively and efficiently. To ensure both objectives are satisfied, the introduction and measurement of skill performance will allow the module to distribute the tasks to the most skilled and experienced workers. Both goals can be achieved through the objective of maximizing the sum of skills. In this way, every technician will be graded between 0 and 9 for every task with the support of the already archived maintenance data and the management input. Table 3 shows the determined KPIs of the workers.

3.3. Constraints and conditions for the CP module

For this optimization to be realistic, multiple constraints and conditions needed to be identified and recognized by the process. The main condition was that no aircraft should be finished after the deadline so that the TAT is met.

The second constraint was the precedence constraint. This means the module will always follow the priority and precedence structure of the tasks that are shown in Fig. 2 while distributing and allocating the tasks to people and A/C. Also, the method has a constraint to avoid overlapping between the tasks of each worker. In other words, no worker should work on two tasks or two lines at the same time.

Overall, the variables can be categorized as follows:

- Technician assignment variables: Indicating which technicians are assigned to which tasks.
- Task scheduling variables: Temporal assignment for each maintenance task, indicating start and end times.

The constraints and conditions that the model will consider:

- **Technical Constraints**:
  - Availability of technicians for specific tasks to be taken from the technicians' calendars.
  - The qualifications of technicians for specific tasks to be taken from the given skill KPIs.
  - Interdependencies between the tasks to be taken from the proposed work package structure.
- **Capacity Constraints**:
  - Limits on the number of maintenance tasks that can be handled simultaneously based on available resources.
  - Avoid overlapping, which means the module will not schedule the same technician to perform more than one task at a time.
- **Time Constraints**:
  - Due dates for the entire maintenance checks (TAT) to minimize downtime.

The mathematical representation of the objective function is as follows:

Maximize: Total_Skill = $\sum_{k=1}^{N} \sum_{i\in Tasks} \sum_{j\in Workers} S_{i,j,k} \cdot x_{i,j,k}$

where:

- $S_{i,j,k}$ represents the skill KPI of the technicians j, for task I, on the aircraft *k*,
- $x_{i,j,k} \in \{0,1\}$ represents a binary variable indicating whether worker. This variable equals 1 if worker *j* is assigned to task *i* on airplane *k* and equals 0 otherwise,
- $i \in$ Tasks represents the set of tasks to be performed on the aircraft,
- $k \in$ Airplanes is the set of airplanes available in the hangar,
- $j \in$ Workers is the set of workers, taken from the employees' records and availability.

The total number of the total constraints for the above general guidelines and conditions was 276, which is a large number to satisfy considering the proposed project example was not especially large.

It is worth mentioning that not all conditions and constraints from Fig 1. were integrated into this optimization, as materials and slot availability were left out. Of course, in the future, they will be included, which will make the results more accurate and inclusive of all parameters.

Table 2

Work packages and tasks specified for the breakdown of each aircraft

A/C	Task	Man-Hours	Deadline	A/C	Task	Man-Hours	Deadline
A0	Open Access	40	28/5/2023	**A3**	Open Access	35	19/5/2023
	CHK	25			CHK	15	
	DET	20			DET	10	
	SDI	15			SDI	15	
	VCK	5			VCK	35	
	GVI	10			GVI	10	
	DEF	115			DEF	15	
	DIS	10			DIS	10	
	SVC	25			SVC	25	
	LUB	5			LUB	5	
	FNC	15			FNC	20	
	OPC	5			OPC	5	
	CloseAccess	60			Close Access	50	
	Total	**350**			**Total**	**250**	
A1	Open Access	35	24/5/2023	**A4**	Open Access	35	17/5/2023
	CHK	15			CHK	15	
	DET	30			DET	10	
	SDI	15			SDI	15	
	VCK	35			VCK	5	
	GVI	5			GVI	10	
	DEF	35			DEF	40	
	DIS	25			DIS	10	
	SVC	25			SVC	25	
	LUB	15			LUB	5	
	FNC	5			FNC	20	
	OPC	10			OPC	5	
	Close Access	50			Close Access	30	
	Total	**300**			**Total**	**225**	

A2	Open Access	30	17/5/2023
	CHK	10	
	DET	10	
	SDI	10	
	VCK	10	
	GVI	10	
	DEF	60	
	DIS	10	
	SVC	10	
	LUB	10	
	FNC	10	
	OPC	10	
	Close Access	30	
	Total	220	

A5	OpenAccess	45	22/5/2023
	CHK	15	
	DET	5	
	SDI	15	
	VCK	5	
	GVI	10	
	DEF	65	
	DIS	10	
	SVC	25	
	LUB	5	
	FNC	5	
	OPC	35	
	Close Access	40	
	Total	280	

