Politecnico di Milano
Facoltá di Ingegneria dei Sistemi

POLO REGIONALE DI COMO

Master of Science in Management, Economics and Industrial Engineering

An application of Design of Experiment in DMAIC projects: Comat srl. Case

Supervisor: Prof. Alessandro Brun

Master graduate thesis by:
Bahadir Sukru YILMAZ Id Number:745894

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Abstract

From it is birth in late 80's; The Six Sigma methodology has evolved and become a corporate philosophy. Nowadays, it is an industrial fashion, since it provides a systematic approach to process improvement projects.

The following work is aimed to show the practical advantages of Design of Experiment in Six Sigma project. Since the Design of Experiments significantly reduces the necessary time and effort of testing phases, it provides important support in the Measure and Analysis phase of the DMAIC project.

As an application, the Design of Experiments tool has been used in a product improvement project of a small sized Italian enterprise, Comat srl. To achieve competitive advantage, a product development project with the aim of reducing 'the total costs of ownership for customers' has been executed. The total costs of ownership, The Design of Experiments significantly reduced the number of necessary experiments, which increased the effectiveness of the project.

Finally, the findings of the analysis have been discussed and the improvement options have been argued both financially and technically. Also the organizational and motivational problems faced trough the project have been listed and discussed to lead the possible future works.

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I Introduction

The global recession in the machining industry forced the Small and Medium Sized Enterprises to be more competitive and challenging. Since the demand kept on decreasing after 2008, the remaining customer’s satisfaction became more and more important for the manufacturers. In the non-critical manufacturing services market, the total costs of ownership had gain a critical superiority over the other decision criteria.

In Comat case, the total costs of ownership had to be decreased in order to stay competitive in the market. The factors affecting the total costs of ownership had to be identified and improved with a scientific methodology.

In this work, the factors affecting the total costs of ownership of super-filtration process of Comat machines had been analyzed and optimized by DMAIC methodology. The scientific, step by step approach of DMAIC methodology led the team to find and offer various improvement ideas, which are offered to the customers as extra services.

In the measurement and analysis phase, the full-length tests were costly and time consuming. The crucial tests have been planned and executed with the help of Design of experiment tool. The design of experiment technique enabled the improvement to execute more reliable tests with less time and effort.

In the first part of the work, a bibliographic review of Six Sigma methodology and Design of Experiment method has been presented. The literature identifies many advantages of both DMAIC methodology and Design of Experiment tool, which had encouraged the project team to focus on these two approaches.

In the following part, an introduction about the Comat, F12 Super-Filtration Machine and Filtration processes has been discussed. The dynamics of a filtration process, which takes roots from fluid dynamics, was a key issue in the DMAIC project. The formulations and assumptions have been summarized in this section.

After the introduction, the procedures and the operations done in the Comat product improvement project has been listed. The steps of DMAIC project and the results are published in this part. Design of Experiment application is also discussed with procedures and results.

Moreover, the organizational and motivational aspects of the project work has been discussed, which will provide key information for the upcoming scholars and professions who are with the aim of executing a Six Sigma project in a different country and culture.

The feedbacks show that the product improvement project is successful, since it provided serious opportunity for the customer to decrease their energy costs by implementing inverter kit. The work is concluded with suggestion to possible following projects over super-filtration machines of Comat.

II THEORETICAL BACKGROUND

1 Process improvement and Six Sigma

The fierce worldwide competition has forced the companies to redesign their processes and products. In the pursuit of higher operational effectiveness and organizational performance, scholars and practitioners are looking for new approaches to improve operational performance, boost profitability, and enhance competitiveness. As a structured methodology emerged from quality management, Six Sigma programs have received considerable attention in the never-ending journey of process improvement (The effect of Six Sigma projects on innovation and firm performance, 2010).

As stated by Buyukozan and Ozturkcan in 2010, Six Sigma methodology is not only a technique, but also a company philosophy. Especially in the last decade, as a change and improvement strategy, Six Sigma has received considerable attention in global companies to generate maximum business benefit and competitive advantage.

The main philosophy of Six Sigma, reducing variability in the processes has a history of 200 years. As Adam Smith stated in his state-of-art, The Wealth of Nations; economic growth can only be made possible with specialization and economies of scale. Since specialization forces the processes to higher levels of conformity, Adam Smith's approach can be considered as the roots of Six-Sigma mentality. However, modern applications of a systematic approach to reduce variability in the processes started with Frederick W. Taylor, generally referred as the Father of Industrial Engineering. Throughout the 20^{th} century the methodologies to challenge the process variability evolved deeply with the contributions of Quality Gurus such as Ford, Deming, Juran and Feigenbaum. (Rath & Strong, 2003)

Nowadays there are two perspectives for Six Sigma processes. First of all, there is a statistical perspective where the practicians discuss the Six Sigma method from a statistical, probabilistic, and quantitative point of view. From the statistical point of view, the term Six Sigma is defined as having less than 3.4 defects per million opportunities or a success rate of 99.9997% where sigma is a term used to represent the variation about the process average.

In a process variation based point of view, the quality of the systems and processes could be defined by the Sigma-level. Sigma refers to the Greek Letter σ which is used to notate standard deviation in statistics and engineering, where Sigma Level shows the processes conformance with predefined limits, such as 4,5 or 6 Sigma. More and more, in critical industries such as aeronautics and aviation, the sigma levels are aimed to be the utopia, 7-Sigma.

As stated by an article published in 2004, the quality costs are highly affected with the implemented sigma level. The following graph shows the relation between sigma levels and quality costs.

Table 1 Sigma Level and Quality Costs,adapted from (KONAK et al, 2004)

Sigma Level	**DPMO**	**Total Quality Costs**
6σ	3,4	<10%
5σ	233	10-15%
4σ	6210	15-20%
3σ	66807	20-30%
2σ	308537	30-40%
1σ	690000	>40%

On the other hand , there is a business point of view in the business world, Six Sigma is defined as a ‘business strategy used to improve business profitability, to improve the effectiveness and efficiency of all operations to meet or exceed customer’s needs and expectations (Antony and Banuelas, 2001). The Six Sigma approach was first applied in manufacturing operations and rapidly expanded to different functional areas such as marketing, engineering, purchasing, servicing, and administrative support, once organizations realized the benefits. Particularly, the widespread applications of Six Sigma were possible due to the fact that organizations were able to articulate the benefits of Six Sigma presented in financial returns by linking process improvement with cost savings (Kwak, et al., 2006).

2 DMAIC methodology

A strategic approach for Six Sigma Projects consists of five basic phases: define measure, analyze, improve and control which can also be symbolized by initials, as D-M-A-I-C. DMAIC is a data-driven approach to improving processes in a logical and methodological was. Its five phases are designed to take a team through a process/product improvement project from inception to completion.(Rath & Strong, 2003). While DMAIC builds on earlier approaches to problem solving such as Plan-Do-check-act, Total Quality Management and Business process reengineering, it differentiates from them with a single distinctive point. DMAIC projects demand a no-shortcuts approach that requires discipline to execute.

As it can clearly be seen from the word DMAIC, the methodology consists of five phases. Before anything else, the project team should define the requirements and expectations of the customer, this phase is referred as the

Define phase, where the team also defines the project boundaries and maps the business flow.

After defining the boundaries, the project team should measure the process, develop a data collection plan and collect data to determine issues and shortfalls in the Measure phase. Measure phase is followed by the Analyze phase, in which the data is analyzed in a scientific way to define the possible causes of the defects, variations and address possible opportunities for the future.

Improving the processes and the solutions is also must have for most of the cases. In the Improve phase, the team improves the processes and tries to create alternatives for further implementations. Finally, the results of improvements have to be kept under control. Improve phase is followed by control phase which is assessment and verification of the implemented solution.

2.1 Define Phase

To follow a scientific procedure, the focus of the project should be defined in the Define phase. The team should define the necessary resources and the possible business benefits of the project. Team should develop a business case to ensure that there is enough reason for expending the time and effort of the company.

Preparation of the project charter is a key issue in the define phase of the project. The project charter is a contract between improvement team and management, as a license to improve. It identifies the current situation with a problem statement and a timeline for the project with necessary resources. Since DMAIC project will require fundamental change in a process, it is also crucial to identify the stakeholders early on and to develop appropriate communication plans. The team should also collect data from stakeholders by principal data analysis, such as Voice of Customer (VOC) and Critical to Quality (CTQ) analysis.

At the end of the define phase, the team should meet with the sponsors and discuss the situation, which is formally referred as ‘the tollgate review’. The sponsor has to approve the work has done so far and lead the project. The tools that are used in the define phase are;

- Project Charter
- SIPOC map
- Stakeholder analysis
- Voice of the customer analysis
- CTQ Diagram
- Affinity Diagram
- Kano Analysis

2.2 Measure Phase

After the definition of project goals and scope in the Define phase, the team should develop a procedure to acquire data about the system. The first step in this effort is to review the process map and the customer requirements, looking for every possible contributor to the development procedure. This will lead the project team to define the possible metrics which should be investigated and measured. Once the procedure is completed, team should define the procedures to be used to acquire data. The type of data (discrete, continuous) and the plan for the recordings should be chosen by the improvement team.

The measurement is a risky and faulty procedure since it can cause stops and fluctuations in the system. The team should also define the scheduling and the method of the data acquire phase considering these constraints. Once the data is acquired by execution of the plan, the team is able to analyze the data. The engineering tools used in the measurement phase are;

- Run Charts
- Control Charts
- Histogram
- Pareto chart

2.3 Analyze Phase

After the data about the system and problem is acquired with a scientific approach, the data should be identified, organized and validate potential root causes. The analysis are expected to lead the project team to the possible solutions (such as implementation of a new process, machine or method), which are also have to be discussed. To verify and quantify potential causes of the problem, the team can use a whole inventory of statistics. By employing cause and effect diagram, the team can list the problems and link them to the possible solutions. The engineering tools used in the analysis phase are;

- Data Collection plan
- Gage R&R
- Prioritization matrix
- Run Charts
- Control Charts
- Histogram or other frequency plots
- Pareto Charts
- Process Sigma Calculation

2.4 Improve phase

In order to acquire the gains of a planned solution, the team should define the procedure to implement the solution to the real world. The team should present the possible solution and reach consensus over the solution. Once the solution is approved, the team precedes with an evaluation of potential implementation risks, using Failure mode and Effects Analysis to identify and evaluate the risk of implementation. In most cases a pilot implementation is necessary to address possible errors of newly established system. The process owner or sponsor’s intense attention is crucial in this period, since the implementation is due to his/her approval. The engineering tools used in this phase are,

- Detailed Process Map
- Cause and effect diagram
- Regression analysis
- Scatter plots
- Hypothesis testing
- Design of Experiments

2.5 Control Phase

Sustaining the gains is the focus in the Six Sigma mentality. Therefore, a control phase is planned and followed by the project team to monitor gains. This monitoring approach prevents the system from faulty improvements and fake gains. The control phase can also provide information about further improvements and implementations. The engineering tools used in the Control Phase are;

- Evaluation, documentation and approval
- QC process chart

- Response plan
- Training plan and standardization
- Project closure

3 Design of experiment

In order to increase efficiency and effectiveness of the processes, engineers conduct test or experiments as a natural part of their work. Designs of Experiment techniques, which have strong statistical basis are useful in the engineering world for improving the performance of a manufacturing world in order to improve the performance of a manufacturing process.

