Experiences of the utilization of Six Sigma tool with the wastewater treatment plant (WWTP) data

Sami Luste and Tuula Löytty

Lahti University of Applied Sciences, Mukkulankatu 19, 15140, Lahti

The present report is performed in a partly EU funded (Interreg Baltic Sea -region) Interactive Water Management (IWAMA) –project as a part capacity development tool "mappings". Six Sigma is a set of techniques for process improvement based to the number analysis. The original aim was to preliminary study the Six Sigma as a capacity development tool for the wastewater treatment plant (WWTP) operators. An effective co-operation model between universities and WWTPs was tested with examples of possible opportunities that Six Sigma analysis may offer for the maintenance- and monitoring development of the WWTP processes.

The present document describes the method, how Six Sigma was used to enhance the local WWT network and the main notifications from the Six Sigma results. The ultimate aim was to identify such dependencies that may help WWTP to develop their monitoring facilities. For example, what kind of new data is required to reach more detailed information from the processes. The Six Sigma was not selected one of the actual capacity development tools produced during the IWAMA project, but hopefully the short report gives some idea of it possible opportunities for future.

The two activated sludge WWTPs were studied. Both of the WWTPs were located near to each other, both with the population equivalent (PE) of 100 000 inhabitants. The WWTP 1 is op erating outdoors, when the WWTP 2 is in cave. The data from the year 2016 was including the following WWTP quantities reviewed table 1 below.

Table 1. Data from the WWTPs.

- Incoming wastewater and treated water flows (m^3)
- Temperature from incoming water and from airation phase(°C)
- pH from Incoming water, pre-clarification and post-clarification stage
- Biological Oxygen Demand (BOD) from incoming wastewater, pre-clarification and from treated water (mg/l)
- Nitrogen (N) from incoming wastewater, pre-clarification and from treated water (mg/l)
- Phosphorus (P) incoming wastewater, pre-clarification and from treated water (mg/l)
- Suspended solids (SS) incoming water, pre-clarification and from treated water (mg/l)
- Return sludge to airation tank (m^3/h)
- Sludge flow rate to the digestion and the biogas flow rate from the digestor (m^3/h)
- Overall energy consumption (kWh)

It is notable, that some measurements, such as BOD-, N-, P- and SS measurement, were laboratory measurements that was performed in weekly bases.

Working method with the WWTP data

In order to learn, develop and innovate, we need to identify new questions. If we continuously deal with the same questions, we propably get also the same answers unless there is something which will break, disrupt and challenge the current state. The following chapter presents the method and reasons for working in such assemply of actors than presented in image 1.

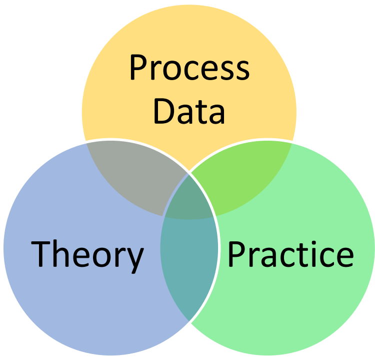

Image 1. The Six Sigma data analysis WWTP was achieved as a co-operation between WWTP operators, University experts from the fields of the data analysis and water management.

The Venn diagram above illustrates the concept which has been under testing. The concept is built of three elements; process data, scientific theory and the practical knowledge.

- The process data is a data base e.g. excel-file which contains fearly long-term data about the process under review. The data includes both data of process factors and data of process outputs.
- The scientific theory covers the laws of natural sciences, the tested and verified models, algoritms and equations as well as the process natural limitations and obstacles.
- The third element is the practice. It includes the practical methods, every day standard procedureses, the working quides and the tacit information.

The iterative testing environment is formed by adequate number of “sprints”, which repeats the same six phases (Image 2).

Image 2. The iterative test cycle of the six steps

Table 2. The six phases of the iterative testing environment

- **Phase 1:** to set-up the problem or challenge
- **Phase 2:** to ensure the know-how
- **Phase 3:** to gather the data
- **Phase 4:** to carry out the data analysis
- **Phase 5:** to review the data analysis in order to identify contradictions, deviations and peculiarities
- **Phase 6:** to identify the new questions, problems or challenges

The line-up of the team consists persons who can convey and share the knowledge about the scientific theory and the practical and empirical experience about the process. The third element of the team is a person who can generate new fact-based information of the process data.

