OMAINTEC Journal
(Journal of Scientific Review)

Optimal Automated Designing Process for Annual Planning and Workload Distribution of Work Orders

Dr. Tarek M. M. Nasab
Lebanese International University
Saida, Lebanon
tarek.nasab@liu.edu.lb

Abstract
Effective planning of preventive maintenance work orders is crucial for the optimal performance and longevity of equipment and systems in various industries. This study investigates a strategic approach to scheduling preventive maintenance tasks by aligning them with common maintenance frequencies, synchronized execution hours, and consistent manpower allocation. The objective is to streamline maintenance operations, minimize downtime, and enhance overall efficiency. By analyzing historical maintenance data and identifying patterns in maintenance needs, the research proposes a model that groups work orders based on their frequency of occurrence, ensuring that tasks requiring similar intervals of attention are scheduled concurrently. Additionally, the model standardizes the execution hours for maintenance activities, allowing for better coordination and reduced disruption to operational workflows. The allocation of manpower is optimized to maintain a uniform number of personnel assigned to maintenance tasks, balancing the workload and preventing bottlenecks. The findings indicate that such an integrated planning approach can significantly improve the predictability and effectiveness of maintenance operations, leading to cost savings and improved asset reliability. This study provides a framework for maintenance managers to enhance their preventive maintenance strategies, ensuring that resources are utilized efficiently and maintenance activities are performed with minimal impact on productivity.

1 Introduction

A Computerized Maintenance Management System (CMMS) provides a comprehensive database of all assets within an organization, including equipment, machinery, and facilities. This ensures that maintenance teams have accurate and up-to-date information about each asset. One of the key features of CMMS is the ability to schedule and automate preventive maintenance tasks. This helps in preventing breakdowns, reducing downtime, and extending the lifespan of equipment. By implementing a proactive maintenance strategy, organizations can save costs associated with reactive repairs and replacements. The conventional strategy for the CMMS is to repeat the maintenance cycle for issuing PM work orders as per the previous year with modifications as per the request; if exists. The proposed optimal automated designing process presents a strategy for the annual planning and workload distribution for work orders that will be based on the input database provided by the CMMS. This strategy is based on the forecasted time required for each PM equipment type plus the required manpower to execute the PM maintenance work for each equipment. A study case is presented that represent the practical application of this strategy on South Lebanese Water Establishment (SLWE) Foundation.

OMAINTEC Journal
(Journal of Scientific Review)

2 Advantages & Disadvantages of PM Grouping of Work Orders

Grouping preventive maintenance work orders can have both advantages and disadvantages [1]. Here are some of them:

Efficiency and Time Saving: 1. **Streamline Planning:** Grouping similar preventive maintenance tasks allows for more efficient planning. You can schedule and organize work orders in a way that minimizes downtime and maximizes productivity. 2. **Bulk Scheduling:** Performing maintenance on multiple assets or systems at once can save time compared to scheduling individual tasks separately.	Advantages
Resource Optimization: 1. **Optimal Resource Allocation:** Grouping work orders helps in optimizing the use of resources such as manpower, tools, and equipment. Technicians can work on related tasks without the need to switch between different types of jobs frequently. 2. **Reduced Time Travel:** If tasks are grouped based on location, it can minimize travel time for maintenance crews.	
Consistency: 1. **Standardization:** Grouping work orders enables the standardization of maintenance procedures. This consistency can lead to better results and more reliable equipment performance.	
Cost Saving: 1. **Economies of Scales:** When maintenance tasks are grouped, there is a potential for cost savings due to economies of scale, especially when ordering parts or materials in bulk.	
Overlooked Details: 1. **Missed Specifics:** Grouping work orders may lead to overlooking specific requirements of individual assets. Some assets might have unique needs that could be neglected in a generalized maintenance approach.	Disadvantages
Flexibility Challenges: 1. **Limited Flexibility:** Grouping work orders may limit flexibility in scheduling, especially when unexpected issues arise. If all tasks are tightly grouped, it may be challenging to accommodate urgent maintenance needs.	Disadvantages

Complexity: 1. **Increasing Complexity:** Managing a large number of tasks in a group can increase the complexity of coordination and oversight. This complexity may lead to confusion or errors if not managed properly.	**Disadvantages**

Table1. Advantages & Disadvantages of Grouping of PM Work Orders

Striking a balance between efficiency and flexibility is crucial to ensuring the effectiveness of preventive maintenance strategies.

