QATAR UNIVERSITY

COLLEGE OF ENGINEERING

IMPROVING THE PROCESS OF PREVENTIVE MAINTENANCE FOR CRITICAL TELECOMMUNICATIONS STATIONS IN QATAR

BY

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ABSTRACT

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Title: Improving The Process Of Preventive Maintenance For Critical Telecommunications Stations In Qatar

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Critical public safety telecommunications networks in Qatar shall be secure, reliable, and fast response networks. These networks are serving the security teams and forces of Qatar. As a result, these networks shall be maintained on the highest standards in order to meet the basic requirements of providing an available and reliable Mission Critical Communications Networks (MCCN). Hence, the goal of this project is to improve the process of preventive maintenance by the Field Maintenance Teams (FMT) in the Ministry of Interior (MOI). Several limitations and challenges are facing these teams while planning and performing the Preventive Maintenance (PM) tasks. This project shall be used to increase the productivity of the FMT by improving the current practices of performing PM activities. A detailed literature review on the areas of lean thinking and scheduling maintenance tasks has been conducted. Then, it was decided to use the VSM (one of the lean thinking tools) to enhance and improve the current PM execution system. There were multiple non-value adding activities that can be planned for and executed before each day of preforming the PM tasks. These activities have been identified and then eliminated, and hence a future state was proposed in this project. This future state system will be implemented directly by the FMT management as it can save almost 40.3% of the total lead time of the system (192 minutes improvement from current to the future system).

DEDICATION

I would like to dedicate my master's project to my parents, wife, and beloved kids for their continuous support and patience since I started pursuing my master's degree.

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CHAPTER 1: INTRODUCTION

1.1. Overview

Qatar's Ministry of Interior (MOI) has its own Mission Critical Communications Networks (MCCN) which provides a highly secure, reliable, and fast public safety communications for all its internal security teams and forces within Qatar. Due to this criticality, it is essential to keep the services always available to the end-users. This need means that the maintenance teams shall be performing their tasks in the most possible efficient and effective manner. Thus, MOI has a Telecommunications Department (TD), which is responsible for designing, operating, and maintaining the MCCN.

Thus, there is a strong need for providing fast and high-quality preventive maintenance services for the systems and equipment of the MCCN. This need shall be ensuring the highest standards of reliability and availability required for ensuring the operations of the service of such kinds of telecommunications systems. As a result, the process of performing the preventive maintenance for the MCCN's equipment and devices shall be increasing its performance as well as its availability. The number of sites where the systems/equipment of the MCCN has increased rapidly during the past few years. On the other hand, the types and amount of resources available for performing maintenance activities have remained unchanged. Therefore, there shall be some studies performed on the current practices and procedures that are being followed at present for making such kind of maintenance activities to provide the best possible level of maintenance services for the systems and equipment of MCCN. These studies will result directly in increasing the quality of service, availability, and reliability of the MCCN's equipment/devices during its life of service for MOI.

There are two types of a PM that are being performed by the Field Maintenance Teams (FMT) that come under the umbrella of TD. These two PM types are the: Time Based Maintenance (TBM) and Condition Based Maintenance (CBM). In fact, the TBM is a type of maintenance that shall be performed regularly on a calendar schedule based on manufacturers' manuals instructions while CBM is triggered by some conditions that appear on equipment or network performance, which mostly may result in equipment's failures or networks outages.

This project shall be providing a method and concepts that will be used for optimizing the workforce resource utilization for the daily PM activities that are being performed by the FMT. It shall be increasing the daily number of maintenance tasks performed by FMT as well as minimizing the completion time of completed daily tasks, which yields in meeting MOI's goal in owning a highly secure, reliable, and fast public safety communications networks.

1.2. Problem Description

Despite the importance of performing the periodical planned PM activities for the MCCN's devices and equipment in order to ensure their continued reliability and availability, the Field Maintenance Teams (FMT) in the Telecommunications Department (TD) of MOI is sometimes facing challenges and scheduling issues. These challenges are delaying the PM activities or sometimes causing them to be canceled due to different reasons and facts. Due to the nature of the work of the FMT, the PM tasks are not the only responsibility given for this team. This team is responsible for the corrective maintenance tasks when triggered by alarms and reported to the FMT by the Network Operations Center (NOC) team. In case of receiving any alarm regarding a system or equipment failure of our MCCN, then the FMT shall be dedicating the least

number of resources, tools, and manpower to restore the system and fix the issues reported which of course will delay and disturb the planned PM activities during that period of the CM activities which may last between few hours to some working days in rare times. Also, the FMT is responsible for some new systems and services installations for the customers of the MCCN networks. These new installations appear to the team suddenly in most cases, and most of the time are requested with high priorities which cause the PM to be delayed or postponed for some other days. Moreover, there are some administrative tasks that cause the PM activities to be suspended. These tasks are mostly related to some sites and locations where the MCCN's equipment and systems are located, and they are not operated by the Telecom Department. For these specific sites, some Access Permits (AP) and Permits To Work (PTW) are required from the FMT to access these sites for performing the PM activities. Most of the time, these types of administrative tasks are delaying the planned and scheduled PM activities. Similarly, some of the PM tasks involve some teams other than the FMT, which requires in some cases their physical inputs or mostly their remote actions in order for the FMT to finish the scheduled PM activities on the planned timings and to avoid delays while maintaining the MCCN's equipment and systems. As a result, this fact requires optimum cooperation from the concerned teams, and mostly those teams are busy with other technical and operational jobs and duties. Thus, the FMT find various obstacles and challenges while scheduling and performing PM tasks. These challenges are negatively impacting the daily scheduled number of PM tasks to be performed on its networks' equipment and devices.

In fact, there are multiple different benefits of conducting the PM activities on its scheduled frequency given by each device's manufacturer. For example, these activities help in improving the operation of the equipment as well as reducing the

chances of failures of the equipment, which results in increasing the performance of the MCCN's systems. Moreover, one of the key benefits for the PM is that it helps in minimizing the number of telecom's systems outages because it reduces the chances of failures for these systems. Also, the PM activities help in discovering and solving the technical issues of the MCCN's devices before they occur, which means it increases the durability of the systems and reduces the costs of systems failures.

On the other hand, there are some risks of delaying or not performing the PM activities. The most important risk that shall be avoided is the fact that delaying the PM tasks may result in increasing the number of equipment failures, which will result in compromising the overall performance of the MCCN. Also, the less the number of PM tasks performed, the more CM activities to appear for the FMT, and this fact means a greater number of equipment replacement will be required to maintain the telecom networks. All these facts will result in another risk of placing more workload on the manpower and resources of the FMT.

After realizing and understanding the criticality of the networks and the risks of not performing the PM activities on time, it appears that there is a need for optimizing the allocated FMT resources to reduce the risks of device failures or network outages.

There are several factors or conditions that need to be considered carefully as they are placing some restrictions or limitations on the scheduling of FMT. Some examples of these factors are the following:

- The corrective maintenance (CM) is not certain in terms of its time of occurrence, which directly impacts the planned and scheduled PM daily activities because FMT members are responsible for both PM and CM tasks.

