Continuous Improvement of Geographic Data Production Processes
Approach and Results of a Case Study

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Abstract: The quality of products – in this case the quality of geographic data representing the facilities of utility companies – depends not only on the used sources and methods of data acquisition but is also significantly affected by the processes applied for the production of geographic data. Study and optimization of production processes are important topics in manufacturing for many years and are widely known as »Process-Based Quality Management«. This means that besides the quality of the final product, the quality of the production processes is also of high interest. In this paper an overview concerning a three years study is given, in which a methodology for a continuous improvement of the geographic information production processes has been developed and applied. Also key figures to describe the quality of products and processes have been suggested. These key figures have been analyzed over a longer period. The overall objectives of this procedure are to reveal the quality of products and processes, to detect deficiencies and weaknesses of the processes and to prove the effectivity of changes of the processes.

1 INTRODUCTION

Quality is an important characteristic of products, maybe the most important one in many cases. Therefore, quality assurance is of high importance for all kinds of productions. Consequently much effort has been spend to improve it in manufacturing for many years ended with the development of the more general concept of ***Quality Management*** *(QM)*. Key drivers for this development were mainly different industrial branches primarily in Japan, the US and in Europe. According to (ISO 9000, 2005) ***Quality*** is understood as “the degree a set of inherent characteristics which fulfill requirements”.

Geographic data quality, also called spatial data quality, has been a core sub-discipline of Geographic Information Sciences / Geomatics since its early development and various related issues have been investigated. Although there are several issues which are still subject of intensive research, the ISO standard 19113 “Geographic information - Quality principles” establishes the principles for describing the quality of geographic data and specifies components for reporting quality information. It also provides an approach to organize information about data quality (ISO19113, 2001).

The quality elements defined in ISO 19113 for describing the quality of geographic data are shortly outlined here:

- Completeness
- Logical consistency
- Positional accuracy
- Temporal accuracy
- Thematic accuracy

Quality Management (QM), according to ISO 9000, comprises various organized actions and arrangements to improve products, processes and services. The fundamental elements of QM (Mahoney and Thor, 1994) are:

- Total involvement (of the organization)
- Continuous improvement (processes)
- Customer orientation

One other important feature of QM shall be mentioned also, which is the ***Process orientation***. It means that in organizations the overlapping processes become more important instead of functions and rigid hierarchies. The definitions for quality refer to the quality of products and services but all relevant QM concepts point out that the quality of the production processes is very important and of course, have an essential influence on the quality of the product, e.g. Masing (1994). Quality of processes will be discussed in section 2.

ISO 9000 is a series of five international standards

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for quality management. The content of these standards and instructions for the application and implementation is published widely, e.g. Mahoney and Thor (1994). An important concept of ISO 9000 for our work is ***Process-based Quality Management*** (PQM) which is also called process-oriented Management by some authors. Some of the key characteristics are:

- Important activities and resources in enterprises shall be described as processes and shall be controlled accordingly
- Cross-functional processes need to be identified, understood and controlled accordingly
- The continuous improvement (CI) of the processes is a permanent goal of an organization

One of the reasons why these standards became well known was the fact that organizations could be certified according to ISO 9000 by specific legitimated third-party agencies. In this paper we are not focusing on certification but on the principles of ISO 9000 as these principles can guide every organization who is implementing a QM system, and are therefore of high interest in this context.

As mentioned, quality of spatial data is investigated intensively but process quality and quality management have not been discussed much in the geographic domain. The application of PQM to production processes of geographic data especially to so-called GIS based Facility Management Systems (FM-Systems) within utility companies were investigated by Stürmer (2007). Within the framework of a project funded by the research unit of the German Society for Quality (DGQ), a PQM related to update processes for geographic data in utilities was developed (Bockmühl and Reinhardt, 2008). This project triggered the idea to evaluate the concepts developed in a practice study over a longer period. The intended goal of the study is to measure the effects of changes in processes, e.g. when new data check methods have been introduced which in other words is the implementation of a continuous improvement cycle for geographic data production processes. For this reason suitable measures had to be developed. In this paper our main focus is put on introducing a developed methodology of CI as well as the results of a case study where this methodology was applied. Also we focus on explaining which measures can be used to unveil the effects of changes of processes.

