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ORIGINAL ARTICLE

IMPLEMENTING SIX SIGMA FOR COST REDUCTION IN THE WATER AND WASTE WATER COMPANY

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ABSTRACT*:* Six-Sigma is a kind of problem solving methodology which can analyze and examine complicated problems of an organization in a structured and step by step manner and consequently produce an effective solution. Nowadays, due to its capabilities in solving various problems, this approach has been able to penetrate so extensively into various industrial and non industrial sections that a major part of Six-Sigma issue literature is related to the presentation of implementation results of this approach in various organizations. Cost reduction, being one of the key goals of Six-Sigma, has been repeatedly considered in articles, but application results of this approach in costs reduction of water and waste water companies have not been reported yet. Costs of maintenance and repairs of installations and equipment are allocated a significant part of water and waste water companies' costs . Hence, in order to decrease maintenance and repairs costs of facilities and equipment of a water and waste water company, this paper deals with a step by step description of Six-Sigma methodology. The results indicate that implementation of Six-Sigma in the company has been followed by a considerable cost reduction. The financial benefits of this project were estimated to be one million dollars. Therefore, the solutions and results presented in this paper can be considered by similar organizations.

Keywords: Six Sigma; DMAIC; maintenance; cost reduction; water and waste water company

INTRODUCTION

Most organizations need improvement approaches for resolving difficulties and weakness spots of their systems and processes in order to enhance efficiency and finally attain competition advantage of stable survival in world trade field. Six-Sigma methodology is one of the quality improvement approaches which was first established in Motorola Company in 1979, whose focus is on the variability reduction of important quality characteristics of products and processes in such a way that they reach an acceptable level and cause customer satisfaction, quality enhancement of product and services and eventually profitability of the organization [1]. This methodology was revived in General Electric in the 1990's such that the outcome results of its implementation in industries such as Samsung [2] and General Electric [3] led to its influence on the other big or small organizations including productive and non productive ones [4]. Six-Sigma is a completely structured methodology. It means that this approach begins the improvement of a product or service by identifying important Critical To Quality (CTQ) and fulfills it through Define, Measure, Analyze, Improve and control stages (DMAIC cycle). In Six-Sigma literature, a considerable research has been devoted to the cases which have significantly been effective on the costs reduction and profitability enhancement of an organization. However, the issue has been considered less in the scope of repairs and maintenance. Most research in this scope is a presentation of a synthesized model based on Six-Sigma and a maintenance and repairs strategy like Total Productive Maintenance (TPM) [5], [6], [7] and [8] or Six-Sigma usage for improvement of maintenance and repairs indices like Overall Equipment Effectiveness (OEE) [9]. In this paper application of DMAIC methodology in reduction of repairs and maintenance costs of facilities and equipment of the water and waste water company is explained. Since activities of a water and waste water company such as generation and distribution of urban water and collection and purification of waste water depend on correct performance of the related equipment and facilities, correct maintenance and repairs play a significant role in correct performance of the equipment. Furthermore, since this company is being transferred to the private sector, implementation of the approach, being followed by energy consumption and wastewater reduction, can have a significant impact on the organization efficiency enhancement.

The company introduction and the project selection procedure are explained in section II. Then DMAIC methodology phases as well as the applied tools and techniques in this project are explained in detail. In the end, the results and

some outcome benefits of the project are summarized in section III.

CASE STUDY

The main responsibility of water and waste water company is distribution of healthy and sanitary drinking water and collecting, transmitting, purifying and sanitary disposal of waste water in the area of the related province cities. In this company, water is obtained from well and dam as the two main sources and enters into the distribution network and urban branches after purification and disinfection stages. In the waste water treatment process as well, the waste water gathered in the network is buried in natural agricultural environments or flowing rivers after purification and standardization of dissolved materials in water. Since sound operation of equipment and facilities has a significant impact on the fulfillment of key processes of the company and its cost represents a considerable percent of total expenditure of the

