Model based quality assurance process in a infra construction project
– Case Riippa-Eskola RU2 double rail project

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ABSTRACT

The model based quality assurance method has been developed to replace traditional manually made quality measurements. The idea is to use the excavator's machine control system to document the accuracy (height and width) of the road at the same time as the structure is completed. This new method has been used for quality assurance for cuttings, embankments and road layers mainly on road construction sites. The aim of this pilot project was to prove the functionality of the model based quality control method also on a rail construction site, where quality requirements are stricter. The accuracy and reliability of the method was verified by making manual total station measurements. After the validity of the method was proven, it was fully taken over for quality control in the Riippa-Eskola RU2 construction project. The usability of the Inframodel 3 format was also tested in a model based infra construction process.

Keywords

Model based construction, BIM, quality assurance, inframodel

1 Introduction

Utilization of information modelling and machine automation has provided significant benefits for infra construction business. The utilization is still expanding. By using this new technology, the dispersion of quality reduces and the lead times for projects become shorter. The adoption process has been challenging. One of the biggest challenges is the lack of modelling regulations and uniform working methods. These have not kept up with technological development.

Traditionally quality control measurements on constructions sites have been performed manually with a total station. While production methods are model based and more automated, also quality assurance should be done with more advanced methods. Machine control models are already transferred to the machines through wireless solutions and also quality data is automatically sent back to server. Site foremen and supervisors can check as-built data by web based tools almost on real time. In addition to the practical use, training and technological development have improved the know-how and readiness to use the new equipment on site. All this has created good environment and greater potential to develop and adopt new model based production methods and quality assurance.

Destia Ltd is a leading contractor in implementation of BIM-based construction processes in Finland. Destia's goal is to exploit model based design and production throughout the lifecycle of an infra construction project. Since 2007, machine control systems have been used in more than 200 projects. Destia has more than 60 excavators, bulldozers, wheel loaders, motor graders and drill rigs equipped with a 3D control system. A model based quality assurance method has been developed and used since 2010.

A national development project called InfraFinBIM was carried out 2010-2014. One part of it was to produce instructions and guidelines for model based quality control. Those instructions were applied in practice in the Riippa-Eskola RU2 railroad construction project. The project consisted of constructing 60 km of new railroad construction several new bridges. The project started 4/2013 and the completion is scheduled for 11/2016. The value of the project is M€85.

Destia, Novatron Ltd. and Infrakit Ltd. have co-operated many years in developing new tools and methods for model based construction processes. Novatron machine control systems and Infrakit model visualizer tool were used as testing environment for the pilot. Novatron's 3D system for excavators consists of a display and computer equipment; sensors for the bucket, stick, boom, and frame; and satellite positioning devices. The interface of the system can be seen in Figure 1. In this system as-built data can be collected and saved by using the excavators bucket as the surveying tool. Work gets documented and the measurement data are then sent to the server wirelessly by using *Infrakit* tools.

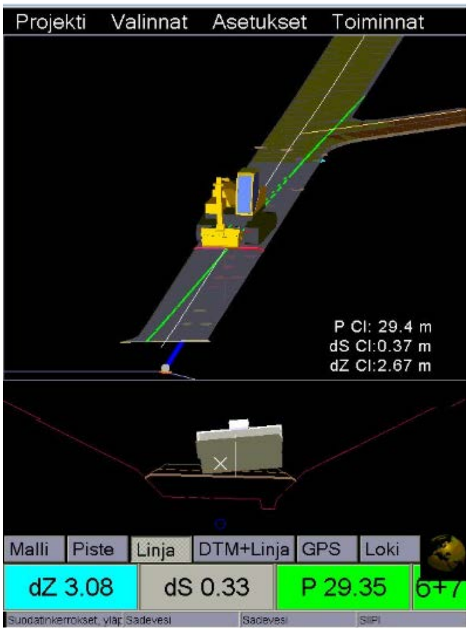

Figure 1. Picture of a Novatron 3D excavator's interface.