Traditionally the scientific research has based on reliable data and verified tests. So, there is no novelty. The process staff utilizes the process data constantly in order to manage and adjust the process. There is then no novelty either. However, the thrilling is the combination of all three elements and also the persistence aim to find contradictions when the process is reviewed from the three different angles. This kind of iteration around the data based phenomena may help the universities and WWTP to upgrade their co-operation based to the observations from the practice.

The gap between theory and practice hampers the cooperation opportunities between the WWTPs and universities. Improving local co-operation and knowledge exchange between the WWTPs and universities has been one of the development objectives of the European Institute of Innovation and Technology (EIT), the European University Association (EUA) and the research & development framework programs of the European Union (e.g. FP7, H2020). The same phenomenon was also verified also during the IWAMA project. According to the

IWAMA surveys for the WWTPs (n=78), the co-operation of WWTPs and universities (also universities of applied sciences) in the Baltic Sea region is the lowest, when compared to the cooperation between the WWTPs and other stakeholders, such as consult offices, associations, other WWTPs and vocational academies (Luste and Medkova, 2019).

The cause and effect diagram (Image 3) presents the starting point to the research. It shows the supposed factors, which may have some kind of effect on the energy consumption at the WWTP.

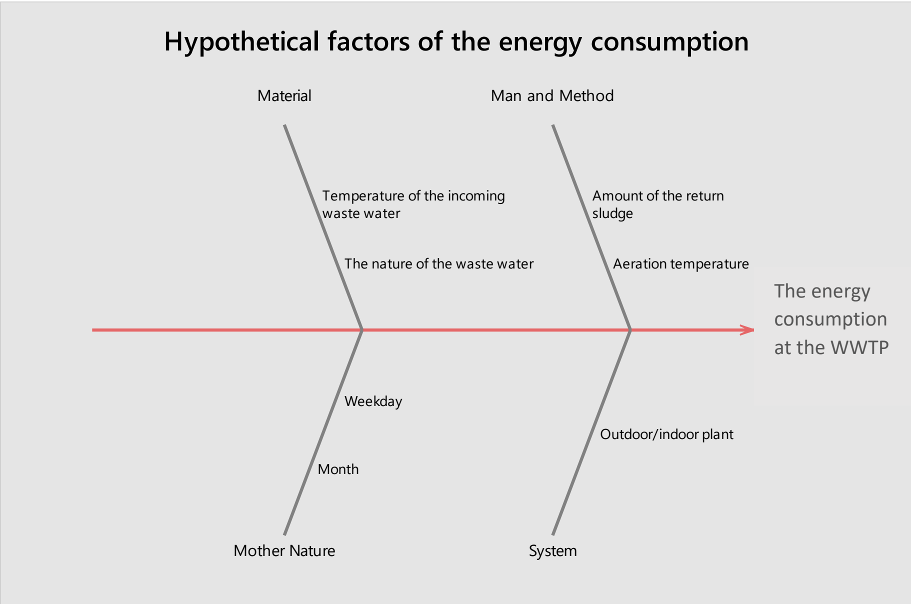

Image 3: Cause and effect diagram at sewage treatment plant

To be able to confirm the hypothesis right or wrong, the process data is collected, cleaned and analysed. The data is historical data. It has been collected day by day and the collection period was one year i.e. 365 days. The data covered two WWTP, which are partly similar, but there are also clear differences. The main parameters, that were paid attention was the dependencies relating drivers from the operation environment (temperature, rainfalls and storm waters, increased wastewater flows from the summer happenings) and the energy efficiency of the plants.

The data was transferred from the excel sheet to the Mintab application. Minitab is a statistical software, which is used in process improvement activities.

Example of the energy efficiency survey by Six Sigma

Below is a short example based to the amount of return sludge that is compared to the energy consumption (kWh), the amount of incoming wastewater per day (m^3) and ratio of the energy consumption and the incoming wastewater (kWh/m^3). The return sludge from the post-clarification stage back to the aeration phase of the WWTP process, is one of the key management processes in activated sludge type of WWTPs. It is connected to the organics- and nitrogen removal as well as energy efficiency. It is also connected to the two key indicators of the process: sludge age and sludge load.

