INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITE DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

WHERE DO DESIGN ERRORS COME FROM – RESULTS FROM AN EMPIRICAL STUDY IN A GERMAN ENGINEERING COMPANY

Stefan Moehringer
Simon Moehringer Anlagenbau GmbH

ABSTRACT
Rising product complexity, shorter development time and cost pressure are determining factors in design. Due to this framework the number of design errors in practice is increasing. Every error incorporates as well chances to improve the product and the product development process. This potential needs to be opened up in a systematic way. A computer-based methodology – an error tracking system – has been developed and introduced in the industrial context of a German engineering company. It supports to record errors in a structured way, to carry out error correction and the involved actions, to analyse errors and transfer errors into knowledge. 396 recorded errors have been analysed and followed up over a one-year-period. It is the objective of this contribution to analyse the error reasons, to group error focuses, to trace the error origins and to identify the involved company departments related to design errors. The effectiveness of the error tracking system will be evaluated and further steps for improvements will be suggested. The main feedback comes from the start-up phase. Stronger interaction between departments is necessary to avoid errors. Outsourcing and global sourcing strengthen the role of suppliers and can create additional errors. The error tracking should therefore integrate the supplier's databases.

Keywords: design errors, error tracking, error avoiding, design validation, learning from errors, computer based tool, knowledge management

1 INTRODUCTION
Designers are facing various challenges in product development: a rising product complexity especially caused by electronics and software components, market demands such as shorter development time and cost pressure as well as communication within heterogeneous company structures. These determining factors lead to an increasing number of design errors in practice.
The number of product call-backs points to this problem. In the automotive industry the number of call-backs because of errors and component defects on the German market increased from 55 cases in 1998 to 123 cases in 2005 [1]. Mechanical defects (84 out of 123 cases) are predominant. In Europe 11 products per week need to be called back because of errors or safety problems [2].
In spite of the increasing complexity and permanent product innovations error situations seem to be partly known from previous cases. In manufacturing even 60% of the failures are known or at least similar [3]. Information about errors comprise obviously a considerable potential to avoid errors in the future. A crucial factor to learn effectively from errors is the feedback (as direct as possible e.g. from the customer or manufacturing/assembly) and the possibility to consolidate information about similar error situations [4]. The information however must be easily accessible and linked to the designer's context in order to be useful [5]. The quality of the documentation and the time allowed to review design steps is essential [6].
In order to record and analyse errors in a systematic way and to bring the error knowledge in the designer's situational context a computer-based error tracking system has been developed and introduced in the industrial context of a mechanical engineering company [7]. 396 errors have been recorded and followed up over a one-year-period.

2 OBJECTIVES

In [7] the basic idea and the process steps of the error tracking system have been explained. It is the objective of this contribution to analyse the recorded errors empirically in order to learn more about design errors and its context. The following questions are raised:

- Error identifier: Which departments are involved to recognize errors?
- Error origin: Where do errors come from? Which error origins can be traced?
- Error reason: What are the main reasons that errors happen? Is it possible to identify error focuses?

Based on these findings further steps for improvements will be suggested.

3 DESIGN ERRORS

3.1 The influence of errors on the design phase

The design department plays an important role: especially during the early design phases the influence on the product attributes is very high. The designer is responsible to determine working principles, to choose the material and to specify the geometric and behaviour parameter. With the cumulative determination of the design parameter the influence drops down rapidly. The error detection rate behaves diametrically: it is usually very low in the design phase; errors are detected at a progressive rate during production, start-up and operation of the product. The error costs are increasing exponentially: it is much more expensive to solve errors when the product is already in operation at the customer than doing corrections during manufacturing or even in the virtual stage (see fig. 1) [8].

