THESIS ON MECHANICAL AND INSTRUMENTAL ENGINEERING E46

Uncertainty Focused Product Improvement Models

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Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any academic degree.

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CONTENTS

ABBREVIATIONS/ACRONYMS/SYMBOLS

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3DP	– 3D Printing
µBGA	– Micro-BGA, with ball spacing less than 1 mm
ADB	– Adapter Design Book
ATO	– Assembly To Order-manufacturing system
AQL	– Acceptable Quality Level
B2B	– Business to Business
CAD	– Computer-Aided Design
CAE	– Computer-Aided Engineering
CAM	– Computer-Aided Machining
CCGA	– Ceramic Column Grid Array, circuit package in which the input and output points are high temperature solder cylinders or columns arranged in a grid pattern. The body of the component is ceramic
CGA	– Column Grid Array, circuit package in which the input and output points are high temperature solder cylinders or columns arranged in a grid pattern
CIT	– Circuit Testing
CNC	– Computer Numerical Control
Cp	– Process Capability
Cpk	– Process Capability Index
CTE	– Coefficient of Thermal Expansion
DC	– Direct Current
DFA	– Design for Assembly
DOE	– Design of Experiments or Designed Experiment
DV	– Digital Video
DVC	– Digital Video Camera
DPI	– Dots per Inch
EAS	– Ettevõtluse Arendamise Sihtasutus
EBM	– Electron Beam Melting
EDM	– Electrical Discharge Machining
ELQ	– Elcoteq
ESD	– Electrostatic Discharge
eROOM	– Virtual workroom, is a hosted collaborative solution that provides midsized businesses with world class collaboration software in a hosted environment

FDM	– Fused Depositing Modelling
FMEA	– Failure Modes and Effects Analysis
FMS	– Flexible Manufacturing System
FR-4	– Flame Retardant 4 laminate made from woven glass fibre material impregnated with epoxy resin
FTA	– Fault Tree Analysis
GD&T	– Geometrical Dimensioning and Tolerancing
GR&R	– Gauge Repeatability & Reproducibility
GUM	– Guide of Expression of Uncertainty in Measurement
ICT	– In-Circuit Test
IFA	– Inter Face Adapter
ISO	– International Standardization Organization
IT	– Information Technologies
IT	– International Tolerance, Grade reference ISO 286
KLMS	– Kitting Line Management System
LCD	– Liquid Crystal Display
LFBGA	– Low profile fine pitch ball grid array, with a square or rectangular array of solder balls on one surface, ball spacing typically 0,8 mm
LMC	– Least Material Condition
LOM	– Laminated Object Manufacturing
LSS	– Laser Sintering System
MIM	– Modular Indication Matrix
MMC	– Maximum Material Condition
MPWS	– Manufacturing Packaging Warehouse System
MTO	– Make To Order-manufacturing system
NIST	– National Institute of Standards and Technology
NMI	– National Metrology Institute
NMP	– Nokia Mobile Phone
NPL	– National Physic Laboratory
OGP	– Optical Ganging Products, Inc.
PAD	– Product Architecture Design
PC	– Personal Computer
PCA	– Printed Circuit Assembly
PCB	– Printed Circuit Board (Alternative names are Printed Wiring Board (PWB)
PCBA	– Printed Circuit Board Assembly

PDMS	– Product Data Management System
PGA	– Pin Grid Array, with a square or rectangular array of solder balls on one surface, ball spacing typically 1,27 mm
Pp	– Process performance
PPI	– Pixels per Inch or pixel density
Ppk	– Process performance index
PWB	– Printed Wiring Board
QFD	– Quality Function Deployment
RF	– Radio Frequency
RoHS	– Restriction of Hazardous Substances Directive (= Lead Free)
SLA	– Stereo Lithography
SMD	– Surface Mount Device
SMT	– Surface Mount Technology
SMEMA	– Surface Mount Equipment Manufacturers Association
SMC	– Surface Mounted Components
SMD	– Surface-Mount Devices
SMT	– Surface-Mount Technology
SLS	– Selective Laser Sintering
SW	– Software
TTS	– Theory of Technical Systems
TRIZ	– Teoriya Resheniya Izobretatelskikh Zadatch, The theory of inventor's problem solving
VOC	– Voice of the Customer
WWW	– World Wide Web

SYMBOLS

α	– coefficient of thermal expansion (CTE) m/mK
λ	– proportional standard deviation
ζ_i	– direction factor for dimensional chain link (−1 or +1)
$\delta_j A_i$	– correction for the measures A_i depending on j influence factor
δRHA_3	– correction of moisture influence
$\Delta_{ti\min}$	– minimal deviations of change of nominal size A_i (for example after temperature influence)
$\Delta_{ti\max}$	– maximal deviations of change of nominal size A_i
Δ_{SYS}	– dependent link systematic factor (summary maximum movement)
$\Delta_t A_i$	– correction factors (link change depending on temperature)
A_Δ	– depending link nominal value
$A_{\Delta COR}$	– dependent link corrected value
A_i	– nominal value of dimensional chain link
D_{nom}	– nominal value (dimension)
E (e)	– (frg. écart) abberancy
Ei	– lower tolerance limit, (frg. inférieur)
Ei_Δ	– dependent link lower tolerance limit
Ei_{sys}	– dependent link lower tolerance uncertainty of systematic factors, µm
Es	– upper tolerance limit, (frg. supérieur)
EiA_i	– size A_i upper and lower limit deviation
Es_Δ	– dependent link upper tolerance limit
Es_{sys}	– dependent link upper tolerance uncertainty of systematic factors
EsA_i	– size A_i upper and lower limit deviation
E_C	– central tolerance limit
Ec_Δ	– dependent link central tolerance limit
i	– tolerance unit
k	– probability level
M	– quantity of influence factors
n	– amount of joints
P	– proportionality factor
Q_i	– sensitivity coefficient

t	– risk factor
T	– tolerance zone
$\mathrm{T}A_i$	– size A_i tolerance
T_Δ	– depending link tolerance
$\mathrm{T}_{\Delta\mathrm{COR}}$	– summary corrected tolerance of dependent link
T_d	– tolerance zone for axel
T_D	– tolerance zone for hole
$u(\delta_\mathrm{T} A_i)$	– tolerance zone standard uncertainty
$u(A_\mathrm{x})$	– combined standard uncertainty
$u_i(x)$	– standard uncertainty
$U(\Delta_\mathrm{SYS})$	– expanded uncertainty
$U(x)$	– expanded uncertainty
$\bar{x}_{Ai}$	– arithmetical mean of size
X_i	– input values $(i = 1, 2, ..., N)$;
Y_i	– output values $(i = 1, 2, ..., N)$;

1 INTRODUCTION

1.1 Background

The doctoral thesis gives an overview of the industrial landscape that has witnessed a change at the beginning of the 21st century and the impact of the globalized market palace on an important aspect of company research and development: effectiveness and speed versus optimization of the production chain and lower costs. Keywords are: competition, quality, production, engineering calculations, and how to combine the use of alternative methods of production, technologies and materials.

The product development phase is extremely short. There is often just a vision of a product, the product is only in design mode, yet simultaneously a production line is being designed for this so-called non-existing product. In the design mode, a product may have several models/versions which, besides having different programming options and all kinds of additional functions, need not be identical. Operating knots/systems are completely different in product testing systems and we need an option that would enable to change and replace them easily along the way without having to tune or stop the production line. Such givens set high standards for test systems designers in the design phase. We need different standards to take account of standardization, unification principles, modular structure, and ergonomics, correct engineering and precision calculations. The plans necessary pre-tests and mobilize different competences to ensure that the established requirements, compatibility and quality are met and system solutions are provided at a better price. The actual competitive advantage in the market lies in offering the best solution to meet the actual needs of the client, speed and quality, and the price of the service. This, in turn, gives an impulse for producers to find new solutions, combine e-Business and e-Commerce with the use of technologies and materials for the production of prototypes and for serial production. A 3D model of the product is sent to a business partner’s printer or the High Speed Machining centre.

Client's needs and intentions are usually shared with selected potential partners and suppliers, who have proven themselves and are prepared to assume the risks of endorsing the client’s plans (predictions) and visions.