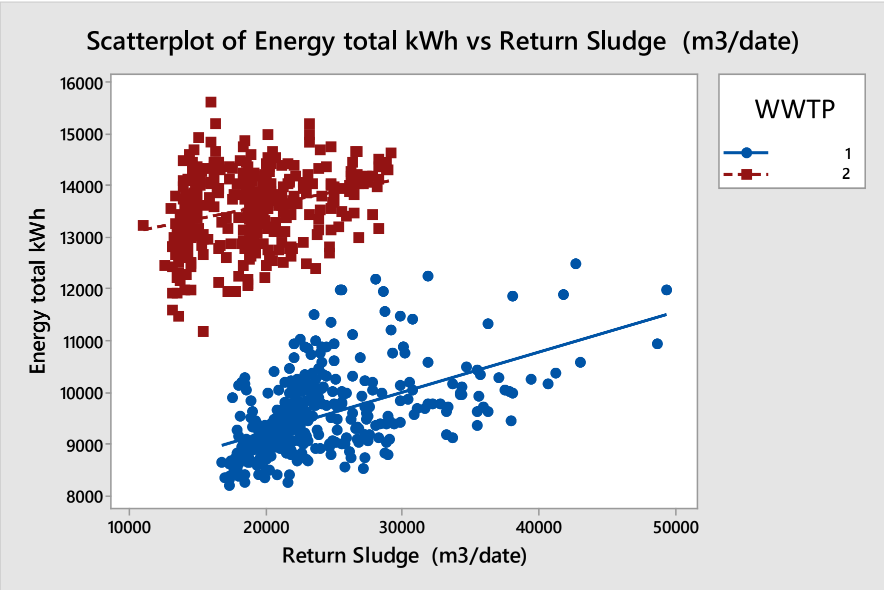

Image 4: The correlation between return sludge and kWh

The image 4 reveals that the WWTP 2 uses more energy than WWTP 1. The image 4 also gives a clue that the WWTP 1 is managed differently compared to WWTP 2.

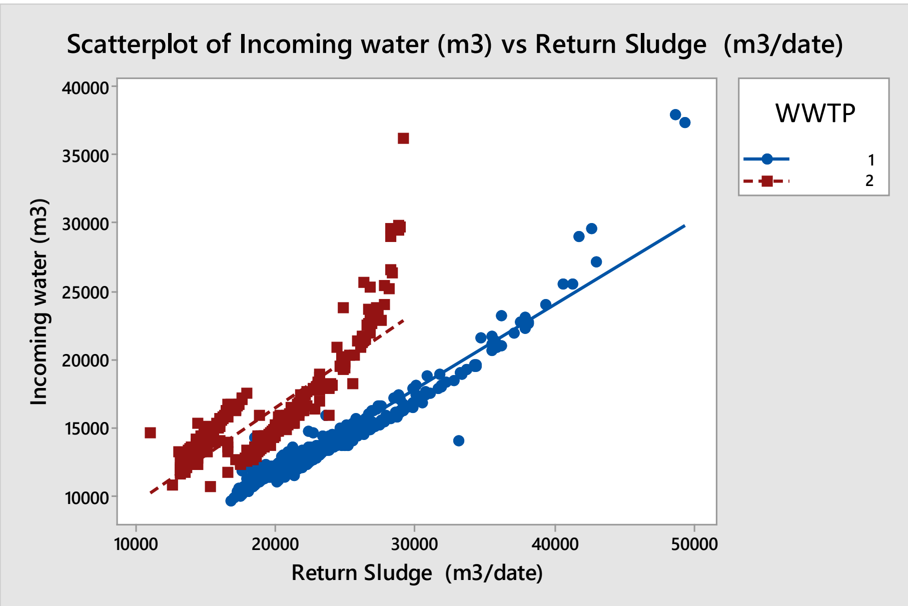

Image 5: The correlation between Return Sludge and incoming water (m^3)

When the return sludge and incoming wastewater are plotted into the scatterplot at the image 5, the curves look very different. The WWTP 1 seem to operate a linear way: When the incoming water volume increases the return sludge increases accordingly. Instead, the WWTP 2 is different. The upper limit of return sludge is about 3000 m^3/day. According to the discussions with WWTP operators was found that the return sludge is limited by the sludge settlement characteristics in the post-clarification. The WWTP 2 is receiving such industrial wastewaters, which content (e.g., filamentous bacteria, yeasts) may effect to the sedimentation characteristics of sewage sludge (Parmar et al., 2001).