3 Strategies & Approaches Application for Planning PM Work Orders for the Yearly Maintenance Cycle

There are different strategies and approaches that can be used to plan work orders for the whole yearly maintenance cycle. Some of these strategies and processes represents the methods that are listed in Table 2:

Calendar-Based Scheduling	It is a maintenance strategy where tasks are scheduled at regular intervals, regardless of the asset's condition. This approach is often used when equipment requires regular maintenance to ensure reliable operation, even if there are no immediate signs of wear or failure. [2]
Condition-Based Maintenance (CBM)	It is a comprehensive and systematic approach to maintenance planning that focuses on preserving the function of critical assets while minimizing costs. The primary goal of RCM is to determine the most effective maintenance strategies to ensure that assets continue to operate reliably within their intended functions. This approach considers the different types of failures that can occur, the consequences of those failures, and the best ways to mitigate those risks. [3]
Run-Time-Based Scheduling	It is a maintenance strategy where tasks are scheduled based on the actual runtime of equipment or machinery, rather than on calendar time or condition. This method is particularly useful for equipment that operates under varying usage patterns, ensuring that maintenance is aligned with the actual wear and tear the equipment experiences. [4]
Task Grouping	It is a maintenance strategy where similar or related tasks are grouped together and scheduled to be performed at the same time. This approach is designed to optimize efficiency by reducing the frequency of maintenance activities, minimizing equipment downtime, and making better use of resources. [5]
Resource-Based Planning	It is a strategy where the scheduling of preventive maintenance (PM) work orders is driven by the availability of resources—such as personnel, tools, equipment, and materials—rather than by fixed time intervals or condition-based triggers. This approach ensures that maintenance tasks

	are planned and executed efficiently, using available resources optimally and avoiding delays due to resource shortages. [6]
Reliability-Centered Maintenance (RCM)	It is a comprehensive and systematic approach to maintenance planning that focuses on preserving the function of critical assets while minimizing costs. The primary goal of RCM is to determine the most effective maintenance strategies to ensure that assets continue to operate reliably within their intended functions. This approach considers the different types of failures that can occur, the consequences of those failures, and the best ways to mitigate those risks. [7]
Failure Modes and Effects Analysis (FMEA)	It is a systematic method for identifying potential failure modes within a system, assessing the causes and effects of those failures, and prioritizing actions to mitigate the risks associated with them. When used in planning preventive maintenance (PM) work orders, FMEA helps organizations focus their maintenance efforts on preventing the most critical and likely failures, thereby enhancing equipment reliability and safety. [8]

Table2. strategies and approaches to plan work orders for the whole yearly maintenance cycle.

4 Optimal Automated Designing Process Strategy

PM grouping and work order planning are crucial components of an effective maintenance strategy. They help in optimizing maintenance activities, reducing costs, and ensuring the reliability and safety of equipment throughout the maintenance cycle year.

Preventive Maintenance (PM) is a proactive approach that involves regularly scheduled inspections, adjustments, and replacements of equipment and systems to ensure optimal performance and prevent unexpected failures. A critical aspect of this approach is the grouping of work orders and planning them effectively throughout the maintenance cycle year.

PM grouping refers to the practice of organizing and consolidating similar or related maintenance tasks into a single work order or a group of work orders. This method is used to streamline maintenance activities, minimize equipment downtime, and optimize resource allocation. By grouping tasks that can be performed simultaneously or sequentially, maintenance teams can reduce the frequency of disruptions and improve overall efficiency.

Work order planning for the maintenance cycle year involves scheduling these grouped tasks at appropriate intervals, ensuring that all necessary preventive maintenance activities are completed within the planned cycle. This planning takes into account factors such as equipment criticality, manufacturer recommendations, historical performance data, and available resources.

Each asset/equipment may have up to four types of frequencies as shown in the table below:

	Type	Frequency
1	Type One	Monthly
2	Type Two	Quarterly
3	Type Three	Semi-Annual
4	Type Four	Annual

Table3. Types of Maintenance Frequencies

If such an asset/equipment has the four types of frequencies, then its highest frequency is the “Annual” one. If it has only types one and two, then its highest frequency is “Quarterly”, and so on. Other types of Frequencies may be added to above table for such certain equipment as per manufacturer recommendation.
The proposed optimal automated designing process consists of four main steps that represent the proposed strategy for the designing process. The input database that are listed in the equipment inventory, where the forecasted time required for each PM equipment type plus the required manpower are listed, represent the required data for this strategy. The strategy for the optimal automated designing process consists of two major steps.
The first step is to set-up the input database for all PM equipment. All the information per equipment are presented, as shown in Figure 1, as it will be considered as an input data for the software that will deal with these data. These data will be classified and re-arranged, as shown in Figure 2, in order to be set into groups.
As per **the second step**, each group consists of same equipment with same frequency, forecasted man-hours and required manpower. Besides, it is also possible to group different equipment together, but with the same frequency, forecasted man-hours and required manpower as well.

