Navigation and Quality of Construction Processes

Wolfgang MÖHLENBRINK, Volker SCHWIEGER, Germany

Key words: Construction process, quality model, quality safeguarding, internal geometry, external geometry, navigation.

SUMMARY

Engineering geodesy and geodetic measurement techniques deliver important information within construction processes. This is valid for all phases of the process: the planning phase, the construction phase itself as well as the monitoring after finalisation of the construction work. The aim is the delivery of information in realtime to navigate construction processes with the help of the latest available geometric data. The basis for the solution will be a integrative description of the process, the data and the quality.
Geodesists and civil engineers often have their own, sometimes non-compatible, way to describe the quality of geometric data. Frequently they are restricted to the use of the quality criteria accuracy, although other criteria like correctness or availability are of the same importance. The authors will show the demand for a quality model that includes inherent quality criteria and parameters through the whole construction process.
The different topics regarding quality demands, quality model, quality assurance, realtime documentation of the construction process and navigation of the construction process are demonstrated for the setting out of high-speed tracks. The positive effects caused by the quality assurance actions will be demonstrated.

ZUSAMMENFASSUNG

Ingenieurgeodäsie und geodätische Messtechnik liefern wichtige Informationen innerhalb eines Bauprozesses. Das gilt für alle Phasen des Prozesses: die Planungsphase, die Bauphase selbst und die Überwachungsphase nach Abschluss der Bauarbeiten. Das Ziel ist die Lieferung von Informationen in Echtzeit um Bauprozesse mit Hilfe der aktuellsten geometrische Daten zu steuern. Die Basis für eine Lösung stellt eine integrierte Beschreibung des Prozesses, der Daten und der Qualität dar.
Geodäten und Bauingenieure haben häufig ihren eigenen Weg - zum Teil sind diese nicht kompatibel - die Qualität geometrischer Daten zu beschreiben. Außerdem beschränken sie sich häufig auf die Nutzung des Qualitätsmerkmals Genauigkeit, obwohl andere Merkmale wie Korrektheit oder Verfügbarkeit die selbe Bedeutung aufweisen. Die Autoren werden aufzeigen, dass der Bedarf für ein Qualitätsmodell mit inhärenten Qualitätsmerkmalen und Parametern für den ganzen Bauprozess besteht.
Die verschiedenen Themen wie Qualitätsanforderungen, Qualitätsmodell, Qualitätssicherung, Echtzeit-Dokumentation des Bauprozesses und Steuerung der Bauprozesses werden anhand der Absteckung einer Schnellbahntrasse demonstriert. Der positive Einfluss der Qualitätssicherungsmaßnahmen kann aufgezeigt werden.

Navigation and Quality of Construction Processes

Wolfgang MÖHLENBRINK, Volker SCHWIEGER, Germany

1. MOTIVATION

Due to new materials and complicated design issues as well as safety requirements caused by automation the construction tasks get more complex. This leads to higher quality requirements for geometric information too. In general geometric quality is described in terms of accuracy. The respective criteria in civil engineering are tolerances. In this paper it will be outlined that there is a demand for further quality criteria to assure a high quality in construction processes.

Road construction is a task that has a high level of automation (Kuhlmann, Heister 2006; Stempfhuber 2006). Building construction is less automated in Europe, but in e.g. in Japan (Yamazaki 2004) examples for automated construction sites exist. Nevertheless a lot of work has to be done in this field. The automation of construction processes leads to smaller tolerances due to the named safety requirements. In general the automation deals with one phase or more often one step of the construction process. An unsolved problem is the automation of the whole construction process, beginning from the planning phase up to the execution of the construction and additionally including the monitoring of the building after finishing the construction works. In this case the construction process may be guided and controlled with help of the results of the proceeding steps. Therefore the geometric information are very important. The geometry is determined by the surveyor on instruction of the civil engineer. Every surveyor should keep in mind that his information are important on the construction site. The automated navigation of construction processes (Niemeier 2006) should be carried through with the help of the surveyor only. To reach this target all results should be documented and quality evaluated in realtime to have them at anybodys disposal on the construction site. The management of the construction process may be automated and optimised regarding quality, time and costs. The paper will outline basic ideas regarding quality requirements and characteristics as well as measurement and propagation of quality criteria. The proposed procedures are discussed on the basis of a project dealing with high-speed slab tracks.

2. INFORMATION WITHIN CONSTRUCTION PROCESSES

2.1 Construction Phases and Information Chain

In general a construction process is a sequence leading to a well defined end, the handing-over of the building to the client. The separate phases are: the inventory, the design, the planning and the execution phase (compare fig. 1). These phases may be followed by the monitoring phase lasting over the lifetime of the building. During the whole process all the planning tasks like cooperate planning, planning of resources and financial controlling are realised centrally to assure a good overview about all activities on the construction site. These activities are summarised as "management of the construction process". The mentioned construction phases need geometric information as input. The geometry-related activities range from the survey of topography and development over Computer Aided Design (CAD) or Geographical Information System (GIS) based support for design, planning, execution up to the guidance of construction machines.