The remainder of this paper is organized as follows: In section two we will give an overview about principles of process tracing and general approaches for CI. We will discuss approaches to define process quality in general and outline how this can be applied for geographic data production processes. In section three some basics of PQM and its application to FM-systems at utility companies within the framework of the project "PQM-NIS" will be outlined. This is followed by a description of the case study which has been carried out, its background, organizational requirements and goals as well as the basic approach of the study, the analysis of ratios, developed from process related data and the results of the study. Finally some conclusions are drawn.

2 PROCESSES – BASICS, QUALITY MODEL AND CONTINUOUS IMPROVEMENT

2.1 Background and Overview

A process in the context of this paper is understood as any kind of single or connected activities which has / have input and output. These activities shall be targeted on the output, for example a product of required quality, see e.g. (Masing, 1994).

As already mentioned, processes have to be monitored and checked (and improved if necessary) continuously. As a general approach for this task the method **DMAIC** *(**D**efine - **M**easure - **A**nalyse - **I**mprove - **C**ontrol) is very suitable (see* Mahoney and Thor, 1994). It includes the following steps:

Define: Define the goals of the process together with the customer (user). Emphasize on the process output and specific characteristics which are chosen together with the customer.

Measure: Measure the characteristics through suitable metrics (indicators) to determine the actual state of the process.

Analyze: Analyze the characteristics of the process and detect the reason for weaknesses and deficiencies.

Improve: Improve the process based on the results of the analyses and discussions with the customer

Control: Check the results of the re-organized processes.

Figure 1 illustrates the CI process adapted to geographic production processes. These general concepts give us guidelines for the CI methodology we have to develop. But we further need:

- A quality model suitable for geographic data production processes which includes proper quality elements

- A way to link the quality elements with the characteristics of the process defined by the customer
- Metrics for the quality elements

These issues will be discussed in the next sections.

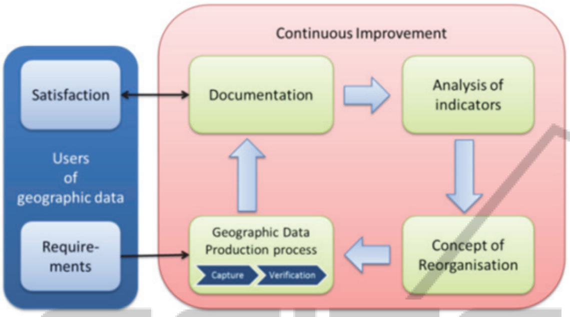

Figure 1: Continuous improvement of geographic data production processes (adapted after ISO 9000).

2.2 A Process Quality Model and Its Application

As QM is applied in a very large variety of domains from health care to mechanical product production and in our case to the production of geographic data, it is clear that the indicators of process quality must be different in the various domains. That means, criteria for the process quality have to be developed in a domain specific way. To the knowledge of the authors, such criteria have not been published for geographic data production processes. As a consequence these criteria for our case study had to be defined by ourselves. A literature study showed that several authors suggested considering software quality characteristics for the measurement of the quality of general business processes. Quality characteristics for software product quality are defined in the ISO/IEC 9126 standard (Satpathy et al., 2001). Table 1 includes this generic process quality model.

This model is very comprehensive and due to its generic approach it offers quality elements for all process characteristics. That means in each application the quality focus have to be defined first and according to this focus the proper elements have to be chosen from this list (table 1). This selection process needs intensive discussions with users to define the focus clearly. In other words: each organization can define its own profile of a quality model, even various profiles for specific cases.

Table 1: Factors and examples of sub-factors of the generic process quality model, after Satpathy et al., (2001).

Functionality	Compliance, Completeness, Consistency, Security
Usability	Understandability, Learnability, Operability
Efficiency and Estimation	Cost/ Effort estimation, Cycle Time, Complexity estimation
Visibility and Control	Progress, Monitoring, Improvement Measures
Reliability	Failure Frequency, Fault Tolerance
Safety	Risk avoidance
Scalability	Scalability
Maintainability	Analyzability, Modifiability, Stability

To structure this discussion a methodology which supports the selection of the suitable elements (and related metrics) for the specific characteristics of a process would be helpful. A very common method for such purposes is the Goal-Question-Metric (GQM) methodology (Satpathy et al., 2001). GQM is applied in a certain project in a way that at first the general goals are specified (together with the customer). An example of a general goal would be to study the efficiency of certain processes. To come to a more precise view and to define metrics a set of questions have to be formulated. Table 2 gives an example of the application of GQM.