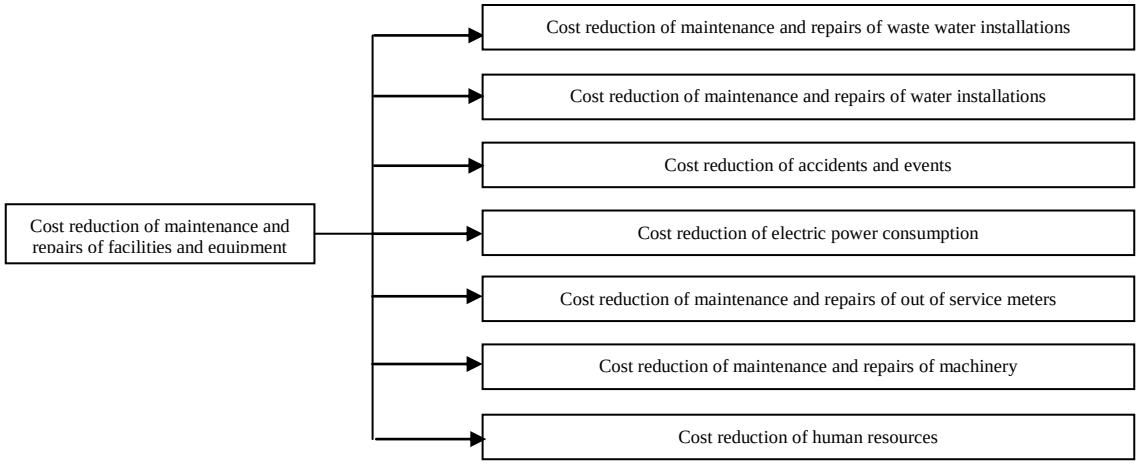


Figure 1. CTQ diagram

Table I. SIPOC diagram

Suppliers	Inputs	Process	Outputs	Customers
Regional Water	Purchased Water	The process is shown in figure 2	Drinking Water	Subscriber
Ministry of Energy	Energy		Refined Waste water	Regional Water
Contractors	Human Resources		Healthy Installations	Company
Corporate Forces				
Suppliers	Raw Materials			
Supplier	Appliances and Goods			
Company	Facilities and Equipment			
Company	Machinery and Vehicles			
Contractor				

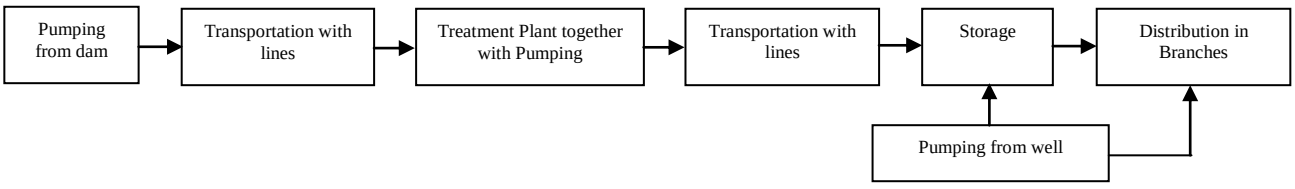


Figure 2. Process of water distribution

Organization as well, the research plan for reducing the costs associated to this sector was defined based on Six-Sigma approach.

A. Problem Description

At first stage, Voice Of Business (VOB) was performed through which opinion of managers of operation, subscribers' services and revenue, planning and human resources, engineering and development, operation of treatment plants and operation of water and energy sector facilities sections about reduction of maintenance and repairs costs and financial and non-financial benefits of execution of this project were investigated. Accordingly, a summary of necessities and the obtained results of this project implementation are as follows:

- Identification of key processes and activities involved in the maintenance and repairs of facilities and equipment
- Development of the necessary background for transferring operation to the private sector
- Water loss prevention
- Possibility of network expansion and building reservoirs
- Saving in using groundwater tables, dams or springs
- Saving in electric power consumption in pumping stations
- Saving in repair of pumps and wells facilities
- Reduction of emergency repairs and their associated costs
- Reduction of costs associated with drilling and equipping new wells
- Reliability enhancement of facilities and equipment
- Reduction of human resource costs and capital resources
- Reduction of waste water treatment costs
- Increase of handling jobs especially in events and emergencies.
- Improvement and promotion of services level.
- Saving in purchase of apparatus and equipment.