2 Model based quality control method

Model based quality control at an infra construction site means that machine control systems are applied in quality control at the same time as the actual work is done. The basis of this method is to check machine control models and machinery accuracy beforehand. In a model based construction process almost everything is done with models and therefore the correctness of the models is essential. By means of this preventive checking action it is possible to reduce mistakes significantly at the site. This method partly replaces the traditional surveyor and decreases surveying costs. This method can also be used for production control and follow-up at the site. Quality measurement points made by the machinery can be utilized to follow up the realization almost on real time. The quality control process at site consists of four main steps:

1. Checking and finishing of the machine control models,
2. Periodical accuracy check of GNSS positioning and machine control system
3. Follow-up measurements with machine control systems,
4. Manual surveying of the completed structure with total station at 200 m intervals.

A web based tool called *Infrakit*, which works Google Maps -environment, was used for data transfer between machinery and office server, for visualizing models and machinery and in the site follow-up. Site supervisors and client's quality controllers used the Infrakit's tablet version as a mobile user interface for the models and quality data at the site. Figure 2 shows part of the Infrakit's tablet interface.

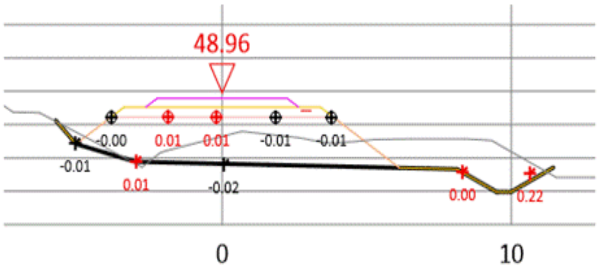

Figure 2. Cross section view of the Infrakit's tablet interface. Project management and supervision can observe the measured as-built and quality points almost on real-time. Also different theoretical surfaces are shown in the cross section view.

The machinery used in the quality assurance was a road roller and a grader. The quality measurements done with these machines were used to verify that machine control systems can be used within the accuracy limits of the official guidelines and instructions. The goal was to stay within two limits:

1. Measurements done with grader with GNSS-positioning have to be within ± **20 mm** from the actual surface,
2. Measurements done with road roller with GNSS-positioning have to be within ± **30 mm** from the actual surface.

3 Model based construction process

3.1 Excavation and construction of railroad foundation

3.1.1 Model based quality measurements

Model based quality measurements were used in the

RU2-project to measure the as-built quality. It was used for excavation (cutting surface) and earthworks of all the structural layers under the railroad tracks.

A machine control system of an excavator, a grader or a roller could be used for quality measurements, if the accuracy of the system had been proven to be sufficient. In this case, sufficient accuracy meant that the surveying results had to be within the given tolerances of the theoretical surfaces.

Generally quality measurements were done with maximum spacing of 20 m along the new railroad. Before the actual measurements could be done, the functionality of the machines and the know-how of the machine operators had to be checked.

As-built data acquired from the Novatron machine control system consists of xyz-coordinates, point numbers, date/time, machine code, infra code and accuracy data. This data can be seen at Infrakit's interface (Figure 3).

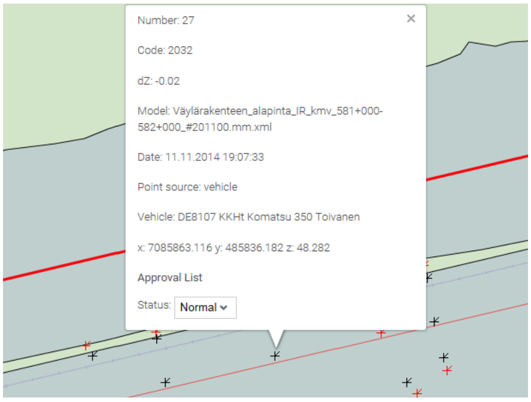

Figure 3. Screenshot from Infrakit, as-built point data opened.

All of the machine operators had a briefing and written manual for performing the measurements correctly. They also had full support from project management during the project if any problems occurred. Automation operators and project management were overseeing the measurements throughout the project.