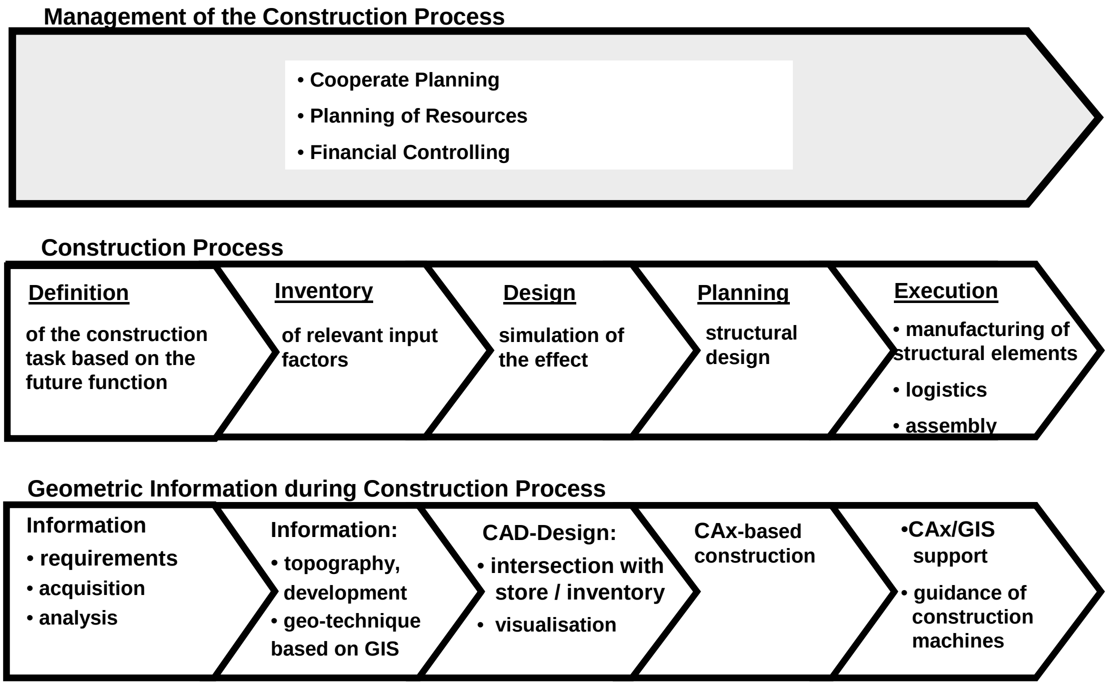

Fig. 1: Construction process and required information input

Any construction site needs a surveyor at least for the survey of the actual state, the setting out and for the acceptance survey. Sometimes the steps in between are supported by surveyors, especially during the execution phase. The surprising fact of the construction work on a construction site is that the information of the different phases is lost when the next phase in entered. This is valid even for different construction steps carried through by different contractors, the so-called crafts. Each craft has to acquire the information again. In the following we will focus on the execution phase, for which automation will be most advantageous.

2.2 Circle Characteristic of the Construction Phase

In chapter 2.1 the linear character of construction processes as well as the relevance of geometric data respectively geodata for all phases of the construction process was outlined. If the acquisition of geodata and the management of these data are integrated into the process, a relationship to the IMAP principle of the GIS community (Chalkin 1977) is seen. The IMAP principle describes the general steps needed for processing geodata using GIS. It shows a linear procedure consisting of data **I**nput respectively acquisition, data **M**anagement, data **A**nalysis and data **P**resentation respectively visualisation. These four steps are required at different stages of the construction processes, too.

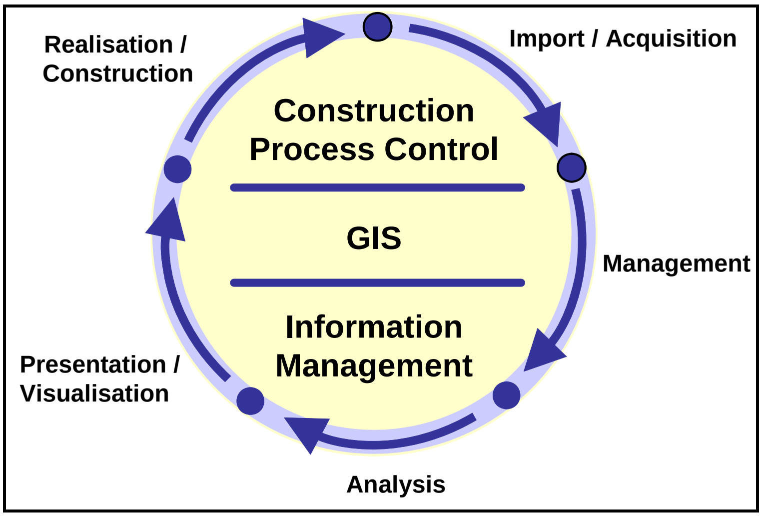

Fig. 2: The construction circle representing the IMAPR principl*e*

In contradiction to this linear principle the analysis and the visualisation of information do not represent the end of the construction sequence. The respective data should be used to construct buildings. After the realisation of the construction or the assembly of a structural element data will be acquired to visualise the current state of the process and the circle will begin again. This circle should be named the construction circle, that follows the IMAP principle completed by **R**ealisation (IMAPR), that is not a linear procedure anymore. The results of the presented data analysis should deliver information to decide about the progress on the construction site. The quality of the results will have an input on the decision; e.g. if a tolerance is not met, the last construction step has to be repeated or corrected. If the description is transferred to more technical terms, one would talk about navigation or guidance of the construction process. The construction circle may be seen as control circle for the management of the construction process.

2.3 Exemplary Realisation for High-Speed-Tracks

In the following example it is focussed on the execution phase of semi-automatic processes for construction. The different construction steps are integrated as control circles into the execution process. The example deals with construction of railway tracks. The institute for applications of geodesy to engineering (IAGB) was involved in setting out the construction of high-speed slab tracks for Köln-Rhein/Main. The tracks were constructed using the construction method “Feste Fahrbahn” meaning that gravel is replaced by concrete (fig. 3). Therefore every 65 cm a concrete ground plate has to be setted out and assembled.
The setting out of the tracks has to be performed very accurate and reliable, because the slab tracks have to be fixed in concrete and the adjustment of the track position may be realised only within some mm after the track fix. The adjustment procedure is described by Ablinger (2000) in detail. This restriction is the reason that the respective setting out as well as a complete measurement concept to control the slab tracks have to be integrated into the construction process. Figure 4 shows the simplified construction circle for fixing the slab tracks in concrete. The demand for and the implementation of the construction circle is

obviously visible.