Conditions toughen and tempo goes up, it is essentially a struggle for market victory (jackpot), the winner takes it all, and that in mind subcontractors and co-operation partners are willing to play along with these conditions. New ideas and the promise of a gain through a successful sale weigh up all prior cons. This is an engine, a motivator, which inspires all parties to the system to act meaningfully in the name of the jackpot. Missing the mark in this might hinder future business. This is an actual environment with clear terms, adopting which is a matter of life and death for companies.

A company must be able to determine factors that influence the end result, also the factors that cannot be predicted, and the limits of their effect and their reliability.

1.1 Problem setting

This thesis "listens" to the Voice of Customer (VOC) and the requirements deriving from that. The paper is based on documents and claims, which should contain technical data and equipment related technical parameters, filed by sales engineers and customer account representatives.

The thesis paper also takes a look at clients' wishes, i.e. what a client expects and what is important for him or her. The most common client expectations to the providers of manufacturing processes automation solutions are the following:

- Time (fast processes);
- Quality;
- Cost;
- Faster beat rate;
- Lower labour cost;
- Less quality issues;
- Increased systems and cells utilization;
- Special test environment;
- Continuous material flow;
- Lower systems maintenance cost;
- More repeatable test environment;
- Faster feedback;
- Increased capacity;
- Better process control.

Problems with circuit boards (PWB) testing

Significant cost savings can be gained by improving the test cell performance with test automation and elimination of the human factor. Typical ICT fault spectrum shown in Figure 1.1 (Used materials: overview of the JOT test automation seminar on 14-15 October 1999 by Pekka Rytkönen)

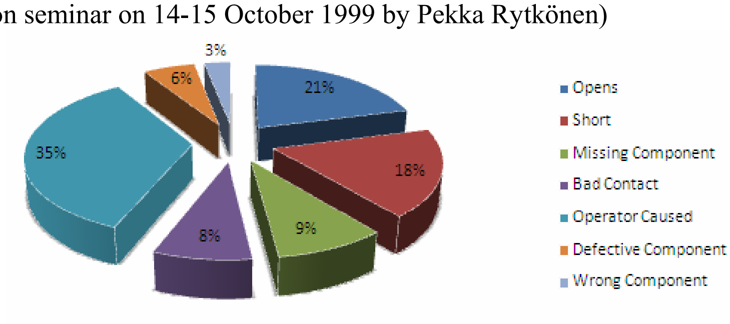

Figure 1.1 Typical ICT fault spectrum

1.2 Quality improvement with automated handling

The data is collected from 10 to 12 production lines of some contract manufacturers. By taking the automated test handler into use, the quality of the process increases mainly in two areas: **operator caused and bad probe contacts**.

I. As there is no operator manually handling the product the faults caused by the operator are naturally non-existent after the automation. These faults are; mechanical faults, electro static defects.

II. Bad probe contacts seem to be the largest single fault source. Out of experience at a large European telecom customer the amount of bad contacts, and at the same time false failures, was decreased by 85% when using automated board handler. This is due to fast probe actuation and vertical movements. This will lead to the decrease of the retest rate and it will free the capacity of test cell for actual production.

Removing these two sources of faults means more capacity on the production line and major cost savings. Quality improvement spectrum shown in Figure 1.2.

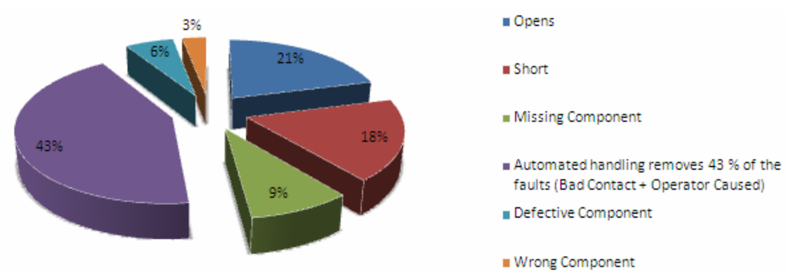

Figure 1.2 Quality improvement: Automated handling removes 43 % of the faults

One way to reduce cost is to improve quality. An example a typical fault spectrum for ICT test: the quality of the process increases mainly in two areas: operator caused and bad probe contacts.

Cost saving means in the design side:

To calculate all strategically important tolerances and optimize the requirements for saving cost it means – Cost Consuming Design.

For engineering is important: in the process of fit calculation or selection, it is necessary to take into consideration the real work situation of fit, the real product with all processes with tolerances and offered mathematical model modulation method makes it possible.

1.3 Problems solved in the thesis/Problems taken in focus

From customer's perspective the most important thing is to eliminate faults that appear in manual testing of the product.

There are always problems with details and nuances not taken care of in earlier stages of product development or not considered important enough to deal with at the right time. Discrepancies concern validity of the conditions and reliability of the information in the company's product specification (preciseness, energy and air consumption etc.).

Coming back from (final) testing related issues to product planning, yet additional problems emerge. The biggest problems lie in the fact that a product is planned and designed as a so-called independent product, without giving regard to additional requirements for the manufacture and handling (product positioning, orientation, scope and other technological grounds/bases). The attempt to find simpler solutions in product handling, assembly and testing causes problems mainly in product planning and development phase:

- Incompetent technical conditions impose unjustified requirements or unacceptably high tolerance values where in fact strict conditions are required. Too strict preciseness requirements for linear measurements of product parts made of certain materials (especially plastic), i.e. tolerance values for linear measurements of product parts made of that material are based on fits and tolerances system qualities number 5, 6 and 7. In reality changes in linear measurements of product components made of plastic and composites greatly depend on temperature and humidity (except those insensitive to temperature and humidity). Thus, the problem to be solved: which manufacturing preciseness level is reasonable for plastic details measurements?
- Impact of subjectivity, i.e. an engineer must base his or her work on technical facts and laws of physics, not subjective opinions. Thus, the thesis must find a solution on how to take specific decisions and how to come to an agreement between relevant competence levels on both sides.
- Insufficient communication and feedback, i.e. possible misunderstandings, misinterpretations and miscomprehension. The more ambiguous and superficial the specified and defined wishes, the bigger the uncertainty regarding those problems. Thus, the paper needs to find a solution on how to lower the uncertainty level.

The classical engineering calculations methodology does not take sufficient account of real life situations. Data values given in handbooks vary significantly, no specifying conditions are given or restrictions (limitations) determined for a range of data. Therefore, results of calculations are over-dimensioned; significant aspects are left out simply because the methodology does not allow accounting for it or is too complex. Hence, the problem to be solved is how to come to a result that determines what is acceptable and what is not?

The thesis views those issues by specific topics, taking a closer look at each: product planning, product concept, product testing planning, product unification, and the specific product measurement chain.

From product and manufacturing plan the paper moves on to production devices and preparation of product components and further on to the next piece in the chain: outsourcing and manufacturing, where the following problems have emerged:

- Problems with varying outsourcing quality. Customer always has the risk of outsourcing stability. He can never be sure what the delivery contains. Risks also include late delivery, disturbances with raw materials supply, late or wrong timing with the order, noise in information chains, disruptions of information chain, human factors, etc.
- Insufficient testing on the part of the subcontractor, i.e. the subcontractor does not control its quality, the control is insufficient, lack on competence, low quality raw materials (components, materials), etc.

The aforementioned problems created an actual need to develop a better product development and engineering calculation methodology for small companies, which would be based on unification and standardization, the new scientifically grounded measurement chains methodology based on the uncertainty theory. The benefit of that would thereafter need to be analyzed. The base method chosen for this paper is the measurement and test laboratories accreditation method used in circular testing. That principle is used in work phase problem-solving and subcontractors' production capability assessments. This allows preparing a mathematical model based on real life situations and the presentation of those results with an uncertainty factor. The paper treats product development problems in the same way [63], according to the relevant measurement model.

Whereas in solving the product development problem inputs into the model are:

- relevant product information (tolerances, materials);
- design environment (metric/inch system);
- work environment: temperature, humidity, vibrations, disruption fields etc.;
- the technical condition of equipment, preciseness, wear and tear, maintenance, servicing schedules, measurement and calibration protocols, measuring devices, tools, etc.;
- competence, the length of employment and experience of employees, the number of errors and claims, motivation, etc., work conditions, opinion surveys, the regularity and course of supervisor interviews, training plan, new workers welcome program;

ISO certificate, ISO handbook, good practices in company, guidance for procedures and rules, Lean Manufacturing principles, etc.