- Some unplanned new installations of equipment/devices are under the scope of work of the FMT, which require to delay, postpone, or maybe reduce the resources allocated for the PM activities.
- Skilled FMT technicians are limited.
- Huge number of sites available under the responsibility of FMT for performing PM.
- Routing between sites consume almost 13% of the daily working hours
- Limited working hours (from 6 AM to 1 PM)
- Due dates of urgent and unexpected services/tasks with high priority to be serviced immediately.
- Fewer working hours due to weather conditions (Ex: hot weather and humidity) which directly impact the safety of the personnel who are working mostly in outdoor sites.
- Some limitations to work during night since the technicians are not permitted to climb the telecom's towers in darkness due to safety restrictions.
- Some sites require prior access permits and approvals, which cause delays that were not being expected or considered while planning and assigning the teams for the PM tasks/activities.
- Transportations and driving challenges for the FMT technicians (Ex: some sites require 4x4 cars which are limited in number).

1.3. Project Objective

The purpose of this project is to develop a methodology that will be used for improving the planning and scheduling of PM activities of the Field Maintenance Teams (FMT) of the Telecommunications Department in the Ministry of Interior

(MOI). This will help the FMT in increasing their daily number of PM tasks maintained and performed as well as reducing the duration of these PM activities. Thus, the FMT shall be able to increase the reliability of the MCCN's equipment and devices, which is directly impacting the goal of MOI in the way of providing means to have a highly secure, reliable, and fast public safety communications networks.

1.4. Report Outline

The purpose of this section of the report is to present the fundamental report assembly for this research project by introducing its chapters and sections in brief. Thus, the upcoming chapter of this report will be the literature review which will brief and introduce some journal papers that have been reviewed in order to get some insights and knowledge on the methodologies that have been used for solving similar types of workforce utilization problems. The following chapter, after the literature review chapter, will show and explain in detail the solution approach that has been used for solving the problem that is under research in this project. The fourth chapter will be giving some applications of lean management that will be used for improving the PM tasks performed by the FMT. The fifth and final chapter will be the conclusion of this project that shall be summarizing this project and suggesting some future works that can be researched and conducted later in order to increase the optimization level of performance for the FMT workforce and resources.

CHAPTER 2: LITERATURE REVIEW

In order to conduct this research project, it is very important to do an extensive literature review that shall be easing the way into meeting the goals of this project in finding a solution for optimizing the process of the FMT to conduct daily preventive maintenance activities. Thus, this literature review will review and assess the current practices and techniques that are being used by the experts in this field (lean management of maintenance tasks as well as scheduling maintenance technicians) in order to understand the methodologies that have been used for improving similar problems as well as trying to find answers for some of the key questions that are being investigated in this research project.

2.1. Overview of Lean Thinking and Waste Reduction

Lean thinking can be thought of as employing focus and efforts that shall be taken for reducing the waste of a process. According to Seth et al. (2009) book, there are multiple methods that can be used for splitting and eliminating the non-value adding activities (wastes) from a certain process for the goal of improving it. These wastes could be in the form of "time, process, operation, or any activity" that are adding no value for the customer or s/he is not willing to give payment to it. Also, the authors of this book suggest that the types of wastes that can be found within a process, operation, or activity of a specific firm are mostly concealed and forgotten wastes within the "operations, information, policies," as well as traditions, and daily working routines.

Seth et al. (2009) stated that "the goal of total waste reduction is to lower time, cost, and other resources required for any or all activities, within or outside the boundary of the production system" (p. 520). Thus, to start finding the waste of a process or a system that is under study, the researcher shall be searching for an answer into two key questions regarding each activity of the process. The first question

regarding each activity if it adds value for the end customer or service, which can be delivered as a product of that process. Moreover, the second question is to predict and see if the customer is willing to consider this activity (that is under study) as a value-adding activity to the end product s/he is paying for it.

According to Seth et al. (2009), there are various root causes and sources for the waste in any process or operation. For example, wastes can be related but not limited to: "defects, poor quality, equipment, overproduction, human resources, start-ups and set-ups, poor planning and waiting, excess material handling, poor communication, and unnecessary paperwork." As per the authors, there are many advantages to implementing lean thinking tools and techniques to minimize or remove the wastes from the system or process in-hand and understudy. The first key advantage is it improves the lead time of the process (reduces it). The second advantage is the increasing system's productivity. Also, it increases the value-adding activities of the process. Moreover, it results in increasing the process utilization for all kinds of resources. All the previous benefits will cause to reduce the costs associated with the final product or service produced in that process that was being improved.

2.2. Lean Thinking for Improving Maintenance Activities

There is no large number of researches done on the area of lean thinking knowledge that can be applied and used for improving maintenance processes. In fact, the concepts of lean thinking can be used efficiently and effectively for improving the maintenance processes and actions within almost any organization as it is already being used within the manufacturing industry, according to Mostafa et al. (2015). The authors of this journal argued on the complexity of "maintenance management" nowadays since it requires both technical and managerial skills. Also, they argued on the point that maintenance management needs to be flexible in order to manage the changing nature

of the organization itself. The main objective of their research was to propose a roadmap for "lean thinking in maintenance," which can be used for minimizing the non-value adding activities of maintenance activities for any maintenance service providers. The proposed roadmap by Mostafa et al. (2015) is flexible and can be adjusted and implemented on different maintenance strategies. The planned "roadmap for lean thinking in maintenance" contains five stages that are built and founded on the five lean principles. As the first step in lean thinking, the lean in maintenance requires identifying the types of non-value adding activities (waste) that are embedded in the maintenance systems and procedures. The most important findings and results reached by Mostafa et al. (2015) is that there are seven maintenance wastes that shall be considered carefully while improving the maintenance processes. These seven wastes are: "unproductive maintenance, waiting for maintenance resources, centralized maintenance, poor inventory management, unnecessary motion, poor maintenance, and underutilization of resources." If these wastes are considered carefully, then the maintenance processes will be improved, and better quality of services will be obtained.

After reviewing different pieces of literature and research papers published on the lean thinking techniques, it can be confidently said that there are several important reasons for using these techniques in improving the maintenance activities of any organization/firm that provide maintenance services. According to Stadnicka et al. (2017), "the cost of maintenance activities ranges from 15 to 70% of the total production cost." This fact positions the maintenance activities as the second big factor, which negatively impacts the operational budget while the cost of energy is the biggest. Hence, the use of lean thinking principles and techniques for improving the maintenance activities is directly increasing its efficiency by removing the non-value

adding activities (waste) from the maintenance processes, which will result positively in minimizing the total cost of the operational budget of the firm/organization.

The authors of Stadnicka et al. (2017) used the value stream mapping (VSM) tools for improving the maintenance activities for "aircraft maintenance services providing firm (AMSPF)." First of all, they have begun their project by studying the current state of their firm in order to find the possible areas of improvement inside their system and based on that study and analysis, and they came up with a new, improved future state. The "key performance indicator (KPI)" used for this project was the "process cycle efficiency (PCE)" which is the relation between the total duration of maintenance activities and the sum of all "waiting times" and "time of realization of each activity". The key result obtained after implementing the VSM tools by the authors of this project (Stadnicka et al. (2017)), was the reduction of the "lead-time" of their activities from "62.6 days into 16.6 days" which resulted in increasing the "PCE from 118.6% to 456.4%". This almost four times improvement reduced the total cost of the maintenance activities by increasing the utilization of the available resources and reducing the costs of lead-time that were available in the current state of the maintenance system.