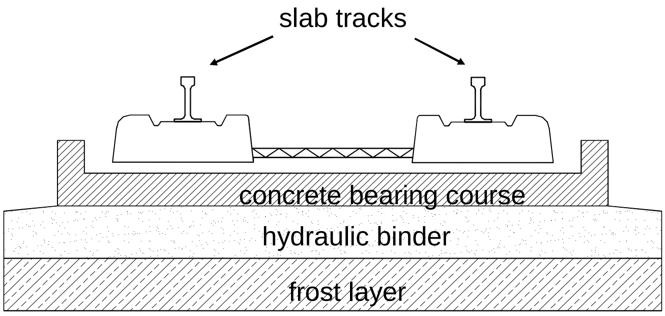

Fig. 3: Slab track construction “Feste Fahrbahn” (principle and example picture)

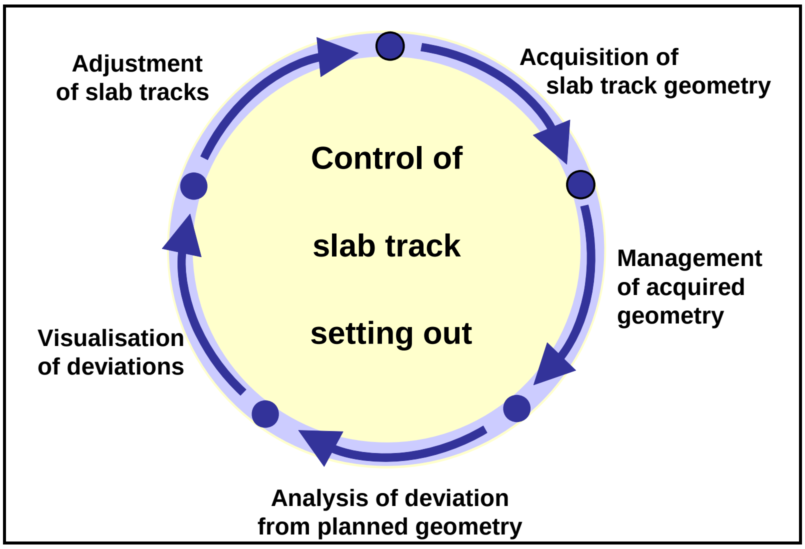

Fig. 4: Construction circle integrated into construction of “Feste Fahrbahn”

3. QUALITY CHARACTERISTICS

3.1 Quality characterictics in civil engineering and engineering geodesy

In engineering geodesy quality plays an important part all the time. Here the most applied quality characteristic is accuracy. In general this characteristic is substantiated by parameters like standard deviation or statistical measures like confidence intervals (e.g. Niemeier 2002). Another important quality characteristic is reliability. In general this term is understood in the same sense as correctness. This means that a measurement or a result is correct, if it coincides with the true value within limits set by accuracy parameters like the standard deviation. For geodetic networks reliability is defined as the possibility to check measurements for correctness through overestimation. Thus the possibility to decide if a measurement is correct or not is described by the reliability measures like redundancy numbers and minimal detectable bias (e.g. Niemeier 2002).

Engineering geodesy has created some more quality characteristics regarding monitoring networks: one is called sensitivity, the other one separability . In both cases the feature of the monitoring network with respect to a given or assumed deformation model is addressed. Sensitivity evaluates the possibility to detect movements following a given deformation model using a given measurement configuration. The parameter is the minimum detectable deformation vector. Separability simply evaluates the possibility to distinguish between two assumed deformation models. Also these characteristics are defined for geodetic networks. More general concepts of sensitivity analysis are discussed and proposed e.g. in Saltelli et al. (2000) and transferred to geodetic problems in Schwieger (2005). Table 1 summarises the quality characteristics of engineering geodesy.

Tab. 1: Quality characteristics in engineering geodesy (related to geodetic networks)

Characteristic	Accuracy	Reliability	Sensitivity	Separability
Exemplary parameters	standard deviation, confidence interval	redundancy number, minimal detectable bias	minimal detectable deformation	minimal separable deformation

On the other hand civil engineers are accuracy driven too. Here the parameters for describing the accuracy are called tolerances (see also chapter 3.2). A lot of standards in construction are dealing with tolerances only (e.g. DIN 2005). The advantage of tolerances is the fact that maximum values for deviations are given too. These maximum values are the limiting values for a decision regarding correctness or non-correctness of a structural element or their assembly within a the construction process. Thus we may interpret tolerances as measures for accuracy as well as for reliability respectively correctness.
Up to now a general quality model for construction processes do not exist. But the demand to know the quality of a construction through the whole process is essential for successful management on and out of the construction site (Wendebaum, Fliedner 2005). Currently different new criteria are in discussion beside tolerances as reliability (of the equipment), availability (of data or systems), completeness (of information), correctness, up-to-dateness and level-of-detail (see e.g. Wendebaum, Fliedner 2005; Reinhardt et al. 2002, Wen-de et al. 2005). It has to be mentioned that these characteristics are not implemented into construction management systems up to now and that the development of a complete quality model including all characteristics and criteria is a challenging task for the future.