1.4 Objective of the doctoral thesis

The objective of this thesis is to approach the aforementioned problems scientifically. For that purpose the paper needs to determine how to map the existing information and how to find appropriate assessment criteria and relevant parameters (modifications) for the mathematical product development model. The main rule is to input all available existing information. Later the mathematical problem solving model selects out relevant data. Experienced operators may be able to determine what the weight of a specific component is already in data input phase and whether or not it contributes to output?

The development of a product development model involving uncertainty, proceeding from organizational culture to be created and client-oriented further development, an optimum standardization method developed for the product, computer-aided engineering model involving all the aspects of computer-aided engineering, and calculation method improved by measurement tolerance.

In order to achieve the established objectives, 5 important tasks (problems) had to be solved in the thesis:

1. Develop such organizational which would guarantee the organization greater flexibility, speed and effectiveness;
2. Develop unification methods as well as principles of unification scheme which enable to:
    - Increase flexibility;
    - Lower prices;
    - Decrease delivery time;
    - Quicken the project throughput time;
    - Decrease the nomenclature of components at product development and
    - Develop a systematic catalogue of standard modules.
3. Develop a concrete technical solution the novelty and technical level of which would conform to the criteria of patentability;
4. Develop engineering calculation methods further and create a method and model for engineering calculations, enabling to scientifically simulate and analyze the computer-aided engineering situations in the product development model and test them virtually;
5. Develop a new calculation method for measuring circuits that includes uncertainty and would enable to:
    - Consider the values characterizing the working environment;
    - The alteration of the values and
    - The qualities of the material.

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2 STUDYING ORGANIZATIONAL CULTURE WITHIN THE ENTERPRISE (COMPANY)

Every organisation always has two goals – the inner and the outer goal. The outer goal is, in the name of which the organisation operates, to which it conduces or which determines its purpose. The inner goal is to achieve co-ordination between material reserves, activities and individual efforts or, in other words organisational and administrative effectiveness. For an information company, whose business ideas originate from the transfer of its know-how to the client in a form of a problem solution, time as such is a critically scarce resource.

The analysis of the planning process in an information company and the improvement of this process are related to the globalisation and increasingly rapid growth, which are accompanied by the restructuring and expansion in the subsidiaries. These actors have displaced the common line connecting different parts of the process.

Looking at the parts of the system, everything seems to be in order because every part separately is operating well. But in case we try to connect the different components into one system for an information company, the system simply stops working. There is a lack of a common axis; ties are broken and insufficient for the today's situation.

2.1 Problem task

Possibilities offered by telecom, communications and computer industry created new principles for the petrified understanding of the limits of computer technology, communication and exchange of information. The geographical frontiers that have hampered the fast operation between different geographical points, states and cultures for so long have eventually faded into the past. This change gave way to new industries and stimulated new services and products at levels and in shapes undreamed of. Those conditions created fertile surface for the development and implementation of new technologies [22, 23]. Materials related research and technology made a huge leap – new structures, new areas, [13, 14, 15, 16, 17, 18]. Management of technological processes was taken to a new level [19, 20, 21, 22, 23]. Solution delivery in digital format to the destination point and then manufacturing by using the rapid prototyping technologies instead of manufacturing and only then shipping/transportation to the customer will increase speed and efficiency of the business.

Reducing time and money spent to transportation, customs and other logistics is one of several advantages of fast prototyping technologies.

Metrology (GUM) brought uncertainty assessments to measuring techniques (practices), bringing the assessments of measuring results to a new level [24, 25, 26].

New possibilities called for changing the existing practices and understandings.

Classical organizational models and rooted business processes and models ceased working or giving the expected result [32].

Radical changes in the turn of the century, from a company's perspective, gave an ultimatum to company managers: existing company structure, culture and understandings need to be quickly brought into conformity with new conditions [30, 31].

2.2 Feasible solution for a company's new way

Communication technology developments have given a strong impact for emergence of virtual organizations [27, 30, 31]. Isolation versus integrated systems. A virtual organization is based on partnerships. Good operation is a relationship based on equality, equal opportunities and conditions for all, both inside a company as well as an equal competition space for subcontractors. That facilitates competition and contributes to continuous development.
A successful virtual organization operates on four presumptions:

1. openness and sharing of competence;
2. mobility, ability to communicate via contemporary means of communication;
3. willingness and readiness to co-operate [27], find alternatives and compromises, right timing;
4. there has to be mutual trust between the members of the organization.

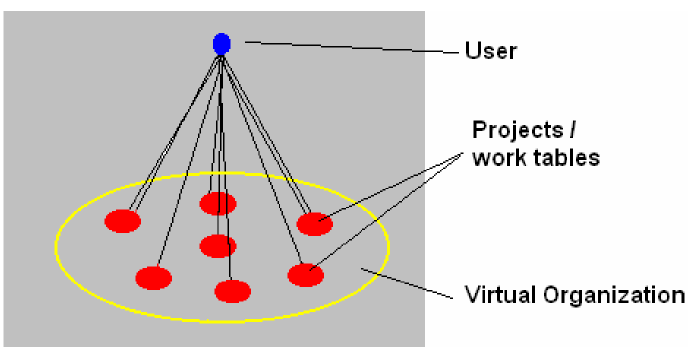

Figure 2.1 Virtual organizations: isolation versus integrated systems (eROOM)

2.3 Existing flow of the processes in an information company

Every project in an information company starts in the sales office of this company. The sales office closes a contract with the client, where the starting date and the deadline of the project are set [1]. As the next step, the project moves to the project department, where it is analysed and the process already in progress depends on the type of the project.

In case of a standard product or a repetitive order, an order will be opened in the database. Information concerning the order goes to the project and purchase department. During the process it will be the duty of the project manager to observe the process progression and to follow the deadline.

In case of a prototype device and lack of information, the project department sends a request to the sales office. After getting the complementary information, the project department informs the engineers about the incoming order. As the next move, everyone involved in the project is called together for the starting meeting of the project.

The following people should participate in the meeting:

- representative of the client (as a rule absent);
- project manager;
- chief constructor, chief of the project department and engineers involved in the project;
- chief of production;
- director of the purchase department;
- salesman (as a rule absent).

During the meeting the existing information is reviewed (if it is available). The purpose of the meeting is to make sure what exactly is sold (type of the machine and function description) and what exactly should be projected. An analysis is made about where to start and how the real projection will look like.

The list of critical parts (long delivery period, for example rectangular axes of Robot, milling equipment, body of a robot) is put together and these parts should be ordered immediately. Time frame needed for production will be set. At the same time the load curves of the existing projects are examined and the resource needs for the projection of the new project are evaluated.

After the first meeting the project department opens a project number for the new project in the database. The project department also sends the new project into the production department and purchase department. An inquiry is put together concerning the lacking information. Based on this inquiry, a list of problems, which need specification, is presented by the project department to the sales department.

The projection starts. The following process based on the existing information is starting according to the principle "to do what we can". As additional information [1] the whole progression in an information company is brought. Connections of the customer and the producer with the project in conformity with the existing model are presented in Figure 2.2. As one can notice, there is no clear overview of the project. Both parties have an overview only of the part they are directly involved in.

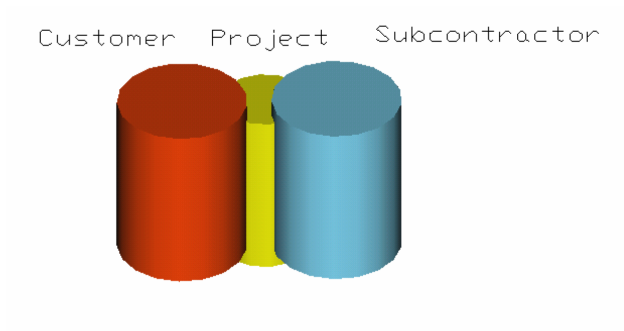

Figure 2.2 The existing work model

2.4 The analysis of the current situation and evaluation of the management structures

The results of the study [1] showed that the current situation could be characterised by following shortcomings, which overlap with the data of [2] also (Figure 2.2):

1. The information moves pursuant to the hierarchy of the organisation – hierarchically, there are too many levels causing (as one reason) disturbances in communication.
2. An independent sales department hierarchically separated from projectors is not suitable for today's situation.