The briefing and written manual contained the following:

- Status of the positioning device needs to be "Fix"
- With a machine using total station for positioning, you have to check that the total station is locked to the prism of the machine in question,
- The machine has to be stopped while performing a quality measurement,
- The quality measurement has to be done with the fixed point of the blade/bucket
- The bottom of excavator bucket has to be parallel to the ground surface
- Measured as-built is saved to a file and pictured on the screen of the machine control system's terminal device.

3.1.2 Verification period for excavators

Before the actual quality control measurements, a verification procedure had to be carried out. This concerned mostly excavators. The verification procedure was done to verify and research the applicability of the method in quality control process.

The verification procedure was carried out during summer 2013 between rail kilometers 580+000-582+000. The excavator, that was taking part in the verification, was control measured daily by the person responsible for measurements in the project. RTK GNSS –based accuracy control inspections were continued as described in the quality control process description.

During the verification, as-built points saved by the excavator every 20 m were compared to the theoretical cut level layer in the reference model. In addition total station surveying was done every 20 meters, in the same location with the excavator. These points were then compared to the theoretical cut level in the reference model. The points measured with total station and excavator were also compared with each other. The points measured by the excavator were compared to the level formed by total station survey points.

The results from the verification procedure confirmed the suitability of the working method as a part of a model based quality assurance process.

3.1.3 Structural layer spreading and soil compaction

In the RU2 quality control process the new finding was that it is possible to utilize motor grader and soil compactor (figure 4) with machine control systems and GNSS –positioning, in quality control of geometrical dimensions and soil compaction in intermediate layers (track foundation) of a railroad track.

With increased accuracy and reliability in GNSS positioning, it became topical to test its applicability in upper layers, as well, where total station positioning has typically been used because of strict demands on accuracy.

Figure 4. The Trimble machine control system was used in soil compactor for quality measurements.

3.1.4 Verification period for grader and soil compactor

Even grader and soil compactor had to go through a verification period if they were to be used in the quality assurance measurements. The verification procedure was carried out in summer 2014 for rail kilometers 579+000 – 589+000. The task was to spread the material and shape the layers with a grader and compact them with a roller. After that the same machines were used for quality control measurements. Both the machines had a 3D-machine control system with GNSS-positioning.

The actual verification of the machinery's applicability included the following steps:

1. Five (5) control measurements for every cross section with 10 m spacing along the railroad with a total station,
2. Three (3) measurements from the same cross sections with the roller,
3. Comparison of the total station measurements to the theoretical 3D-model,
4. Comparison of the roller measurements to the theoretical 3D-model,
5. Comparison of the roller measurements to a surface made from total station measurements,
6. A map was formed for every comparison to demonstrate the differences,
7. Statistical analysis (average, min, max, dispersion) of the measured data.

3.1.5 Quality control measurements for the intermediate layer of a railroad and the base layer of a road.

Based on the verification periods the soil compactor and grader were employed in the quality control process. The grader and soil compactor were used for the upper structural layers throughout the whole project.

The implementation and control of the grader with 3D-machine control system consisted of the following:

1. Distance to a GNSS-base station not more than 2 km,
2. Accuracy check of the positioning of the machine control system with a total station in a local coordinate system before starting the earthworks
3. Accuracy check of the grader's blade with a total station twice for every kilometer and layer. Check included the height and slope of the blade.
4. Accuracy check of the GNSS base station every week.
5. Saving the data from all the checks in a project data bank.

The implementation and control of the soil compactor with 3D-machine control system consisted of the following:

1. Distance to a GNSS-base station not more than 2 km,
2. Accuracy check of the positioning of the machine control system with a total station in a local coordinate system before starting the earthworks
3. Accuracy check of the positioning of the machine control system with a total station twice for every 2 km of every new layer.
4. During the compaction, the roller's operator observes how the newly built surface differs from the theoretical surface. If the differences exceed the tolerance, the operator reports to the supervisor.
5. Once the compaction is done, two (2) quality control measurements are done for predefined cross sections (20 m spacing along the railroad). Measurement is done while the roller is stopped.
6. The measurement data are transferred from the machine control system to the office wirelessly via Infrakit-system.
7. Quality reassured with total station by measuring points every 100 m on straight and densely around curves of the track.
8. The operators of the rollers are briefed and a written manual is given to them for making the measurements correctly.