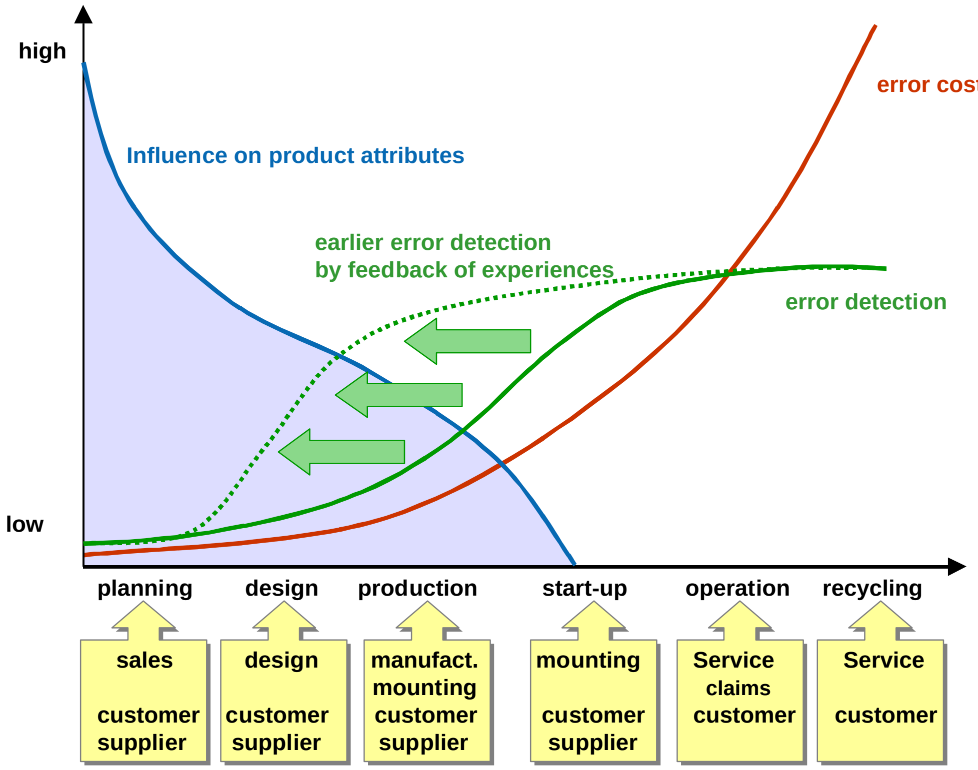

Figure 1. Errors and their effects [8], [9]

There are many participants during the product creation process which can detect errors: company departments e.g. design, manufacturing, service, claim management as well as suppliers, customers etc. If one can manage this various error information and initialize a systematic backflow to the design department the error detection curve can be moved to the left side. That means errors can be detected earlier which will decrease the error costs significantly.

3.2 Error tracking process

In order to organize a systematic error feed-back an error tracking process is needed [7], [10]. The error tracking process is described as a sequence of process steps (recording errors, classifying errors, solving errors, evaluating errors and providing knowledge) which typically need to be passed through when handling errors (see fig. 2). Each process step is supported by the software tool. The process step "classifying errors" allows to record the error identifier, error origin and error reason. In the process step "evaluating errors" the data are grouped to error focuses and can be evaluated related to customer projects, functional similarities etc. Especially the relation between error identifier, error origin and error reason can be analysed.

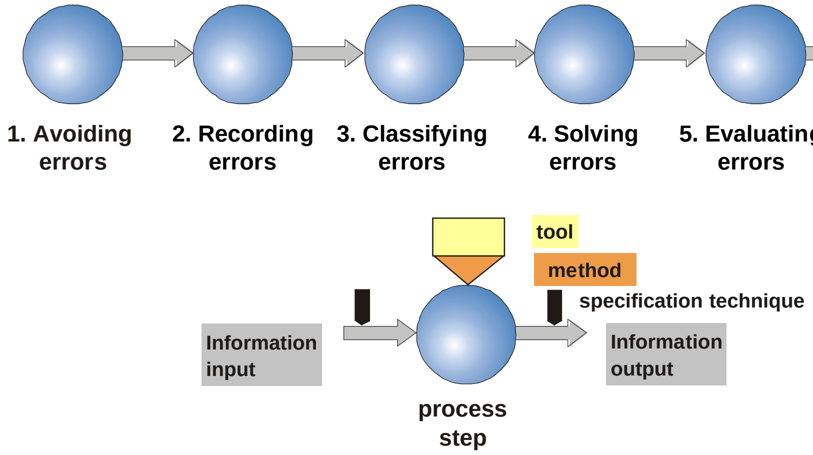

Figure 2. Error tracking process

4 EMPIRICAL STUDY ON DESIGN ERRORS

The computer-based error tracking system has been implemented in a medium-sized mechanical engineering company in Germany. Core competence of this company is to design customized plants for the woodworking industry produced in small series or single copies. In every project process-specific particularities and innovations are involved. Therefore errors can generate valuable process knowledge for future projects.