The result is that the salesman does not know what he has sold and the client cannot define what he has bought. The following factors cause such a situation:

- decision-making based on the existent – non-existent (or lacking) information;
- incorrect analysis of data (if an analysis made at all);
- incompetence;
- lack of corporation between projector and sales support;
- "fishing" for new clients − a deal with a new client must be closed whatever it may cost.

At the moment the biggest resource of a company are considered to be the machines (the equipment), not know-how or people. The management takes place in the form of commands like "It must be changed".

Why the changes are necessary remains often unknown. There is no overview of the project as a whole. It is not analysed what kind of results the change might have for the project. No evaluation of value judgements or needs of the market is made and only the value judgements of one source are taken into account. Financial rewarding alone is not enough, a person must understand his part in the production process on an emotional basis, he must be aware which consequences his bad performance may have on the whole process. A good employee and a job well done must be acknowledged.

Using only the competency of experts in order to get evaluation and solve problems is not a correct solution. There is a lack of using the competency of the company as such, See Figure 2.3.

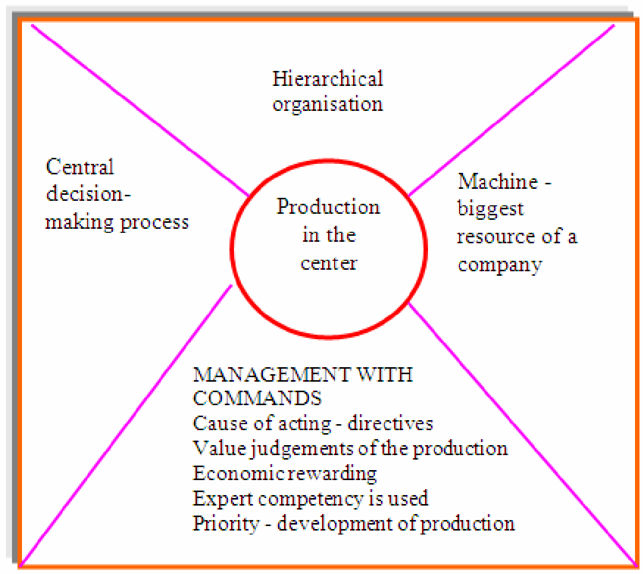

Figure 2.3 Existing management doctrine

2.5 The elaborated quality guide methods in planning process

In order to arrange the planning process according to quality methodology, today's know-how must be taken into account. When considering a problem, one should first of all pay attention to the following know-how elements of quality control:

- the role of the planning phase, recognising the importance of the planning phase and
- introducing and developing a role of client-oriented planning [3, 4, 5, 6, 7].

Primarily, we observe the role of the planning phase in guaranteeing the quality or the place of the planning phase in the quality noose (Figure 2.4). Planning is an action which follows the marketing or sales process and starts in the moment of selling a concrete device.

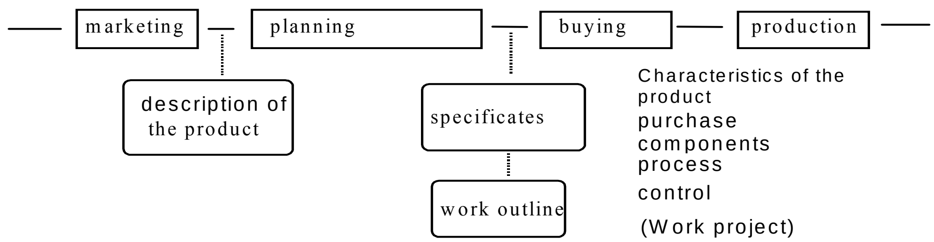

Figure 2.4 Place of the planning process in the quality noose

The planning phase is the most important phase in planning the quality of a product or a service. Miscalculations made in this phase will prove costly and irredeemable when production is started (Figure 2.5, curve 1).

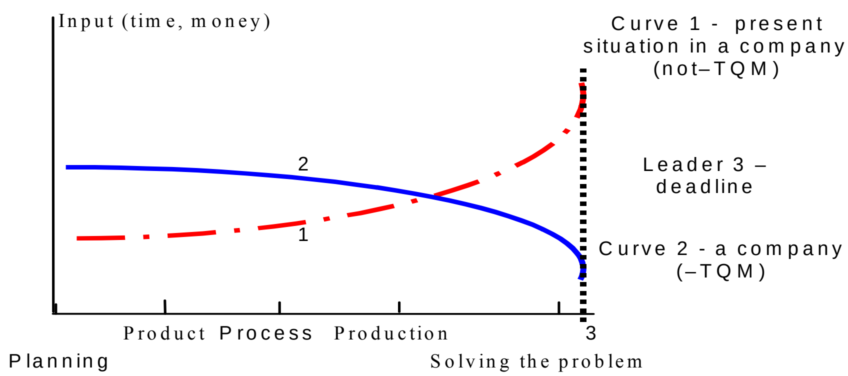

Figure 2.5 Different strategies in planning phases

So there should be more investments in planning – anticipate the problems, do everything right already in the beginning and think (Figure 2.5, curve 2). One of the biggest problems for the producer is to get correct information from the client in proper time.

In order to guarantee smooth projecting and to guide the process, specific forms have been elaborated in co-operation of the project department and sales support – namely summary tables of initial data which correspond to the different product groups [1].

These tables:

- give the client an overview of existing solutions/possibilities and determine concrete needs and wishes of the client;
- offer the client different kinds of possible solutions;

- give the possibility to analyse the initial data and its sufficiency – analysis of the variety of the parameters incl. tolerance calculations;
- specify the initial data;
- give the opportunity to provide the client with the information which needs specification and;
- set the real terms for getting lacking and inaccurate information.

The quality actions were analysed using the QFD (Quality Function Deployment) method. The QFD method is used to "translate" the demands of the client into an initial data matrix suitable for the company and that is done during the different phases of the production. This matrix connects the characteristics of the product in client's mind with the technical characteristics required for achieving these characteristics (outline specification). QFA can be presented as a 4-phase process of action (Figure 2.6). The figure shows that the most important is the first phase of QFD, where the main planning is taking place.

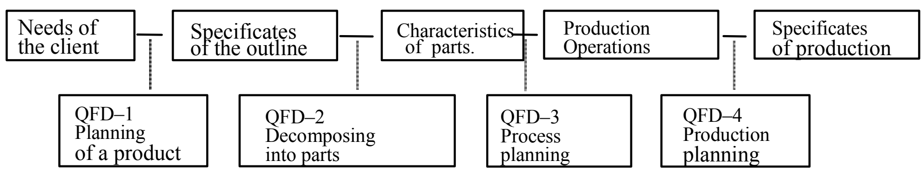

Figure 2.6 Customer-oriented planning

The needs and wishes/demands of the client are today orientated to rapidity and quality. Parallel to the completion of the new product in client's laboratories/research institutes there must exist a possibility to start the production immediately in order to be the first on the markets introducing the new product.

The time factor is nowadays one of the main criteria of a company active on the market, it goes hand in hand with high and continuous quality. Without these two factors it is almost impossible to stay competitive.

In order to solve the problem of the whole customer-oriented planning, the organisation must be changed into an arena open for dialogue, where open business stands in the centre of attention (Figure 2.7). As a result of that the co-operation of the sales organisation and projecting teams improves. An improvement should also occur in the elaboration of projects and initial data before taking the orders.