A research paper performed by Gopalakrishnan et al. (2015) studied the effects of carefully planning the maintenance activities of different industries and services companies. Also, it studied the methodologies that are being used by these companies for analyzing their critical actions and resources (if any) in order to minimize the costs and effects of such actions on the overall quality of the maintenance activities performed by these companies. This paper presented their work that was performed using three methods for gathering the data from the chosen companies. The methods were the following: "survey/questionnaire sent via emails for almost 80 respondents, interviews conducted within a maintenance fair, and other interviews with maintenance

managers of their partner companies". The most important finding of this paper is that most companies are giving careful attention and importance for ranking the maintenance activities in terms of their urgency and risks of delays. However, few companies are sorting these activities in terms of criticality and bottlenecks, which means that there is still a gap between the proper planning of maintenance activities and its criticality classifications, which in case of performed and updated regularly will result in increasing the overall quality of maintenance services provided by these companies.

2.3. Using Heuristics for Scheduling Maintenance Tasks

According to Cordeau et al. (2010), scheduling maintenance tasks for telecommunications firms is very difficult, and it sometimes takes more than one day to accomplish a specific task in a scheduled location. In the real world, there are different circumstances and conditions that push the teams as well as the tasks and activities to be disturbed or postponed into another day. For example, some tasks vary in their difficulty, and they require either specific experience, number of technicians, or even a particular tool for performing the maintenance activity. The authors of this paper have developed a "construction heuristic and an adaptive large neighborhood search heuristic (ALNS)" in order to participate in a challenge organized by the French Operational Society (ROADEF) back in 2007. Their proposed construction heuristic and mathematical model promoted them to win the second-place among 31 participants in this ROADEF competition. According to the authors of this journal, they made additional improvements to their original algorithm, which enabled them to obtain solutions nearer to the top solutions that have been made in the competition.

There is another research paper that presented a "Biased Random Key Genetic Algorithm (BRKGA)" for solving a problem related to scheduling field technicians of

service companies that make disruption for them. The main objective of this algorithm was to get the best possible result of the grand total of important values that make the daily maintenance tasks as adding value for those companies. Examples of such important values for the maintenance tasks are: “performing tasks in different city locations, with different time windows, priorities, and processing times” (Damm et al. 2016). In this paper, the maximization of the total sum of the important values for the maintenance tasks was being obtained using two methods which were: “constructive heuristic and the proposed BRKGA.” These two methods have been compared with each other on a small and large number of tasks. The proposed BRKGA gave better results for large tasks occasions (500 – 1000 tasks) compared with the constructive heuristic. The authors of this paper are suggesting future works to be done to enhance the performance of the BRKGA of some other mixed problems.

Also, one of the found papers studied the benefit of “Benders Decomposition” for solving the preventive maintenance scheduling problem of a “stochastic large system.” Some researchers argued that the assignment of the workforce to perform certain tasks on multiple numbers of locations could be completed for a long period of time. This assignment can be “as a function of cumulative-over-time risk associated with the impact of the network dispatch cost and component damage to minimize the risk of wide-area bulk transmission system failures.” (Jiang, et al. 2006). In their paper, they have proposed three methods for finding the optimal solutions for assigning and scheduling the workforce for variant facility locations. These methods are the “heuristic, branch & bound, and dynamic programming heuristic (DPH)”. They have evaluated the results obtained in their research as being able to assign the maintenance resources and enabling the managers to properly maintaining the facilities.

2.4. Using Flexible Systems for Scheduling PM Maintenance Tasks

In fact, several papers and researchers undertook similar technician scheduling problems differently. There are some researchers who believed in the concept of "Employee empowerment" to give more flexibility for the employee in the decision-making process of decisions related to their daily tasks. As was explained by (AlSheddy & Tsang 2011) in their research paper that was titled "Empowerment scheduling for a field workforce," the participation of the employee in the scheduling decision-making process could bring countless profits for their jobs. This type of flexibility given for the employee would be a "motivation source" that shall be providing an improved and unbiased working environment because the employee will be able to decide their daily tasks, and this should minimize the unhappiness among the team members. The authors of this paper proposed a modified version of an optimization problem where the objective function of the model is to stabilize between the interest of the company and the self-satisfaction of the workforce. They called their proposed model as "New Empowerment Scheduling model (EmS)." According to the authors, they have performed multiple trials in order to assess the performance of the EmS model. They have obtained efficient and reliable outcomes, which improved the fairness among the workforce as well as their self-satisfaction, which of course, will increase the overall productivity of their daily tasks.

There is a different paper that argued on the idea of having a dynamic and flexible system for scheduling the maintenance tasks. This paper was titled "Technicians and Interventions Scheduling for the Maintenance Service of Container Ships," and it was presented by (Meneghetti, et al. 2016). The authors were studying the impact of delays and interventions on the technician scheduling for the maintenance services within MSPC container ships company, which they provide for their

customers. The main idea of this model is to postpone the scheduling of the daily tasks until reaching a confidence level regarding some information required for conducting the maintenance tasks, which can be delayed most of the time due to some metrological circumstances in this specific industry. The authors argued that scheduling maintenance service requests might be delayed until the decision-maker owns a piece of more reliable information regarding the maintenance service requested and within the confirmed window in which the containers shall be reaching the harbor during that maintenance window. The most important conclusion that was derived from this study was that providing a quick response for the clients of MSPC with the maintenance services has a negligible percentage on the total costs (around 3% of total cost). So, there was a small and partial negative impact on MSPC's total cost due to delaying the maintenance services requested by their customers or maximizing the interventions which impact the actual timing when the services can be performed.

The last journal paper under this section argued on the importance of servicing both deterministic and stochastic customers with constrained resources efficiently, which means there shall be given some flexibility for the scheduler to rank and prioritize the customers based on certain criteria. According to Paraskevopoulos, et al. (2017), allocating resources such as: "skilled technicians, and nurses" to serve customers in different geographical locations make the process of meeting the customers' requirements more difficult because of some limitations associated with routing and scheduling of these resources. For example, the scheduled patients to be visited on a day may be located far away from each other, and the travel time between these patients may consume more than 30% of the nurses working hours on that day. This example is valid on the field technicians also as they may need to provide technical services in different areas during a single day, which results in having some necessary

non-value adding activities for the technical service provided. This "Resource-constrained routing and scheduling" study by Paraskevopoulos, et al. (2017) argues on the importance of servicing the customers efficiently with the constrained resources available. Thus, it can be argued that serving all customers, almost always, not achievable. The authors in this paper found that this researched issue, "Routing and scheduling," is very important for the service providers to reach their customers' satisfaction while increasing the overall efficiency of the provided service. Also, this field has not yet reached an acceptable level of full growth based on the authors of this paper, which means more scientific and research efforts are essential for minimizing the challenges met during scheduling and routing the workforce resources for the previously mentioned services.