B. Definition

In this stage, definition of scope, goals, resources and time of the project implementation is determined. In this step it is necessary to examine the details of processes and the available documentation of the organization processes to develop a comprehensive understanding of the existing processes for the team members. Cases to be considered in the project scope and the problems not included in the project should be determined. In this stage the problem of reducing cost of facilities and equipment maintenance and repairs was converted to small problems and is shown by CTQ diagram of figure 1. The project charter including the problem title, goal, members of solution team, financial benefits of project implementation, implementation time, limitations and project sponsors was defined accordingly. Furthermore, SIPOC diagram as well as the process of generation and distribution of water are shown in table I and figure 2 respectively. Among the defined problems, reducing human resource cost needed a work study and it was defined as a separate project. In addition, reducing cost of maintenance and repairs of machinery was insignificant, so it as was deleted from the problems list. In the end, five teams were created for reducing costs associated with maintenance and repairs of waste water installations and water installations, accidents and events, electric power consumption, maintenance and repairs of out of service meters.

C. Measurement

The aim of this phase is to develop a perfect understanding of the current performance of the system by identifying potential causes. In this stage, at first the necessary forms were designed and the available data was gathered for each team. Then brain storming meetings were held in each team and the potential causes effective on each of five mentioned problems were listed. Cause and effect diagrams of each team are shown in the figures 4, 5, 6, 7 and 8.

Water loss is one of the most serious problems in the water and waste water companies. Considering to reports of this company, sigma level of water loss was estimated 2.23. The approximate distribution is shown in figure 3. Hence, it was paid special attention to the water loss reduction in this project.

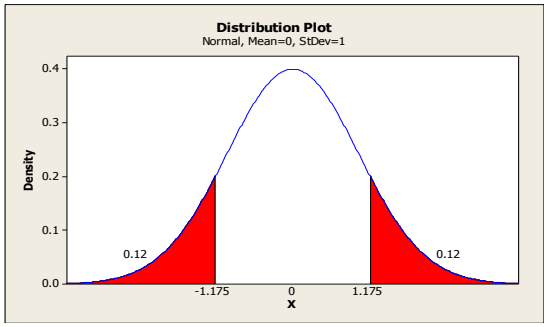


Figure 3. Approximate sigma level of water loss

D. Analysis

The purpose of this phase is to authenticate the accuracy of root causes identified for the problems. In this stage various specifications of the process are compared and decisions are made for those options which have improvement chance. Each team calculated the potential causes costs on the basis of financial investigations and Pareto diagram was drawn to prioritize the potential causes. Figures 9, 10, 11, 12 and 13 show Pareto diagrams for each one of the problems. Furthermore, table II indicates the identified root causes.