Designing an experiment for parameter estimation involves two steps. The first one is qualitative, and consists of selecting a suitable configuration of the input/output ports so as to make, if possible, all the parameters of interest identifiable. The second step is quantitative, and based on the optimization of a suitable criterion (with respect to the input shapes, sampling schedule . . . .) so as to get the maximum information from the data to be collected. (Qualitative and Quantitative Experiment Design for Phenomenological Models, 1990) The results of design of experiment can lead the engineers to,

- Decrease the percentage of defective products
- Reduce variability in the critical processes and closer conformance to nominal target requirements
- Reduced design and development time
- Reduced cost of experiments and Project

More and more, the experimental design methods are useful in engineering design activities, where new products are developed and existing ones are improved. Design of experiment is a very useful tool in the measure and analyzes phases of a DMAIC or DMAIC Project, since; it enables effective results with less experiment and effort.

Every experiment can also be designed in a sequential and methodological way, such as Six Sigma projects. Montgomery stated that the experimental design projects have four main steps and activities: Conjecture; Experiment; Analysis and Conclusion. This methodology enables the managers to track the effectiveness of the experiments and fits the Six-Sigma philosophy.

In the search of high quality and reduced process yield, precision is crucial. This makes the statistical methods essential for good experimentation. Statistically designed experiments permit efficiency and economy in experimental process, and the use of statistical methods in examining the data results in scientific objectivity when drawing conclusion.

In design of experiment, the controlled variables are named as factors and the uncontrolled variables are named as the responses. The methodology aims to understand and summarize the relation between the factors, which can affect the responses. In the literature, many statistical methods have been applied to solve the problems and understand the effects. The main common analysis is the factorial experiments and response surface methods. When several factors exists in an experiment, a factorial experiment approach is the first option that engineer use since it is less complex and easier to use. By a factorial experiment, the all possible combinations of the factors are being investigated.

The experimental design methods can also be used to model systems with the aim of high precision. A research made by Franceschini and Marchetti shows the possible modeling applications of experimental design techniques. The design of experiment methods enables the engineers to model both controlled and immeasurable variables. In the same research, the possible variables which can be measured and analyzed by design of experiment techniques are listed as;

- Time varying control variables
- Constant controls
- Sampling times and measured responses
- Initial conditions
- Duration of the experiment.

Also the uncontrollable variables such as the systematic errors of the experiment and the random errors of the experiment can be analyzed throughout statistical techniques and approaches.(Montgomery, et al., 2004)

4 Six Sigma Projects and Design of Experiments

In literature, in the selection of the right scheduling for Sig Sigma Projects, many methodologies are suggested by professional and scholars. The widely suggested methodologies are DMAIC, DMADV and Design for Six Sigma, where aim and the focus of the projects is similar: Increasing process quality and reducing yields with a systematic and scientific approach.

In the measurement and analysis phase of each methodology precise the data have to be acquired precisely and analyzed scientifically. Design of Experiment helps the engineers to facilitate the design of robust products and services.

Design of Experiment method is widely suggested when there is no or not enough historical data about a system or a process. Since it is rare to find a cause-and-effect relationship just by passively observing a process, the Design of Experiments offers a systematic approach to analyze the relation between input and output data.(Montgomery, et al., 2004)

The design of experiment technique has various applications in the literature. In a product development project, the scholars used design of experiment to optimize the drag in airplane winds. AS stated by the applicants, design of experiment has superiority to computational fluid dynamics since design of experiment is much quicker and precise.(Munson, et al., 2006) This research has led the Comat project in a very important aspect, since it stated that the fastest and easiest way to test the fluid dynamics. The Comat case is a mixture of fluid dynamics and fundamental physics, where the computation techniques would need too much expertise and effort. This supports the Boards idea to use design of experiment, rather than Computational Fluid Dynamics.

Apart from engineering, the method is also applied to other irrelevant disciplines, such as theoretical chemistry. Chinese scholars preferred the design of experiment since it reduced the number of necessary experiments from 81 to 9, which decreased the time and effort spent on the project. (Chou, et al., 2003)

An interesting conference, which has been established in London, shows the multi-disciplinary nature of design of experiment. The conference involved contributions from many disciplines and research fields, such as genomics, computer sciences and clinical tests. (Design of Experiments, 2008)

As a powerful statistical tool, Design of Experiment can be used to analyze the factors affecting the overall service quality or efficiency. Since it offers a systematic approach, it highly suits the mentality of Six Sigma philosophy. In our current case, an experiment will be designed to analyze the factors that affect a key response, The Total Cost of Ownership.

5 Critical success factors in Six Sigma Projects

A research done by Process Quality Associates in United States has listed the critical success factors in Six Sigma projects and sorted them according to their importance (2009). The research also supports the general idea of the importance of the commitment of top management to the Six Sigma Projects.

- **Top management leadership & commitment** are essential to Six Sigma QMS success. Top management should act as key driver in continuous improvements, communicate to employees about organizational goals, and establish an environment for supporting organizational & employee learning.
- **A well-implemented customer management system** is critical to Six Sigma QMS success. Processes need to be established in order to monitor customer satisfaction levels, to receive customer feedback, and to resolve customer concerns.
- **The education and training system** should provide continuous courses to employees for equipping them with quality-related knowledge and problem-solving skills.
- **A well-organized information and analysis** system should be designed to collect the performance measures in order to monitor the quality of key business processes.
- **A well-implemented process management system** that identifies, improves, and monitors the key business processes has a positive impact on Six Sigma QMS success. The quality assurance system, work unit performance measures, and statistical techniques are essential to process management.
- **A well-developed strategic planning system** must translate into executable action plans with related performance measurements. The necessary human & financial resources must be allocated to support the implementation of business action plans.

- **A well-developed supplier management system**, where the main criteria for selecting suppliers is based on quality aspects, has a positive impact on Six Sigma QMS success. Processes need to be built in order to monitor the quality performance levels of suppliers.
- **Throughout the organization, from manageme**nt to employees, equipping all with quality tools has a positive impact on Six Sigma QMS success. Quality tools should be used in production and non-production processes.
- **A well-developed human resource management** system has a positive impact on Six Sigma QMS success. A job advancement system is important to human resource development. Various methods are developed to facilitate the communication between the organization and its employees. To promptly improve performance, employees need to receive their performance feedback from their supervisors.
- **A well-developed competitive benchmarking** system should be capable of collecting market and competitors' information. The process of benchmarking information collection needs to be evaluated to ensure its effectiveness.

6 An example: In search for the Perfect Poached Egg

Having a higher level of quality can be an aim for different professions. Hypothetically, even a top chef like Gordon Ramsay can use the Six Sigma methodology to find the best process to cook the Perfect Poached egg.

On his TV show, The Food Word, Gordon Ramsay defines the best poached egg as "taste should be balanced, it shouldn't be overcooked and should look like a mozzarella ball"

First of all, since the raw materials define the boundaries in culinary industries; Ramsey must purchase the most suitable egg for a poached egg. In order to have the most pleasant taste, the poached eggs has to have the optimal mineral ingredients and acidity balance.

Ramsey's genetic research team should list the possible genes and races of the chickens which are able to breed. Ramsey should taste the possible combination of parents for eggs and decide which race to use.

The logistics can also cause a problem and should be kept under control. The best humidity and temperature values to keep the eggs should be defined and satisfied by both the supplier and Ramsay's kitchen staff. These conditions are key aspects for the overall quality of raw material. The variation in these values can cause defective and non-conforming poached eggs. The variation of these values should be kept under control using Statistical Process Control tools.

Since the most important process in the adventure of a poached egg is cooking, Ramsay should define the best cooking and cooling time for his process. He should follow a systematic approach to decide the best combination, such as Design of Experiment tool where he can design tests to find the interaction between the cooking and cooling processes. He should also ask for the help and the opinion of his assistant chefs, since they can contribute the project.

Finally he has to keep the Poached Eggs quality under control by taste testing some samples defined by the statistical sampling methods. This simple hypothetical example shows that the systematic approach of Six Sigma philosophy is a must have in all process development projects.

In conclusion, Six Sigma methodology is a systematic approach with intense contribution of statistical methods and data analysis tools with the aim of reaching and maintaining successful processes and customer relations.

III Comat And Super-filtration Systems

1 Introduction

1.1 Comat

Comat srl. , is a small sized Italian company which is located near Milan, Ossona. Comat Srl offers management solutions for liquid, gas and aerosol cutting aid materials. There are various filtrations, cooling and treatment products and services offered by Comat, which are highly reputed in the Italian and European Market.

Comat Srl focuses their time and effort on liquid management, where they dominate the market with their unique super-filtration system, F DQ series. They also offer filtration systems and technologies for industrial air conditioning.

Figure 1 The emblem of Comat srl.

In 2010, Comat recorded a 3.000.000 Euros of revenues. By January 2011, Comat has 6 blue white collar and 7 blue collar workers; which is supplied by part-time workforce during peak seasons. The shareholders of Comat also own a co-company named CBC which operates in chemical market.

Comat supplies and markets necessary chemical materials from CBC, which is a win-win situation for both of the companies. The recession in the European Machining Market has significantly damaged the sales and financial performances of Comat, which lead the board for radical decisions.

Figure 2 General Overview of Ossona Plant

1.2 F12 DQ Super-Filtration machine

Comat Spa produces super filtration machines is various size and dimensions. In the selection of the appropriate filtration machine and method, the main criteria is the demand of clean oil for the machining centers. Each filtration machine has different filtration surface, which indicated the model. For this project and designed test, a Super Filtration machine, F-12 is provided by the company. The main characteristics of this machine are;

- Has a single pump of 1,8 KW

- Has a single filtration bulb
- Has filtration surface of 12 m²
- Has semi-automatic control system

The main components of Super-Filtration Machine

The main components of the F12 can be seen in the following illustration.

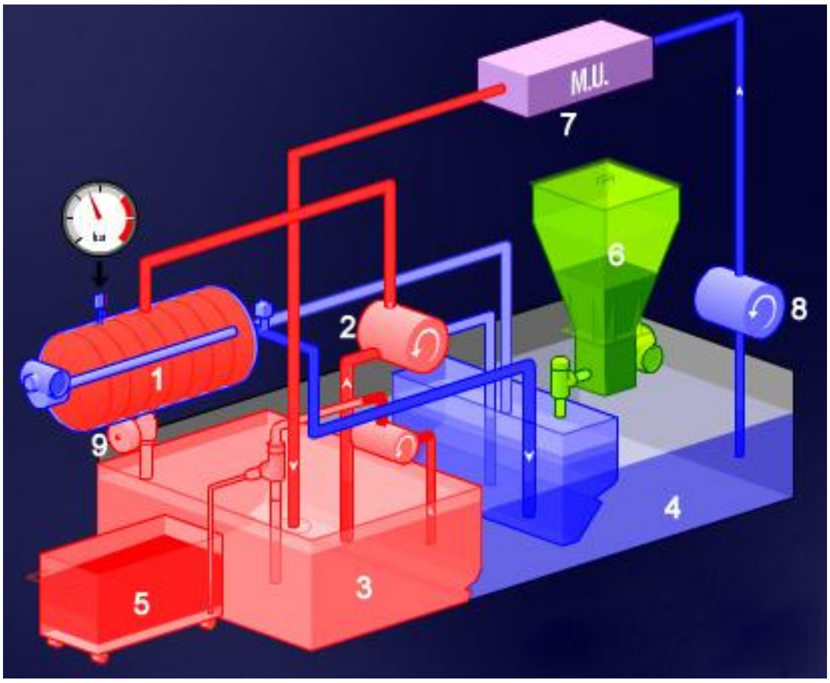


Figure 3 The parts of F12-1-Filtration bulb, 2- Filtration pump, 3-Dirty oil tank, 4-Clean oil tank,5-Sludge drying tank, 6-Filter-aid feeder, 7-Machining unit of the customer, 8-Distribution pump, 9-Sludge disposal valve

1.2.1.1 Filtration Bulb

Filtration bulb is the main element of a filtrating system. It has number of disks made of fabric, which holds the filter-aid to create filtration surface. The number and size of the disks differ in each model.