Table 2: Example of GQM application.

Goal	**Object of study**: Selected data acquisition process **Purpose**: To assess Focus: E.g. Functionality Points of view: Relevant actors
Question	Are the data check methods in data capture suitable? **Metric**: Number of errors detected.

The process quality model introduced here together with the GQM method is a suitable framework for implementing a CI for geographic data production processes. But it has to be emphasized that it requires intensive discussions with customers (users) who have good process knowledge to select the quality elements, to ask the proper questions and to choose the metrics (see 3.2).

3 THE CASE STUDY

3.1 Background of the Study

In many countries utility companies are committed by legal regulations to keep records of the position and other properties of their facilities like pipes, cables etc. These facilities are stored in GIS based Facility Management (FM) Systems, also called Network Information Systems (NIS). The continuous updating of the data bases is a very important permanent task.

The data (and the GIS) is used for many purposes like the construction of new facilities, failure management (e.g. in case of a breakdown), planning of network extensions etc. In the case of any road constructions which require digging the data also is used to avoid damages of pipes and cables. Therefore, utility companies have a high interest in ensuring the quality of their geographical and other data.

Against this background, in 2007, the project "PQM-NIS" was started with the general goal to develop a PQM for the updating processes of the data bases of utility companies. The results were comprised in a best practice booklet which includes the description of the relevant basics and the update processes, the quality relevant actions as well as a guide to introduce a PQM. For details see Bockmühl and Reinhardt (2008).

Within this project the idea was born to prove the effects of a PQM in practice and especially to implement a CI for the update processes and study the effects over a longer period of time. Finally the case study was started in 2011. The details are explained in the following sections.

3.2 Approach of the Case Study

The study has been carried out with five utility enterprises in the southern part of Germany. The study is scheduled to be carried out till December 2013. The paper includes results from the first two years (2011-2012).

The strategic goals of the study:

- ⇨ To detect deficiencies in the processes and to identify options to eliminate them.
- ⇨ To demonstrate quantitatively that any changes of the processes were effective (or not). Typical process changes are for example the introduction of new check methods.

To convert these strategic goals to operative goals the following steps have to be carried out:

- ⇨ Selection of processes /sub-processes which shall be traced
- ⇨ General PQM activities
- ⇨ Definition of the detailed (operative) goals and metrics

These issues are discussed in the next sections.

Selection of Processes /Sub-processes. The selection of processes and/or sub-processes has to be carried out with very good process knowledge e.g. by involving the relevant actors of the processes. In this case processes had been selected which the involved operators indicated as "high potential for improvements". These processes were "Data Capture" (DC), that is data acquisition of newly constructed pipes (geometry and attributes), mainly pipes that are connecting houses to main pipes and "Data Input to GIS (DI GIS)" which consists of "Preparation", "Input of data into GIS" and "Quality Assurance in GIS after input" (see fig. 2).

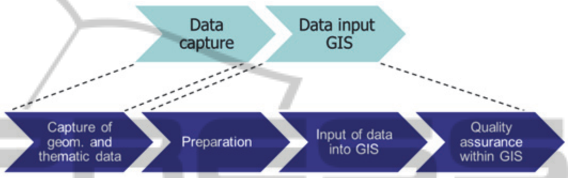

Figure 2: Processes considered in the case study.

General PQM Activities. To perform such a study and to implement a QM-concept like CI requires a series of additional actions which are also very important for the success of such a project like

- the involvement of people or
- the compilation of relevant documents e.g. process descriptions etc.

With regard to the length of the paper these issues are not discussed.

Refinement of Goals. This step was also carried out together with different actors of the processes of the enterprises. It was agreed with the partners that the main focus within the first part of the project should be put on efficiency of the processes as it was known that the performance within some of the sub processes was pretty low. Other issues were the categories and the number of detected errors within these categories. To refine this and to choose metrics the GQM method (see section 2) was applied. Table 3 presents some of the results of this part.