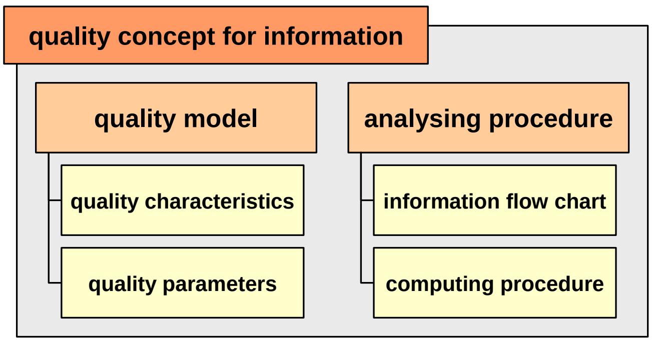

Fig. 5: Interdisciplinary quality concept (Wiltschko 2004)

Due to the lack of complete quality models in engineering geodesy and civil engineering the attention has to be drawn to models in neighboring disciplines. Quality models have been developed in geodata domain as well as in other disciplines like mechanical engineering or traffic applications. At IAGB an interdisciplinary quality model was developed that combines the criteria of the geodata domain with quality concepts of mechanical engineering, IT-systems and vehicle systems for road traffic. For further detail regarding parameters and definition of characteristics is referred to Wiltschko (2004). In the following the defined characteristics are given:

- availability and up-to-dateness
- completeness, consistency and correctness as well as
- accuracy.

Figure 5 describes that besides quality characteristics and parameters a method to determine and analyse the quality was developed. The speciality of the quality model is the fact that the model may propagate the inherent quality criteria through the whole process using Boolean algebra. Figure 6 gives a realisation example for modeling the information flow for road data that should be used for so-called speed advice systems. The research and implementation was carried through within the project EuroRoadS granted by the European Commission.

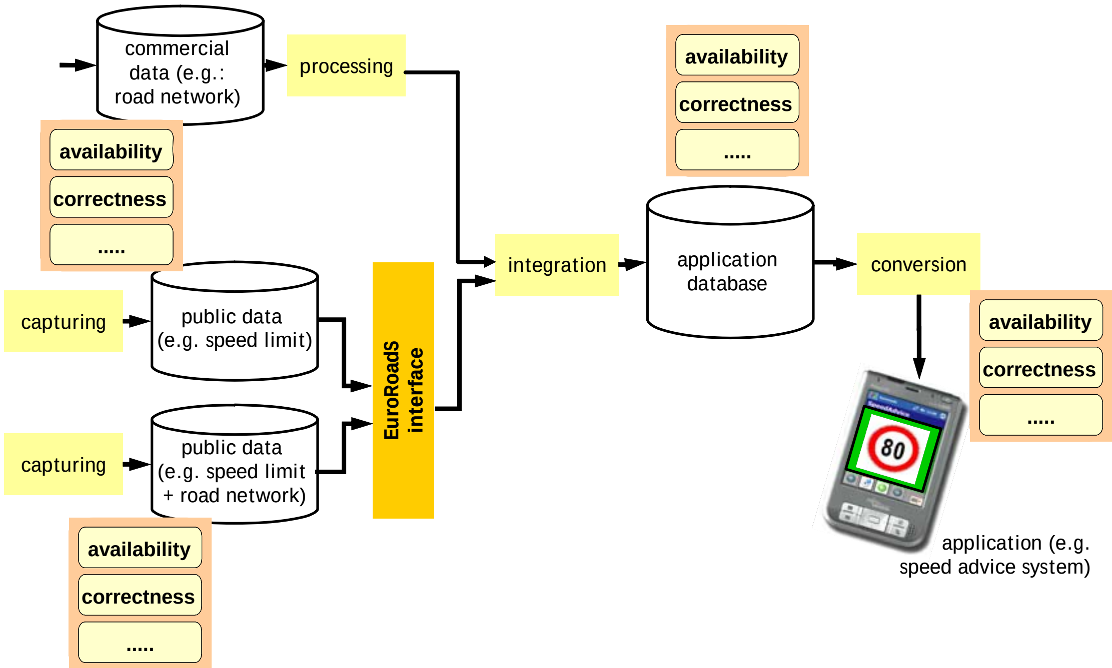

Fig. 6: Information flow for speed advice system (Kaufmann 2006, EuroRoadS)

For the case of construction processes another interdisciplinary model has to be developed; geodata plays in important part too. Theses arguments make it obvious to use the model of Wiltschko as the base model for further developments. The importance of the mentioned criteria for the management of construction processes and the question if new quality criteria have to be added like e.g. the so-called level of detail described by Reinhardt et al. (2002) will be one future task.

The propagation of the quality measures through a complex process is in some cases a problem using Boolean algebra. Assumptions are necessary concerning the results of the complex processing steps. A more sophisticated method is the use of Monte-Carlo simulation, that may propagate through complex processes with high computational costs. A useful tool for this task is the variance-based sensitivity analysis that uses Monte-Carlo samples as input. Independently of the model characteristic information about the influence of the input quantities on the output quantities is gathered (Saltelli et al. 2000, Schwieger 2005).