1.2.1.2 Main filtration pump

The main pump can be considered as the heart of the whole system. It is the main energy consumer of the system and works non-stop and in full-power in the traditional system. The motor of F12 has the power of 1,8 KW. An inverter, which is a simple electronic device, can control the frequency, the speed and the power of the pump. However, it is not installed on the pump in the traditional scenario.

1.2.1.3 Dirty and clean oil tanks

The bottom of the filtration machines consists of two main compartments to accumulate dirty and clean oil. Clean oil is pumped to the machining units via a distribution pump (an auxiliary pump) . The oil creates the precision environment by taking the particles and smoke away from the machining surface. The dirty oil composed after this precise machining process is accumulated to the dirty oil tank and pumped by the main pump directly into the filtration bulb. The filtered oil is then sent into the clean oil tank.

As an exception, in the pre-coating phase the clean oil is sent to the filtration bulb in order to create the filtration surface by covering the disks with filter aid.

1.2.1.4 Discharge valve

A small valve which is used to discharge the mixture of oil, filter aid and filtered material in the sludge disposal tank. This valve is controlled pneumatically by the PLC and is opened only in sludge disposal phase.

1.2.1.5 Sludge drying pump

A small vacuum pump sucks the oil in the sludge disposal tank and sends it to the dirty oil tank. The pump works as an on-off pump (works 1 minute and stops 1 minute) in order to avoid emulsions in the dirty oil tank. The emulsions create disturbance and turbulence in the filtration surface, which reduces precision and quality.

1.2.1.6 Electrical Board (PLC)

The main electrical board helps the users to control the filtration process, switch between different phases of filtration and creates pre-caution signals for emergency cases. In the last decade, the main board has evolved a lot. There are now models full-automatic with touch screen, where the PLC controls the whole process and the phases. However, in this project, a model with the manual PLC has been used to be more flexible and compact.

1.3 Phases of filtration process

There are 3 main phases in a cycle of the machine. These are pre-coating, filtration and sludge disposal phases. After the sludge is disposed, the residue is dried in order to regain the oil and filtrated precious material. Each cycle starts with pre- coating phase and is followed by filtration phase. The filtration phase's length varies in each case. Each filtration cycle ends when the inner pressure of the bulb reaches 1,8 atm. , which is defined as the threshold for quality and security.

1.3.1.1 Pre-Coating

In the beginning of each cycle, the disks inside the bulb must be covered by the filter-aid. In the beginning, the filter-aid is filled in the dosing device which feeds the filter-aid to the clean oil tank. The pump, pumps the mixture of clean oil and filter-aid to the filtration bulb. This pushes the filtration particles to the outer surface of the disks to create a filtration surface. The process takes around 15 minutes and requires supervision.

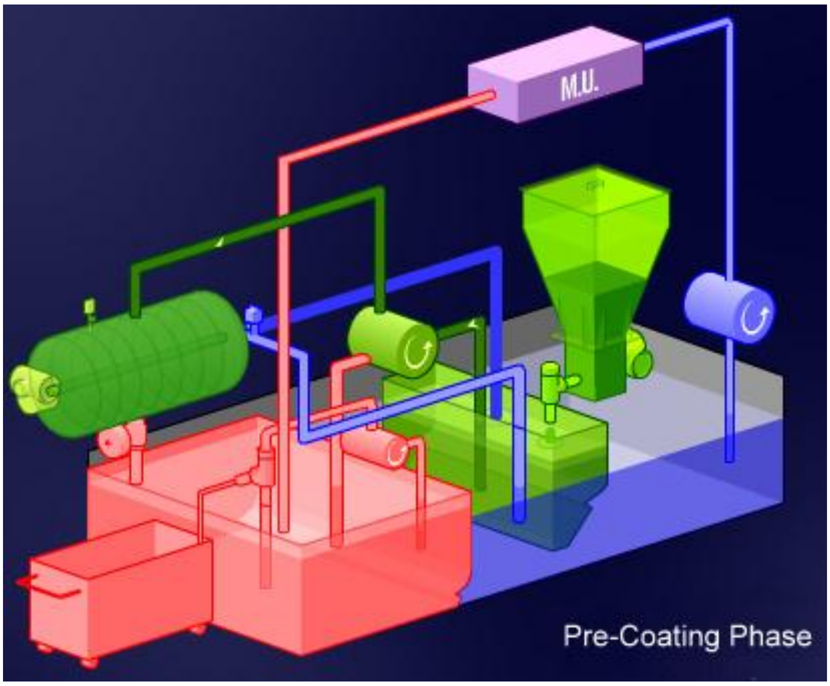


Figure 4 Pre Coating Phase

1.3.1.2 Filtration

In this phase, the main pump feeds the filter with dirty oil and the filtrated oil is accumulated in the clean oil tank. During the process, the particles in the dirty oil is held in on the filtration surface, which increases the resistance of the filtration. The increase in the resistance causes a significant increase in the inner pressure on the bulb, which causes saturation in the process. A threshold of 1,8 atm. was defined as a limit in the inner pressure and reaching that limit causes with the end of cycle.

The filtration rate starts with 220 liters per minute and decreases over saturation and time. I was observed that the filtration rate reaches 100 liters per minute when the pressure inside the bulb is 1,8 atm. The feed rate of the filtration pump is not adjustable.

The time necessary to reach the saturation varies in each case and the filtration process does not need any supervision.

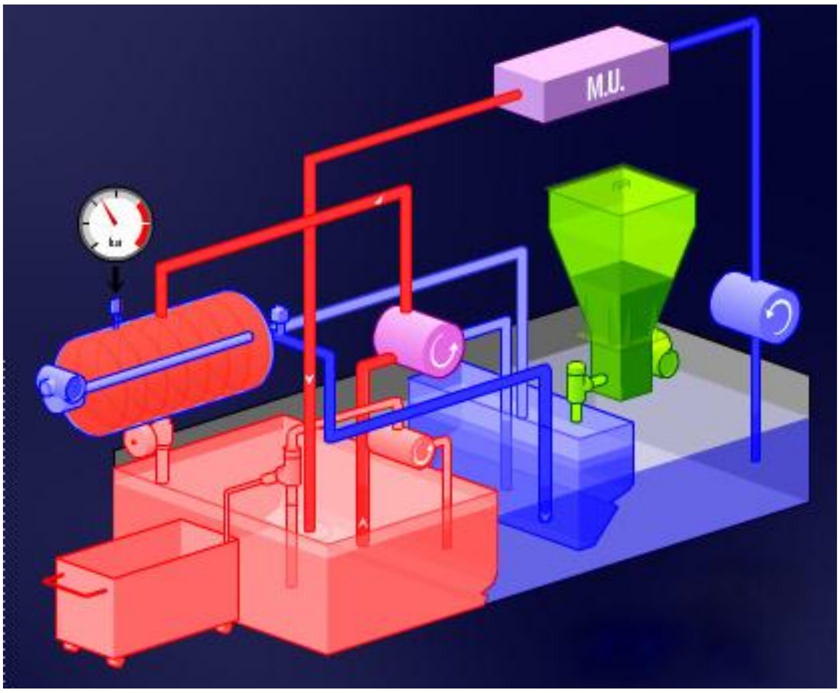


Figure 5 Filtration Phase

1.3.1.3 Discharge and sludge disposal

After the filtration phase, the bulb has to be cleaned and prepared for the next cycle. Discharge valve is positioned just under the filtration bulb and is opened in the discharge phase. The mixture of filter-aid, oil and sludge is disposed into the sludge disposal tank . The oil inside the sludge disposal tank is sent to dirty oil tank by a vacuum pump. The sludge remaining in the bottom of the sludge disposal tanks is cleaned manually and has to be managed. The process takes about 15 minutes and requires supervision.

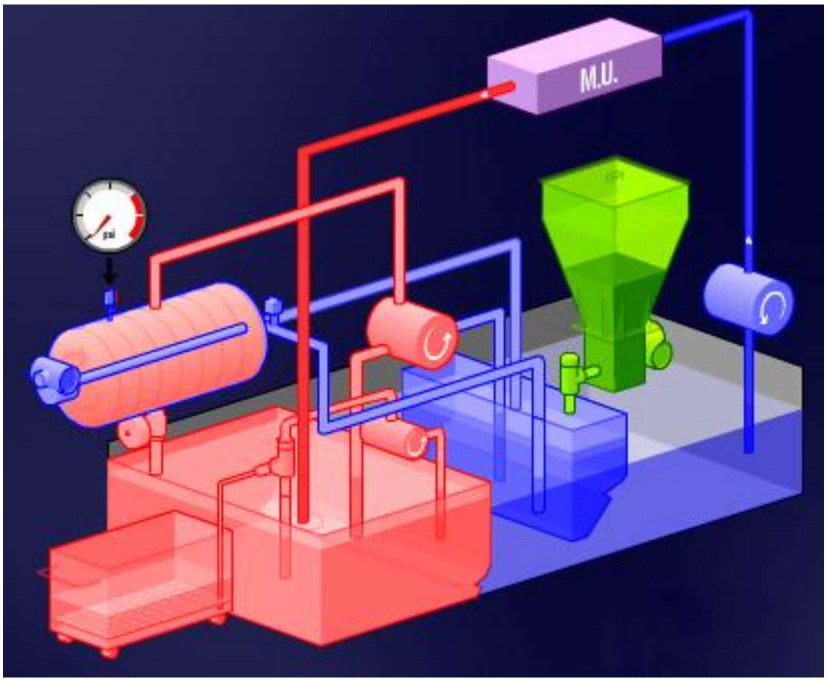


Figure 6 Sludge discharge and disposal

2 Scientific analysis of the Super-Filtration System

Before the project, there have never been made any scientific research about the filtration system, F12. In order to start the optimization of the filtration system, the components must be analyzed and defined in a scientific way. The most important

2.1 Filtration

Due to the necessity to reach the highest precision in the machining processes, there is a need of high precision cutting fluid filtration. Filtration can be defined as the process of separating dispersed particles from a dispersing fluid by means of a porous media. The dispersing medium can be a gas or a liquid. In the Comat case, a filtration process of lubricant oil through a porous filter aid will be discussed. It is generally mentioned as solid-liquid filtration with filter-aid.

The term solid-liquid filtration covers all the processes in which a liquid containing suspended solid is freed of some or the entire solid when the suspension is drowned to the porous medium. The main features of the filters will be shown and discussed in the next section.

2.2 Dynamics of a filtration system

In a scientific point of view, the filtration process can be characterized by several parameters. In every filtration process there is a difference between ingoing and outgoing pressures of the filtered fluid.

The pressure drop of the filter Δp is defined by;

$$\Delta p = p1 - p2 \qquad (3.1)$$

Where $p1$ is the surface pressure before the filter and $p2$ that behind the filter. This quantity is dependent only on the properties of the fluid and on the properties of the porous substance used as a filter, in the case of clean filter.

The choice of a filter design for a given process depends on many factors. Among these, properties of solid particles to be removed, particle size and shape distribution , the properties of the fluid, the quantity of the metal to be handled and the value of the materials being processed are considered as the most important aspects.

On the other hand, the source of the driving force of the systems, which may be gravity, suction or positive pressure is the main element in the designing of the filtration surface. The super-filtration machines of Comat rely on positive pressure, which is provided by the main filtration pump.

Filtration processes are divided into three classes for convenience when considering the mathematical analysis of the factors involved. These classes are;

- **Medium filtration:** Where the filtration process only takes place on the surface of the filtration medium.
- **Depth filtration:** Where the filtration process occurs within the medium, instead of the surface.
- **Cake filtration:** Where the solid material accumulates on the filtration medium, creates another filtration bed , which is called the cake.