Servicem (Parent)						System (Child)						PM	Frequency				Manhours				Manpower			
	Family	Description	Group	Description	MU	Service	Family	Description	Group	Group description	MU		M	Q	S	A	M	Q	S	A	M	Q	S	A
1111	WLL	WELL	110	WATER WELL 1	SET		PMP	PUMP	1090	SUB. 90 HP	PC	X	X			X	0.5			2	1			2
1111	WLL	WELL	111	WATER WELL 5	SET		PMP	PUMP	1090	SUB. 90 HP	PC	X	X		X		0.3		0.3		1		1	
1111	WLL	WELL	110	WATER WELL 1	SET	1111	ACC	INSTRUMENT	1100	PRESSURE GAGE WITH ISOLATING VALVE	PC	X	X		X		0.3		0.3		1		1	
1111	WLL	WELL	114	WATER WELL 3	SET		ACC	INSTRUMENT	1100	PRESSURE GAGE WITH ISOLATING VALVE	PC	X	X		X		0.3		0.3		1		1	
1111	WLL	WELL	111	WATER WELL 5	SET		FLW	FLOW METER	1100	ELECTROMAGNETIC FLOW METER	PC	X	X			X	0.3			2	1			1
1111	WLL	WELL	114	WATER WELL 3	SET		FLW	FLOW METER	1100	ELECTROMAGNETIC FLOW METER	PC	X	X				0.5			2				
1111	WLL	WELL	110	WATER WELL 1	SET		VAV	VALVE	1100	GATE VALVE DN100	PC	X	X			X	0.5			2				
1111	WLL	WELL	111	WATER WELL 5	SET		VAV	VALVE	1100	GATE VALVE DN100	PC	X	X		X		0.3		0.3		1		1	
1111	WLL	WELL	111	WATER WELL 5	SET		VAV	VALVE	1100	GATE VALVE DN100	PC	X	X			X	0.2			2	1			1
1111	WLL	WELL	110	WATER WELL	SET		ACC	INSTRUMENT	1110	PRESSURE TRANSMITTER	PC	X			X		0.3		0.3		1		1	
1111	WLL	WELL	111	WATER WELL 5	SET		ACC	INSTRUMENT	1110	PRESSURE TRANSMITTER	PC	X				X								
1111	WLL	WELL	114	WATER WELL 3	SET		VAV	VALVE	1110	GATE VALVE DN100	PC	X	X			X								
1111	WLL	WELL	111	WATER WELL 5	SET		ACC	INSTRUMENT	1120	PRESSURE GAGE	PC	X			X		0.3		0.3		1		1	
1111	WLL	WELL	114	WATER WELL 3	SET		PMP	PUMP	1150	SUB. 150 HP	PC	X	X											
1111	WLL	WELL	110	WATER WELL 1	SET		VAV	VALVE	1150	GATE VALVE DN150	PC	X	X			X	0.5			2	1			2
1111	WLL	WELL	111	WATER WELL 5	SET		VAV	VALVE	1150	GATE VALVE DN150	PC	X	X		X		0.3		0.3		1		1	
1111	WLL	WELL	114	WATER WELL 3	SET		VAV	VALVE	1150	GATE VALVE 150	PC	X	X		X		0.3		0.3		1		1	
1111	WLL	WELL	110	WATER WELL 1	SET	1111	ACC	INSTRUMENT	1200	STRAINER DN150	PC	X	X			X	0.5			2	1			1
1111	WLL	WELL	114	WATER WELL 3	SET		ACC	INSTRUMENT	1200	STRAINER DN150	PC	X	X		X		0.3		0.3		1		1	
1111	WLL	WELL	110	WATER WELL 1	SET		FLW	FLOW METER	1200	MECHANICAL FLOW METER	PC	X	X		X				0.3				1	
1111	WLL	WELL	110	WATER WELL	SET		ACC	INSTRUMENT	1300	FLOW SWITCH	PC	X				X								1
1111	WLL	WELL	114	WATER WELL 3	SET		ACC	INSTRUMENT	1300	FLOW SWITCH	PC	X				X	0.5			2	1			1
1111	WLL	WELL	110	WATER WELL 1	SET		VAV	VALVE	1415	DUAL PLATE CHECK VALVE DN150	PC	X	X		X		0.3		0.3		1		1	
1111	WLL	WELL	111	WATER WELL 5	SET		VAV	VALVE	1415	CHECK VALVE DN150	PC	X	X		X		0.3		0.3		1		1	
1111	WLL	WELL	114	WATER WELL 3	SET		VAV	VALVE	1415	CHECK VALVE DN150	PC	X	X		X		0.3		0.3		1		1	
1111	WLL	WELL	110	WATER WELL 1	SET		VAV	VALVE	1500	RELEASE VALVE WITH ISOLATING VALVE I	PC	X	X											
1111	WLL	WELL	111	WATER WELL 5	SET		VAV	VALVE	1500	AIR RELEASE VALVE DN65	PC	X	X			X	0.5			2	1			2
1111	WLL	WELL	114	WATER WELL 3	SET		VAV	VALVE	1500	RELEASE VALVE WITH ISOLATING VALVE I	PC	X	X			X				0				1
1111	WLL	WELL	110	WATER WELL 1	SET		VAV	VALVE	1600	GLOBE VALVE DN150	PC	X	X		X		0.3		0.3		1		1	
1111	WLL	WELL	114	WATER WELL 3	SET		VAV	VALVE	1600	GLOBE VALVE DN150	PC	X	X		X		0.3		0.3		1		1	
1111	WLL	WELL	110	WATER WELL 1	SET	1111	ACC	RUBBER JOINT	1700	RUBBER JOINT DN150	PC	X	X		X		0.3		0.3		1		1	
1111	WLL	WELL	114	WATER WELL 3	SET		ACC	RUBBER JOINT	1700	RUBBER JOINT DN150	PC	X	X			X	0.2			2	1			1
1111	WLL	WELL	110	WATER WELL 1	SET		ACC	RUBBER JOINT	1710	RUBBER JOINT DN100	PC	X	X			X	0.5			2	1			1
1111	WLL	WELL	111	WATER WELL 5	SET		ACC	RUBBER JOINT	1710	RUBBER JOINT DN100	PC	X	X		X		0.3		0.3		1		1	
1111	WLL	WELL	114	WATER WELL 3	SET		ACC	RUBBER JOINT	1710	RUBBER JOINT DN100	PC	X	X		X		0.3		0.3		1		1	
1111	WLL	WELL	111	WATER WELL 5	SET		ACC	SMANTELING JOII	1720	DISMANTELING JOINT DN 100	PC	X	X		X		0.3		0.3		1		1	