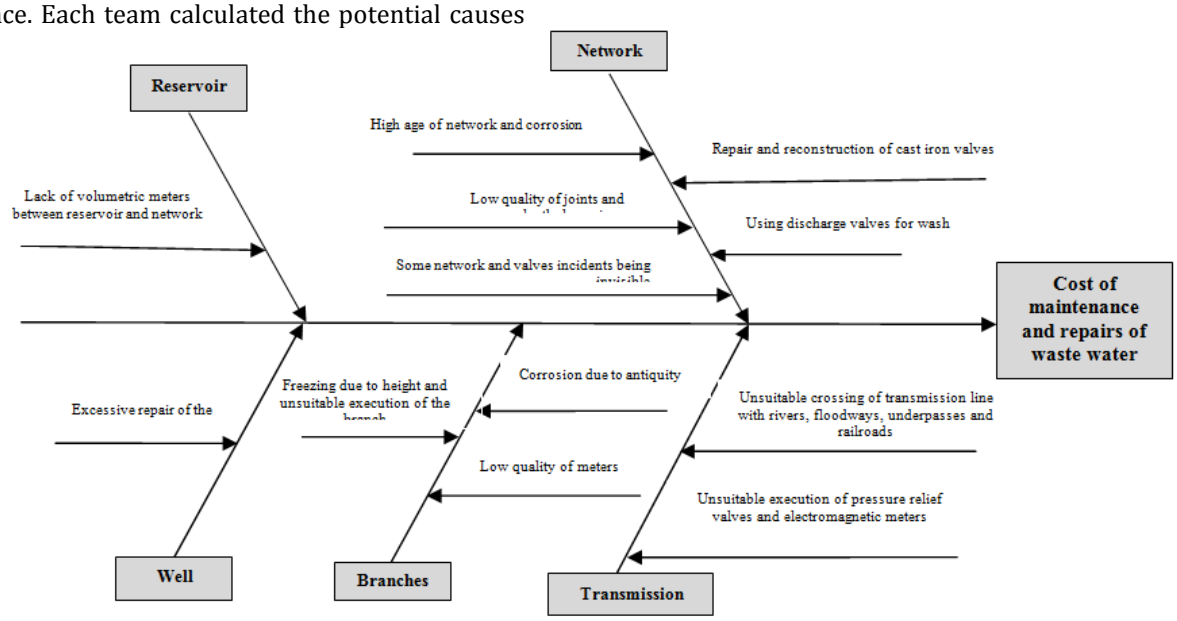


Figure 4. Cause and effect diagram of maintenance and repairs cost of waste water installations