In the Comat case, the filter-aid covers the outer surface of the filtration disks to create a filtration bed. The filtration only takes place in the surface of the filter, which leads us to define the system as Medium Filtration System. In such systems, the filtered particles that accumulated on the filtration base increases the resistance of the filter over time, which leads us to increase in inner pressure and saturation point. To better analyze the situation, Bernoulli Equation can be used.

$$(p_1 - p_2) + \rho \cdot \frac{(v_1^2 - v_2^2)}{2} + A_{12} \quad (3.2)$$

v_1 and v_2 stands for the velocities of the liquid in the first and second sections. In the given equation p shows the density of the fluid and A_{12} shows the Pressure loss due to friction of the surface between first and second sections.

In general, given that the flow and speed are directly related, the pressure drop can be seen as a function of scale, and the resistance is dependent on the physical characteristics of filter. By moving from that assumption, the pressure loss is modeled as, we reach the equation

$$\Delta p = \rho \cdot \beta \cdot \frac{v^2}{2} \quad (3.3)$$

In the equation, β is used to describe the overall friction coefficient of the filtration system, including the walls and the filtration system. If we replace velocity with flow and β with the resistance indicator, R we can simplify the equation as;

$$\Delta p = \rho \cdot R \cdot Q^2 \quad (3.4)$$

Where resistance of the system throughout the experiments can be shown as the slope of Δp over Q^2 line. This assumption will be very useful to calculate the total resistance of a given setup.

2.3 R, the total resistance of the system: Analysis of affecting Factors

Filtration systems are generally modeled as number of unitary resistance units working in parallel. In physics, the equivalent resistances working in parallel are modeled as,

$$R_{eq} = \frac{R}{n^2} \qquad (3.5)$$

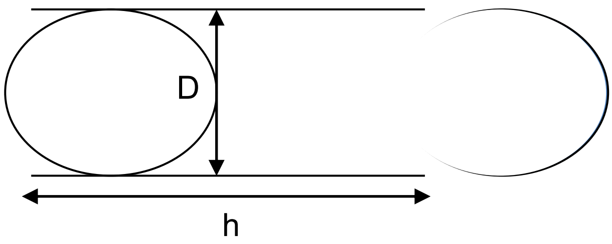
By indicating total surface of a filtration system by *S* and the surface of a filtration unit by *su*, we can describe the R_{eq} as;

$$R_{eq} = \frac{R_{su} \cdot su^2}{S^2} \qquad (3.6)$$

Every surface unit can be modeled as number of pores working in parallel, where d_p indicates the density of pores in a given filtration unit.

$$R_{eq} = \frac{R_p}{n_p^2} = \frac{R_p}{d_p^2 \cdot su^2} \qquad (3.7)$$

A pore can be seen as a fractious tube, which as a specific dimension and length.



Where *D* describes the fineness required in the filtration process. By combining the first equation with the second equation, we reach the;

$$\Delta p = \rho \cdot \lambda \cdot \frac{l}{D} \cdot \frac{v^2}{2} = \rho \cdot \lambda \cdot \frac{h}{D} \cdot \frac{Q^2}{2 \cdot S^2} = \rho \cdot \tau \cdot \frac{h}{D^5} \cdot Q^2 \qquad (3.8)$$

In the final equation, delta describes the tortousity of the filtration system. This coefficient is useful in order to model the saturation level of the filter.

To conclude and summarize, the resistance of a filter can be modeled as,

$$R = \tau \cdot \frac{h}{d_p^2 \cdot S^2 \cdot D^5} \qquad (3.9)$$

We can clearly see that the resistance is dramatically affected by the necessity of precision and the level of tourtousity(τ). Level of tourtousity is directly related to the saturation level which is assumed to be linear since the machines are expected to have the same work-rate throughout the filtration process. These assumptions will be used to analyze the dynamics of the filtration system.

Also the work power required to filter an amount of oil is believed to be a function of flow rate and resistance. The equation simplifies the relation as

$$W_i = R \cdot Q^3 \quad (3.10)$$

2.4 Assumptions and summary

Before starting the measurement and analysis phase of the project, the assumptions are based on the following equations. These assumptions were done after a theoretical review of references (Matteson, 1987) and (Munson, et al., 2006).

$$P_1 - P_2 = \left(R_{vp} + R_{cp}\right) \cdot Q^2 \quad (3.11)$$

$$P_2 - P_3 = R_F \cdot Q^2 \quad (3.12)$$

$$P_3 = R_{vu} \cdot Q^2 \quad (3.13)$$

$$R_F = R_{fv} + R_c(c) + R_s(s) \quad (3.14)$$

2.5 Filtration Model

In order to understand the mechanics of the system, a model of the system was prepared using the resistances notation. This model is used as a basis during the processes, which was very helpful to simplify the system and the data on a single paper. Resistances (R) , Pump (P) and Filters were modeled and the measurements (P_i) were recorded.

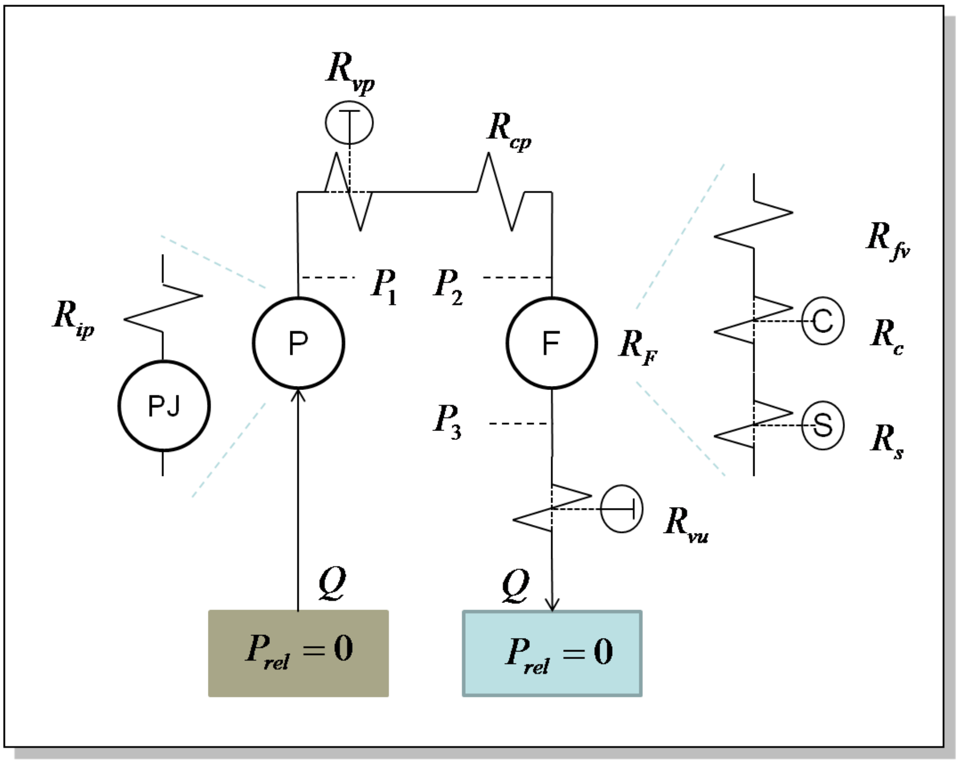


Figure 7 The filtration model

3 Push-Pull difference: Customer point of view

Initially, Comat was designed for manufacturing systems with continuous 24 hour filtration requirement. As- Is condition of the machine doesn’t allow the manufacturers to adjust the filtration requirement and forces them to filter at %100 rate throughout the working cycle. During the filtration the filter gets filled with the filtrated particles which increases the saturation of the system. This increase in saturation, decreases the flow rate significantly over time. After a point, the pressure increase in the filter bulb doesn’t allow the filtration to keep on, since the flow rate diminishes down to 50 litres/minute, which is not acceptable.

This is obviously a push system, which uses the clean oil tank as a buffer, where the pump pushes the filtered oil at the highest possible rate. Demand doesn’t provide any input to the production system, which is by far the most orthodox way of production mentality. The filtration process is not highly critical to the machining since it is only a side process, not an effective process.

Savar’s simulation analysis provided a serious statistical data to prove the advantages of pull systems over push systems. In the research, it is stated that, if the yearly production capacity is adequate to supply the yearly demand, the systems should be designed with pull mentality.

The flow rate of the machine could be adjusted by the implementation of an electronic device, a frequency inverter. The inverter adjusts the output frequency to modulate the work-rate of the pump. In the project phase, the Board of Comat wants the project team to analyze the feasibility of an inverter implementation, which will convert the system from push to pull.

IV AN APPLIACTION OF DMAIC METHODOLOGY AND DESIGN OF EXPERIMENT: COMAT CASE

1 The global economic crisis, it's effects of manufacturing and re-positioning of Comat

In September 2008, a worldwide economic crisis, triggered by defaults of mortgage bonds in US gave severe damage to the global industrial markets. Crisis is flowed by deep recession in both US and Euro-zone which caused a serious decrease in worldwide industrial goods demand. The recession affected the machining industry, which lead the companies to cut jobs and decrease production.

The Comat Superfiltration Machines are generally used by high precision machining companies in Euro-zone which are deeply affected by the crisis. Since most of the models in the production line of Comat were designed for full-time and full-capacity production conditions, recession damaged the competitive advantage of comat over cartridge filters. Cartrige filters have higher flexibility and lower energy consumptions, which are considered as a must have in post-crisis competition. The average orders per month decrease from 12 to 4 after the crisis, which can possibly cause long-term financial problems.

1.1 The product development project

Due to the loss in competitive advantage, the board of Comat formed by Giorgio Colombo, Daniele Cassani, Martina Colombo and Fausto Galli decided to start a Six-Sigma project with an allocated budget of 11.000 Euros. The project scope was defined as ‘’redesign of the production system to lower the total costs of ownership’’

Although a machine (F12) was supplied for the tests, there have never been made a scientific analysis on the filter and the system. There are no data available for primary analysis and all data had to be acquired on the field.

The project was planned and programmed as a DMAIC project where most of the effort, time and money will be spent in analysis phase.

2 Define

Although the main purpose of the project was defined as ‘’ redesign of the production system to lower the total costs of ownership’’, some sub-purposes was defined as;

- To acquire scientific data about operation of the system
- To find different selling points
- To form a suitable basis for logical design and automatic system
- To increase reliability of the system
- To analyze the feasibility of the inverter implementation

The bulletlist of possible factors affecting the Total Costs of ownership was defined by a team formed by Head Engineer Fausto Galli, Manager Daniele Cassani and Responsible Engineer Bahadir Yilmaz. The bullet-list was formed with the experience and literature research. These factors are;

- Type of the machine used
- Type of the pump
- Size of the filtration surface
- Type of filter-aid used
- Number of cycles in a year
- Operating temperature
- Type of oil used
- Operating schedule of the manufacturer
- Unit Energy prices

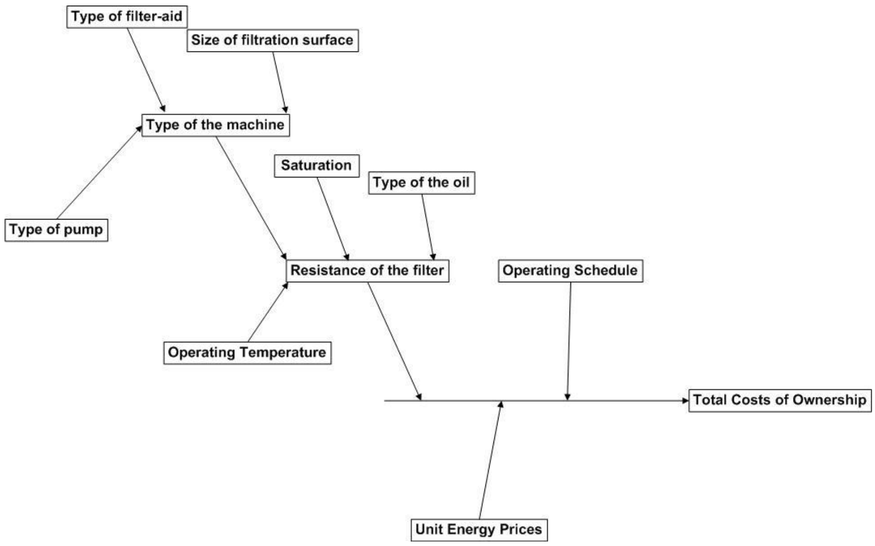


Figure 8 Fishbone diagram of factors affecting total costs of ownership

3 Measure/Analyze

The energy consumption of the pump is thought to be the most important element in the total ownership costs of the filtration system. The energy consumption of the system is caused by the main filtration pump which is used to pump dirty oil to filtration bulbs. In the preliminary research, some factors are defined as the primary factors affecting the energy consumption of the pump. Factors can be divided into two main groups as machine driven and system driven. The machine driven factors are;

- Type of the pump
- Saturation level of the filters
- Type of the fitler aid used
- Type of the oil
- Operating temperature

The system driven factors can be listed as the operating schedule of the machine and the unit energy prices.