3.2 Accuracy criteria

3.2.1 Tolerance and standard deviation

According to the explanations of chapter 3.1 the paper will focus on the accuracy criteria in engineering geodesy and civil engineering. To get a relation between standard deviation in engineering geodesy and tolerance in civil engineering the possibility to transfer the two criteria among each other has to be established. The relationships have been described e.g. in Möhlenbrink et al. (2002). A summary is given below. In general the tolerance T is composed of the components production tolerance T_P, assembly tolerance T_A and surveying tolerance T_S. These components are summed up quadratic to determine the tolerance

$$T = \sqrt{T_P^2 + T_A^2 + T_S^2}\ .$$

The relationship between surveying tolerance and tolerance is given in the following

$$T_S = T \cdot \sqrt{1-(1-p)^2}\ ,$$

where p denotes the percentage of the surveying tolerance of the tolerance. The resulting surveying tolerance is not identical to the standard deviation σ_s of a survey e.g. of the point coordinates, since the tolerance is defined two-sided and the limits of the tolerances are values that should not be exceeded. In general it is assumed that the limits of tolerance coincide with the limits of a confidence interval. In this case the standard deviation belonging to a surveying tolerance may be determined using a factor k, that depends on the significance level, by

$$\sigma_S = \frac{T_S}{2 \cdot k}\ .$$

Figure 7 defines the terms in relation to tolerances. If normal distribution is assumed and the significance level is chosen to 5 %, a common value for engineering tasks, the factor $k \approx 2$ is defined. A smaller significance level leads to a larger factor and therefore to a smaller standard deviation. If the equations should be filled with numerical values, as a rule of thumb the portion p of the surveying tolerance of the whole tolerance is fixed to a third and the significance level is chosen to 5 % or 0.3 % leading to a factor of k = 2 respectively k = 3. Thus the resulting ratio between tolerance and standard deviation is given by

$$\sigma_S \approx 0.2 \cdot T \ \text{ for } \alpha = 5\% \ \text{ and } \ \sigma_S \approx 0.15 \cdot T \ \text{ for } \alpha = 0{,}3\%\ .$$

This relationship follows – as written before – a rule of thumb only. The exact relationship is defined in a contract between the civil engineer and the surveyor. They may refer to standards like DIN (1998), where e.g. a ratio of approximately 1:10 to 1:5 is defined.

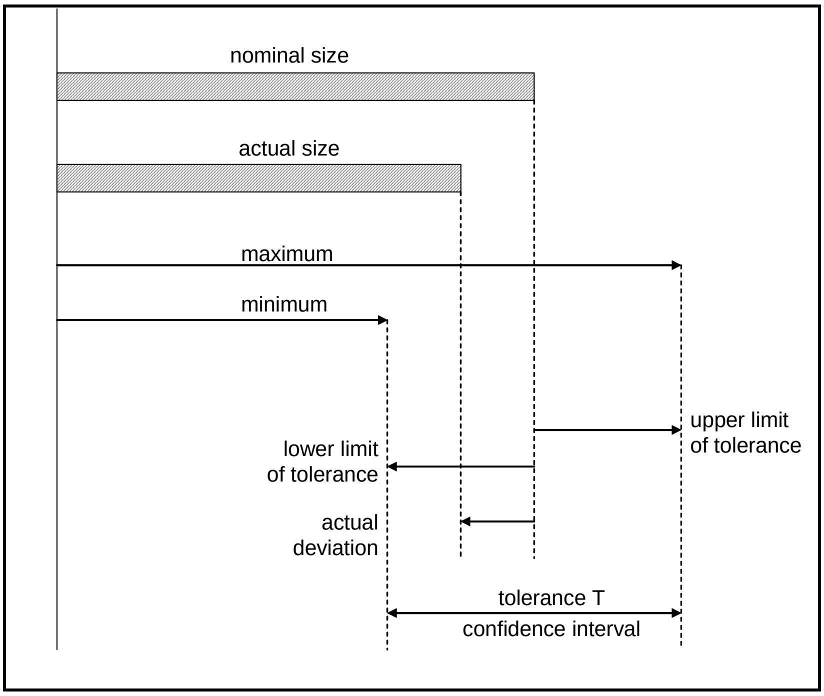

Fig. 7: Tolerance, deviations, limits and confidence interval

3.2.2 Internal and external geometry

At first one has to evaluate, if the given tolerance is a measure for the shape or the position of the object that has to be constructed. In the first case one has to talk about the internal geometry of the object, in the second case one has to consider the external geometry of the object. The second specifies the relation to other objects that could also be a global coordinate system. For construction purpose this distinction is quite clear: any relation to other objects will be called external geometry. Accuracy parameters like tolerances have to be assigned to external and internal geometry.

As an example a crane runway on a construction site may be the object to be surveyed. The lineage of the single tracks as well as the parallelism of the two tracks are characteristics of the crane runway and can be considered as internal geometry. Here the demands for internal geometry may be quite high due to the safety issues during the crane movement. In opposite the external geometry with respect to e.g. a building under construction are of less importance and demand for a less accurate determination, since the crane boom has a rather large span width.

In geodesy the terms internal and external accuracy are in use too. The internal accuracy (repetition accuracy) stands for the accuracy determined by the measurement system itself. The external accuracy (comparison accuracy) describes the accuracy determined by an evaluation using true values or quasi-true values. These terms have no relation to the

geometry based terms that are important for construction processes.
Additionally the terms absolute and relative accuracy are applied in geodesy. Absolute accuracy is defined with respect to a global coordinate system. Relative accuracy stands for differences between measured points or even observations. The terms do not distinguish between relative quantities defined on one object e.g. a structural element and relative quantities defined between two or more objects. Table 2 outlines the difference between internal and external geometry on the one hand and absolute and relative accuracy on the other hand. For construction processes the distinction between quality measures related to internal and external geometry is the only essential one.