2.5. Scheduling Multi-Period Technicians with Stochastic Customers

Another paper presented by Chen et al. (2017) showed how to use the "Markov Decision" for assigning the workers at the beginning of each day based on their every day gained experience and types of tasks requested to be performed on that day (multi-period). Also, this paper explained the "Myopic Approach" for solving a single-period technician scheduling problem based on their existing productivity and identified experience level. The researchers in this project were assuming that most of the daily demand for a certain service requested in each day are not known until reaching that service day. They have developed an "Approximate Dynamic Programming (ADP)" which has been used for allocating multi-period workers to the available daily tasks. As per the results found in this research, the ADP method provided more optimal future scheduling results compared with "Myopic Approach" which considers the single-period experience of the technicians and do not account for the fact that technicians are

gaining experience every day which impact their future productivity (less time required in the future for completing the tasks).

2.6. Summary

At the end of this literature review, different approaches and concepts have been researched in order to find a solution for meeting the primary objective for the FMT, which is increasing the number of Preventive Maintenance activities to be performed each working day. In fact, after analyzing the current system of performing a daily PM activity by the FMT, it has been noticed that there is an area of improvement for this system as some necessary activities can be planned for and accomplished one day before reaching the actual day of performing the scheduled PM tasks. Thus, the concept of lean thinking has been chosen for implementing this research project in order to reach the goal of increasing the number of PM tasks performed daily. Also, this project studied other ideas, tools, and models that are being implemented by some companies and organizations, such as some scheduling optimization techniques. However, it was found that using the lean thinking concepts are more beneficial and practical for meeting the goals of this project since there is a great opportunity for improving the current PM systems by removing some wastes and unnecessary activities. So, the solution approach and methodology that was used for this project will be explained in detail in the next chapter of this report.

CHAPTER 3: SOLUTION APPROACH / METHODOLOGY

The purpose of this chapter is to go in detail over the solution approach and methodology that have been used for meeting and satisfying the main goal of this project. In this chapter, the reasons for choosing lean thinking concepts will be explained in detail. Also, this chapter will clear up the image of how to execute the value stream mapping in studying and analyzing the current state of the Preventive Maintenance tasks and procedures that are being performed on the MCCN's equipment and systems by the FMT in MOI. Also, based on the current state VSM, a future state VSM will be proposed for improving the current practices and procedures that are being implemented at this time for performing only one PM activity by a single FMT team.

3.1. Using Lean Thinking for Improving PM Activities

As it was explained earlier, the number of PM activities that are under the responsibility of the Telecommunications Department (TD) of MOI in QATAR is increasing quickly over the past years due to the expansion of the network. Also, there are different benefits for conducting these PM activities within the time frame recommended by each supplier of each system or equipment used for providing the telecommunications services for MOI. So, the PM service provider's team (FMT) is looking towards making the best possible utilization of the available resources (both human and material) in order to meet and satisfy the goals, standards, and required quality of services for the telecommunications equipment of the MCCN. Due to this critical and most pressing need, the lean thinking concepts will be used for optimizing the process of conducting PM tasks/activities by the FMT. The following are examples of some of the benefits of using lean thinking concepts in the processes of PM activities execution:

- The logic behind the lean thinking concepts is to study the current state of a defined system/service (PM tasks & activities in this project) for the purpose of defining its value-adding and non-value adding activities. Thus, it shall be increasing the efficiency of the chosen system, which is under the study by removing or minimizing the unnecessary activities from this system.
- Increasing the efficiency of the PM systems and activities shall be increasing its productivity because unnecessary activities are removed from the current state of the system.
- Lean methods and concepts are reducing the lead time of the studied system, whereas the lead time is the time interval between initiation and closing of a system or provided service.
- Using lean thinking methods for the process improvement of PM tasks shall be increasing the quality of these PM services provided because these concepts are leading towards continuous system improvement.
- Lean thinking is benefiting the services providers in increasing their customers' satisfaction since it is resulting directly in gaining all the above-mentioned benefits.

On the other hand, there are several and critical risks that are threatening the reliability and availability of these equipment/systems in case of missing or delaying the execution of these PM activities for any reason. These risks are exactly contradictory to the previously mentioned benefits, such as: (low systems efficiency, possible system failures, less productivity, increased lead time, bad quality of service, and less customer satisfaction, etc.). As a result, it is very important for the management of FMT in the TD to find a solution for the increasing number of PM activities to be executed due to the increasing number of telecom sites during the recent few years.

3.2. Using VSM for Improving The "Current-State" of The PM Activities

It is found that lean thinking concepts are not used widely for improving the procedures and processes of maintenance activities. However, the Value Stream Mapping (VSM) can be applied to improve the processes of maintenance activities for the purpose of removing the non-value adding activities from these processes. By removing the unnecessary activities from the PM activities' system, the total lead time of the daily procedure for performing a single PM activity will be minimized. Then, there will be a chance to increase the number of PM activities completed daily, which will result in achieving the benefits of performing PM activities within its recommended time frame, which were explained in the previous section of this chapter.

There are multiple sequential steps that shall be followed in order to improve the process of executing daily PM activities by the FMT in MOI's Telecom Department. These steps are as follows:

A. The first step is to collect necessary information and data regarding the system of executing a preventive maintenance activity by the FMT. This step was done by interviewing the supervisor engineer of the FMT. Based on his 15 years of experience in this position, all the necessary information for the creation of a VSM flowchart for the system of daily PM activities execution has been collected and documented (including waiting & processing times and walking distances between each station). This information includes the actions/operations that are being followed daily by the team starting from the initiation of a PM activity until closing this activity and leaving the site where the activity is to be performed on that day. This process or step can be called "process mapping," and it is the first step of implementing lean thinking.

Moreover, the average waiting and processing time in which each activity consumes shall be collected in this step.

B. The second step is to sketch and draw the VSM of the actions/operations found in the previous step in order to visualize the system and determine its inefficiencies and possible areas of improvement.

C. Then, the start points (supplier = FMT as the service provider of a PM activity) shall relate to the first action in the process flow all the way to the downstream (endpoint) using the appropriate arrow shapes as a necessary step in creating the VSM.

D. In this step, the timeline of each step/action of the daily PM activity shall be documented in the data box associated with each step/action.

E. Now, the VSM shall be ready to be analyzed, whereas the areas of improvements can be found after studying and discussing the current state VSM with all the stakeholders and FMT members.

After making all the above necessary steps for creating the VSM of the daily PM activity, then it means all the values for the customers are defined using a correct method/process. Now, it can be said that the objective of this project can be achieved by eliminating or reducing the unnecessary (non-value adding) activities from the PM activity execution. In the next section of this chapter, the solution approach and methodologies that shall be used for creating the future state VSM of the PM activity will be explained in detail.

3.3. Implementing Future State VSM for a PM Activity

After creating the current state VSM for analysis and improvement, the future state VSM will be ready to be implemented. In the future state VSM, most of the non-value adding activities (waste) that were embedded within the current state activities shall not be found in this VSM state after making the process improvement for the system.

In the future state, the system shall be reached after showing the proposed system for the stakeholders (FMT in this project) in order to allow them to decide the level of possibility and reliability of applying this system in the future. This can be done after drawing the new VSM of the future state for the actions and processes it takes to perform a daily PM activity by the FMT.