Type of the pump: The size and type of the pump on the machine has a significant effect on the total operating costs. There are different models starting from 1,8 KW power with different characteristic curves.

Saturation level of the filters: As discussed in the previous chapter, the saturation level of the filters affects the resistance significantly. Increased resistance will decrease the oil flow and the work done by the pump (It will also reduce the energy consumption) On the other hand, the efficiency of the system (Energy/Oil pumped) is expected to decrease over time.

Type of the fitler-aid used: Different types and amounts of filter-aids are expected to have different resistance. (and also characteristic curves) It will have a significant effect on the cycle time and unit energy consumption.

Type of oil: Different types of oil will have different viscosity; therefore they will force the filtration bulbs with different resistances.

Operating temperature: Change in temperature will affect the viscousity of the oil and will affect the resistance.

Schedule: Operating Schedule affects the cycle lenth of the system.

Unit energy prices: Different regions may have different unit energy prices and this difference has to be considered.

As a primary phase of analysis, an experiment is planned to be designed. The main purpose of this experiment is defined as to define operating characteristics of the system under different factors.

3.1 Factors

In order to start the design of experiment, the factors that will be used in the experiments were defined by the expert team.

The energy consumption/work done curves are available from suppliers for every type of pumps. The work done by the pump can easily be related to the flow (Q) value acquired during the tests. This makes it unnecessary to add levels for types of pump factor. The type of pump is kept at 1,8KW value during the experiments.

The saturation of the pump is believed to be the most important factor in the experiment. Therefore, this factor was defined with 5 levels.

There are two main types of filter-aids used and suggested by Comat. These are Farina and Cellulose. They are mainly used in two different areas and have different disposal procedures. This factor is also designed with two levels.

Comat generally sells the machines with their company suggested oil and the type of oil is decided to be kept as single level.

The primary researches stated that the temperature difference can also affect the energy consumptions. To test the hypothesis a stress test was done with 15 and 30 degree operating temperatures.

3.1.1.1 The inverter

As described in the previous sections, the Comat super-filtration machine was not designed with adjustable speed control and off mode. The machine had to work at full-speed during operating hours and at night. However, a frequency inverter which is a small electrical device could be implemented to the pumps. The inverter will give the customers to have lower amount of filtration during off-peak hours. The system will also be more economics since the inverter will minimize the energy consumption at non-operating hours.

The head-engineer, Mr. Galli purchased and implemented a frequency inverter for the design of experiment phase, which will be used for the experiments with different flow levels. The inverter has a continuous scale. However it is assumed to be with 13 levels from 22 hertz to 50 hertz.

3.2 Design of experiment- Phase 1

To understand the differences between two main filter-aids primary experiments with two levels, a single level test was designed and performed. The main purpose of this preliminary experiment is to understand the relation between pressure, saturation and flow for both filter-aids. Both filter-aids are tested for 5 different dosages. The dosages are 0, 0.5, 1, 1.5, 2 and 2,5 kilograms of filter-aids. Each installation was tested for different saturation levels on a continuous scale.

The factors in the first design of experiment are;

- Type of filter aid (2 levels)
- Dosages of filter aid (5 levels)
- Saturation of the filters (5 levels)

In order to make experiments faster and more reliable, the resistance of the filtration bulb was increased by a valve placed on the exit section.(p3) since this was planned as a preliminary experiment, the tests main purpose is to calculate and control the general behavior of the system.

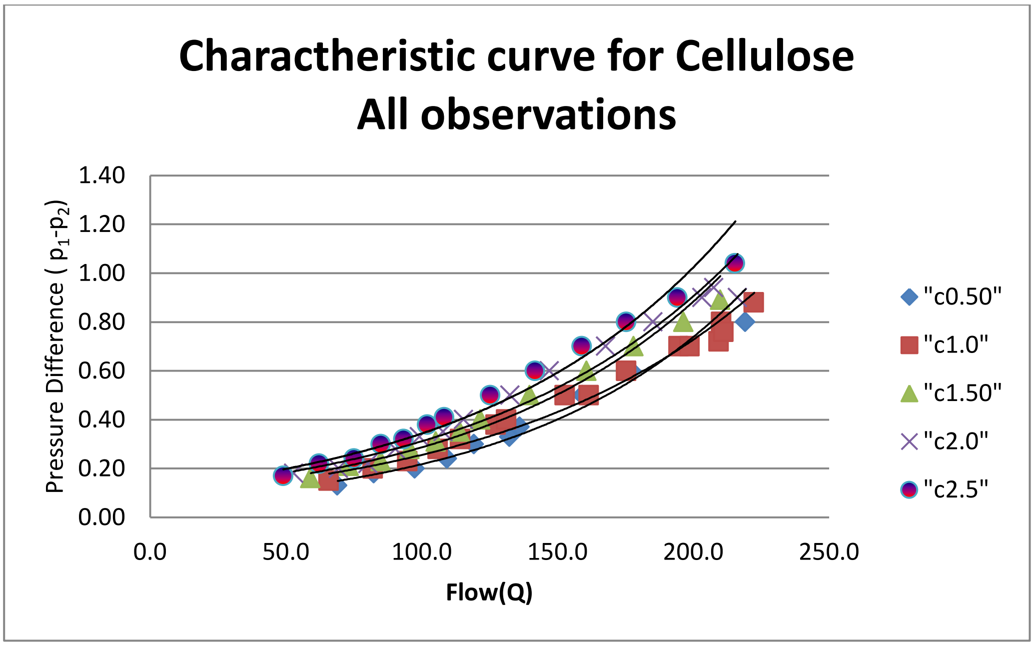
During the experiments, 3 output data was controlled with data acquire tool called Pitagora. These responses are;

- Output pressure of the pump (P1)
- Input pressure of the filter (P2)
- Flow (Q)

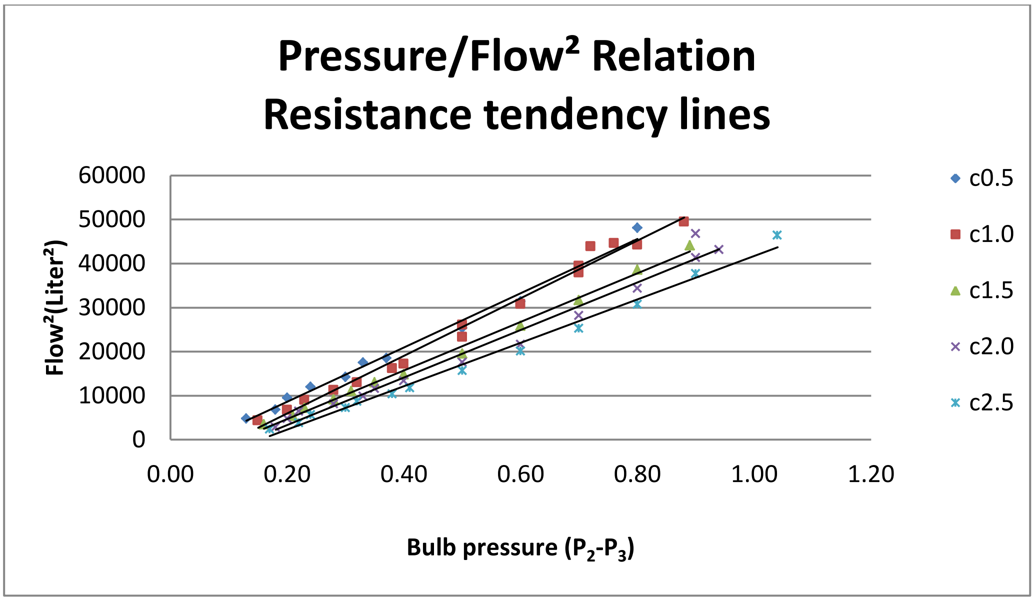
For each experiment, the valve in the exit section of the system was manipulated. The pressure formed by the valve is described as P_3. As described in the previous section, the relation between Flow and Pressure difference shows the resistance and the behavior of the filtration system. The values of $\Delta p/Q^2$ are expected to be on the characteristic curve of the pump.

Moreover, for each setup, the slope of the linear regression for Δp versus Q line states the total resistance of the system.

Using the characteristic curves, the resistances of different filter aids with different amounts of adductions were calculated. These values are planned to be used to estimate the energy consumption of different scenarios in the second parts of the experiment.



Furthermore a regression analysis has been made for the values of Pressure Difference and Flow². The theoretical analysis showed that the slope of Pressure Difference/Flow² line for each installment is equal to the total resistance of the system.



A regression analysis for the values of Pressure Difference (y) and Flow² (X) have been made with the Ordinary Least Squares method. The resistances acquired with the analysis for half kilogram adductions for both farina and cellulose are shown in the following table.

Table 2 Adduction and resistance relation (Cellulose)

Setup	**Resistance**
Cellulose 0 Kg	16,3390
Cellulose 0.5 Kg	18,24857
Cellulose 1.0 Kg	18,36923
Cellulose 1.5 Kg	22,2427
Cellulose 2.0 Kg	22,8123
Cellulose 2.5 Kg	25,7638

Table 3 Adduction and resistance relation (Farina)

Setup	Resistance
Farina 0Kg	16,3390
Farina 0.5 Kg	16,939

Farina 1 Kg	17,889
Farina 1.5	18,6855
Farina 2.0	20,8295
Farina 2.5	21,7142

3.3 Conclusion of first experiments

The results state that the cellulose is causing more friction relative to the Farina. The micro-structural situation of the cellulose layer is less regular than Farina, which causes greater cavities and thicker filtration surface. This causes more energy consumption and shorter cycles.

Generally different filter-aids are suggested for different machining types. Farina is generally used in High-Precision lathing operations since the sponge-like phsyics of farina filters the rod-like particles of the operation.

On the other hand, some operations such as the milling and honing have bigger particles, which can be filtered in both Farina and Cellulose. For those situations, Farina, which makes longer cycles available has to be used and considered.

3.4 Design of experiment-Second Part

The first part of the experiment have been very useful, since the relation between the filter-aids, resistance, flow and pressure have been cleared. On the other hand, there still haven't been made any analysis on the total costs of ownership, which was stated as the main purpose of the project.

For the second part of analysis, an inverter is implemented on the testing machine, F14. The inverter will be used to control the working frequency of the main pump, which controls the flow and the energy consumption. The inverter will be used to calculate the relation between flow and energy consumption under different testing conditions.