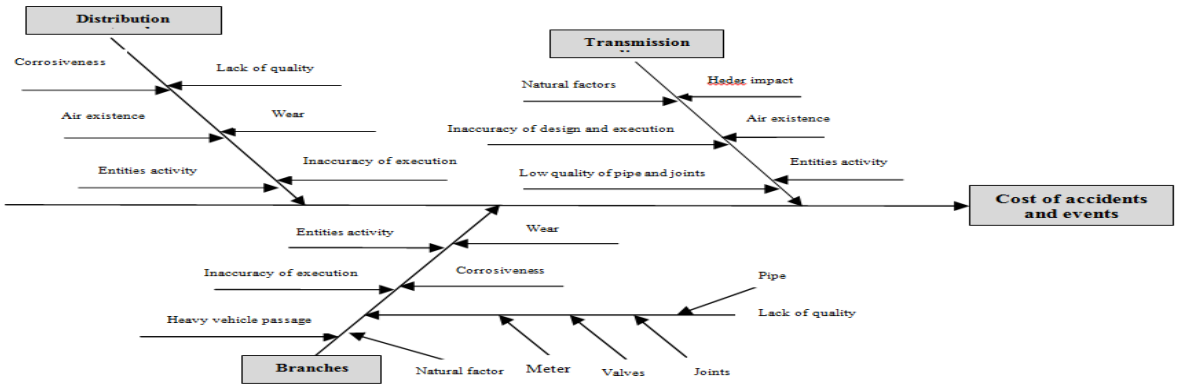


Figure 6. Cause and effect diagram of accidents and events cost

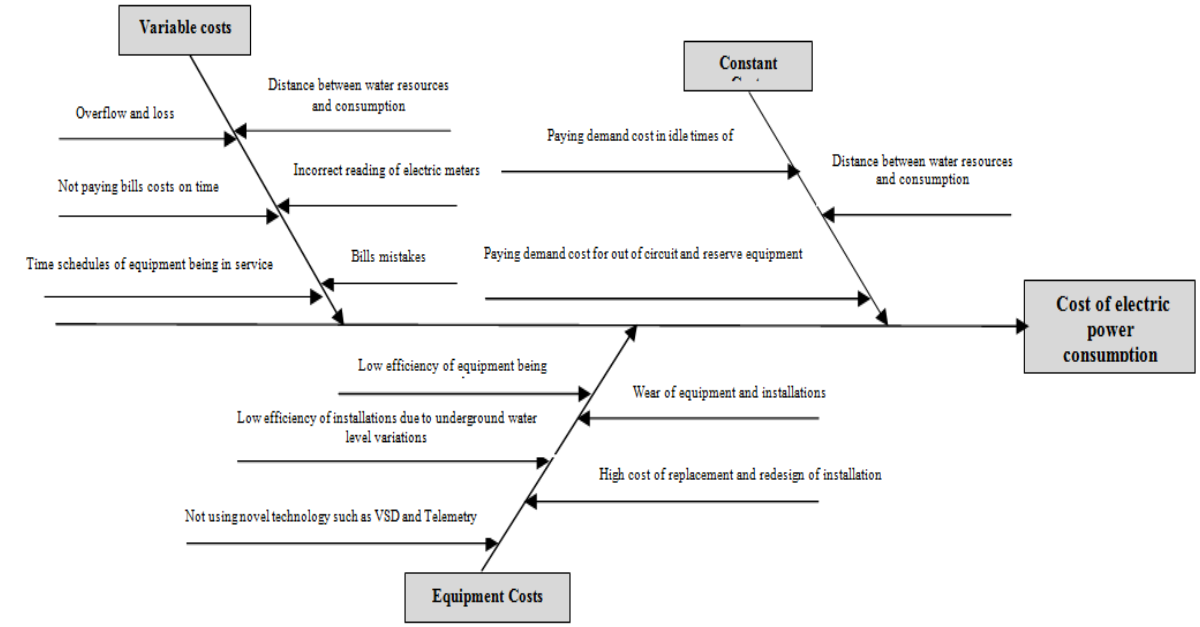


Figure 7. Cause and effect diagram of electric power consumption cost

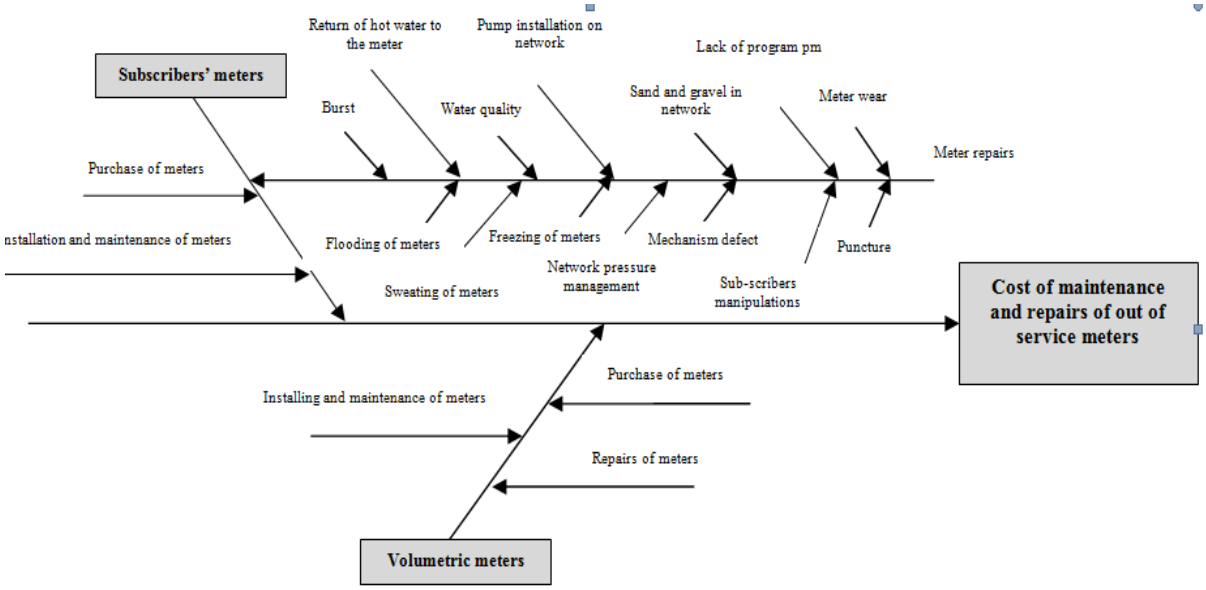


Figure 8. Cause and effect diagram of maintenance and repairs cost of out of service meters