Figure 1: Partial listed data for Equipment Inventory for SLWE Foundation

The objective of the second step is to group the equipment as per its common frequency, forecasted man-hours and manpower as shown in the same Figure. For instance, and from Figure 2, the PM Group D100 represents 8 pumps with different types, but with the same frequency, forecasted man-hours and manpower. It is expected that 11 Monthly and one Annual work orders will be generated for the D100 PM Group.
Figures 2 presents the list of equipment that is related to a water substation that can be grouped and be fed as input data into the CMMS system. CMMS system will determine the number of equipment that can be assigned to one work order as per the available manpower. If the CMMS system is a homemade

software, it can be modified to execute the process of this proposed input data design. Otherwise, an Excel file, for instance, can be used in order to set-up the data as shown in the previous figures, then be fed into the CMMS system. The purpose of this proposed strategy is to reduce the number of generated work orders per equipment that will result in reducing the required manpower to plan and execute them.

Record #	Site	Service	Location Code	System Code	Subsystem Code	Frequency				PM Group	Forecasted Man Hours				Required Manpower				Total Forecasted Man Hours				
						Monthly	Quarterly	Semi-Annual	Annual		M	Q	S	A	M	Q	S	A	M	S	A	Tot	
1	1010	1111		WLL 110	PMP 090	M			A	D100	0.5			2	1			2	5.5		2	7.5	
2	1010	1111		WLL 110	FLW 200	M			A	D100	0.5			2	1			2	5.5		2	7.5	
3	1010	1111		WLL 111	PMP 090	M			A	D100	0.5			2	1			2	5.5		2	7.5	
4	1010	1111		WLL 112	PMP 090	M			A	D100	0.5			2	1			2	5.5		2	7.5	
5	1010	1111		WLL 113	PMP 090	M			A	D100	0.5			2	1			2	5.5		2	7.5	
6	1010	1111		WLL 114	PMP 150	M			A	D100	0.5			2	1			2	5.5		2	7.5	
7	1010	1111		WLL 115	PMP 060	M			A	D100	0.5			2	1			2	5.5		2	7.5	
8	1010	1111		WLL 116	PMP 090	M			A	D100	0.5			2	1			2	5.5		2	7.5	
9	1010	1111		WLL 116	PMP 025	M			A	D100	0.5			2	1			2	5.5		2	7.5	70:30 hours
1	1010	1111		WLL 110	ACC 700	M		S		D101	[illegible]		[illegible]		1		1		3.0	1		4	
2	1010	1111		WLL 112	ACC 700	M		S		D101	[illegible]		[illegible]		1		1		3.0	1		4	
3	1010	1111		WLL 113	ACC 700	M		S		D101	[illegible]		[illegible]		1		1		3.0	1		4	
4	1010	1111		WLL 114	ACC 700	M		S		D101	[illegible]		[illegible]		1		1		3.0	1		4	16 hours
		⋮					⋮												⋮				
1	1010	1111		WLL 116	VAV 240	M		S		D119	[illegible]		[illegible]		1		1		3.0	1		4	
2	1010	1111		WLL 116	VAV 240	M		S		D119	[illegible]		[illegible]		1		1		3.0	1		4	
3	1010	1111		WLL 116	VAV 240	M		S		D119	[illegible]		[illegible]		1		1		3.0	1		4	
4	1010	1111		WLL 116	VAV 240	M		S		D119	[illegible]		[illegible]		1		1		3.0	1		4	
5	1010	1111		WLL 116	VAV 240	M		S		D119	[illegible]		[illegible]		1		1		3.0	1		4	20 hours
																			379:50 hours				

Figure 2: Grouped Equipment with common frequency, man-hours, & manpower

OMAINTEC Journal
(Journal of Scientific Review)

The third step is to determine the starting date of these planned PM Group work orders according to the highest frequency of each equipment as it is shown in Figure 3. Besides, the data for the Equipment inventory in above figures represent the partial data for the water substations that feed the Saida City and around villages with fresh water. A sample of this data were considered to demonstrate the proposed strategy for the optimal automated designing process for annual planning and workload distribution of work orders.