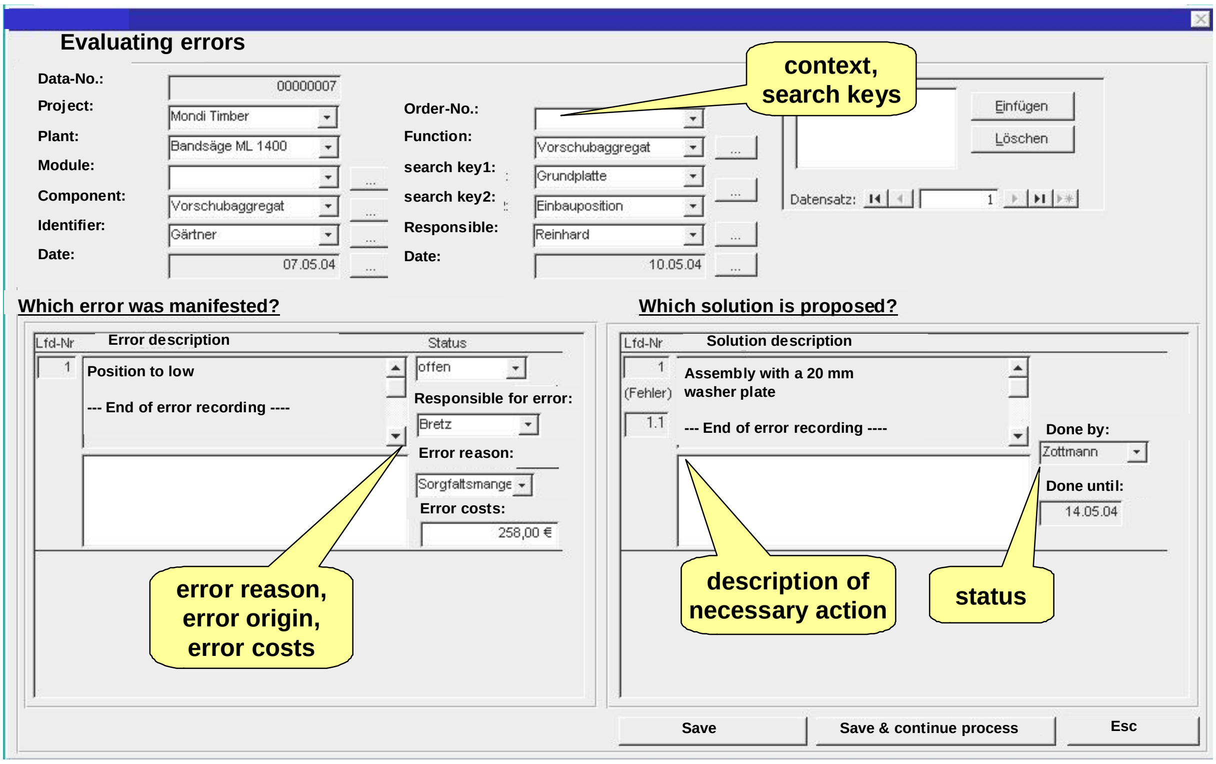

Figure 3. Error evaluating module

Over a one-year period every error occurred has been recorded in the system. The quality manager makes sure that the errors are not only followed up and solved but also classified and described correctly. With the help of the error evaluation module (see fig. 3) error identifier, error origin and error reason can be analysed.

4.1 Error identifier

The error identifier (fig. 3) shows where the feedback comes from: 170 errors have been recorded by mounting/start-up engineers (who are at the building site), 146 by project managers, 32 by production staff, 20 by electronic designers, 10 by the quality department, 8 by the service department, 6 by the board of management and 4 by the accounting.
Approx. 43 % of the errors have been identified at the building site outside the company during the final assembly and the start-up of the components. Additionally 36% have been recorded by project managers. They work as an interface between the customer and the manufacturer ensuring that the mounting and start-up process runs as scheduled concerning time, quality and costs. They get the error information mainly through on-site visits, furthermore by communication with the customer or suppliers. Another 5% of the errors are recorded by departments (service, accounting, general management) which generate the information via the customer, e.g. complaint calls, unusual wear etc.
Consequently 84% of the recorded errors have been identified outside of the company.