Table 3

Assigned worker KPI for each task

Task	**Employee1**	**Employee2**	**Employee3**	**Employee4**	**Employee5**	**Employee6**
Open Access	7	4	5	3	9	9
CHK	7	0	5	8	1	9
DET	0	7	0	5	2	9
SDI	5	8	0	0	3	9
VCK	6	7	9	3	4	9
GVI	0	9	6	9	5	9
DEF	8	0	5	7	6	9
DIS	5	5	0	5	7	9
SVC	5	6	9	1	8	9
LUB	7	2	0	2	0	9
FNC	1	5	3	4	6	9
OPC	0	3	0	1	2	9
Close Access	9	3	6	1	2	9

4. RESULTS

The module was constructed in Python using the CPLEX library. The reason for choosing this library is that CPLEX is a high-performance mathematical programming solver for linear programming, mixed integer programming, and quadratic CP ~~constraint programming~~ [21].

The platform that was used to run the module and the simulation of the solution was Google Colab, which provides access to computing resources, including graphics processing units (GPUs) and tensor processing units (TPUs), allowing for the execution of the code through the hosted Jupyter Notebook service [31].

After running the CP module framework, it was shown that, as previously indicated, the model had 276 constraints and 480 variables. Also, the solving status was feasible, and the solving time was 3.12 seconds. This means that the tasks were distributed and allocated to people without any breach of the TAT constraint in a rather short time. The results are shown in the form of a Gantt chart in Fig. 3.

Each color in the chart refers to one of the aircraft. The flowchart indicates that at the start date, the MRO company needs to work on six aircraft in parallel to perform the open-access tasks on all of them. However, these parallel operations do not mean that the decision-makers need to rethink the capacity because the CP module already calculated these results while considering the number of available workers/technicians as shown in Fig. 4. Also, the more man-hours are required, the more frequent the work is on the related aircraft.

This optimization approach does not guarantee the maximum time utilization of the workers/technicians because the allocation of the tasks is based on the maximization of the performance and skill KPIs, meaning that the workers who are graded with lower performance KPIs will have more free time to join training and/or help other skilled workers to gain experience. However, in case of a busier schedule, the module will eventually start distributing tasks to lower-skilled technicians to adhere to the contracted TAT agreement. The work and the tasks were distributed based on the maximum sum of the skills. This means higher-rated technicians in certain tasks had a higher chance of getting those specific tasks, which they could perform in a way that guaranteed the fastest operations and enhanced the odds of finishing the job on time.

5. CONCLUSIONS AND FUTURE WORKS

The dynamic and continuously changing MRO environment increases the industry's need for new developments and innovative solutions. As the global aviation market continues to grow and expand [32], MRO service providers must enhance their operational performance and work effectiveness to stay relevant and keep up with their major competitors.

However, the complexity and diversity of the planning process make it extremely hard to keep a high level of working processes without any errors. Furthermore, as the work increases so will the difficulty of the planning and scheduling problem. In this context, effective and accurate scheduling and planning methodologies are needed and are becoming more of a strategic tool for MRO enterprises and decision-makers. Their significant effect is due to their economic importance in addition to enhanced accuracy and decreased wasted administrative time.

In this paper, an innovative CP module was introduced to support upper management and planners in making transparent and more accurate decisions in a relatively short time. This module can improve MRO processes to meet the demands of the modern industrial landscape through a thorough integration of variables, inputs, and objectives to create the desired goal or output. CP is a fundamental part of AI and is helping to solve many complex problems in dynamic environments such as the MRO work environment.

The module constructed in this study was successful, as it was capable of automatically splitting the maintenance work package into smaller modules based on zones and task types. Additionally, it was capable of considering 480 variables and 276 constraints to achieve the goal in a solving time of 3.12 seconds. The Gantt chart shows that all work was finished on time and no aircraft was delayed beyond the contracted TAT. Also, the CP module plotted the schedule of the workers so that every technician knows what to do, when to do it, and on which line to do it early on.

In future work, the introduction of new variables and constraints will take place. The next step is to expand the simple example considered in the present study to include more details and take more limitations into consideration. For example, the skills and qualifications of the technicians were inserted only from the perspective of the skill KPI; for more accuracy, these aspects will be considered based on the type of training the technician has received. More objectives are necessary to reach an even higher level of results. Infrastructure, hangar slots, the features of the hangar slots, facilities, equipment, spare parts, and tools should be considered. Furthermore, the optimization above deals with all the aircraft as new jobs and does not consider already existing jobs in the hangar. Thus, it will rearrange everyone and everything every time the MRO receives a new package, which might cause confusion and a lack of focus.