Tab. 2: Classification of accuracy characteristics

geometry	**external**		**internal**
function	**position** of an object		**shape** of an object
accuracy term	**absolute**	**relative**	
description	**absolute** position in a global system	**relative** position between two or more objects	**relative** position on one object

3.3 Example of Design to Quality for High-Speed-Track Surveying

At this stage the authors return to the example of the High-Speed-Tracks "Feste Fahrbahn". The only quality criteria given are tolerances that have to be separated into tolerances of internal and external geometry. If we assume normal distribution, the choice of the significance level for the confidence interval defines the rate for the correctness implicitly. In this case we choose $k = 3$. Therefore a correctness rate of 99.7 % is determined.
The external geometry is defined through tolerances regarding the position of the rail tracks with respect to existing neighbor tracks or other neighbor objects. These tolerances are not derived from driving dynamics. This is the reason that the requirements are not as high as for the internal geometry. In practice this external tolerance is defined with respect to the control network near the track by IAGB (2000) to 20 mm.
On the other hand internal geometry reflects the shape of the rail tracks, especially the curvature of the tracks. To substantiate the shape control two criteria are defined in IAGB (2000); both follow the well known Nalenz-Höfer procedure (compare fig. 8). The ordinate with respect to the chord normal to the track for the horizontal component and in track direction for the height component are the two measures to be taken. For both measures a tolerance for a 5 m distance and for a 150 m distance was defined. The first one should eliminate dominant individual deviations. The high accuracy demand is based on driving dynamics. The second less demanding measure should eliminate long-periodical effects. As far as the authors know driving dynamics play no role for this distance.

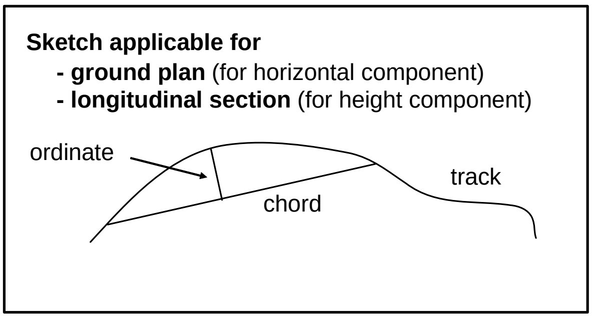

Fig. 8: Ordinates with respect to the chord according to Nalenz-Höfer procedure

Additionally criteria regarding the width of the tracks as well as other differences to the planned geometry are under consideration. The following table gives an overview about the different requirements on internal geometry. All tolerances are given in deviations from the planned track gauge, planned transverse inclination or planned ordinates. Table 2 shows that the tolerances for internal geometry are outstanding, especially if one takes into account that the standard deviations should reach approximately 15 % of the tolerance values according to chapter 3.2. Obviously standard deviations of 0.6 mm are quite difficult to achieve.

Table 2: Tolerances for internal geometry (IAGB 2000)

internal geometry criteria	tolerances
track gauge	4 mm
transverse inclination	4 mm
ordinate for horizontal component 5 m point distance 150 m point distance	 4 mm 20 mm
ordinate for height component 5 m point distance 150 m point distance	 4 mm 20 mm

4. QUALITY SAFEGUARDING FOR CONSTRUCTION PROCESSES

The quality realised within the process may be in accordance with the required and planned quality or not. The planned quality is based on the quality demands and the a-priori evaluation. Due to the fact that any real process do not follow the simulation, the quality has to be measured during the process.

In the following the way to model processes presented in figure 6 for road data will be projected on the construction process for high-speed-tracks described before. The construction phases respectively construction steps in the execution phase are related to the surveying activities as well as the quality assurance activities to reach the tolerances given in chapter 3.3. The assurance activities are classified according to their influence on the quality characteristic accuracy of external and internal geometry in figure 9.

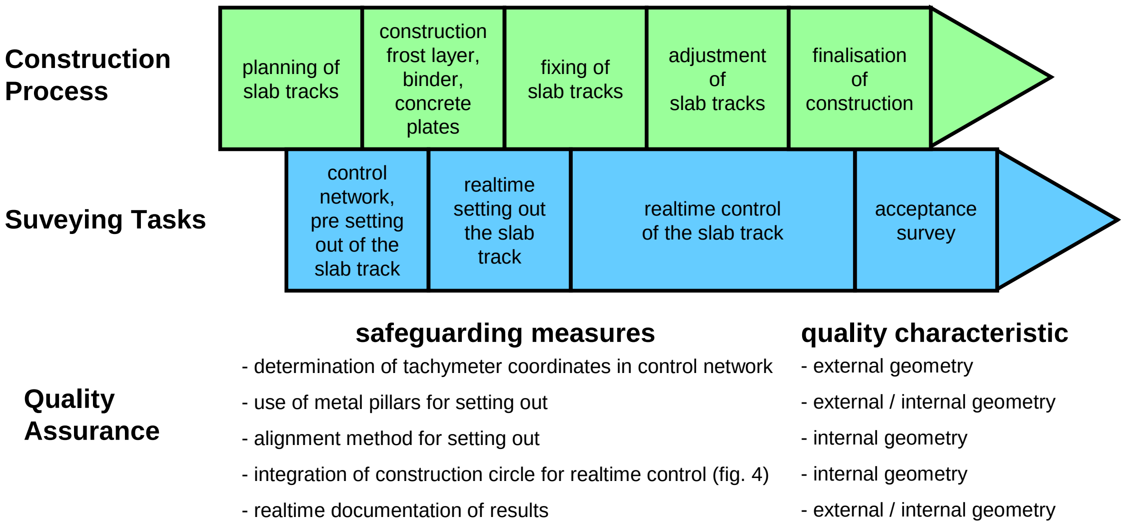

Fig. 9: Construction process and safeguarding quality for construction of high-speed tracks

To reach the standard deviations described in chapter 3.3. an a-priori simulation was carried through. The use of robot-tachymeters for the setting out and the quality control during the construction process was the only possibility to reach standard deviation of 0.6 mm, because GPS cannot provide this accuracy in an affordable amount of time. Additionally the simulation shows that a high precise and stable control network near the track using forced centering has to be established. Based on this network the setting out of the rail tracks has to be realised. For this task a track measuring vehicle (Amrhein, Gerth 1999) was used in connection with a tachymeter installed on special metal pillars in trough wall (see fig. 10). The pillars were installed on points on the track itself that are marked by means of threaded bolts. They assure a centering accuracy of approximately 0.1 mm. The distance between the points on the tracks is below 65 m.