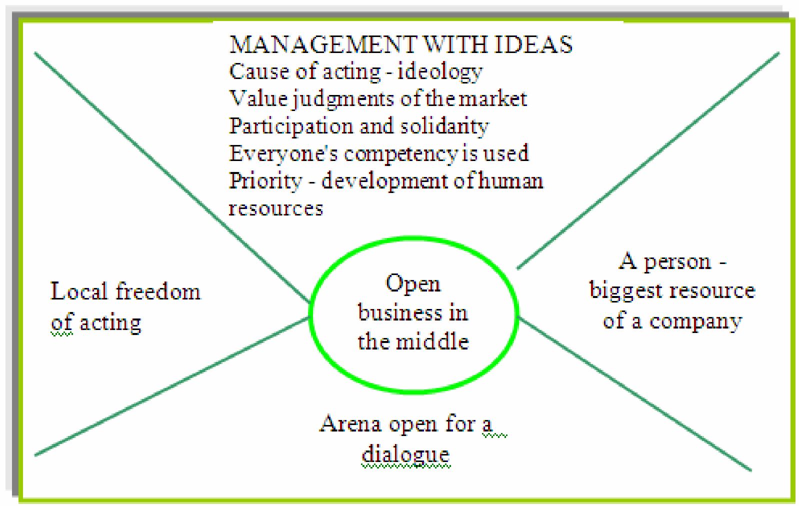

Figure 2.7 New management doctrines (Sveiby)

The ultimate goal is framing the client and client's initial data according to concrete protocols and directions. It is a strategic plan and grounded on this plan the order will be protocol led, following concrete regulations and a concrete plan of action.

The client is setting the time when the protocol ling should take place and all further changes and additional wishes will already be drawn up as an additional order. For this additional order a new separate timetable, which is connected to the project's deadline, will be set.

In order to make the planning process faster and more flexible and to connect different companies involved in the project, a new improved model of the planning process is presented.

In case of this model, both parties have full overview of the project – t is a space open for a dialogue (Figure 2.8). The idea and the fulfilment according to the brought model will be realised by the specialists and the whole process passes from the lowest level onward to the higher levels.

The model presented in Figure 2.8 makes the best of assuring the information for an information company and gives the best survey required for the guidance of the process. At the same time it guarantees fast and proper solution for the problems of the client and also the sufficient information in the primary stage of the process. Such an approach requires that the companies know and trust each other. The producer opens its know-how to the client and the client opens to the producer its new products to be prepared for introduction.

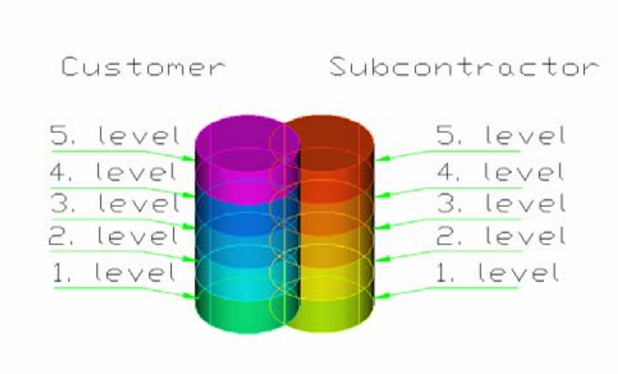

Figure 2.8 The new doctrine - time-space open for a dialogue

2.6 Co-operation in the virtual room, e-Business (B2B)

The present article embraces the main problems of the planning process in an information company. These problems accompany globalisation and the more and more accelerating growth of an information company (a company is growing to a business concern), which have displaced the common line connecting different parts of the process. Based on the analysis, a synthesis has been made, as a result of which an improved model of the planning process is presented. The purpose of this improved model is the alteration of the planning process to be faster and more flexible to unite the companies co-operating in the project. In case of this kind of scheme, both sides have a full review of the information embracing the given project – time-space open for a dialogue. The idea and the fulfilment according to the given model will be realised by specialists and the whole process passes from the lowest level onward to the higher levels.

The presented model of the planning process makes the best of assuring the information for an information company and gives the best survey required for the guidance of the process. At the same time it guarantees fast and proper solution for the problems of the client and it also guarantees the sufficient information in the primary stage of the process, where all strengths are put to the gathering of the information and making it exact.

Conditions and tools for a virtual organization:

1. A well operating and flexible work environment for the management of fast and dynamic processes.
2. Dismantle barriers inside the organization – OPENNESS – relationships based on equality, mutual trust, willingness and readiness to co-operate, a chance for self-realization, respect for colleagues.

3. We will adopt a five year cycle of processes improvement, developing and remodelling, in order to implement management practice in every-day management activities:

DEFINE – MEASURE – ANALYSE – IMPROVE – CONTROL = DMAIC.

DIMAC implementation – pre testing systems, See Figure 2.9

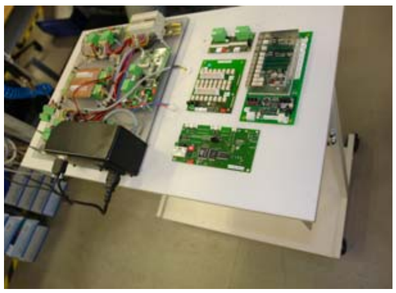

Figure 2.9 Pre-testing station for PWB modules

4. We will use tools and approaches that produce results with least effort and are the simplest. Both small improvements and big changes play a significant role. A sample of multifunctional modular storage rack, See Figure 2.10. We replace TQM with 6σ.

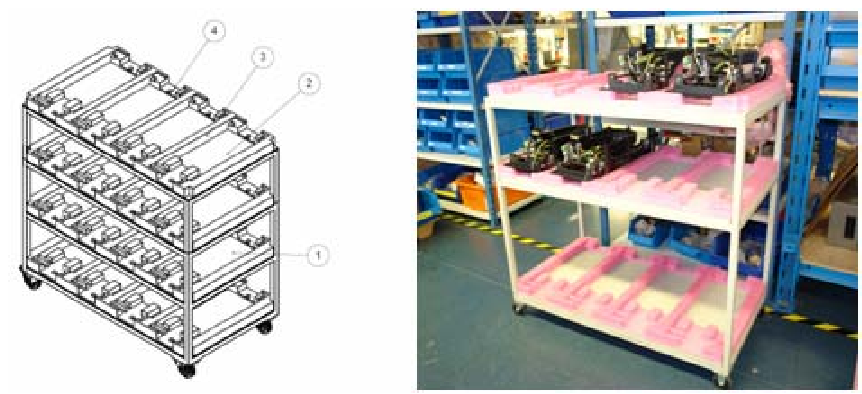

Figure 2.10 Multifunctional modular storage rack: model and rack in use

5. We can adapt to the changing and toughening customer and market requirements, and are prepared to realize and measure their performance. VOC (Voice of the Customer): listen, consider and offer the best.
6. Be aware of new technologies and be able to develop them quickly into vibrant products.

7. Training. Dedication to training is a constant and continuing sacrifice and investment.
   Connect training with workers' tasks and produce measurable indicators.
8. Make co-operation agreements with companies who develop products and systems before offering the product to final customers.

2.7 Conclusions of chapter 2

As a result of applying the above-described new organizational culture, it is possible to:

1. Develop a new vision for the internal functioning of the enterprise along with increasing the efficiency of product development;
2. Develop new trends in product development for cooperation with subcontractors and clients, and possibilities for realizing them;
3. Remodel the production and logistics area;
4. Change the attitude of employees and provide retraining for effective functioning of the new organizational culture in product development.

3 THE EXTERNAL ORGANIZATIONAL CULTURE OF THE ENTERPRISE (COMPANY). SERVICES AND CO-OPERATION

Technological and information technology breakthroughs have enabled the electronics industry to take its place as a leading industrial sector in today's world. Increasingly rapid product development, tougher competition, and real-time quality assurance have made it necessary for industry players to manage their operations more holistically. With product life-cycles getting shorter all the time, products must be able to design and commercialise new technology at an ever-faster pace.

Manufacturers need to be able to generate maximum production volumes for their new products as rapidly as it is possible in today's world. This, in turn, means that the manufacturability of a product, together with the efficiency and performance of the material process flows associated with it, must be optimised from the design phase onwards. Manufacturers also need to be able to control and modify production timetables, even at the last minute, to deal with fluctuations in demand.

Used optimal and mixed manufacturing methods with new materials for producing [19, 20, 21, 22, 23] such as e-Manufacturing and e-Business (3D printed parts) [29, 30, 31], as well as highly efficient planning [29] of production systems, on-line information flow (Virtual organization: e-Business, e-Commerce) and optimisation of the constructions (Unification-Standardization) are essential. When the relationship between the manufacturer (customer) and production automation partner works effectively, manufacturers have the potential to farm out the entire process solution successfully. Services spare parts ordering and support on the Internet 24h/7d.