The factors and sub-factors of the generic process quality model (included in "focus" in the table) together with the GQM method allows for a user-defined adaption to any other goals. An important step is, as usual in QM, an involvement of people to include their deep process knowledge.

To be able to determine the metrics relevant measurements have to be performed, preferably automatically whenever it is possible. Some remarks on terminology: the term "metrics" in GQM is called "process indicators" or "ratios" in general literature on business processes. Therefore the term ratio is used in the following.

Table 3: Result of the GQM application.

Goal 1	**Object of study**: Processes DC / DI GIS **Purpose**: To assess Focus: Functionality Points of view: Relevant actors
Question	Are check methods in DI GIS suitable to detect errors? **Metric**: Number of errors detected by a specific method.
Goal 2	**Object of study**: Processes DC / DI GIS **Purpose**: To assess Focus: Efficiency Points of view: Relevant actors
Question 1	Is the duration of considered processes / sub-processes adequate? **Metric**: Process duration (in days).
Question 2	Is the elapsed time of certain sub-processes (e.g. problem management) adequate? **Metric**: Elapsed time of the sub process (in hours).

Procedure applied in the Study. In the first period of the project the documentation of the processes and workflows of the enterprises were checked and completed. Also some software components were developed to be able to collect the necessary process information and to calculate the defined process ratios. At the end of the first year we were able to start with the process of collecting data, calculate ratios, analyze the ratios and recommend process changes. The calculation of ratios was performed monthly.

3.3 Results of the Case Study

In this section we present selected results from the study to illustrate the methodology and to discuss the most important issues. Due to the length of the paper this requires a rather restrictive selection. Please note that with respect to data privacy protection all the data have been biased mainly in the absolute values, but all the effects described here have been observed with the real data.

The first area of interest was the duration of jobs related to processes and sub processes. Figure 3 shows the average duration of jobs (including data capture and data input to GIS) for one of the involved enterprises for a period of 9 month. In green colour the jobs without any problems and in blue colour the jobs with problems are given. Problem in this case means that something was unclear and had to be clarified by further investigations e.g. phone calls or discussions with people who were involved in the job. In red colour the duration is given which was needed to solve the problem. Figure 4 includes the corresponding durations of the sub processes of the processes DC and DI GIS.

These figures illustrate some important facts:

- The duration of jobs (DC and DI GIS) in general is very long (around 100 days!). The target duration (which is the goal) of the enterprises is different, but is between 20 and 40 days. In general the utility companies would need a higher up-to-dateness, but with regard to the costs they accept these duration of 20-40 days.
- In case of problems the duration of jobs is around 30% higher than without problems.
- At around 10-15% of the jobs problems occurred. With regard to the time needed for problem management there is a high potential for savings if it's possible to reduce this percentage.
- Figure 4 also shows that for the sub process capture of data the duration is at least double compared to other sub processes. This is not caused by a very complex data capture but just by the fact that the delivery of the results in general is delayed.

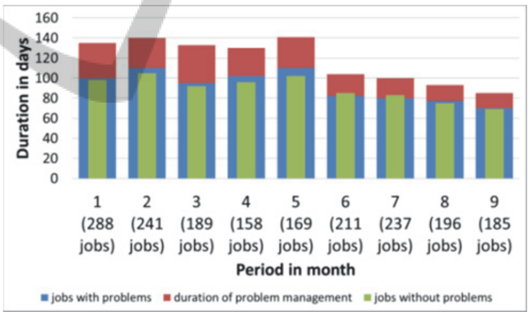

Figure 3: Duration of jobs (DC and DI GIS) for a period of 9 month.

- Data capture in general is performed by external companies or the companies who are doing the construction. Figure 4 shows that after 5 months the average duration of data capture was reduced by about 30%. This was just caused by negotiating with the external companies and a change of the contracts. It is expected that this will be reduced even more in future.
- Also the duration of the input of data into the GIS is pretty high (around 30 days). This is due to limited human resources working for this task. In future organizational changes shall help to decrease the duration of this step also.
- In general there is still a high potential to reduce the duration of the jobs especially related to data

capture or the delivery of the results respectively and related to the data input to GIS.