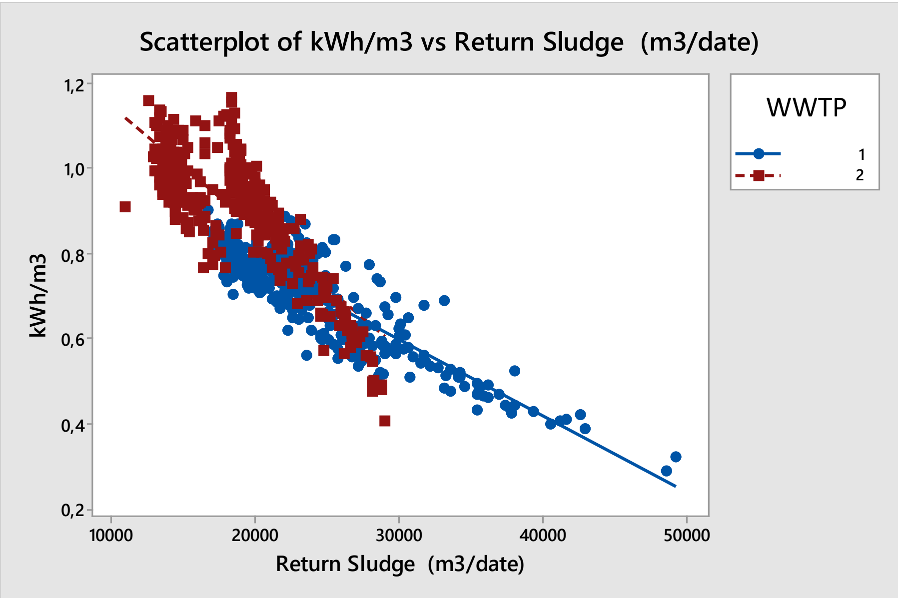

Image 6: The correlation between return sludge and kWh/m^3

In the image 6 the Y-axel is a ratio of energy consumption and incoming waste water per day. The X-axel is the amount of return sludge per day. This image also tells the same fact that the WWTP 2 requires more energy to process the wastewater compared to WWTP 1 as well as that the processes are carried out in a different way. The image shows also pretty clearly the linearity: when the amount of return sludge increase the energy efficiency improves.

The image shows also pretty clearly the linearity: when the amount of return sludge increase the energy efficiency improves. We can see that WWTP 1 (~1,5 m^3 of treated water/ kWh of electricity) treats its water more efficiently than WWTP 2 (~1,1 m^3 of treated water/ kWh of electricity). For the lower energy consumption could be many possible reasons. One of this is that the indoor WWTP 2 requires a very large ventilation system, since it's underground, so this could make up for a large portion of the energy usage. The energy consumption of indoor WWTP is stable throughout the year than in WWTP 1 the energy consumption is lower during colder temperatures (Data not shown). Colder temperature usually means longer sludge age, but also relatively decreased aeration need, thus oxygen is dissolved easier. For example, when the water temperature rises from 10 ºC to 25 ºC, aeration need increases by over 30 %. This has also high effect to energy consumption of the process.

The purpose of return sludge is to enhance the bacteria population working with organics and nitrogen removal, when the organic load (i.e. amount of incoming wastewater) increases. However, according to the image 7, the amount of return sludge do not have effect to the removal efficiency of the organics (Chemical Oxygen Demand; COD) in the WWTP 1.

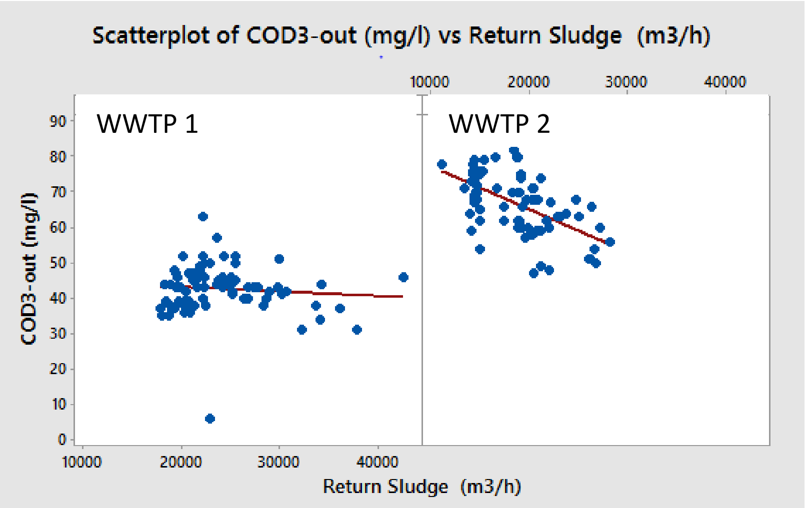

Image 7: The correlation between return sludge and COD concentration in the treated water.