Electronics production will face a number of major challenges in the next few years, as pressures associated with global markets and local production, shorter delivery times, intensifying product development cycles, and increasingly individualised product requirements start to make their presence felt.

Many players in the electronics industry have discovered that the optimal design of the production process for their products is a core competence area in itself. In order to define the correct steps for developing electronics production systems, the requirements for improving sub-processes, such as SMT phases, testing, and final assembly, needs to be studied in depth. This covers areas such as resolving optimal capacity utilization and capacity increase requirements in the light of essential resources and product quality requirements.

Global companies concentrating on their core competencies have discovered that cooperation with production automation partners capable of offering total solution enables them to source line planning, equipment, training, and maintenance from a single reliable supplier.

The building-blocks = modules - of electronics production automation are board/product handling, test handlers (which is one of the most time-consuming processes in this row), final assembly, and as a recent renewal the automation and warehousing of the packaging of the final product.

Below the different stages of automation and their concepts are introduced more closely.

After selling a product such factors as the schooling of the client, supply of the spare parts, modification of the equipment, service and maintenance must be considered as very important parts of the process also [1].

3.1 Test handlers' automation

Test Handlers carry out either functional testing of an end-product or sophisticated in-circuit testing (CIT), in which components' functions and values as well as soldering quality are tested (See Figure 3.1). The main advantage of automatic in-line testing, or testing that takes place on the production line, is the real-time test data it generates, and which allows operators to react very quickly to any defects observed in the process.

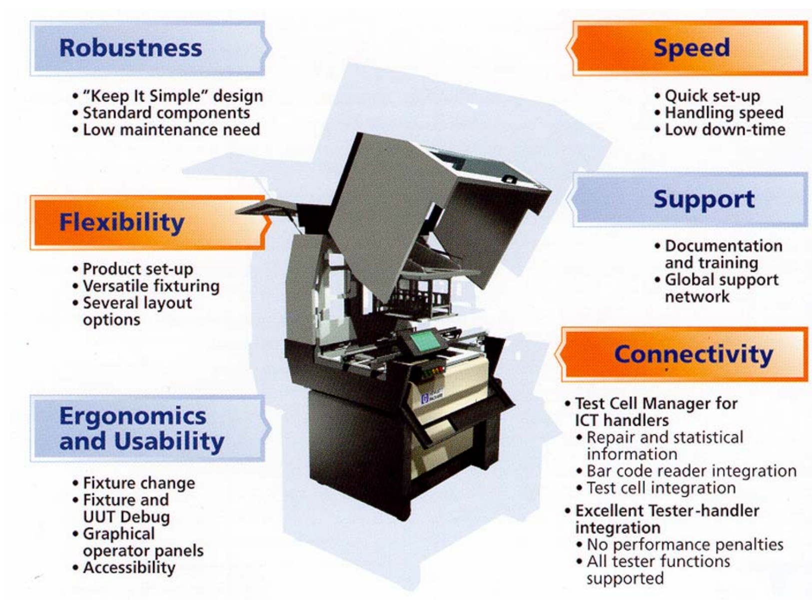

Figure 3.1 Why choose Information Co. Automation in Test?

Main points of a significant importance for the client are lower labour costs, less quality issues, increased tester utilization, RF shielded test environment, continuous material flow, lower fixture maintenance costs, more repeatable test environment, faster feedback increased capacity and better process control.

Main ideas of Automate Test:

1. Quality:
   - Automated Handling removes 43% of the faults of typical ICT faults spectrum (overview of the JOT test automation seminar in 14-15 October 1999 by Pekka Rytkönen):
     - Bad Contacts (8% faults of typical ICT faults spectrum)
     - Human Factor = Operator Caused (35% faults of typical ICT faults spectrum).
2. People:
   - Improving Ergonomics & Decreasing Variance
3. Time:
   - Faster Beat Rates & Faster Test Speeds
4. High flexibility / variability:
   - In same time possibilities to test different products in line
5. Profits:
   - Lower Labour Rates & Increased Machine Utilization
   - Copy-Paste Line and –Factory.

Significant cost savings can be gained by improving the test cell performance with test automation [48].

As a result the process quality improves, the production throughput increases and the material flow integrates.

Significant cost savings will be gained with the test automation.

3.2 Final assembly automate

Final Assembly is based on a pallet system for moving and guiding material flows. Various types of robots can be integrated into a pallet system as volumes rise, to increase the speed, precision, and efficiency of production. Robots are used at the downstream end of the production line for automating high-precision processes such as de-panelling, routing, soldering, labelling, component placement and assembly (See Figure 3.2, segment IV)

Some characterizing features of the final assembly's capacity are high production effectiveness, short cycle time (=capacity), high utilization rate and predictability.

The quality is high and sustainable. The automatic operation is accurate and continuous compared to manual assembly. The used components can be reliably linked to the products. The economical risk is minimized.

Labour costs per product decrease, production volume increases while having fewer employees. The pauses due to human needs and manual handling were not needed.

Material costs decrease and there will be less semi-finished products. The yield will be better due to efficient process and the lead-time in production is also faster.

The main ideas behind the final assembly solution are reusability and capability to deliver whole production system using large range of standard products.

Product specific know-how: Long term co-operation with the customer for improving product DFA and optimum automation level.

Long term efficiency through the reusability: Consultation for reuse modules in new lay-outs from Information Company and modifications for customized parts.

Flexibility with semi-automation concept: Manual assembly line, semi-automated assembly line and automated assembly line.

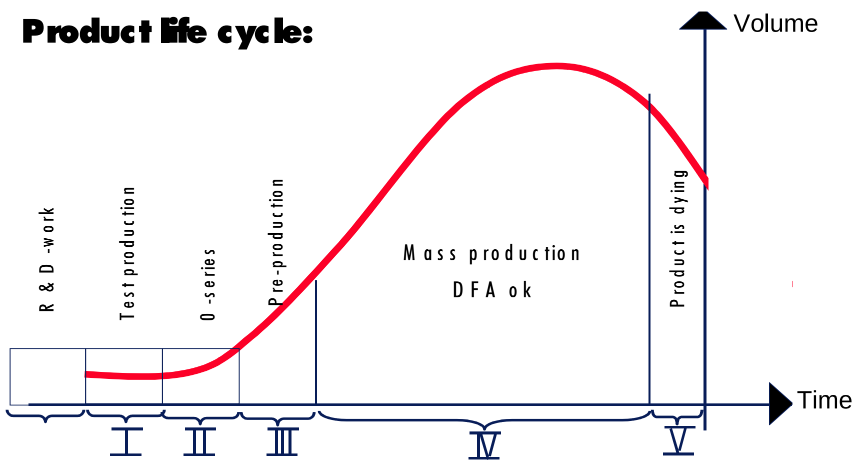

Figure 3.2 Product life cycle

Recognizing customers' requirements means first of all to recognize the rate of DFA of the customers' product, to recognize phases which can be automated in the first step and to recognize future needs of increasing the automation level.

Engineering Process:

- DFA – Optimize the automation rate
- Platform modules – Use standard solutions
- Product-specific needs – Specific grippers, feeders, pallets, etc.
- Control - Integrate the line control to the customer's factory system.

Final Assembly Automate allows saving by automation, flexibility with semi-automation concept, capability to deliver the whole production system and a "Copy-Paste-Factory".

A product is not ready for the customer before it is in the package!

3.3 Automated packaging

Packaging automation is the newest building-block in the electronics automation (See Figure 3.3). The automation of this process speeds up and rationalises the final stages of the manufacturer's value chain, by automating both packing and warehouse logistics to ensure the just-on-time delivery of individualised products.

The value of product package can be described as follows:

- The product is not ready until it is in the sales-package;
- The quality of the product package is as important as the quality of the product itself.