In addition, the materials, tools, equipment, and slot variables, together with their and other contribution's calendars, need to be integrated into the module to make the simulation of operation work as close to reality as possible and offer a mathematical representation of all constraints and conditions needed to provide not only a feasible solution but an optimal one as well.

The final vision is to combine what was created in this research and expand on it to create a full and reliable system that can create the optimum maintenance schedule starting from the slot allocation to the distribution of tasks, employees, tools, and materials.

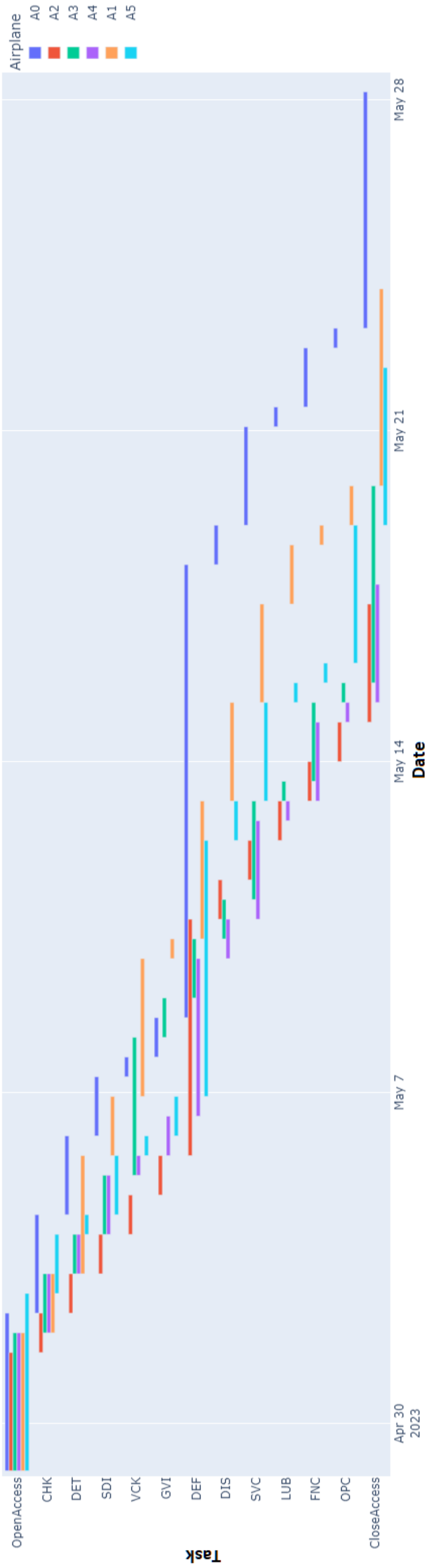

Fig. 4. CP module: preliminary results of the work in the form of a Gantt chart

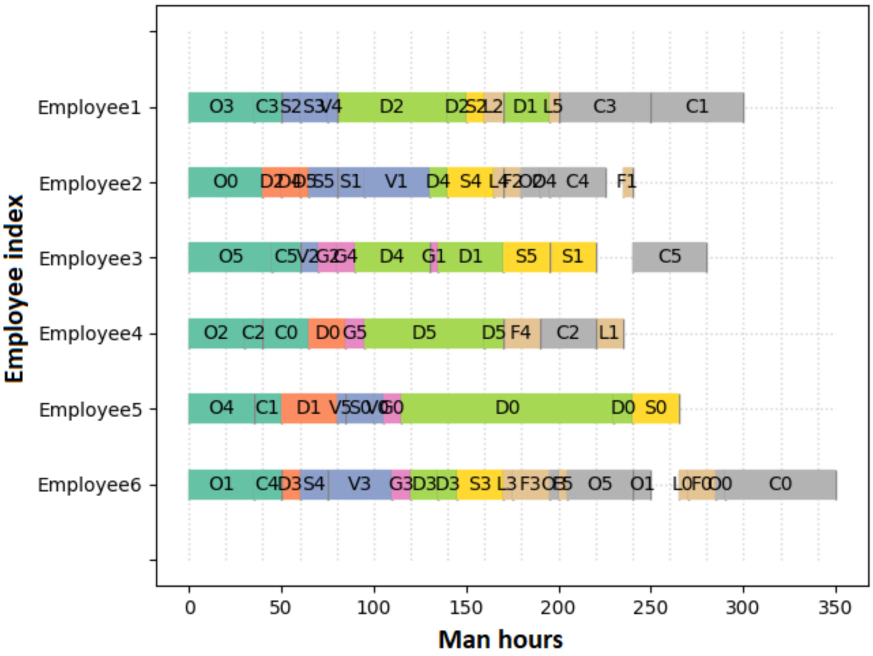

Fig. 5. CP module: preliminary results of the workers' schedule

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