Increased amount of return sludge increases the sludge age, but decreases the sludge load (kg COD/kg MLLS d). The longer sludge age usually means higher quality end product due to the longer treatment period. The sludge age need to be lengthen, for example, when the decreasing temperature is slowing down the bacteria. This may partly explain the differences between the outdoor (WWTP 1) and indoor (WWTP 2) facilities.

Besides the temperature, also the rainfalls has effect on energy consumption of the WWTP due to the increased amount of the incoming wastewater volume (Image 8). The amount of influent is rising at certain regular times during the year, but also after the heavy rains or during snow melting seasons.From the energy efficiency point of view, it would more efficient to regulate the process according to the incoming concentration of the organics than the volume of the incoming wastewater. This would also have indirect effect to the energy efficiency, via the improved biogas yields via the increased amount of excess sludge removed from the process to the digesting reactors.

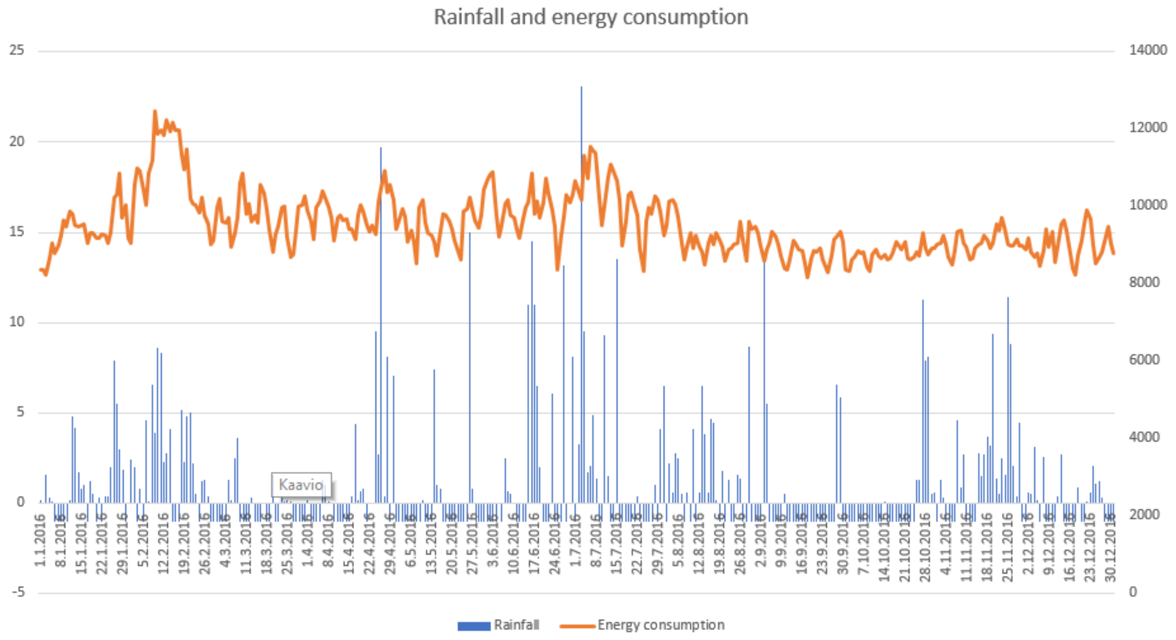

Image 8. WWTP 1 and energy consumption`s relation to the rainfalls in 2016.

The other monitoring need identified (data not shown) was the methane production from the WWTP sludge reactors. At the moment only the volume of the biogas (containing mainly methane and carbon dioxide) is measured. The inhibition of the most sensitive digestion bacteria, methanogens, may take place due to the incoming inhibitors, such as too high or low pH (varying from 5.0 to 8.3), too strong concentration of degradation intermediates (e.g. volatile fatty acids, ammonia) and industrial wastewaters (e.g. detergents, chemicals, yeasts). Moreover, the data from the incoming industrial wastewaters as well as integrated weather information would enhance the predictability for the resource efficient systemic level process management.

Conclusion

Listed notifications regarding the tool and the working method.

- A lot of data from the different parts of the process is needed as well as "silent knowhow" expertise, for example, the actual measurement points and working practices.
- Via the data based iteration process it is possible to identify (especially) the factors relating to monitoring needs and development of the data collection system toward more energy efficient as well as increase the predictability perspectives for more systematic process management.
- Iterative working around the questions rising from the data is highly fruitful way to increase the practice driven co-operation between the WWTPs and Universities. This is also effective way to for the students involved to the process get good overall

picture of the WWTP activities. Data based iteration could be done, for example, similarly with the first level energy audits of the WWTPs.

References

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