Also a high precision multi-meter (Pitagora) which will be used to measure pressures(P_1,P_2 and P_3), the flow (Q) and the energy consumption (W) is installed on the machine. The data will be acquired by pitagora and will be sent to the computer in XLS (Excel) format for further analysis.

Factors affecting the total costs of ownership have been discussed in the previous section. To estimate total costs of ownership for different customers, schedules and scenarios, the operating behavior of the pump under different conditions has to be analyzed.

In this phase, a 3 factorial multi-level experiment is designed to analyze the average energy consumption for different installments and saturation levels. The factors and the levels are shown in the following table.

The inverter level changes the pressure of the pump and the flow of the oil throughout the system.

Table 4 Factors and levels

Factors	**Number of levels**	**Levels**
Inverter Level	12	100,95,90,85,80,75,70,65,60,55,50, 45)
Type of filter-aid	2	Farina, Cellulose
Saturation	5	0 Kg; 1Kg; 1,7 Kg; 2,7 Kg; 3,7 Kg

The energy consumption of the pump is related with the resistance of the filter caused by the filter-aid and the filtrated material. Since an analysis over the resistances of different filter-aids has been done in the previous phase, the tests are planned to be done by only farina. Since a test for an installment takes up to 7-10 days (the time required for saturation), this interpretation is planned to save considerable time and effort.

The measures were taken for all levels of factors Inverter Level and Saturation. The results are shown in the following table.

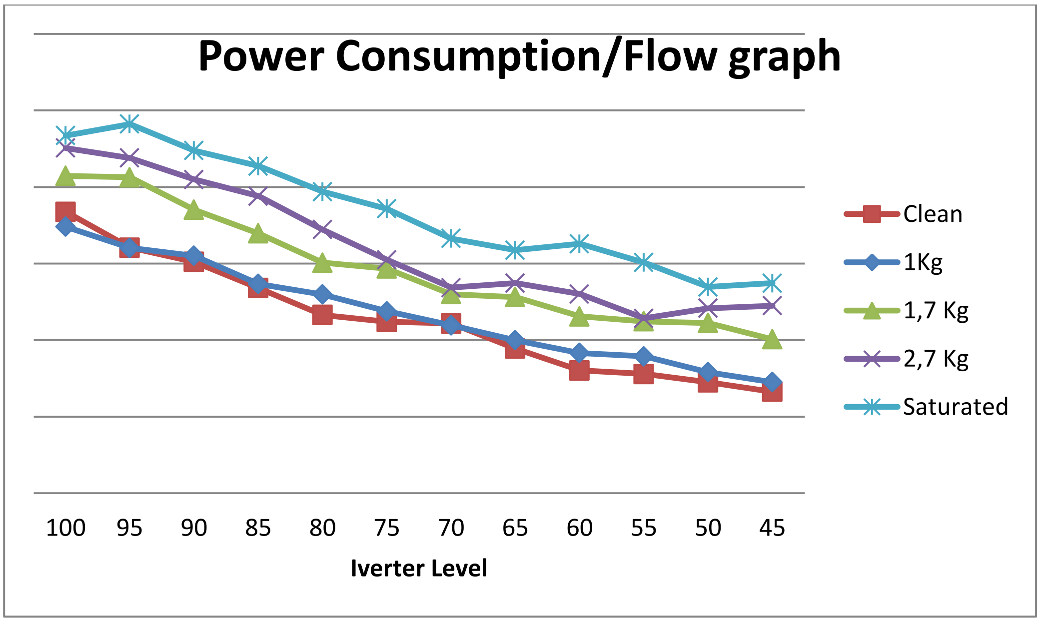
Table 5 Designed experiments and results

#	Inverter	Saturation	Flow(Q)	Power Consumtion (W)	% Relative Energy Savings	% Cumulative Energy Savings	Energy Consumtion/Flow
1	100	Clean	218	**1602**		0%	7,348624
2	95	Clean	216	**1386**	-14%	-14%	6,416667
3	90	Clean	215	**1299**	-6%	-19%	6,04186
4	85	Clean	202	**1083**	-17%	-32%	5,361386
5	80	Clean	186	**866**	-20%	-46%	4,655914
6	75	Clean	174	**779**	-10%	-51%	4,477011
7	70	Clean	161	**714**	-8%	-55%	4,434783
8	65	Clean	149	**563**	-21%	-65%	3,778523
9	60	Clean	135	**433**	-23%	-73%	3,207407
10	55	Clean	125	**390**	-10%	-76%	3,12
11	50	Clean	112	**325**	-17%	-80%	2,901786
12	45	Clean	98	**260**	-20%	-84%	2,653061
13	100	1 KG	220	**1580**		0%	7,181818
14	95	1 KG	219,7	**1407**	-11%	-11%	6,404188
15	90	1 KG	202,4	**1256**	-11%	-21%	6,205534
16	85	1 KG	194	**1061**	-16%	-33%	5,469072
17	80	1 KG	175,1	**909**	-14%	-42%	5,191319

18	75	1 KG	164	**779**	-14%	-51%	4,75
19	70	1 KG	153	**671**	-14%	-58%	4,385621
20	65	1 KG	140,8	**563**	-16%	-64%	3,99858
21	60	1 KG	130	**476**	-15%	-70%	3,661538
22	55	1 KG	115	**411**	-14%	-74%	3,573913
23	50	1 KG	102,7	**325**	-21%	-79%	3,164557
24	45	1 KG	89,5	**260**	-20%	-84%	2,905028
25	100	1,7 KG	188	**1559**		0%	8,292553
26	95	1,7 KG	175,8	**1451**	-8%	-8%	8,253697
27	90	1,7 KG	163,7	**1212**	-16%	-23%	7,403787
28	85	1,7 KG	153,1	**1039**	-14%	-34%	6,786414
29	80	1,7 KG	140,2	**844**	-19%	-47%	6,019971
30	75	1,7 KG	129,1	**758**	-10%	-52%	5,871418
31	70	1,7 KG	116,6	**606**	-20%	-62%	5,197256
32	65	1,7 KG	105,6	**541**	-11%	-66%	5,123106
33	60	1,7 KG	93,7	**433**	-20%	-73%	4,621131
34	55	1,7 KG	82	**368**	-15%	-77%	4,487805
35	50	1,7 KG	73	**325**	-12%	-79%	4,452055
36	45	1,7 KG	59,2	**238**	-27%	-85%	4,02027
37	100	2,7 KG	153,7	**1386**		0%	9,017567
38	95	2,7 KG	143,4	**1256**	-9%	-9%	8,758717
39	90	2,7 KG	132,1	**1083**	-14%	-22%	8,198335
40	85	2,7 KG	120	**931**	-14%	-33%	7,758333
41	80	2,7 KG	110	**758**	-19%	-45%	6,890909
42	75	2,7 KG	99,4	**606**	-20%	-56%	6,096579
43	70	2,7 KG	88,7	**476**	-21%	-66%	5,366404
44	65	2,7 KG	78,9	**433**	-9%	-69%	5,487959
45	60	2,7 KG	70,7	**368**	-15%	-73%	5,205092
46	55	2,7 KG	61,6	**281**	-24%	-80%	4,561688
47	50	2,7 KG	49,3	**238**	-15%	-83%	4,827586
48	45	2,7 KG	44,2	**217**	-9%	-84%	4,909502
49	100	3,5 KG	136,7	**1277**		0%	9,341624
50	95	3,5 KG	125,7	**1212**	-5%	-5%	9,642005
51	90	3,5 KG	116,1	**1039**	-14%	-19%	8,949182
52	85	3,5 KG	106,4	**909**	-13%	-29%	8,543233
53	80	3,5 KG	96,2	**758**	-17%	-41%	7,879418
54	75	3,5 KG	87,4	**650**	-14%	-49%	7,437071
55	70	3,5 KG	78,1	**520**	-20%	-59%	6,658131

56	65	3,5 KG	71,6	**455**	-13%	-64%	6,354749
57	60	3,5 KG	59,8	**390**	-14%	-69%	6,521739
58	55	3,5 KG	50,3	**303**	-22%	-76%	6,023857
59	50	3,5 KG	44,2	**238**	-21%	-81%	5,384615
60	45	3,5 KG	35,5	**195**	-18%	-85%	5,492958

Also a graph for Power Consumption/ Filtration Rate has been plotted. The effect of resistance and saturation over energy consumption can clearly be seen on this graph.



The analysis shows us that the energy consumption of the pump is related to the saturation level of filters. By considering saturation level as a variable, the energy consumption can be predicted. The analysis with Minitab statistical analysis software has shown that for every inverter level, the relation between energy consumption and the saturation level can be estimated with linear regression.

4 Interpretation of characteristic equations for different scenarios: the Regression Analysis

In order to understand the operating characteristics of different scenarios, a series of regression analysis has been made for three different scenarios. These are;

The full power mode: As-Is case of the machine where the machine always works at %100 inverter level (without inverter)

The sleep mode: The researches state that if the inverter is set to the minimum level (22 Hertz, 45 Percent of Inverter), the coating on the filter stays on. This situation enables the customers to turn off the machine to an economically friendly sleep mode where the flow and the energy consumption are minimized.

The auto-control, 120 liters/minute mode: A survey on customer shows us that the required filtration rate for most of the cases is 120 liters per minute. However, without the inverter, the filtration rate is much higher which increases the energy consumption and the costs. In a hypothetical scenario, a computing device can control the inverter level according to supply necessary flow throughout a cycle. The energy consumption is simplified to a function of saturation level and scenario.

4.1 Regression analysis for Farina

Using the acquired data, three regression analyses have been made. The energy consumption equations for three different scenarios are given below.

For the as-is condition

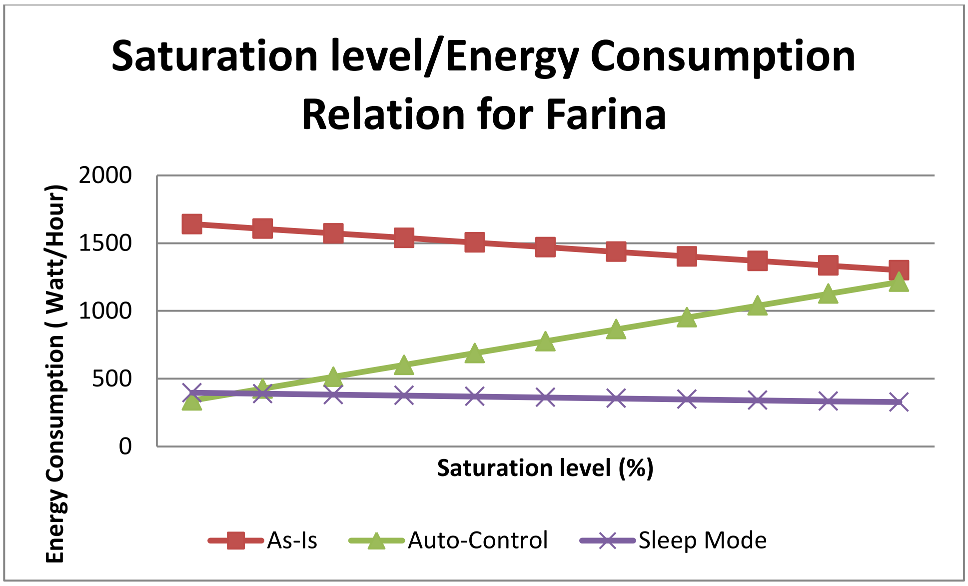
Energy Consumption (Watts/Hour) =1634 + 340* Saturation Level (%)

For sleep-mode option

Energy Consumption (Watts/Hour) =339 + *875 Saturation Level (%)

For the full-automatic inverter option

Energy Consumption (Watts/Hour) =269 + * 69Saturation Level (%)



4.2 Regression analysis for cellulose

The analysis in the previous section showed us that the cellulose is %11 percent more fractious than the Farina. With a simple assumption, the energy consumption of the cellulose can be interpreted using the values of Farina. The equations of energy consumption for three different scenarios with cellulose are given below.