Fig. 10: Track measuring vehicle and tachymeter on special pillar

The advantage of this measurement configuration is that the accuracy of the setting out is effected by the direction measurement only. Due to the fact that direction measurement is more accurate than the distance measurement for distances of 70 m, an obvious improvement for the setting out accuracy is obtained. Therefore the measurement configuration may be

called alignment. For the inner geometry of short distances (5 m as given in table 2) only the influences of direction measurements from one pillar have an effect. Errors that influence this direction measurement systematically like e.g. axis errors of theodolite or constant refraction in the atmosphere do dot effect the accuracy between two setted out points measured from one pillar (Kuhlmann 2001).
As shown in figures 4, 9 and 10 any built track is controlled directly and corrections are carried through due to the deviations from the planned geometry. The realtime evaluation respectively control is directly integrated into the construction process.

5. CONCLUSION AND OUTLOOK

In this paper the demand for the introduction of inherent quality characteristics and parameters for construction processes is described. Quality assurance including safeguarding measures has to be integrated into the construction process. This comprises

- a-priori evaluation,
- quality measurement, propagation of quality measures and realtime evaluation,
- realtime documentation of results and quality measures.

The different topics were demonstrated for the setting out of high-speed tracks. The positive effects caused by quality assurance actions integrated into the construction process could be demonstrated.
The guidance and navigation of construction processes using documented and quality controlled results is the target for the future (see figure 11). This paper focuses on the outer control circle for the management of the construction process. Figure 11 additionally presents the inner control circle that guides the construction machine. The discussion of topics related to the inner circle is beyond the scope of this paper.

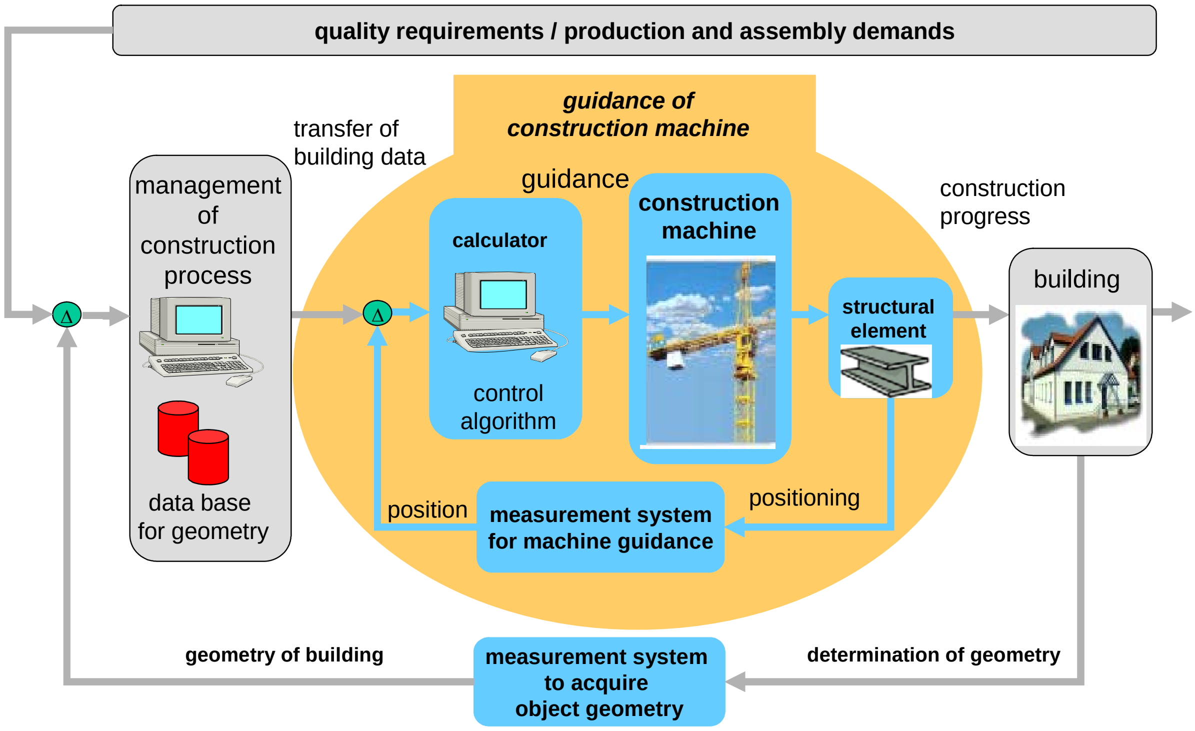

Fig. 11: Quality driven control circles for the construction process

Another important aim is to obtain the required quality with as less time and cost effort as possible; meaning to find efficient ways to assure quality demands. Efficiency may be understood as an additional quality criteria as well as a quality demand could be the constraint of the efficiency optimisation.

An important aim seems to be the development and implementation of a design-to-quality process in surveying engineering exceeding the up-to-now prioritised concentration on accuracy. This is an unsubstitutable technology for semi-automatic construction processes with guidance and control driven by geometry.

REFERENCES

Aiblinger, P. (2000): Vermessen und Einrichten der Festen Fahrbahn. Publication of Company Bahnbau Wels GmbH, Wels, Austria.