In case the proposed system is achievable and can satisfy the customer needs and requirements, then the researcher can perform some studies and comparisons of the results between the current and futures VSM states. One of the main and key measures between the current and future states is the “lead time” that it takes the process to be completed (time from start to end of a process). The purpose of these studies is to calculate the Key Performance Indicators KPI’s of the systems in order to visualize the theoretical difference between the reality (current state) and the planned (future state). This will help in the decision-making process of implementing the planned and improved system based on the differences (improvements) that will be measured and simulated. Also, it will benefit in applying the “cost-benefit analysis” for the future state VSM, which can show a comparison between the costs of applying the improvements on the system and the benefits behind this planned change (Future state VSM).

The next chapter will cover all the necessary information and details that have been followed in this project in order to apply the use of VSM tools and techniques for improving the current practices by the FMT and PM teams in the Telecommunications Department. The process mapping of the current state will be explained first, followed by its current state VSM figure. Then, it will show some possible areas of improvement in the current state. Based on these improvements, the future state will be proposed, and some analysis and comparisons will be given.

CHAPTER 4: APPLICATIONS OF LEAN MANAGEMENT OF PM TASKS AT MOI'S TD

The purpose of this chapter is to present and show some applications of lean thinking in the management of performing PM activities, and specifically speaking, the use of the VSM tool for improving the processes of performing a daily PM activity. This chapter will go through the steps that were taken for collecting the necessary information, types of information collected, how each process was defined, process and waiting time it takes for each action/activity, types of waste in the system, the possible areas of improvement, the proposed future state of the system, and comparison between the current and future states for the process of performing a PM activity by the FMT.

4.1. Building PM activity's Current State System

This project aims to use one of the lean thinking concepts and tools, which is the VSM, in order to minimize and remove the non-value adding activities of the PM system. This step will increase the ability of the FMT to perform more PM activities daily, which will result directly in increasing the number of PM tasks to be performed each month. Thus, the FMT shall be able to respond efficiently and as soon as possible to the increasing number of sites that are falling under the responsibility of the TD.

As a result, the first step that was taken for building the current state system for the performance of a daily PM activity by the FMT is gathering all the necessary information regarding the activities/actions which are being performed to complete a single PM task each day. In order to conduct a realistic value stream mapping for the process of

performing a maintenance activity, the information collected regarding the system shall be reliable and correct. Thus, it is necessary to construct a process mapping diagram that visualizes the way of performing the process, the flow of people, material, and information from one activity of the process to another.

As a result, an interview with the supervisor engineer of the FMT was conducted. The purpose of this project was explained in detail for him as well as the lean thinking concepts and specifically speaking the VSM tool. Based on his input and recommendation, it was decided to use the average waiting and processing times for each action because these times are changing from day to day due to several circumstances and reasons. For example, the action of assessing the tools/equipment needed for the PM teams to perform the activity ranges between three and ten minutes in some rare occasions. However, based on the 15 years of experience for the supervisor engineer, all the waiting and processing times are the average recordings of these activities.

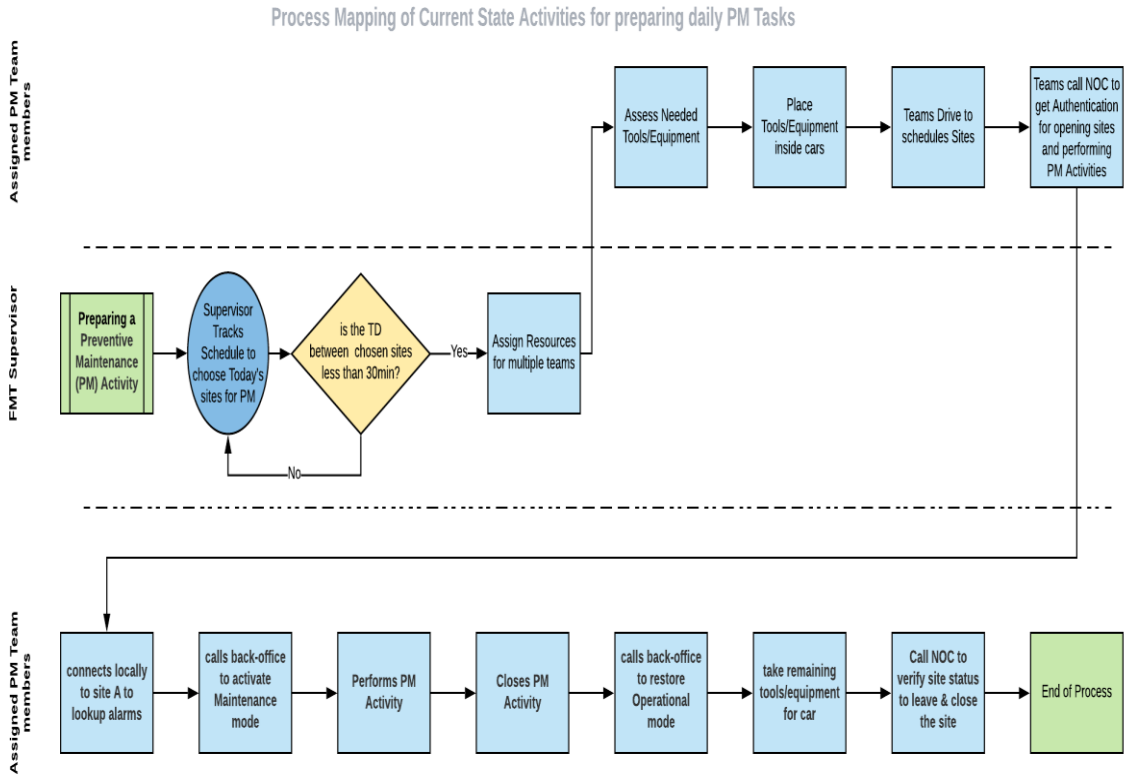

Figure 1. Process Mapping of Current State Activities for preparing daily PM Tasks

Figure shows the process mapping of the system that shall be improved for performing a daily PM activity. As it can be seen from the introduced process mapping of the current state activities in the previous page, the system or daily procedure of preparing a daily PM activity starts at the beginning of each working day by the FMT supervisor engineer. The first step of this process is to open the schedule of PM activities, which is already prepared for the whole year (for daily activities) for all the sites of the Telecommunications Department. Then, the supervisor inspects the scheduled sites for that

day if they are located within 30 minutes of traveling time. This factor/inspection is essential due to several factors such as follows:

- FMT can provide support for others if needed by any team.
- More PM sites can be serviced daily if the routing distance is small during the day of service
- The nature of telecom sites are connected in adjacent cells located or placed nearby others.

The last responsibility that falls under the supervisor engineer before coming to the PM team members' responsibilities is the assignment of the FMT on the chosen sites that shall be serviced on that day.