For the as-is condition

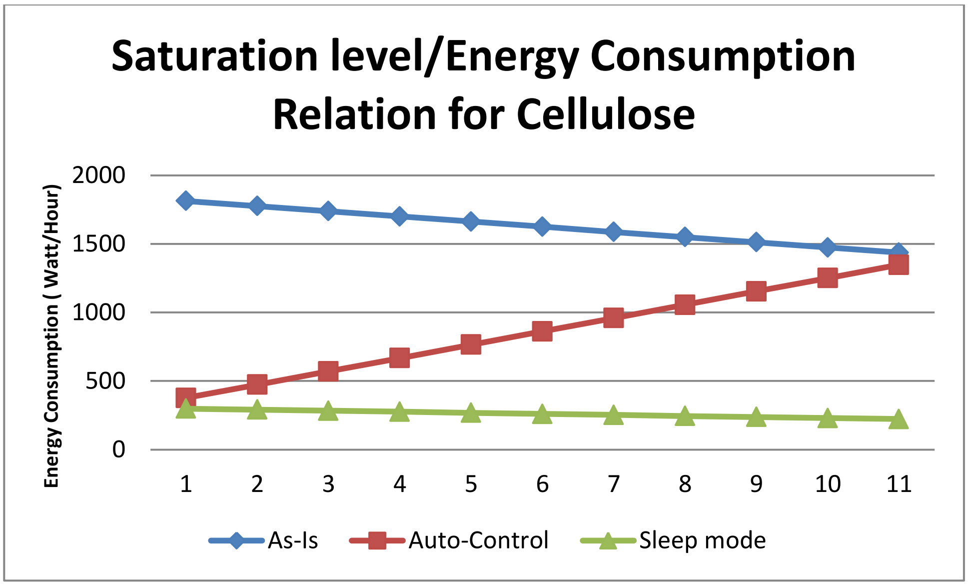
Energy Consumption (Watts/Hour) =1814 + 377* Saturation Level (%)

For sleep-mode option

Energy Consumption (Watts/Hour) =376 + *971 Saturation Level (%)

For the full-automatic inverter option

Energy Consumption (Watts/Hour) =299 + * 77Saturation Level (%)



The regression analysis shows us that the energy consumptions with the implemented inverter diminish down to %85 percent. However the effect on the costs will need further analysis with the consideration of scheduling and pricing variables.

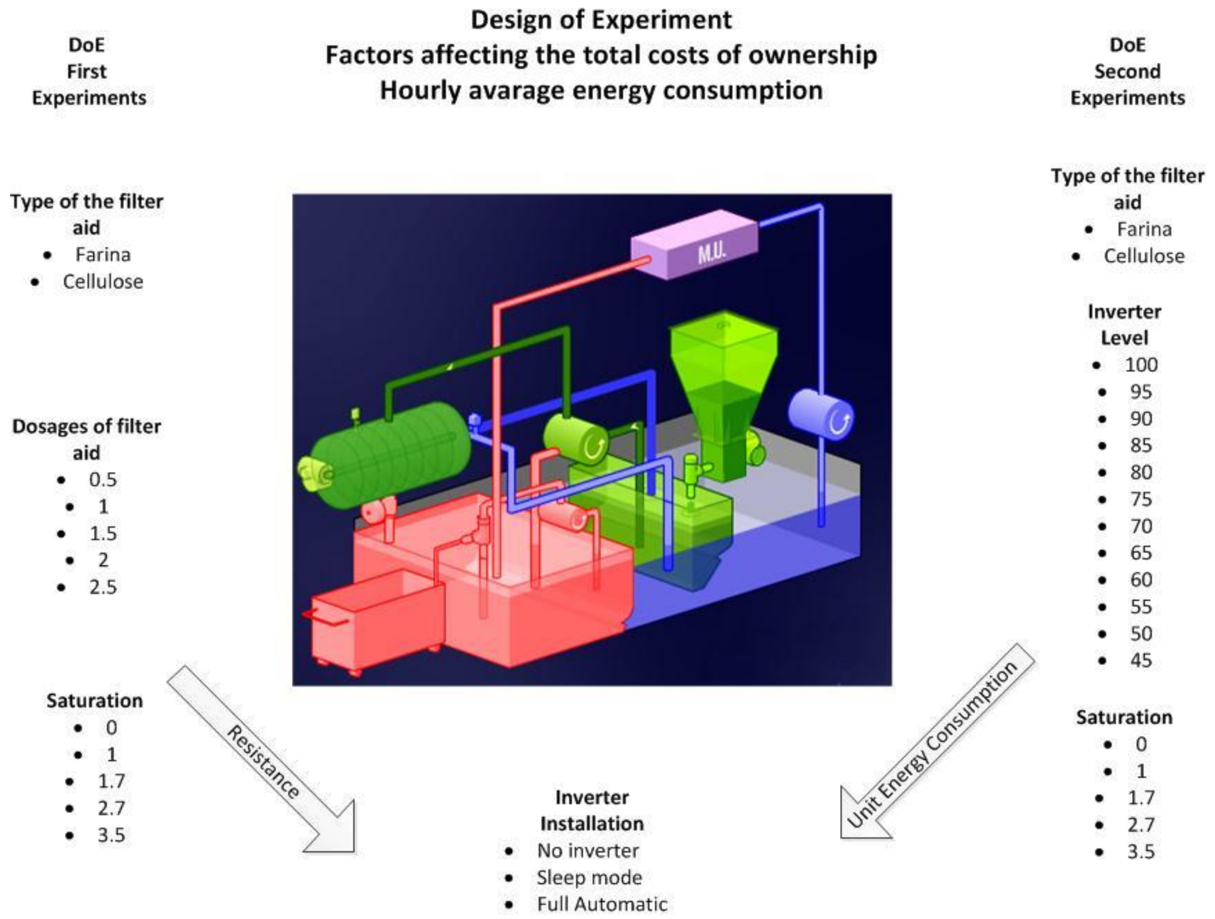


Figure 9 Factors Affecting the Total Costs of Ownership

4.3 Conclusion for regression analysis

Total Costs of ownership-Improvement solutions implementation costs analysis

The measurements in the first phase showed us that the as-Is condition of the filtration machines; where there is no option for demand and speed flexibility is causing energy inefficiency. On the other hand, a frequency inverter, which can be implemented on both new and used machines can provide customers the options to decrease the work rate in off-peak and non-working hours. The analysis in the previous part has shown that the energy consumption of the pump is related to the type of filter-aid and the saturation of filters. The equations to calculate the energy consumption of the pumps have been defined and they are planned to be used in the analysis part.

However, the implementation of the possible solutions has reasonable costs, where the pros and cons should be deeply analyzed. As stated in the previous section, the feasibility analysis of the given options depends on the customers schedule, region and machining policy. In order to define if the possible gains compensate the costs of the implementation, a full scale anaylsis should be performed by the company for each customers.

The measurement showed us that there are two possible improvement options with different costs and savings. These options are The Sleep Mode Button and Full-Automatic Control.

The Sleep Mode Button: As it can clearly be seen from graph xx, the energy consumption of the pump during the non-working hours can be cut up to %85. The Frequency Inverters , which are planned to be implemented have the option of a connection of a small button, which decreases the working rate of the pump to 22 Hertz, %45. The cost of implementation of this inverter is depending on the model and quality. The managers decided to use Schneider Electrics Frequency inverter, which can run the motors up to 3,5 KW. The inverter can be implemented at a cost of 1000 Euros.

The Full-Automatic control: The customer data shows us that the necessary flow rate generally doesn't exceed 120 litres/minute. However, the superfiltration machine always works at the full rate and filters higher amounts. The implemented inverter can control the flow according to the the rate of the distribution pump. The market research showed that the implementation costs would be much higher than the sleep mode option. Besides from inverter, there is also a need for flow meter and a computing unit. The costs are of possible implementation is planned to be 3000 Euros.

5 Total costs of ownership analysis for different scenarios

In order to start the analysis, the factors affecting the energy savings have also to be defined. These factors are

- The operating schedule of the job-shop
- Location of the job-shop (Effects the unit energy prices)
- The tariff option that the company is subscribed
- The type of filter-aid used
- Number of the pumps implemented on the machine

The effects of filter-aid and pumps have been already been analyzed in the previous phases. The Boards has asked for a customized spreadsheet where the possible cost-savings for each specific customer can be calculated. Matrix calculation has been used to estimate the yearly gains of possible implementations.

The weekly operating schedule, which can be considered as a 0-1 matrix (24 x 7) where each hour of a week is considered as a cell. This matrix will be used to evaluate the sleep mode on-off state of the job shop. If the machines are considered as not working, the equation of the sleep mode will be used to analyze the total energy consumption of the pump.

The spreadsheet also has to include the location (country) of the customer, which affects the tariff and the unit energy prices. The unit energy prices are also put in a matrix (24 x 7), which will then be multiplied by the unit energy consumptions for the given hour.

The number of pumps and the type of filter-aid is one of the most important variables in the spreadsheet. The equations defined in the previous section will be used to calculate the actual hourly average energy consumption of the machine.

The following tables show an example of calculations for an Italian customer located in Torino. As we can see from the following table, the customers works with 2 shifts on weekdays and Sunday. They also have a holiday on Sundays.

Table 6 Operating schedule of the Customer Matrix

Start	End	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
00:00	01:00	1	1	1	1	1	1	0
01:00	02:00	0	0	0	0	0	0	0
02:00	03:00	0	0	0	0	0	0	0
03:00	04:00	0	0	0	0	0	0	0
04:00	05:00	0	0	0	0	0	0	0
05:00	06:00	0	0	0	0	0	0	0
06:00	07:00	0	0	0	0	0	0	0
07:00	08:00	0	0	0	0	0	0	0
08:00	09:00	1	1	1	1	1	1	0
09:00	10:00	1	1	1	1	1	1	0
10:00	11:00	1	1	1	1	1	1	0
11:00	12:00	1	1	1	1	1	1	0
12:00	13:00	1	1	1	1	1	1	0
13:00	14:00	1	1	1	1	1	1	0
14:00	15:00	1	1	1	1	1	1	0
15:00	16:00	1	1	1	1	1	1	0
16:00	17:00	1	1	1	1	1	1	0
17:00	18:00	1	1	1	1	1	1	0
18:00	19:00	1	1	1	1	1	1	0
19:00	20:00	1	1	1	1	1	1	0
20:00	21:00	1	1	1	1	1	1	0
21:00	22:00	1	1	1	1	1	1	0
22:00	23:00	1	1	1	1	1	1	0
23:00	00:00	1	1	1	1	1	1	0

Table 7 the tariff schedule of the energy supplier

	Monday	Tuesday	Wednesd ay	Thursday	Friday	Saturday	Sunday
0	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3
1	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3
2	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3
3	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3
4	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3
5	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3
6	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3
7	Fas. 2	Fas. 2	Fas. 2	Fas. 2	Fas. 2	Fas. 2	Fas. 3
8	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 2	Fas. 3
9	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 2	Fas. 3
10	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 2	Fas. 3
11	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 2	Fas. 3
12	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 2	Fas. 3
13	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 2	Fas. 3
14	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 2	Fas. 3
15	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 2	Fas. 3
16	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 2	Fas. 3
17	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 2	Fas. 3
18	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 1	Fas. 2	Fas. 3
19	Fas. 2	Fas. 2	Fas. 2	Fas. 2	Fas. 2	Fas. 2	Fas. 3
20	Fas. 2	Fas. 2	Fas. 2	Fas. 2	Fas. 2	Fas. 2	Fas. 3
21	Fas. 2	Fas. 2	Fas. 2	Fas. 2	Fas. 2	Fas. 2	Fas. 3
22	Fas. 2	Fas. 2	Fas. 2	Fas. 2	Fas. 2	Fas. 2	Fas. 3
23	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3	Fas. 3