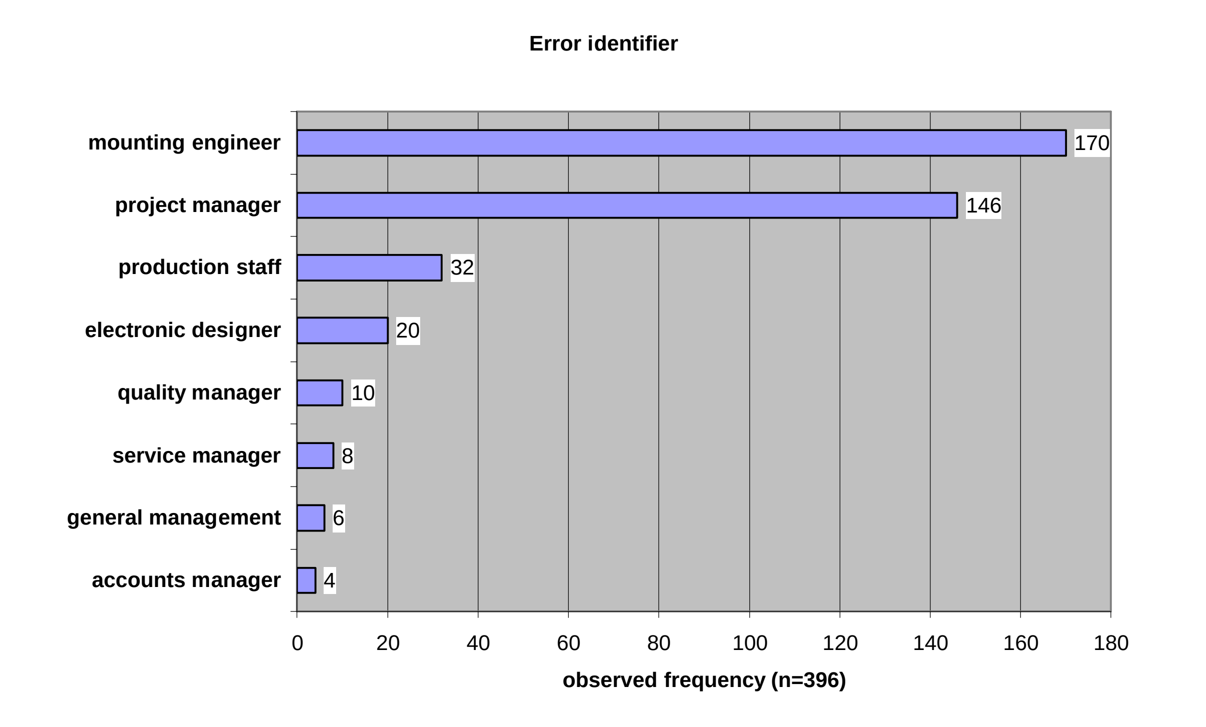

Figure 4. Observed error identifier

4.2 Error origin

The error origin (fig. 4) is related in 220 cases to the design department, 76 to suppliers, 42 to the production, 24 to the electronic design department, 12 to the sales department, 8 to customers, 8 to the purchasing department, 4 to the mounting department and 2 to the shipping department.
It is not astonishing that the majority of cases (55%) is related to the design department as it is responsible for the product determination. Nevertheless significant errors (38%) are coming from suppliers, production, electronics and sales. Especially the suppliers play an important role which may even increase depending of the nature of the project. In turn-key projects where the company as the general contractor integrates several suppliers with an independent scope of works the percentage of errors related to these suppliers is certainly higher.