Also, the process mapping displays the set of actions which are taken by the PM team members starting from assessing the needed tools/equipment for the performance of a PM task until reaching the last action/activity which is calling the NOC to close the PM activity, verifying the status of the site, and closing the site. By reaching this step, the performance of a PM activity shall be finished by this step, which is shown on the process mapping diagram to be ("end of a process"). This process mapping diagram was used to get more understanding and knowledge regarding the current system of preparing and performing daily PM activities. Also, it was used for studying the system and locating the non-value adding activities (wastes) of the system.

Figure 1 shows the VSM of the current state system of performing a daily PM task by FMT

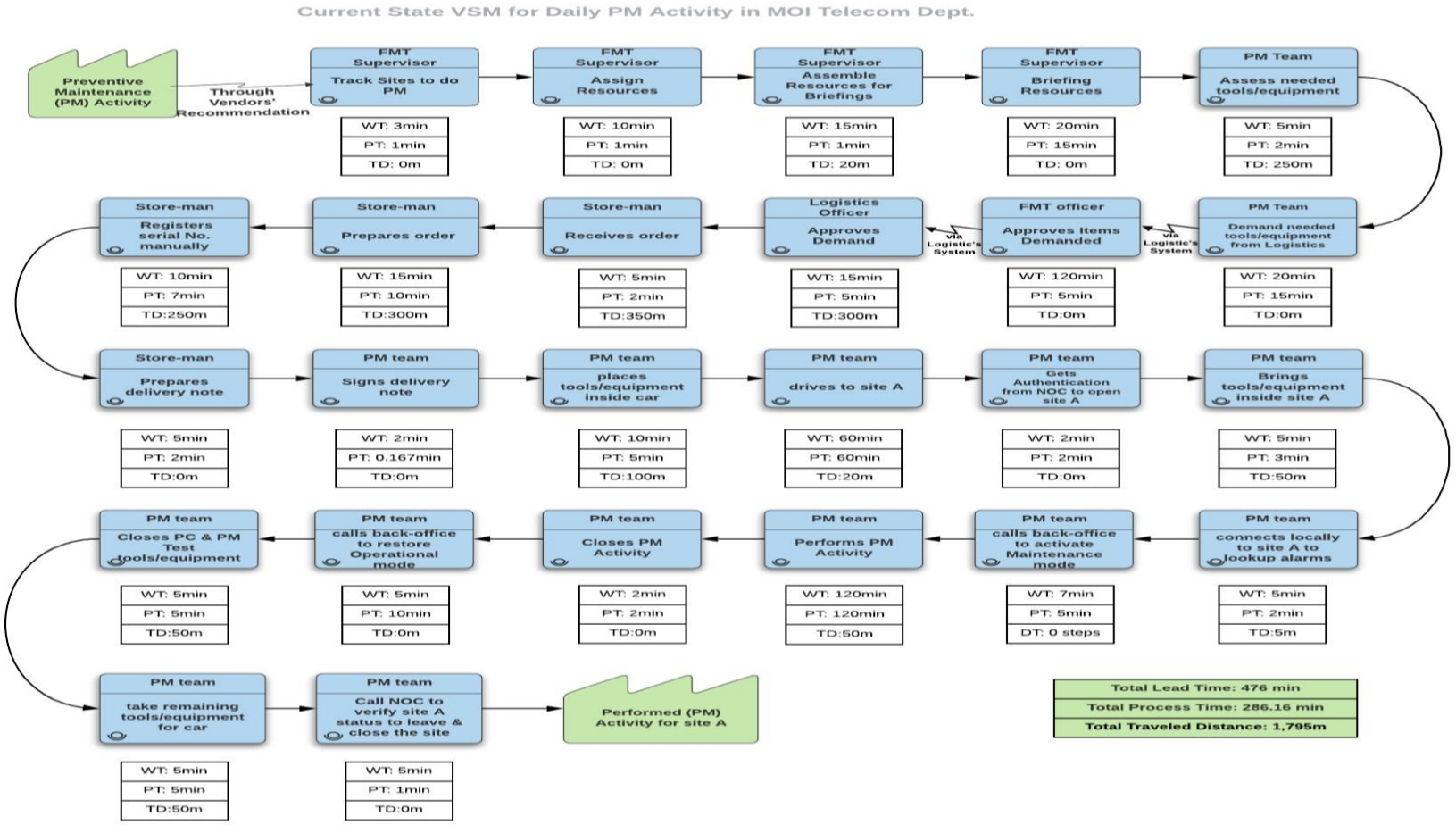

Figure 1. VSM of the current State for a PM activity in the MOI Telecom Dept.

Also, Table 1 shows the current state VSM activities and their corresponding average waiting and processing times. Moreover, it shows the activity type as well as its description as being performed by the FMT.

Table 1. Current State VSM For Processes of Daily PM Activities Performed By FMT

Activity Description	Activity Type	Avg. Waiting Time (min)	Avg. Processing Time (min)	Traveled Distance (m)
Track Sites to do PM	Value-Adding	3	1	0
Assign Resources	Value-Adding	10	1	0
Assembling Resources	Value-Adding	15	1	20
Briefing Resources	Non Value-Adding	20	15	0
PM Teams Assess needed tools/equipment	Non Value-Adding	5	2	250
PM Teams Demand needed tools/equipment from Logistics	Non Value-Adding	20	15	0
FMT officer approves items demanded	Non Value-Adding	120	5	0
Logistics officer Approves demand	Non Value-Adding	15	5	300
Store-man receives order	Non Value-Adding	5	2	350
Store-man prepares order	Non Value-Adding	15	10	300
Store-man registers serial No. manually	Non Value-Adding	10	7	250
Store-man prepares delivery note	Non Value-Adding	5	2	0
PM team to sign delivery note	Non Value-Adding	2	0.167	0
PM team places tools/equipment inside car	Value-Adding	10	5	100
PM team drives for to site A	Value-Adding	60	60	20
PM team get authentication from NOC to open site A	Value-Adding	2	2	0

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Activity Description	Activity Type	Avg. Waiting Time (min)	Avg. Processing Time (min)	Traveled Distance (m)
Team brings tools/equipment inside site A	Value-Adding	5	3	50
Team connects locally to site A to lookup alarms	Value-Adding	5	2	5
call back-office to activate Maintenance mode	Value-Adding	7	5	0
Performing PM Activity	Value-Adding	120	120	50
Closing PM Activity	Value-Adding	2	2	0
Calling back-office for restoring Operational Mode	Non Value-Adding	5	10	0
Closing PC & PM test tools/equipment	Non Value-Adding	5	5	50
take remaining tools/equipment for car	Non Value-Adding	5	5	50
Call NOC to verify site A status to leave & close the site	Non Value-Adding	5	1	0
	Total	476	286.1666667	1795

Note that the total average waiting time for performing a single PM activity by a single team is 476 minutes (almost eight hours). This fact means that it is almost impossible to perform more than a single PM activity by a single team in one day. Also, it can be

noticed that fourteen out of twenty-five activities of the system are non-value adding activities. Almost all these non-value adding activities are necessary and cannot be removed or eliminated from the process. However, there are some of these activities that can be planned for and performed in a day before the actual day of performing the PM activities. For example, the responsibility of demanding the needed tools/equipment for the day can be taken by the supervisor engineer in order to plan for it and prepare it one day before. If this step is taken and a new planning procedure is introduced for the assignment of PM tasks, then there is necessary (non-value adding) managerial actions will be removed from the proposed future state VSM. These actions are the following: (FMT officer approves items demanded, Logistics officer Approves demand, Store-man receives the order, Store-man prepares the order, Store-man registers serial No. manually, Store-man prepares delivery note, and PM team to sign delivery note). The total waiting times of this non-value adding activities are 192 minutes on average during each day of preparing a PM activity.