Table 2. Root causes

Problem	Root causes	Variable
Cost reduction of maintenance and repairs of waste water installations	Wear due to antiquity	X_{10}
	Low quality of joints and polyethylene pipes	X_2
	Lack of volumetric meters between reservoir and network	X_6
Cost reduction of maintenance and repairs of water installations	Water shortage and re design	X_5
	Water hardness increase	X_9
	20 kV power becoming 2-phase and electric power swing	X_6
	Unsuitable execution of pressure control valve	X_1
	Pipe fracture due to unsuitable crossing with rivers, floodways and direct pumping	X_8
	Lack of middle line valve	X_3
Cost reduction of electric power consumption	Time schedule of equipment being in service	X_2
	high cost of replacement and redesign of installation	X_1
	Paying demand cost in idle times of equipment	X_4
	Paying demand cost for out of circuit and reserve equipment	X_3
Cost reduction of accidents and events	Branch accessories wear	X_6
	Low quality of accessories material	X_1
	Corrosiveness	X_7
Cost reduction of maintenance and repairs of out of service meters	Mechanism defect	X_9
	Meter wear	X_1

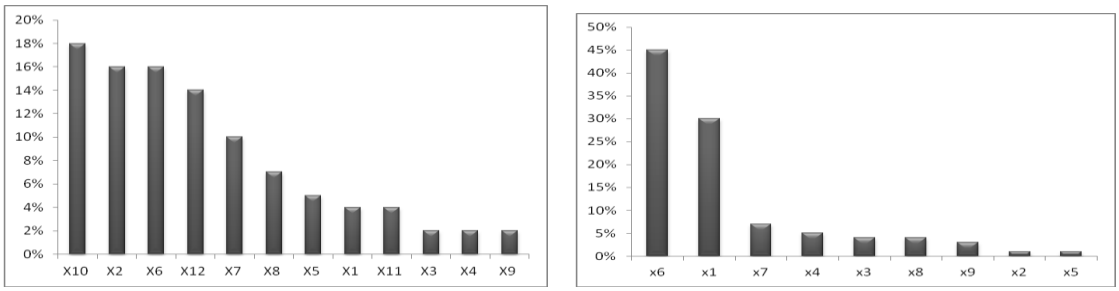


Figure 9. Pareto diagram of maintenance and repairs cost of waste water installations

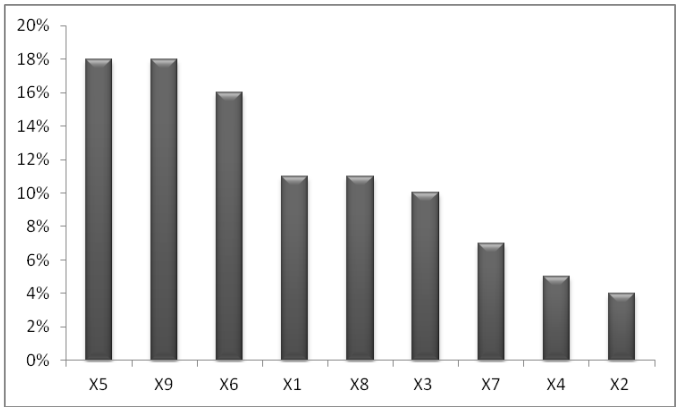
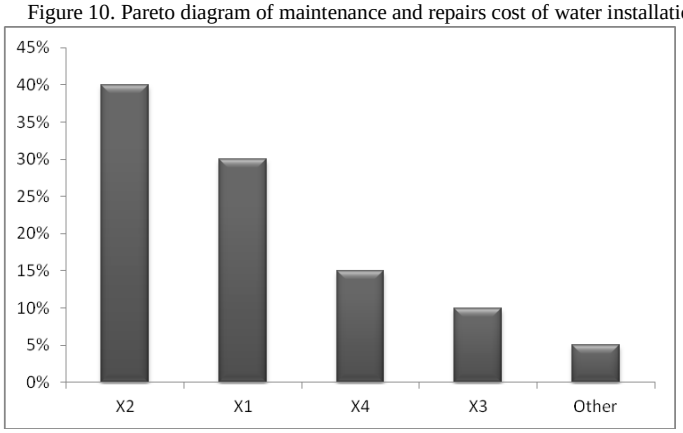