A1	MA1	MA2	MA3	MA4	MA5	MA6	MA7	MA8	MA9	MA10	MA11	PMP 090	A - M
S1	MA12	MA13	MA14	MA15	MA16	S2	MA17	MA18	MA19	MA20	MA21	ACC 700	S - M
S3	MA22	MA23	MA24	MA25	MA26	S4	MA27	MA28	MA29	MA30	MA31	VAV 150	S - M
S5	MA32	MA33	MA34	MA35	MA36	S6	MA37	MA38	MA39	MA40	MA41	ACC 100	S - M
A2	MA42	MA43	MA44	MA45	MA46	MA47	MA48	MA49	MA50	MA51	MA52	VAV 500	A - M
A3	MA53	MA54	MA55	MA56	MA57	MA58	MA59	MA60	MA61	MA62	MA63	FLW 200	A - M
A4	MA64	MA65	MA66	MA67	MA68	MA69	MA70	MA71	MA72	MA73	MA74	VAV 415	A - M
S7	MA75	MA76	MA77	MA78	MA79	S8	MA80	MA81	MA82	MA83	MA84	VAV 100	S - M
A5	MA85	MA86	MA87	MA88	MA89	MA90	MA91	MA92	MA93	MA94	MA95	ACC 200	A - M
S9	MA96	MA97	MA98	MA99	MA100	S10	MA101	MA102	MA103	MA104	MA105	VAV 600	S - M
A6												ACC 300	A
A7												ACC 110	A
S11	MA106	MA107	MA108	MA109	MA110	S12	MA111	MA112	MA113	MA114	MA115	ACC 710	S - M

A8	MA116	MA117	MA118	MA119	MA120	MA121	MA122	MA123	MA124	MA125	MA126	PMP 090	A - M
S13	MA127	MA128	MA129	MA130	MA131	S14	MA132	MA133	MA134	MA135	MA136	VAV 150	S - M
S15	MA137	MA138	MA139	MA140	MA141	S16	MA142	MA143	MA144	MA145	MA146	VAV 415	S - M
A9	MA147	MA148	MA149	MA150	MA151	MA152	MA153	MA154	MA155	MA156	MA157	VAV 500	A - M
S17	MA158	MA159	MA160	MA161	MA162	S18	MA163	MA164	MA165	MA166	MA167	ACC 710	S - M
S19						S20						ACC 120	S
A10												ACC 110	A
A11	MA168	MA169	MA170	MA171	MA172	MA173	MA174	MA175	MA176	MA177	MA178	FLW 100	A - M
S21	MA179	MA180	MA181	MA182	MA183	S22	MA184	MA185	MA186	MA187	MA188	ACC 720	S - M
S23	MA189	MA190	MA191	MA192	MA193	S24	MA194	MA195	MA196	MA197	MA198	VAV 100	S - M
S25	MA199	MA200	MA201	MA202	MA203	S26	MA204	MA205	MA206	MA207	MA208	VAV 100	S - M
	⋮					⋮					⋮		

A30	MA731	MA732	MA733	MA734	MA735	MA736	MA737	MA738	MA739	MA740	MA741	PMP 025	A - M
S107	MA742	MA743	MA744	MA745	MA746	S108	MA747	MA748	MA749	MA750	MA751	ACC 730	S – M
S109	MA752	MA753	MA754	MA755	MA756	S110	MA757	MA758	MA759	MA760	MA761	ACC 730	S – M
S111	MA762	MA763	MA764	MA765	MA766	S112	MA767	MA768	MA769	MA770	MA771	VAV 240	S – M
S113	MA772	MA773	MA774	MA775	MA776	S114	MA777	MA778	MA779	MA780	MA781	VAV 240	S – M
S115	MA782	MA783	MA784	MA785	MA786	S116	MA787	MA788	MA789	MA790	MA791	VAV 430	S – M
A31	MA792	MA793	MA794	MA795	MA796	MA797	MA798	MA799	MA800	MA801	MA802	FLW 100	A - M
S117						S118						ACC 100	S

Figure 3: Work Order distribution according to the frequencies of each equipment

OMAINTEC Journal
(Journal of Scientific Review)

The fourth step belongs to the software itself to plan and distribute the PM Group work orders according to the starting date of each group as per its highest frequency, as shown in Figure 4. Besides, the software will also equally distribute the load of maintenance work, on an annual basis, according to a rhythm that will be presented as per Figure 7.