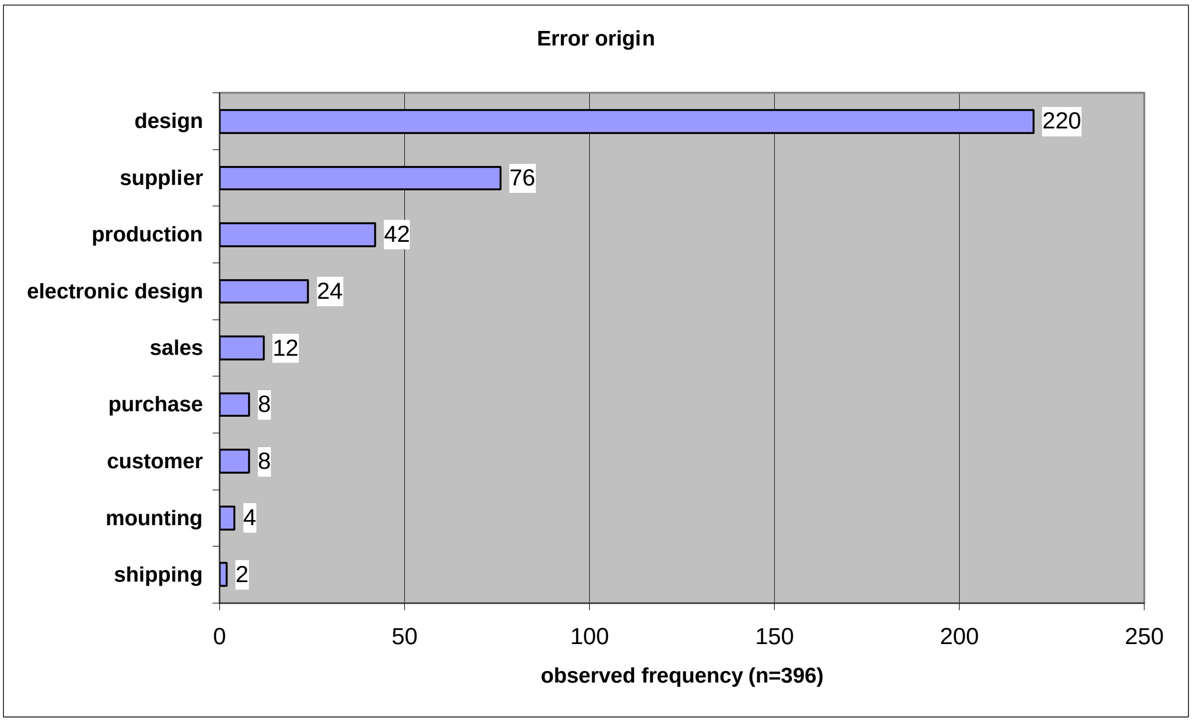

Figure 5. Observed error origin

4.3 Error reason

The following error reasons (fig. 5) could be identified:

- functional failures (92), e.g. inappropriate part fixation, missing protection, wrong component shape, missing software features
- dimensional failures (80), e.g. wrong material or components
- production errors (68), e.g. missing accuracy, delivery incomplete, imprecise assembly or adjustment
- project planning errors (52), e.g. concept errors, collision with infrastructure provided by customer, wrong foundations
- part collision errors (42)
- start-up errors (22), e.g. wrong configuration and fine tuning
- documentation errors (18), e.g. missing details, incomplete documentation of modifications during start-up
- purchasing errors (8), e.g. incomplete order specification, missing claim management
- ergonomic errors (6), e.g. mounting or demounting very difficult
- operation/maintenance errors (6), e.g. wrong operation, missing maintenance
- mounting errors (4), e.g. wrong part assembly or alignment

For a more detailed analysis 38 error classes have been are aggregated. The most important are:

- functional failures due to new design requirements
- functional failures with supplier responsibility
- control system failures due to software errors
- premature breakdown of mechanical or electronic components
- design documentation errors