In the next paper, the previously explained modifying procedure will be shown on the current state VSM figure that was introduced for the current state process.

Figure 2 shows the VSM of modifying the current state system of performing a daily PM task by FMT

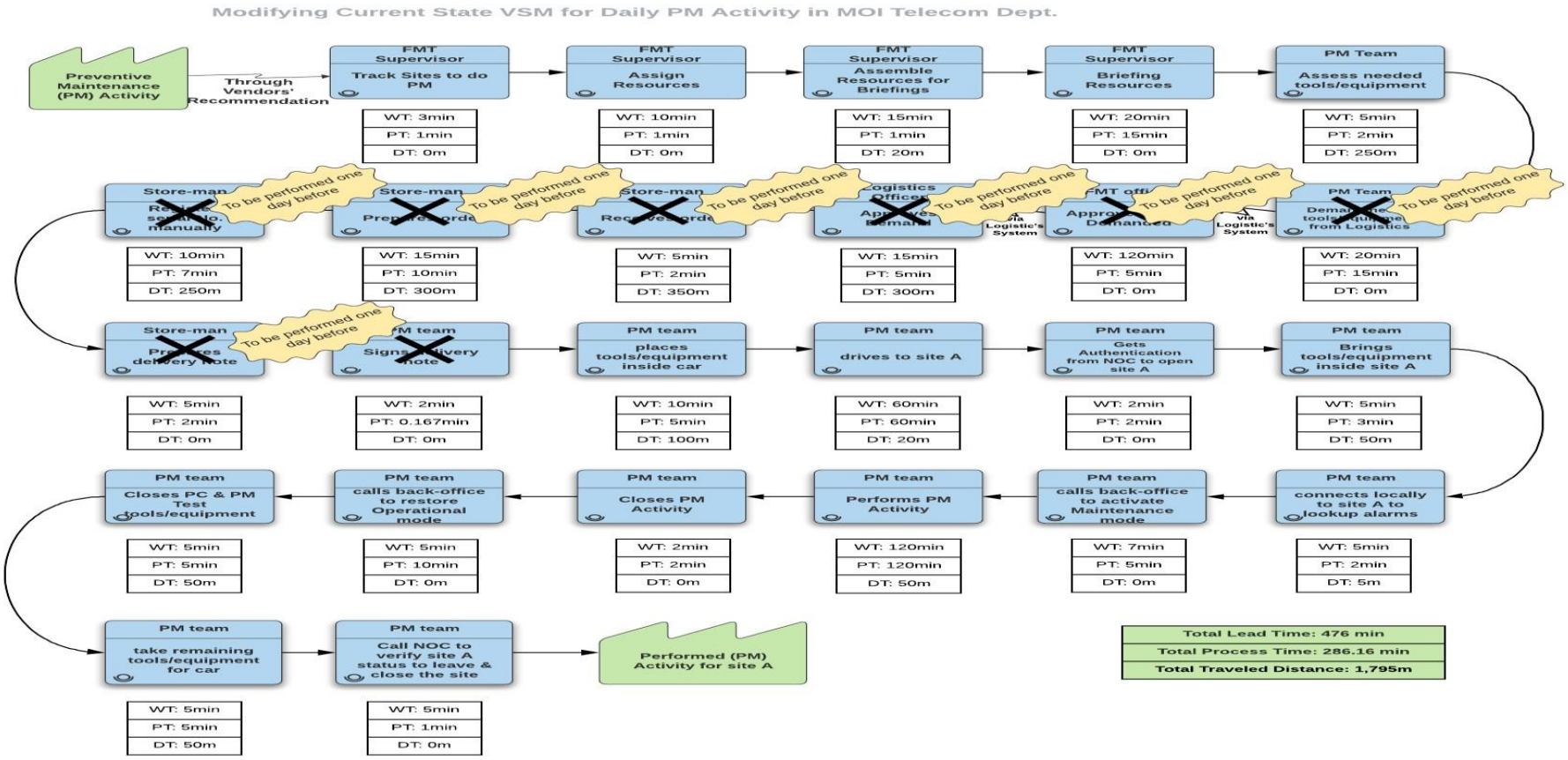

Figure 2. VSM of modifying the current State for a PM activity in MOI Telecom Dept.

4.2. Proposed PM Activity's Future State System

Based on the modifying VSM that was proposed and introduced in the earlier page, a new future state VSM was sketched and prepared to be implemented by the FMT for conducting and performing daily PM tasks.

Figure 3 shows the VSM of the proposed future state system of performing a daily PM task by FMT.