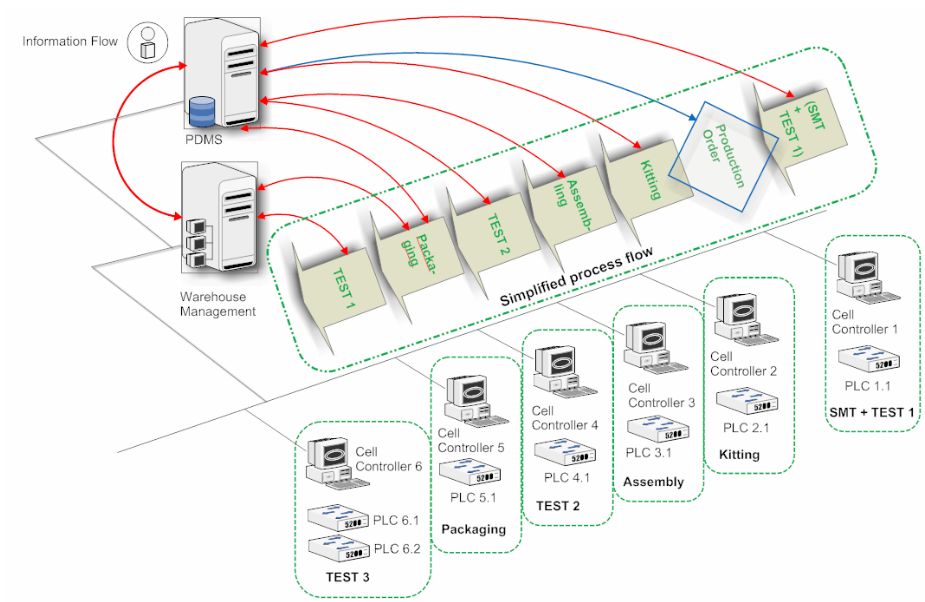

Figure 3.3 KLMS and simplified process flow

The bulk phase is the SMT and the first test (engine of the product). All product variations (mass customizing) happen in kitting and building process. After production order comes kitting and then building (assembly and packing, See Figures 3.4 and 3.5). Communication to product data and warehouse management systems is critical.

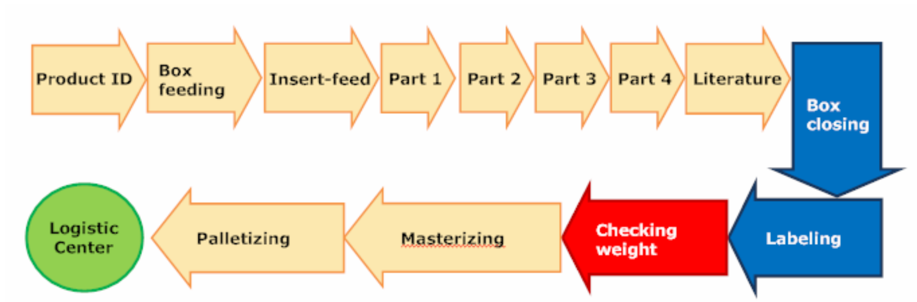

Figure 3.4 Typical packaging process

Packaging is the second part of the build process. Most of the product variations happen in the packaging phase. The logistics of the process is the key to productivity.

Packaging must be a seamless part of the automated process (See Figure 3.5).

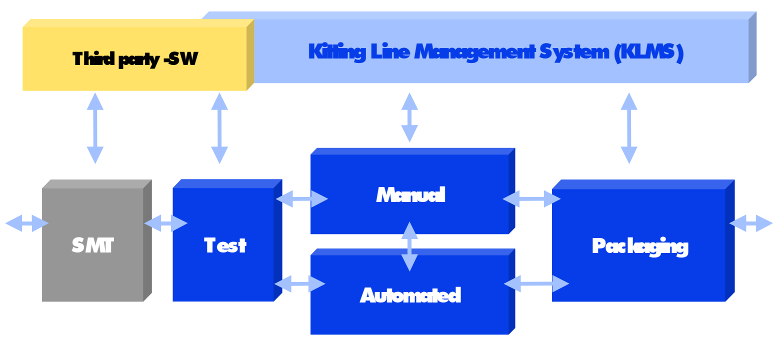

Figure 3.5 Seamless Line Control

Inside and between phases, SMEMA is typically used between different process units. KLMS controls and monitors the whole line (See Figure 3.3).

In order to speed up the availability of a product for the customer's continuous flow of materials, one-stop production and Make To Order-manufacturing system are necessary. The ability to handle a random mix of different product models must exist. In order to reduce the value of inventory, one should decrease the amount of stock-items and speed up the circulation of the stock-material. The efficient handling of individual orders can be enabled by KMLS=Kitting line management Systems by Information Company (See Figure 3.6), PDMS= Production Data management System, and MPWS= Manufacturing Packaging Warehouse System.

Real-time controlled packaging process consists of the pallet-based conveyor system with escort memories, check-weighting, monitoring proper operations and simulation of process.

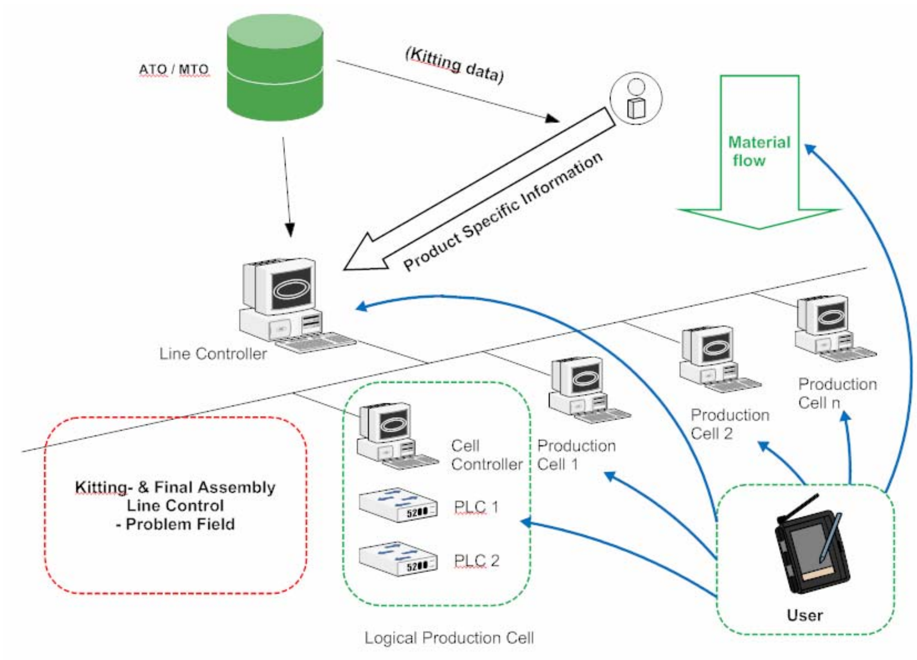

Figure 3.6 Kitting line management system (KLMS)

Cutting labour costs releases skilled people for productivity tasks and increases the job satisfaction with better working environment.

Summary of benefits: the automated packaging speeds up the availability of a product for customers, reduces the value of inventory, enables efficient handling of individual orders, minimizes mistakes made during the packing process and cuts labour costs. Information Company integrates the packaging process into the automation process with a unique concept and standard modules.

High modularity: the idea of the concept is that an information company offers manual, semi-automated and automated packaging lines with same principals, the same logistics and the same lay-out. Unification and standardization of modules, cells and systems are the key factors here.

The end user must interact with several interfaces. The interface consistency and ergonomics are the key factors to the productivity. The complexity of kitting (mass customizing) phase is handled by the line controller.

Summary of Benefits:

- Standardization – rigorously limited selections, high volume, low cost, fast delivery,
- Unification – Unified modules, - systems,
- High Modularity

The effectiveness and optimal dismembering level of modular robot systems for electronic industry is based on industrial experience. A retrospective look at modular design philosophy is brought out and the present state-of-art in this field is analysed. It is pointed out that the driving force for modular systems development of robots is the speeding up of innovation in electronics industry resulting in the short life cycle of product lines. This requires faster product development from production lines manufacturer, meeting all requirements of clients and flexibility in alterations. The above mentioned can be realized by increasing the level of dismembering robot modular systems in the manner dependent on time and technology. Further, the rational dismembering and interface policy at the development of modular robot systems are under observation. Based on industrial experience it is shown that integrated approach concerning technology-dependent robot systems modularization and using concurrent engineering principles has resulted in cutting down manufacturing lines delivery time from 18 to 8 (4) weeks so far.