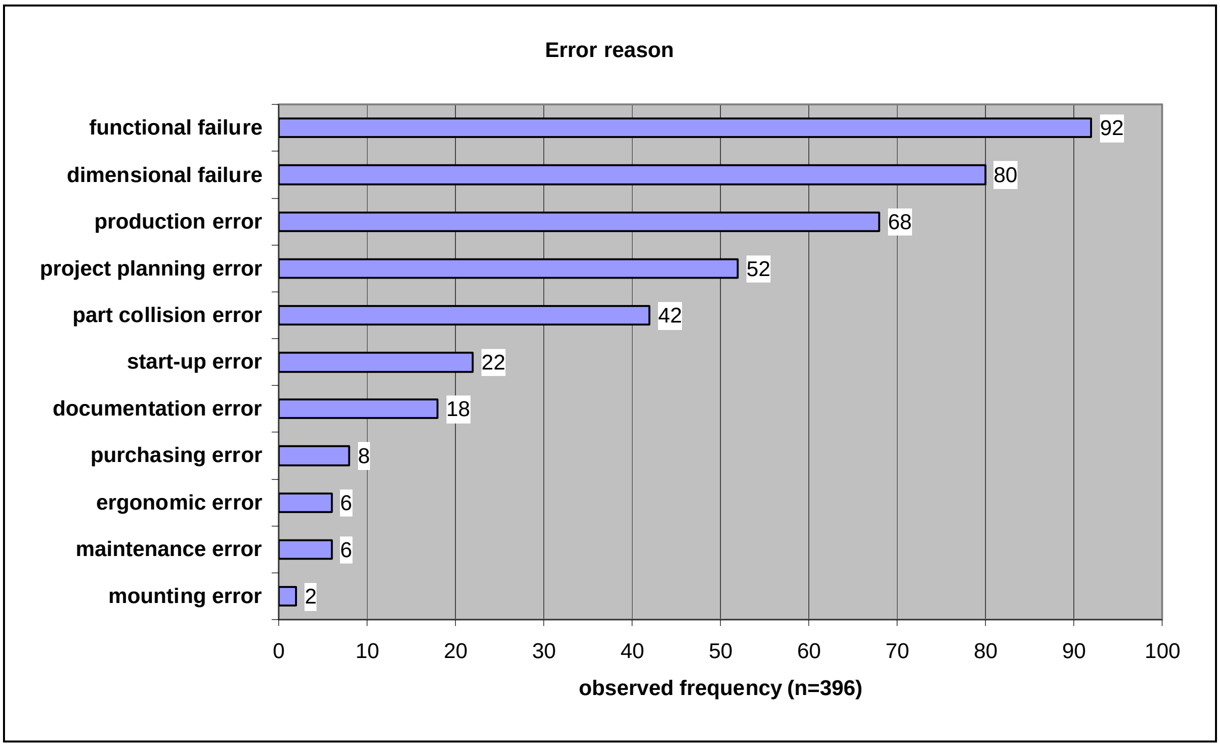

Figure 6. Observed error reason

5 CONCLUSIONS

5.1 From error identification

The main feedback comes from the start-up phase at customer's site: 79% of the errors are identified during installation and start-up of a plant and recorded by the mounting engineers themselves or the project designers.

This shows that designers depend very much on the external feedback to solve errors and to improve the product features for future projects. Their "usual range" – from the design department to the shop floor – is not sufficient for a huge number of errors. The need to record errors especially during the later product creation phases is certified herewith.

There is an important task encouraging mounting and start-up engineers to record the errors.

The error evaluation need to be scrutinized in a deeper way: is the high rate of error identification during start-up part of the business characteristics (customized plant engineering in small series) or are the methods to avoid errors (FMEA, functional test, virtual prototyping etc.) not performed in a sufficient way? A further evaluation would have to analyse whether the errors could have been identified during an earlier design stage.

Long-term failures should be identified by the service to improve the product quality. But only 2% of the errors have been recorded by the service in the considered period. This may require longer-term studies to analyse the after-sales effects.

5.2 From error origins

The analysis showed that 38% of the errors are coming from suppliers, production, electronics and sales.

Stronger interaction and co-ordination between departments is necessary to avoid these errors. Outsourcing and global sourcing strengthen the role of suppliers and can create additional errors. The error tracking should therefore integrate the supplier's databases.

5.3 From error reasons

Out of the main error focuses 3 groups of errors can be aggregated:

- **errors influenced by the system dynamics:**
  (functional failure, dimensional failure, start-up error = 49%). These errors occur during start-up or the first months of production. The anticipation into an earlier product creation phase demands modelling and simulation methods (FEM, hardware-in-the-loop etc.) and therefore a considerable expense.
- **errors influenced by the system geometry and kinematics:**
  (project planning error, part collision error = 24%). These errors occur mostly during mounting when the geometrical boundary conditions (local infrastructure, packaging of components from different suppliers etc.) are completely known. The anticipation into an earlier product creation phase demands 3D geometrical modelling, collision simulation and the close co-operation between project planning, customer and suppliers.
- **errors influenced by production:**
  (production error = 17%). These errors occur mostly during mounting when parts are finally assembled. The anticipation into an earlier product creation phase demands a more accurate product quality control.

The errors of the second and third group represent together 41%. There is a strong potential to learn from these errors and to improve the methodical and organisational proceeding in order to avoid similar errors in the future.
The errors of the first group are much more difficult to anticipate, especially regarding small series and the cost-value-ratio of simulation in this context.