Figure 10. Pareto diagram of maintenance and repairs cost of water installations



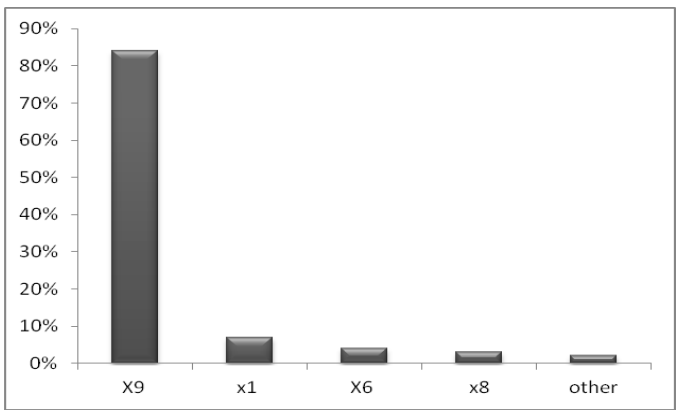


Figure 12. Pareto diagram of cost of accidents and events

Mechanism defect of the meters was one of the root causes whose improvement could have a significant effect on project savings. The observations showed that the 1047 meters of the 11865 inspected meters overestimated water consumption and the 2451 meters of the 11860 meters underestimated in other sample. Considering to the result of following hypothesis test was concluded that there is a statistically significant difference between the two groups of meters at significance level $\alpha = 0.05$. In other words, the proportion of the meters which underestimated water consumption was significantly more than those overestimated. Hence, mechanism defect was identified as the root cause.

$$H_0: p_1 = p_2$$
$$H_1: p_1 \neq p_2$$

$$Z = \frac{\hat{p}_1 - \hat{p}_2}{\sqrt{\hat{p}(1-\hat{p})(\frac{1}{n_1} + \frac{1}{n_2})}} = 26.08$$

TABLE 3. PROPOSED IMPROVEMENTS

Problem	Root causes	Proposed improvements
Cost reduction of maintenance and repairs of waste water installations	Wear due to aging	- gathering data about network incidents density and branches - events classification based on incidence and event type - Network and branches modification - careful examination of manufacturing factories - continuous visit of production process - quality control at site using standard tests - careful loading, shipment and unloading according to instructions - careful supervision of installation process - Installing and commissioning of meters - data recording
	Low quality of joints and Polyethylene pipes	
	Lack of volumetric meters between reservoir and network	
Cost reduction of maintenance and repairs of water installations	Water shortage and redesign	- New arrangement - Probing reliable and new resources - Using new surface resources - resource management and loss prevention - Design of pressure management - Real network pressure zoning - Using after sale services - Having periodic coordinated visits of manufacturing factory at least every 6 months
	Water hardness increase	
	20 kV power becoming 2-phase and electric power swing	
	Unsuitable execution of pressure control valve	
	Pipe puncture due to unsuitable passage from rivers, floodways and direct pumping	
	Lack of middle line valve	
Cost reduction of accidents and events	Branch accessories wear	-modifying the quality control system of purchased goods - commissioning a software suitable for the events and incidents in big cities - holding related training courses
	Low quality of accessories material	
	Corrosiveness	
Cost reduction of electric power consumption	Time schedule of equipment being in service	-Training and notification of managers and operation administrators about management of supply and distribution of water and installation usage - Execution of control systems such as telemetry, reservoirs water level control and working hours etc. for installations - examining water generation and consumption levels and storage reservoirs volume and management and planning for supplying water in low load and usual periods. - Replacing one and two tariff electric meters with 3 tariff electric meters for subscribers without multi tariff meters.