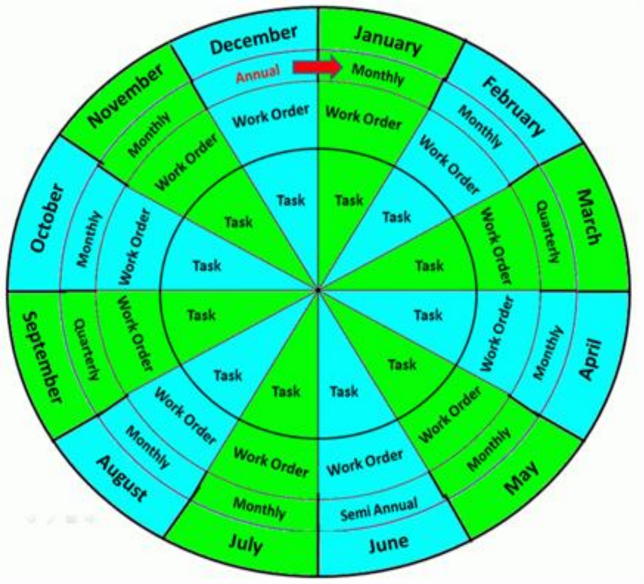

Figure 4: Maintenance Cycle Loop.

Figure 5, shows the pre-arrangement and post-arrangement data of the equipment inventory. The left side of the figure lists the PM Groups of the whole water substation, starting from PM Group D100 and ends with D119. On the right side of the figure, it lists all PM Groups of D100 together and so on till D119.

Location Code	System Code	Subsystem Code	Frequency				PM Group	Forecasted Man Hours				Required Manpower				Total Forecasted Man Hours			
			M	Q	S	A		M	Q	S	A	M	Q	S	A	M	S	A	Tot
	WLL 110	PMP 090	M			A	D100	0.5			2	1			2	5.5		2	7.5
	WLL 110	ACC 700	M		S		D101	0.3		0.3		1		1		3.0	1		4
	WLL 110	VAV 150	M		S		D102	0.3		0.3		1		1		3.0	1		4
	WLL 110	ACC 100	M		S		D103	0.3		0.3		1		1		3.0	1		4
	WLL 110	VAV 500	M		S		D104	0.3		0.3		1		1		3.0	1		4
	WLL 110	FLW 200	M			A	D100	0.5			2	1			1	5.5		2	7.5
	WLL 110	VAV 415	M		S		D105	0.3		0.3						3.0	1		4
	WLL 110	VAV 100	M		S		D106	0.3		0.3		1		1		3.0	1		4
	WLL 110	ACC 200	M			A	D107	0.2			2	1			1	2.2		2	4.2
	WLL 110	VAV 600	M		S		D108	0.3		0.3		1		1		3.0	1		4
	WLL 110	ACC 300				A	D109				1				1			1	1
	WLL 110	ACC 110				A	D110				1				1			1	1
	WLL 110	ACC 710	M		S		D111	0.3		0.3		1		1		3.0	1		4
	WLL 111	PMP 090	M			A	D100	0.5			2	1			2	5.5		2	7.5
	WLL 111	VAV 150	M		S		D102	0.3		0.3		1		1		3.0	1		4
	WLL 111	VAV 415	M		S		D105	0.3		0.3		1		1		3.0	1		4
	WLL 111	VAV 500	M		S		D104	0.3		0.3		1		1		3.0	1		4
	WLL 111	ACC 710	M		S		D111	0.3		0.3		1		1		3.0	1		4
	WLL 111	ACC 120			S		D112			0.3				1			1		1
	WLL 111	ACC 110				A	D110				1				1			1	1
	WLL 111	FLW 100	M			A	D113	0.5			2	1			1	5.5		2	7.5
	WLL 111	ACC 720	M		S		D106	0.3		0.3		1		1		3.0	1		4
	WLL 111	VAV 100	M		S		D106	0.3		0.3		1		1		3.0	1		4
	WLL 111	VAV 100	M		S		D106	0.3		0.3		1		1		3.0	1		4

Record #	Site	Service	Location Code	System Code	Subsystem Code	Frequency				PM Group	Forecasted Man Hours				Required Manpower				Total Forecasted Man Hours				
						Monthly	Quarterly	Semi-Annual	Annual		M	Q	S	A	M	Q	S	A	M	S	A	Tot	
1	1010	1111		WLL 110	PMP 090	M			A	D100	0.5			2	1			2	5.5		2	7.5	
2	1010	1111		WLL 110	FLW 200	M			A	D100	0.5			2	1			2	5.5		2	7.5	
3	1010	1111		WLL 111	PMP 090	M			A	D100	0.5			2	1			2	5.5		2	7.5	
4	1010	1111		WLL 112	PMP 090	M			A	D100	0.5			2	1			2	5.5		2	7.5	
5	1010	1111		WLL 113	PMP 090	M			A	D100	0.5			2	1			2	5.5		2	7.5	
6	1010	1111		WLL 114	PMP 150	M			A	D100	0.5			2	1			2	5.5		2	7.5	
7	1010	1111		WLL 115	PMP 060	M			A	D100	0.5			2	1			2	5.5		2	7.5	
8	1010	1111		WLL 116	PMP 090	M			A	D100	0.5			2	1			2	5.5		2	7.5	
9	1010	1111		WLL 116	PMP 025	M			A	D100	0.5			2	1			2	5.5		2	7.5	70:30 hours
1	1010	1111		WLL 110	ACC 700	M		S		D101	0.3		0.3		1		1		3.0	1		4	
2	1010	1111		WLL 112	ACC 700	M		S		D101	0.3		0.3		1		1		3.0	1		4	
3	1010	1111		WLL 113	ACC 700	M		S		D101	0.3		0.3		1		1		3.0	1		4	
4	1010	1111		WLL 114	ACC 700	M		S		D101	0.3		0.3		1		1		3.0	1		4	16 hours
⋮								⋮											⋮				
1	1010	1111		WLL 116	VAV 240	M		S		D119	0.3		0.3		1		1		3.0	1		4	
2	1010	1111		WLL 116	VAV 240	M		S		D119	0.3		0.3		1		1		3.0	1		4	
3	1010	1111		WLL 116	VAV 240	M		S		D119	0.3		0.3		1		1		3.0	1		4	
4	1010	1111		WLL 116	VAV 240	M		S		D119	0.3		0.3		1		1		3.0	1		4	
5	1010	1111		WLL 116	VAV 240	M		S		D119	0.3		0.3		1		1		3.0	1		4	20 hours
																			379:50 hours				