This pilot was carried out in a remote district. This caused insufficient mobile GSM levels and therefore some problems occurred in the data transfer from the machinery to the office. These disturbances were solved by changing to another the service provider. A in the beginning of the pilot machine operators needed continuous training and technical support to document the as-built work thoroughly. After a while operators were noticed to be motivated and they took responsibility for doing the as-built measurements.

3.1.6 Utilization of Inframodel 3 -file format in construction and quality management.

Inframodel 3 is a XML-based file format for storing 3D-models and metadata. In this project the Tekla Civil design software is used for producing 3D-models for model based construction. The 3DWin-software is used, by surveyors, for checking and correcting for errors of the models used in the machines. Both main tools, the Tekla Civil and the 3DWin-software have a sufficient support for Inframodel 3. 3D-models are exported in Inframodel 3 –format and transferred to the machines. The model used in the machines is a break line model or surface model.

Before exporting the models the following items were checked:

- Coordinate system and geodetic datum,
- Coding of break lines and surfaces,
- Continuity of break lines,
- Parallelity of break lines,
- Crossing and overlapping of different break lines,
- Distances of subsequent break line vertices,
- Height difference from road geometry line,
- Individual points,
- Triangulation of surfaces.

In this particular project a comprehensive checking of the used software was also performed. The checking was about the support for Inframodel 3 -format. The most important surveying programs 3D-Win, SBG Geo Professional and Trimble Business Center all had a support importing and exporting Inframodel 3 format. Novatron's machine control systems had also a support for Inframodel 3 and the Infrakit, which was used for transferring the models wirelessly. The compaction rollers used Trimble's machine control system. The models written with 3DWin had to be rewritten with the Trimble Business Center for them to work.

3.2 Results

The accuracy of the GNSS-positioned machine control systems were gained by statistical analysis of the measurement data. The accuracy of GNSS-positioned grader: (compared to the theoretical model):

- Station 576-577 km: **98%** of the measurements within ± 20 mm,
- Station 586-590 km: **99%** of the measurements within ± 20 mm.

The accuracy of GNSS-positioned compactor: (compared to the theoretical model):

- Station 576-577 km: **85%** of the measurements within ± 20 mm,
- Station 586-590 km: **90%** of the measurements within ± 20 mm.

The accuracy of GNSS-positioned compactor: (compared to total station):

- Station 576-577 km: **92%** of the measurements within ± 20 mm,
- Station 586-590 km: **87%** of the measurements within ± 20 mm.

The structures made with the grader were very accurate with the tolerance of ± 20 mm. The accuracy of the roller was not quite so good but still it was clearly within the range of ± 30 mm.

3.3 Conclusions

As a result of this quality assurance pilot project, a new quality assurance method was created. The new method uses GNSS-positioned machine control system for as-built measurements. The same method was used for controlling the compaction rate of different soil layers.

The model based quality measurement clearly recuired less resources in both geometrical measurements and compaction measurements than traditional surveying. The surveyed quality data were also usable almost on real-time with the wireless synchronization of different systems.

The Inframodel 3 –file format was concluded to be mainly functional. It also supports and reinforces the whole BIM-based construction, planning and quality assurance process. All major surveying, planning and modelling software worked well with Inframodel 3. It is also justifiable to demand the Inframodel to be used in future projects. Nonetheless, all software used in the infra construction business does not yet support the Inframodel 3, so further development is needed for full implementation of this file format.

Model based quality management and measurements are not widely used yet, although the construction business clearly benefits from them. In the near future it is important to put an effort on expanding these methods throughout the business. As-built data could also be used in the next phase of the lifecycle, namely maintenance. This is a fairly new area for model based methods and it needs to be researched.

References

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