TABLE 3. PROPOSED IMPROVEMENTS (cont.)

Problem	**Root causes**	**Proposed improvements**
Cost reduction of electric power consumption (cont.)	high cost of replacement and redesign of installation	- control and mechanization of wells pumping tests with electromagnetic flow meters and installation of working hours clock or CCTV camera while testing pumps - Design of pumps on the basis of accurate results of pumping tests and considering underground tables drop and water shortage of wells - operation control of installations such as electrical, hydraulic and qualitative parameters in a periodic manner and action for replacement and redesign if necessary - using electrical pumps with high quality for the installations (considering negative rating in tenders)
	Paying demand cost in idle times of equipment	- Increasing marginal load factor (time percentage per year for usage of energy consuming appliances - decreasing discharge capacity and increasing working hours by redesign of equipment - In case of lack of water shortage, not using newly installed resources
	Paying demand cost for out of circuit and reserve equipment	- collecting or moving equipment and demand of out of circuit installations - increasing or decreasing demand of installations in operation circuit with respect to change in conditions and redesign
Cost reduction of maintenance and repairs of out of service meters	Mechanism defect	- purchase of high quality meters with tested mechanisms - preventing sand and gravel from entering network - Preventing pumps installation on the network by subscribers - Installing one way valve to prevent hot water to return to the meter - network pressure management
	Meter wear	- meters replacement according to the time schedule suggested by the supplier - preventing meter pool from being flooded or freezing - Execution of a regular cluster test schedule of meters to ensure their accuracy and also to evaluate the most suitable type of meter. - Purchase of meters with suitable durability and guarantee

Where,

$$\hat{p} = \frac{x_1 + x_2}{\hat{p_1} + \hat{p_2}} = 0.147$$

$$\hat{p_1} = 0.21, \ \hat{p_2} = 0.09$$

E. Improvement

In this stage, some solutions are presented and applied for confirmed root causes. In fact, the purpose of this phase is to demonstrate that presented solutions solve the problems and result in process improvement. Some of the proposed improvements were selected after risk analysis. Table III shows proposed improvements for root causes.

F. Control

The purpose of this phase is to authenticate and execute control actions. In this stage one should make sure of maintaining obtained improvements. For this purpose process control is used. Effective methods are standardized and documented. In this project all of the applied modifications have been converted to methods and added to the quality control system as well. In addition, a team has been selected to monthly monitor the execution of these modifications and a checklist was designed for being assured of the control.

CONCLUSION

Six-Sigma as one of successful approaches of quality enhancement with the aim of presenting free of defect products and services, financial saving and customer satisfaction, has been used repeatedly in various industries and organizations. Cost reduction is one of the issues which have been frequently considered in the academic six-sigma papers. However, reviewing the research in this scope reveals that no specific effort about cost reduction of maintenance and repairs, as a major part of an organization cost, has been done so far. Considering importance of reducing energy consumption in recent years and transferring state-owned enterprises to private sector, this issue has gained a special importance. In this paper DMAIC methodology steps for reducing maintenance and repairs costs of installations and equipment in one water and waste water companies was described. Implementation of Six-Sigma methodology was followed by considerable profit from saving in electric power consumption in pumping stations, reducing water loss, reducing emergency repairs and their associated costs and reducing water purification costs. Benefits obtained from execution of this research plan in the company indicate that the approach can be used by similar companies to reduce cost associated with various sections including maintenance and repairs.

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