Figure 5: Pre and post data arrangement for the equipment inventory

The data that is shown in Figure 3 is then fed into the CMMS system in order to generate the work orders for each Group, D100 – D119. Next is to balance, per week, the distribution of the forecasted man-hours, and to balance the number of work orders per week as well. The annual work order distribution per week will start by considering the highest frequency per equipment. The rhythm of distribution of grouped work orders will starts as follows; the highest frequency for PMP 090, as shown in Figure 3 - first row, is Annual, where it is Semi-annual for ACC 700. The CMMS system will read the arranged data from Figure 3 and distribute according to the following algorithm. The 12 work orders for PMP 090, with annual highest frequency, will first start on week #1 of January with the annual work order "A1" and will be followed with MA1 on week #1 of February, then with MA2 on week #1 of March, and so on till distribution process reaches to MA11 on Week #1 of December. Same distribution will be done for the "S1" work order. S1 work order will be assigned to week #2 of January, then MA12 on week #2 of February, and so on till MA21 on week #2 of December. Besides, S5 will be assigned on week #4 of January, and will end up with work order MA41 on week #4 on December.

Next, a new distribution cycle will start with work order A2, 5th row of right table of Figure 6. It will start on week #1 of February, and MA51 will be assigned on week #1 on December, where MA52 will be assigned on week #1 of January. Same process is repeated for work order A5. It will start on week #1 of March, and so on till MA93 on week #1 of December, followed by MA94 on week #1 of January, and will end up with MA95 on week #1 of February. And so on till the complete of Figure 3 will be read and distributed according to the distribution algorithm planned for this optimal automated designing process of PM Group work orders.

January				February				March				April			
Wk1	Wk2	Wk3	Wk4	Wk1	Wk2	Wk3	Wk4	Wk1	Wk2	Wk3	Wk4	Wk1	Wk2	Wk3	Wk4
A1				MA1				MA2				MA3			
	S1				MA12				MA13				MA14		
		S3				MA22				MA23				MA24	
			S5				MA32				MA33				MA34
				A2				MA42				MA43			
MA52					A3				MA53				MA54		
	MA63					A4				MA64				MA65	
		MA74					S7				MA75				MA76
			MA84					A5				MA85			
MA94				MA95					S9				MA96		
	MA104				MA105					A6				A7	
		MA112				MA113				MA114				MA115	
			MA123				MA124				MA125				MA126
MA132				MA133				MA134				MA135			
	MA142				MA143				MA144				MA145		
		MA153				MA154				MA155				MA156	
			MA163				MA164				MA165				MA166
MA170				MA171				MA172				MA173			
	MA181				MA182				MA183				S22		
		MA191				MA192				MA193				S24	
			MA201				MA202				MA203				S26
MA210				MA211				MA212				MA213			
	MA221				MA222				MA223				MA224		
		MA231				MA232				MA233				MA234	
			MA241				MA242				MA243				MA244
MA250				MA251				MA252				MA253			
	S36				A13				A14				MA260		
	MA269				MA270					S37				MA271	
		MA279				MA280					S39				MA281
			MA289				MA290					A15			

Figure 6: Weekly Work Order Distribution for the whole annual maintenance year.

The distribution of all PM Group work orders is partially shown in Figure 7. The huge data cannot be presented in a figure. Figure 7 shows the equally distributed PM Group work orders on a weekly basis. The range of weekly PM Grouped work orders is between 19 to 21 work orders. The results demonstrate the effectiveness of this proposed strategy.