5.4 Learning from one's errors and the evolution of the number of errors

The main objective and expected effect of the system is to increase the designer's knowledge to avoid errors by learning from similar design situations. The observed one-year period is still too short to quantify the positive effects of the error tracking system. Probably the number of errors even increased initially because errors could be recorded systematically for the first time. Furthermore the attention and motivation for a new methodology is high at the beginning and decreases after a phase of disillusion to a level of normalization. The first year is necessary to gain experience with the system and to reach this level of normalization. A quantitative analysis about the evolution of the number of errors can be started subsequent.

6 OUTLOOK

At the beginning o this paper it was hypothesized that the feedback (as direct as possible e.g. from the customer or manufacturing/assembly) and the possibility to consolidate information about similar error situations are crucial factors to learn effectively from errors.

An empirical study analysing 396 recorded errors within a mechanical engineering company was made to learn more about error identifiers, error origin and error reasons.

The role of the feedback can clearly be underlined. The analysis of error identification shows that approx. 80% of the errors have been recorded during installation and start-up phase offering a direct feedback from the user (applying engineer, customer). The ability to consolidate information of these errors and to transfer them in a similar design context is given by an appropriate error tracking system [7]. Search keys and classified errors help to specify the specific design situation.

The error origin is more diversified and demands a closer interaction between the involved departments such as design, supplier, production, electronics and sales.
The different error reasons allow a first argumentation that a considerable part of the errors (approx. 40%) could be avoided applying more detailed project planning, collision avoidance testing and quality control.

Further empirical analysis is necessary to identify repeated or similar errors indicating the effectiveness to avoid errors by error knowledge transfer. A comparison of the analysed error cases with the following one-year period could give information about the learning effect of the error tracking system.

Another interesting investigation can be done by analysing the error reasons of errors recorded during installation and start-up. The quality of the feedback can then be evaluated in a better way. There could be the finding that a part of these errors could have been identified during an earlier design stage.

REFERENCES

[1] Kraftfahrtbundesamt. Jahresbericht 2005: Kraftfahrzeugtechnik - Typgenehmigungen, Produktsicherheit und Rückrufe, Flensburg, 2005, www.kba.de

[2] PriceWaterhouseCoopers. Germany – European champion for product call-backs, Frankfurt am Main, 04/2005, http://www.pwc.com

[3] Wuenscher, T.; Feldmann, D.G.; Krause, D. Product and Process Improvements based on Data Mining of Shop-Floor Information, *Proceedings of the 9th International Design Conference DESIGN 2006*, May 15-18, 2006, Dubrovnik – Croatia, Zagreb, 2006.

[4] Gries, B.; Gericke, K.; Blessing, L. How companies learn from design flaws: results from an empirical study of the German manufacturing industry, *Proceedings of the 15th International Conference on Engineering Design*, The Design Society, Melbourne, 2005.

[5] Bennett, R.; Sloan, C. Repeating Design Errors or "Where's the History"? Engineering Tommorow's World Today INCOSE 2003 - *13th Annual International Symposium Proceedings*, June 29-30, 2003, Washington, DC, 2003.

[6] Suther, G.: Evaluating the perception of design errors in the construction industry, University of Florida, Gainesville, 1998.

[7] Möhringer, S. From Design Errors to Chances – a Computer-based Error Tracking System in Practice, *Proceedings of the 9th International Design Conference DESIGN 2006*, May 15-18, 2006, Dubrovnik – Croatia, Zagreb, 2006.

[8] Ehrlenspiel, K. Integrierte Produktentwicklung – Methoden für Prozeßorganisation, Produkterstellung und Konstruktion, Carl Hanser Verlag, München, Wien, 1995.

[9] Lindemann, U.; Reichwald, R. (Hrsg.) Integriertes Änderungsmanagement, Springer Verlag, Berlin et al., 1998

[10] Möhringer, S. Entwicklungsmethodik für mechatronische Systeme, Habilitation, Universität Paderborn, Paderborn, 2004.

Contact:
PD Dr.-Ing. Stefan Moehringer
Simon Moehringer Anlagenbau GmbH
Industriestrasse 1
D-97353 Wiesentheid
Germany
Phone: ++49-9383-950-29
Fax: ++49-9383-95015
e-mail: stm@moehringer.com
URL: http://www.moehringer.com