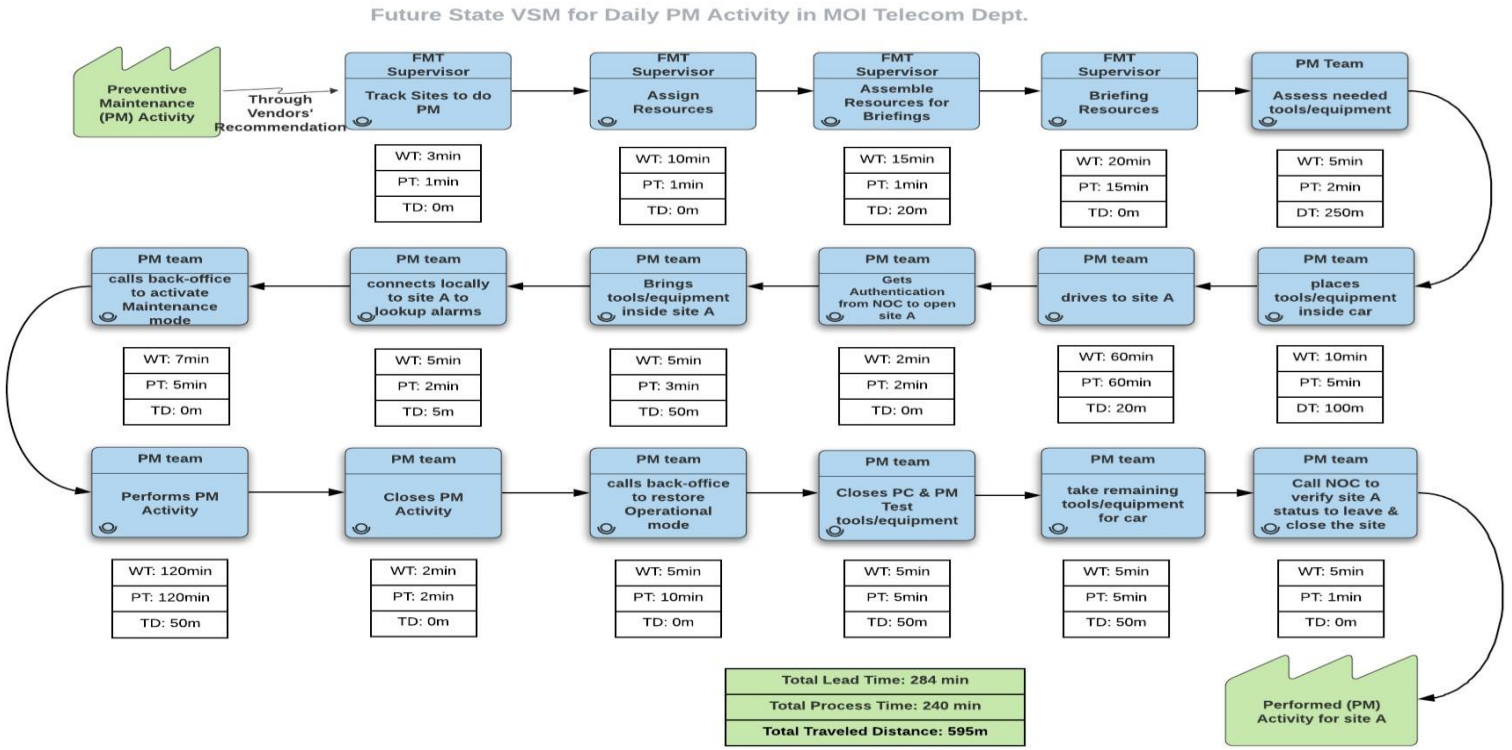

Figure 3. VSM of the Future State for a PM activity in MOI Telecom Dept

4.3. Improvements from Current to Future State Systems

In this specific project, it was found that the daily procedures (in the current state system) that are taken by each team for performing the PM activities seem to be longer than it should be. Several factors and reasons are causing these delays. For instance, sometimes, the team who is doing the PM is facing some challenges in obtaining some necessary approvals from the officers in charge of the FMT management. The delays that are causing a long lead time for the performance of daily PM activities can be due to some of the following:

- In-charge officers are having some training activities in the early morning of frequent and random days as some requirements and periodical tests shall be passed by each officer in MOI.
- FMT team-members are not having access to the daily staff attendance list, which means that they need to spend some time looking and searching for the available officers who are located in different buildings, which increase the non-necessary waste in the PM activity system.
- The online system that is being used for demanding the necessary equipment/material for doing the scheduled PM activity may have some downtime every once in a while due to technical issues, which results in a need to go through manual and slow procedures for demanding the material from the logistics.

- Some necessary actions that shall be performed for obtaining the equipment from the logistics section are consuming almost 40% of the total daily waiting time of the eight-hour shift (nearly 192 minutes are wasted).

There are seventeen activities in the proposed future state for the system. This means the percentage of reduction for the total number of activities in the current state system is almost 32%. This reduction or removal of activities (to be planned for and prepared in prior day/s) has improved the total lead time of the system from 476 minutes into 284 minutes. This theoretical improvement is almost 40.3% savings from the total lead time of the current state system. It shall be mentioned that there is an improvement in the total processing time of the activities between the current and future states of the system. This improvement is a reduction from 286 minutes (from the current state) into an average of 240 minutes for the future state. The total saved time shall be utilized for performing another PM activity on the same day.

It is important to mention that applying these improvements shall not impact the performance of the PM teams because the responsibility of demanding and preparing the needed tools and equipment from the store will be taken by the FMT's supervisor. The supervisor is not visiting the sites for performing the PM tasks physically due to other multiple managerial tasks which come under his responsibility.

Thus, there are no costs of implementing the proposed improvements into the future state system. Table 2 shows comparisons between the current and future state systems:

Table 2. Comparisons Between Current & Future States

Metric	Current State	Future State	% Improvement
Number of Activities	25	17	32%
Total Value-Adding Activities	11	11	N/A
Total Non-Value Adding Activities	14	6	57.10%
Total Lead Time	476min	284min	40.30%
Total Processing time	286.167min	240min	16.13%
Total Traveled Distance	1,795m	595m	66.85%

CHAPTER 5: CONCLUSION / FUTURE WORK

5.1. Conclusion

In summary, the preventive maintenance activities performed by the FMT of the telecommunications department are essential to ensure the reliability and availability of the critical networks owned by MOI. The current practices and procedures that are taken by the FMT consume a long time daily, and it is impossible to perform more than one PM task by one team each day. The goal of this project was to increase the performance of the FMT via minimizing the waste of the current state system, which shall result in increasing the number of sites visited for PM tasks each day. So, a process mapping diagram was created, reviewed, and approved to be realistic by the FMT's supervisor. The average waiting and processing times for each activity of the process were determined based on his input. Then, the VSM tool was used to locate the areas of improvement. In the proposed future state system, a total of eight activities were eliminated from the system as they can be shifted to earlier days in which they can be implemented. These activities shifting have reduced the total lead time of the system from 476 to 284 minutes (40.3% improvement), which shall be saved for performing another PM activity by the same team each day. This change will not cause any costs or negative impacts on the performance of the PM teams in the future because demanding items from the store will be the responsibility of the FMT's supervisor who is not performing physical PM activities as the other team members.

5.2. Future Work

As it was explained in the summary section of the literature review chapter, it was decided not to use the scheduling concepts and methods for this project due to several reasons. It was found that lean thinking concepts can significantly improve the current system. Also, due to the lack of time and complexity of the available scheduling optimization problem, it was decided to move the implementation of scheduling knowledge for future work, which can be applied to the "future state system" that was obtained in this project.

There are multiple recommendations and areas of research that can be conducted in the future to increase the utilization of FMT resources which will result directly in increasing their productivity. For example, it is suggested to build models for scheduling the FMT based on a certain flexible system. The decision variables of this system could be well-defined flexibility given for the workforce in the decision-making process of the sites chosen each day. This shall be building a better working environment for the team members as well as it shall be increasing their satisfaction. Another idea and recommendation for future research can be building a model based on some heuristic tools and techniques for scheduling the PM tasks. The suggested model shall be considering the limitations and challenges that were discussed earlier in the problem description of this project. For instance, variance in the level of experience among team members, the huge number of sites all over Qatar, limited daily working hours, the travel distance between sites, high priority urgent requests for other tasks received at times of performing PM tasks, etc. shall be part of the objective function of the proposed model in the future work. All these

limitations and constraints will help in generating realistic solutions for the current problem at hand.

Another beneficial and challenging future work can be implementing an integrable digitalized system for performing some of the PM activities remotely as well as for monitoring the performance of the PM activities that are being done physically. This idea of digitalization shall be minimizing the teams needed for performing PM activities which will help in utilizing the human resources available for the other responsibilities of the FMT. Also, it will help in improving the maintenance process in general because it offers some decision support functions which will be providing proper planning and more coordination for the FMT members. Moreover, the digitalization process will be adding other valuable advantages for the FMT as it will be enhancing their working routines by introducing some organizational developments via implementing new regulations for the monitoring process. These advantages will be increasing the sustainability of the maintenance systems as well as minimizing the costs associated with the maintenance activities. However, there are some challenges for applying this future work (digitalization) which can be related with some critical security concerns regarding the security of PM information and more importantly the security of the critical telecommunications networks.

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