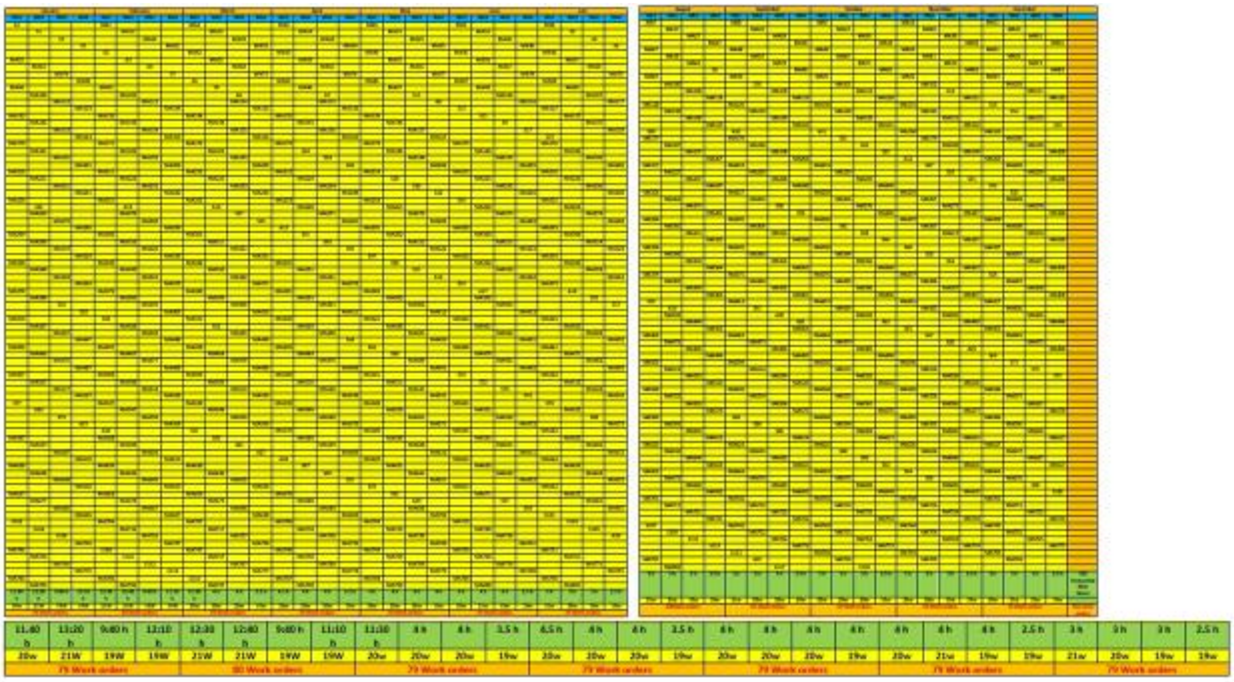

Figure 7: Totally equal distributed PM Group work orders on a weekly basis for whole maintenance year.

The numbers and types of the distributed PM Group work orders are shown in Figure 8. Instead of issuing 951 work orders for the active equipment at the Water Substation, only 119 PM Group work orders is issued and distributed across the executing schedule for the whole maintenance year.

Total Number of Work Orders: Monthly =	802
Semi-Annual =	118
Annual =	31

	951

Figure 8: Numbers and types of the distributed PM Group work orders for the whole maintenance year.

5 Conclusion

By implementing a systematic approach to PM planning of work orders, the annual maintenance workload can be evenly distributed across the year, ensuring consistent resource utilization and minimizing operational disruptions. By strategically grouping Preventive Maintenance work orders based on similar frequencies, same manpower requirements, and man-hours as well, it is possible to achieve a balanced and efficient maintenance schedule. This approach ensures that the workload is evenly distributed on a weekly maintenance calendar basis throughout the year, optimizing the use of resources and minimizing operational disruptions. The proposed strategy enhances productivity by aligning tasks that require similar resources, reducing the need for frequent adjustments in staffing or scheduling. Ultimately, this strategy promotes a smoother maintenance process, with predictable workloads that facilitate better planning, resource management, and overall operational efficiency.

References

[1] Anthony Kelly, "Maintenance Strategy: Optimal Equipment Life-Cycle Decisions", 2nd edition, Butterworth-Heinemann, 2006.
[2] Richard D. Palmer, "Maintenance Planning and Scheduling Handbook", 4th edition, McGraw-Hill Education, 2019.
[3] R. Keith Mobley, "Condition-Based Maintenance and Machine Diagnostics", 1st edition, Butterworth-Heinemann, 1991.
[4] R. Keith Mobley, "Maintenance Fundamentals",3rd edition, Elsevier, 2011.
[5] Don Nyman and Joel Levitt, "Maintenance Planning, Coordination, & Scheduling", 1st edition, Industrial Press, 2001.
[6] Alan Wilson, "Asset Maintenance Management: A Guide to Developing Strategy and Improving Performance", 1st edition, Industrial Press, 2002.
[7] Adolfo Crespo Márquez, "The Maintenance Management Framework"**, 1st edition,** Springer, 2007.
[8] Raymond J. Mikulak, Robin McDermott, and Michael Beauregard, "The Basics of FMEA", 1st edition, Productivity Press, 1996.