Amrhein, M., Gerth, M. (1999): Qualifizierte Vermessung für Feste Fahrbahnen. Der Eisenbahningenieur, volume 5, pp 24-27, Tetzlaff Verlag, Hamburg.

Chalkin, H. (1977): Information Systems Development in North America. In: Tomlinson, R.F. (Ed., 1977): Proceedings Commission on Geographical Data Sensing and Processing, Moscow, pp 93-113.

DIN (2005): DIN 18202 - Toleranzen im Hochbau. Deutsche Norm, Beuth Verlag, October 2005.

DIN (1998): DIN 18710-1 – Ingenieurvermessung – Teil 1: Allgemeine Anforderungen. Draft, Deutsche Norm, Beuth Verlag, October 1998.

IAGB (2000): Kommentar zur Abnahme und Vermessung der Festen Fahrbahn. Deutsche Bahn: Anforderungskatalog der Festen Fahrbahn, IAGB, Universität Stuttgart.
Kaufmann, T. (2006): Quality Assured Road Data by Using the PDCA-cycle – experiences from EuroRoadS. Lecture at Transport Research Arena – Europe 2006, Göteborg, Sweden, june 12 -15.
Kuhlmann, H. (2001): Alignment of rails on slab track with robotic tacheometers. The 3rd International Symposium on Mobile Mapping Technology, Cairo, Egypt.
Kuhlmann, H., Heister, H. (2006): Steering problems and solutions during construction for roads. Proceedings on 3rd IAG Symposium on Geodesy for Geotechnical and Structural Engineering, Baden, Austria, May 22-24.
Möhlenbrink, W. (2004): High-Speed-Track Köln-Rhein-Main Robot Tacheometers for semi-automatic Construction Processes. Proceedings on 3rd International Conference on Engineering Surveying, Bratislava, Slowakia, november 11-13.
Möhlenbrink, W., Kuhlmann, H., Dünisch, M. (2002): Vermessung „Feste Fahrbahn“, Verfahren für die Vermessung der Bauart „Feste Fahrbahn“. Eisenbahn-Ingenieur-Kalender 2002, Tetzlaff-Verlag, Hamburg.
Niemeier, W. (2002): Ausgleichungsrechnung. Walter der Gruyter, Berlin, New York.
Niemeier, W. (2006): Geodetic Techniques for the Navigation, Guidance and Control of Construction Processes. Proceedings on 3rd IAG Symposum on Geodesy for Geotechnical and Structural Engineering, Baden, Austria, May 22-24.
Reinhardt. J., Akinci, B., Garret, J.H. (2002): Using Customized Navigational Models to Deliver more Efficient Interaction with Mobile Computing Devices on Construction Sites. Proceedings on 19th International Symposium on Automation and Robotics in Construction, September 23-25, Gaithersburg, Maryland, USA.
Saltelli, A., Chan, K., Scott, E.M. (Ed., 2000): Sensitivity Analysis. John Wiley and Sons, Chichester.
Schwieger, V. (2005): Nicht-lineare Sensitivitätsanalyse, gezeigt an Beispielen zu bewegten Objekten. Deutsche Geodätische Kommission, Reihe C, volume 581.
Stempfhuber, W. (2006): 1D and 3D systems in machine automation. Proceedings on 3rd IAG Symposum on Geodesy for Geotechnical and Structural Engineering, Baden, Austria, May 22-24.
Wendebaum, J., Fliedner, J. (2005): On-machine control and documentation systems for the quality management of roads. Proceedings on 22nd International Symposium on Automation and Robotics in Construction, September 11-14, Ferrara, Italy.
Wen-de, Y, Shao-Shung, L., Gang-wei, F. (2005): Real-Time Decision-Making with Partial Information for Construction Management. Proceedings on 22nd International Symposium on Automation and Robotics in Construction, September 11-14, Ferrara, Italy.
Wiltschko, T. (2004): Sichere Information durch infrastrukturgestützte Fahrerassistenzsysteme zur Steigerung der Verkehrssicherheit an Straßenknotenpunkten. Dissertation, Fortschritt-Bericht VDI, Reihe 12, volume 570, VDI-Verlag, Düsseldorf.
Yamazaki, Y. (2004): Future Innovative Construction Technologies: Directions and Strategies to Innovate Construction Industry. Proceedings on 21st International

Symposium on Automation and Robotics in Construction, Jeju, Korea, september 21-25.

BIOGRAPHICAL NOTES

Wolfgang Möhlenbrink

1973 Dipl.-Ing. in Geodesy (Technical University Berlin)
1984 Dr.-Ing. in Geodesy (Universität Stutgart)
1988 – 1996 Head of Traffic Guidance and Control Research (Daimler-Benz Research)
1996 Director of Institute for Applications of Geodesy to Engineering, Universität Stuttgart.

Volker Schwieger

1989 Dipl.-Ing. in Geodesy (University Hannover)
1998 Dr.-Ing. in Geodesy (University Hannover)
2003 Head of Department “Positioning and Measurement Techniques” at Institute for Applications of Geodesy to Engineering, Universität Stuttgart
2004 Habilitation (Universität Stuttgart)

CONTACTS

Prof. Dr.-Ing. Wolfgang Möhlenbrink / Dr.-Ing. habil. Volker Schwieger
Universität Stuttgart
Institute for Applications of Geodesy to Engineering
Geschwister-Scholl-Str. 24 D
D-70174 Stuttgart
Germany
Phone: ++49/711-685-84040 / 84064
Fax: ++49/711-685-84044
Email: wolfgang.moehlenbrink@iagb.uni-stuttgart.de
volker.schwieger@iagb.uni-stuttgart.de
Web http://www.uni-stuttgart.de/iagb/