Table 8 Unit Energy prices input table

Unit Energy Prices	Phase 1	Phase 2	Phase 3
Italy	0,117	0,1	0,074
France	0,078	0,078	0,062
Germany	0,2	0,14	0,14

Table 9 Weekly energy prices/hour table

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0,062	0,062	0,062	0,062	0,062	0,062	0,062
0,062	0,062	0,062	0,062	0,062	0,062	0,062
0,062	0,062	0,062	0,062	0,062	0,062	0,062
0,062	0,062	0,062	0,062	0,062	0,062	0,062
0,062	0,062	0,062	0,062	0,062	0,062	0,062
0,062	0,062	0,062	0,062	0,062	0,062	0,062
0,062	0,062	0,062	0,062	0,062	0,062	0,062
0,078	0,078	0,078	0,078	0,078	0,078	0,062
0,078	0,078	0,078	0,078	0,078	0,078	0,062
0,078	0,078	0,078	0,078	0,078	0,078	0,062
0,078	0,078	0,078	0,078	0,078	0,078	0,062
0,078	0,078	0,078	0,078	0,078	0,078	0,062
0,078	0,078	0,078	0,078	0,078	0,078	0,062
0,078	0,078	0,078	0,078	0,078	0,078	0,062
0,078	0,078	0,078	0,078	0,078	0,078	0,062
0,078	0,078	0,078	0,078	0,078	0,078	0,062
0,078	0,078	0,078	0,078	0,078	0,078	0,062
0,078	0,078	0,078	0,078	0,078	0,078	0,062
0,078	0,078	0,078	0,078	0,078	0,078	0,062
0,078	0,078	0,078	0,078	0,078	0,078	0,062
0,078	0,078	0,078	0,078	0,078	0,078	0,062
0,078	0,078	0,078	0,078	0,078	0,078	0,062
0,078	0,078	0,078	0,078	0,078	0,078	0,062
0,062	0,062	0,062	0,062	0,062	0,062	0,062

The operating schedule is used to determine the state of the machine in these two different scenarios. The energy consumption of the pump for the given hour of the week is calculated using the regression equations. The unit energy prices are also considered and used in the calculations with the Phases matrix. The matrix calculations done by Microsoft Excel Spreadsheet have given the following results. As we clearly can see, different regions with different energy prices will have various energy savings, which needs further analysis/

Table 10 Yearly savings table (Output)

Yearly savings	Italy	Germany	France
With sleep mode	324,9792	595,7952	270,0422
Automatic control	533,21372	934,0344	419,4216

6 Improve

The main marketing activity of the company is expositions performed in industrialized countries and regions. In the expositions, Comat Marketing Manager Daniele Cassani started to use the spreadsheet in order to explain the customers their possible gains with the available options.

The Sleep-mode option which has relatively lower implementation cost and less than two year payback time is preferred by most of the customers.

On the other hand, the theoretical auto-control option is thought to be infeasible for most of the cases, where customers avoid spending extra 2000 Euros. The payback time could reach up to 6 years, which is a lot in today's vital fierce competition.

A German customer, with an operating schedule of 2 shifts (8-16; 16-24) has ordered a super-filtration machine with a single pump, working with Farina. The marketing team used the spreadsheet to calculate possible gains of the customer and used it to as a proof. The company acquires the inverter for a cost of 510 Euros and implements them for an extra 1000 which is both a selling point and profitable business.

Most of the customers are believed to favor from the implementation of the project since they financially benefit from the project.

Moreover, the analysis showed that the implementation of the inverter might provide some benefits in the workplace security and reliability. Since the implementation of the inverter decreases the working rate of the pump, the lifetime of moving parts is expected to be longer. Also the inverter will force the moving parts to work in slower rate, which will increase the workplace safety level.

In January 2011, the company has decided to analyze technical feasibility of low-cost inverters, which will increase the margin for the company. There are also some pumps with build in speed control, which also have to be analyzed.

Moreover, the inverters are able to run the machines in various ways, according to different curves and algorithms. The inverters could be programmed to drive the pump in a more efficient way. As a further discussion point, the relation between the torque of the pump (which can be adjusted by the inverter) and filtration system dynamics may be analyzed. This further research can alsp provide serious low cost implementation ideas.

7 Control

In November 2010, the project has been approved and the inverter option is given for the worldwide customer network. However the problems and drawbacks have to be tracked down after the implementation of the solutions.

Few key aspects have been defined by the project team to be observed over time. First of all, the starting point of the project, the energy consumption must be tracked down in the real case situations.

The company contacted few customers who use the machines with the inverter implemented. They have been kindly asked to contribute our project with installation of some measuring tools. The first interviews have been positive and the company plans to execute some on place tests to evaluate the benefits in real case.

In the case that the benefits are the same or more than planned, the company plans to research the auto-control case with another project with a higher budget. If realized, this project is planned to have more benefits than the fist project since it will change the technological aspects of the process and product.

Finally, the reliability of the inverters has to be tracked down since the electromagnetic behavior of the frequency inverter causes noises in the electric infrastructure which can cause reliability issues in the long run.

8 The Motivational And Organizational Problems Faced Throughout The Project

The project was first proposed by Martina Colombo, who has a strong background in Industrial Engineering and Management. She has seen the 2008 crisis as a contemporary, long time issue and planned an improvement and redesign project. Instead of being a Board member of Comat, she is a reputed executive Manager in a Top Italian government bank. Her experience and oversight in the business has sparkled the project.

However, there has been some opposition from the managers of Comat, since the project was expected to be costly and risky. Martina Colombo started a pre-research and convinced the other board members to allocate an 11.000 € budget for the project. Due to her professional career in Rome, she wasn't able to manage the project herself. Bahadir Yilmaz has been assigned as a responsible engineer by Martina Colombo to research the topic and execute the project with the help of Head of Engineering Fausto Galli and Daniele Cassani.

On the other hand, there were some managerial and authentication problems faced throughout the project. These problems will be discussed in the following section.

8.1 Low commitment of Experienced Top Management

'Commitment of Top Management' is one of the most boring clichés for people who have lectures or seminars about the process improvement and Six Sigma project. Due to its epic positioning in most of the presentations done by the scholars and professionals, it gives an empty and simple expression over the students and employees. Although these negative effects of this cliché sentence, it has been realized that this is the most important issue affecting the success and the process of the project.

Due to risk of not-reaching any solution, top management didn't support the project as required. In the measurement and analysis phase, there has been a need for a high precision data acquire tool, The Pitagora, which costs few thousand euros and could have been paid from the allocated budget. However, there have been fierce resistances, stating "there is no need for such a big investment which won't be used after the project".

However, strong argumentations of process owner, Martina Colombo have forced the management to acquire necessary tools for the project. Moreover, after the data acquire tool, there have been a need for suitable measuring sensors for pressure, flow, current, voltage and power. The high costs of current and voltage meters let the managers to acquire low cost manual volt and ammeters. This situation has ended with decreased efficiency and effectiveness in the measurement phase of the project. Also, the measurements that are taken with two different ammeters gave two completely different results, which ended with doubling the effect spent on the measurements.

8.2 Confidentiality issues

The super filtration system was designed by Mr. Galli and Mr. Cassani in the late 80's and has been improved through the time. Although the procedure and the system are not complicated, there is a belief of " the dynamics of the machine" must be kept secret. Top manager didn't want the external experts to get too involved in the process. During the analysis phase, a total redesign of the tank and pump systems was proposed by the project team. However, the Board has denied the proposal since they think that the complicated design of the tank is a key to stay away from low-cost country competition. This problem hasn't been overcome but is filed as an opportunity for further improvement.

8.3 Data collection takes to much time and effort

The Board has warned the project team to expedite the process of data collection. However, as stated before the problem of this delay was lack of measurement tools and resources allocated for the project. Also a test of full saturation took more than a week and engineering resources was available for only part-time.

8.4 Delegation of Non-Delegable Role of Executives

As mentioned in this section, the process owner Martina Colombo has another professional career which she should handle from Rome. Due to her departure, her responsibilities to manage the project were delegated to the responsible engineer, Bahadir Yilmaz who didn’t have any knowledge about the company and the process. There were also cultural differences and language barriers which decrease the effectiveness of the process. This multi-cultural and multi-location situation of the project management caused initial problems which had to be managed throughout the project.

8.5 Lack of continuous improvement philosophy

Comat is a small sized enterprise where the engineering and management operations are held by only few people. This overloaded situation has moved the focus to execution of operations, rather than process improvement, which ends with products that don’t conform the customer expectations. The company is forced into a mentality and focus change by Martina Colombo, which created a significant difference in the attitude of top management. The missing philosophy of Total Quality Management, Continuous Improvement and Six Sigma cannot be seen by the top management, since they see their processes capable and high quality. Company has many ISO certifications which generally represent nothing in terms of operational quality and conformance. The company should dedicate more time and effort working on their process and organization by implementing Six Sigma Philosophy.

8.6 Misunderstanding of improvement option

The analysis done in the project has shown two possible implementation options. Although the Full-Automatic control option provides a more efficient solution, it is generally described by the management as ‘financially not feasable’.

On the other hand, the full-automatic option has superiority on the other two options on other areas. First and the most important, the full control mode will make it a ‘pull system’, which will increase the energy efficiency class of the machine according to European standards. The regulations in top-tier energy efficiency countries such as Germany, forces the enterprises to decrease their total energy necessity by moving to higher technologies.

Secondly, sleep mode will also require a reasonable amount of man-power to adjust the rate of the machine. Without the full-control mode, there may be fluctuations in the supply of the machine, which can cause serious customer complaints and damage the reliability of the company.

Finally, the full control mode can be implemented as a part of Computer Aided Manufacturing System, which will increase the overall efficiency of the whole production system. According to the customer feedbacks, the current situation of the machine doesn’t allow them to implement Comat Superfiltration Machines to their established company information system.

These points are not well understood by the top management, which keeps them away from setting a marketing strategy over these selling points. The managers are too focused on old-fashioned financial feasibility option, which must change to compete better in the market and increase margins.

V Conclusion and Suggestions

To achieve sustainable financial results, the companies should find ways to be more competitive. In the hard times, pennies spent on quality can seem as the most expensive and unnecessary expenditure. Comat, a small sized Italian company, which was struggling in the market has chosen to spent their money and effort to improve their system. The results of the DMAIC project, which had been executed in 2010 shows that to spend money on process improvement at hard times is a very successful decision.

A product development project has been planned and executed, where intensive on-site tests and design of experiments was used. By using DMAIC methodology, the project team used a systematic and scientific approach to address problems and find solutions. The design of experiment tool has provided serious help in the data analysis part of the project, since it decreased the necessary testing time from months to weeks. This work proved that in the DMAIC projects, the Design of Experiments is one of the best tools in the total arsenal of statistics.

The mentioned product improvement project has clarified that there are two simple product improvement options, which can decrease the energy consumption of the filtration process up to %85. A spreadsheet to analyze the feasibility of these implementation options have been prepared, which will be used to convince the customers that the implementations will provide gains.

This project also revealed that the project development teams should consider the cultural and national differences between the members, which could be a key issue in the effectiveness in the process. Different cultures have different improvement graphs which could affect the process of the project.

For further analysis and improvements, the gains of full-control mode should be analyzed more precisely. The possibility of full control mode with less cost and more efficiency will boost the feasibility of the option, which is both a better selling point and process improvement. It is also recommended to control the gains of the sleep-mode option, since the miscalculations due to error in measurement devices may have given over-feasible results.

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