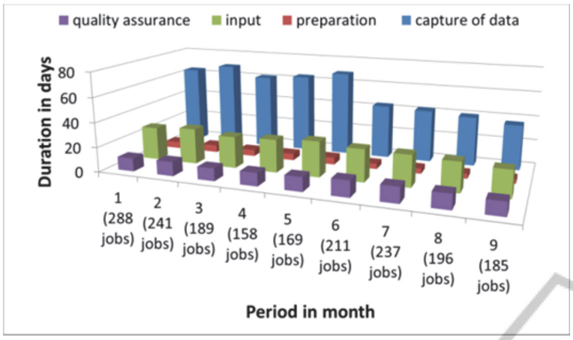

Figure 4: Duration of sub processes for a period of 9 month.

Figure 5 shows the average elapsed time per job for problem management (not the duration as in the other cases!). Problem management means finding the reason for the problem and/or clarifies the situation and delivers a correct data capture result.

- The average duration of problem management is around 40 h per job, which none of the orgs would have expected. It also can be recognized that there are considerable differences between the internal departments and the external company dealing with that. The reason for this has to do with education / skills of people and cannot be further discussed here.
- The reduction of the elapsed time of problem management after 5 months, which can be seen also in figure 5, was caused by an organizational change in the problem management process.

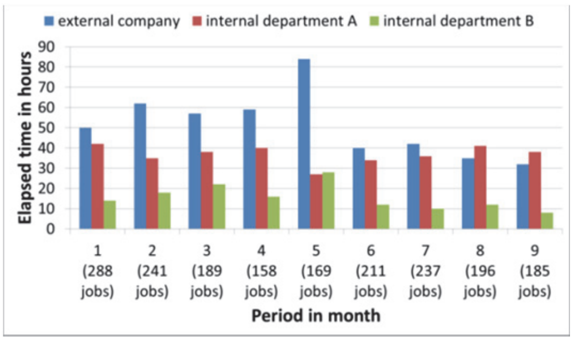

Figure 5: Elapsed time for problem management of different org units.

Figure 6 shows examples of detected errors of certain error types aggregated for 6 month.

- It clearly shows that in two enterprises the number of incomplete data sets were much higher than in the third one. It is assumed that the reason for this was an unclear communication of the rules what the data set should include. This figure also shows a very high number of geometric errors (detected after input into the GIS and corresponding checks) for one enterprise. In this case the reason probably was that not proper skilled personal (construction workers) did the surveying. In future these assumptions have to be verified. Generally in both cases a considerable reduction of the corresponding numbers of errors is expected.

Figure 6: Detected numbers of errors of certain error types.

These examples show that the methodology developed and applied offers the opportunity to analyse processes based on objective figures. In principle much more data can be captured and analysed in this context as we were able to demonstrate. In our case study the findings about the duration of the projects and the possible improvements (e.g. shorter durations) leaded to further and deeper investigations related to the efficiency of the processes so that other issues have been neglected in the first period of the project.

4 CONCLUSIONS AND OUTLOOK

We have presented a methodology for a continuous improvement of geographic data production processes based on objective figures and results from its practical application. Continuous Improvement is one of the most important parts of a process-oriented quality management. This method allows for a quantitative presentation of the quality of data production processes as well as the product (geographic data). A variety of different kind of information can be used as quantitative measures (also called process ratios) like efficiency or functionality indicators. Based on time series of these ratios, reorganizations of the processes can be designed and its effectivity can be checked and verified.

The method has been applied to geographic data production processes within utility companies but the method doesn´t include any utility specific things. In consequence it can be applied to the whole geographic data domain. The only things which of course can be specific are the processes itself which means that the analysis of the processes itself can be specific also.

Also the generic process quality model (presented in 2.2) is that comprehensive and allows for a specific adaption with regard to the focus of the specific investigation. In our case study mainly efficiency issues have been discussed but in other applications the focus can be different, of course.

Within the remaining period of the study we will focus on untreated process characteristics and we will investigate the usage of other analysis methods, e.g. methods of the Seven Basic Tools of Quality.

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