- Full Range Concept
- Software (KLMS – Kitting Line Management Software)
- After Sales Support

3.4 After sales concept

After Sales building blocks (reports) are full service, training, modification, service & support and spare parts. After Sales Concept ensures uniform content and the quality of an Information Company After Sales.

After Sales Concepts include service concept for customers, logistics concept for customers, network concept for customers and representatives for customers.

A holistic approach to the customer's production process is required. The After Sales Concept ensures uniform content and high-quality Information Company services all over the world.

Partnership: Benefits to customers include customer satisfaction, increased output and module modification. In case of a new product, it is important that there would be a possibility for line modification, and in case of continuous process improvement, scheduled maintenance, service contracts and unscheduled maintenance play an important part.

Partnership Customer Satisfaction includes services from local representatives Experienced integrator and longer life span through modifications.

Maximum output of investment!

Long term customer care requires the following from representatives:

Internal training for Information Company products and after sales concepts, capability to local installations, local service and support for your customers, local Spare Part Kit, warranty responsibility and warranty service. It also includes reporting to the Information Company.

Information Company's support to representatives consists of training programs for representatives, spare Part logistics, tailored ramp-up support for representatives and field service experts for special customer needs. It should be possible to get all services from local representatives.

Integration Back-up: Experts available for demanding integration need:

- Wide experience in the integration of process machines into the market
- SMEMA-interface
- Optional, customised interface (e.g. Panasonic, FUJI, Siemens)

Modifications of existing lines and systems:

Case: Modification history of Information Company's Depanelling Cell

After Sales Products:

- Information Company Tailored Field Service.
- Specialists can be ordered from the nearest representatives, customised service agreement can be concluded, including 24-hour field service support, which in special cases can be located at the client's facilities.

Ramp-up Programs for system deliveries: Ensure that the client reaches maximum production volume as fast as possible.

- Customized ramp-up plan with each system delivery.
- Information Company's global Ramp Up team supports the process as long as needed.
- Information Company's experts can also provide off-site ramp-up support by telephone.

Information Company's Spare Part Services – spare parts are stored locally at the representative's offices and facilities world-wide. Critical parts are ready for fast delivery.

Regional spare part centres support local representatives.

Customer Training Programs: Three training options exist: training before delivery, training during installation and ramp-up and tailor-made training programs in local languages for operators, maintenance personnel and engineering personnel.

Services from local representatives, experienced integrator and longer life span through modifications can be brought forward as benefits to customers. Maximum output of investment should also be mentioned.

Services → e-Services 24h/7d: Spare parts services and programmes version support and SW update kit handling on the Internet = e-Business (B2B) Replacement and enhancement of existing paper transactions between the customer and the supplier with (Internet based) electronic mechanisms.

3.5 e-Business services

Once the art of automation has been mastered, it offers major benefits to the producer. A well-designed, well-functioning system offers a total production package for high-quality; high-efficiency manufacturing that is capable of responding rapidly and flexibly to the changing needs and tastes of a manufacturer's end-customers.

A good automation partner plays an important role throughout the life-cycle of a product, providing the installation, training, commissioning, and maintenance services required to make such transfers seamless and rapid, See Figure 3.5.

Figure 3.7 e-Business's after sales products

Vision of the company's current co-operation model was compiled on the basis of sales presentations available in the company and introduced to the new virtual environment. In order to improve the rules of procedure with the aim of better operation, different levels of the company were taken to open communication in e-rooms.

Requirements to remove existing flaws were specified, operating processes and rules of behaviour improved.

Personnel training and technical support (internal IT-Help – Help Desk) have played an important role in launching and operating the new work environment. Directing, aggregating and controlling data which moves through different communication channels in virtual space (minimization of information noise).

As the result of the research:

1. New work environment was developed for the company, where lists of product parts are automatically extracted from CAD into the database at the end of the design phase. Simultaneously, another list is generated for spare parts. The system automatically compiles module based spare parts kits and Internet based customer support and a possibility to buy them on the Internet. The technical solution was implemented and is working in the company, offering permanent customer support.
2. Obligatory testing of spare parts kits was introduced.
3. A database was compiled for preparing and saving correct post-testing test reports.
4. Proper requirements were developed for the test base and new test documents were prepared for the company.

5. The realization of the virtual work room idea has materialized into e-Business's (B2B) Internet based post-sale provision of spare parts and program alterations support, which means that supplementary packages and new program versions are handled in the virtual work room. A client's or a company's IT-engineer is then invited to the work room, where an update package with relevant programs and guidelines, and documentation with updates and improvements of a specific device or production line are uploaded. After certain operations, the program of the customer's equipment is updated and documentation is adjusted. This system enables to react quickly.
6. A virtual work room was also developed for subcontractors and co-operation partners in order to coordinate and receive outsourced project work in online.
7. Customer co-operation was also taken to a new level by taking the phase of finding new solutions to the virtual work room (launching of e-ROOM).

3.6 Conclusions to chapter 3

As a result of the conducted research, the following was developed:

1. Virtual workplace for subcontractors/cooperation partners;
2. Due to the use of virtual workplace it is possible to take the cooperation with clients to a new level;
3. Hold Internet-based e-Business (B2B) sales of spare parts and provide after-sales support for program.

4 PRODUCT UNIFICATION SCHEMES-METHODS AND UNIFICATION MODEL FOR THAT

4.1 About contemporary history of unification

Optimisation principles and common procedures for unification were developed for the needs of large industries, especially at the end of 1980s for the Soviet Union's planned economy. A product, process or service can be an object of unification. At the time, several studies which described mathematical principles for unification of machinery and apparatus products where issued, Kmetovicz R.E. [7].

Nowadays it is needed more often to apply unification principles in medium-sized or even in small industrial plants. The main reason for this is to have more economy in the production process while not damaging the quality of production. Next reason for applying unification activity in Estonian medium-sized production plants is because they work greatly as subcontractors and they shall take account of the requirements of various clients, make various kinds of products while keeping the production costs low. Unification work shall be planned and it involves the development stage. For medium-sized production plants the main task is to find suitable unification objects which can be used as the basic product or the basic construction. For the basic object or construction the mathematical model and analysed losses and wins from the unification process shall be found. As the final result of the unification work, it is suitable to have a parametrical row on the basis of the basic object or construction.

In this study, the aforementioned cases are tackled and as conclusions recommendations are given in the form of aspects of unification which have importance for medium-sized production plants, especially in the machinery and apparatus production area.

The most common modularization methods

Each method has its advantages and disadvantages. To summarize:

1. The Pahl method: Modular Product Structure (1996), Modular Product Development (1998). Suitable mainly for a modular system which is created on the basis of market requirements without using any earlier solutions. Applying the method is not suitable for robotics system, as the module system has to be created on the basis of existing systems. The method is not available for reference evaluation [75, 76].
2. The Erixon method: modular function deployment (1998) and MIM. Is also suitable for a modular system which is created on the basis of market requirements without using any earlier solutions. The method enables to calculate parameters for evaluating modules. These calculations are not

suitable for modular robotics systems, as the latter are too complicated [67, 68, 69].

3. The Kahmeyer method (1994). Resembles the two previous ones and also starts with creating a modular system, dividing it into fractals on the basis of market requirements. The method does not enable to calculate the parameters of a modular system. This method is also unsuitable for creating a modular robotics system [70].
4. The Ulrich and Eppinger method (1995) Is suitable for dividing a product into modules, functional elements are grouped into chunks, DSMs, but evaluating intermodular connection surfaces is a complex process. This method is getting too complicated, as there are mechanical, electrical, pneumatic and data connection surfaces in the robotics system. It is not practical to apply this method [78, 79, 80, 81].
5. The Wilson method (1993). This method is simple, but its disadvantage is its low level for analysis. In order to get a modular system, a product specification is composed which is divided into all possible modular system parts. Connection surfaces-connections between parts are essential here [82]. Wilson method is intended for improvement and advance development of the products already created, so there is no need for market analysis. According to the Wilson method, the creation of the system has been divided into three parts:
   a. Partial allocation of functional elements.
   b. Definition of main subassemblies and modules.
   c. Creation and development of some schemes of joints.

   Determinative factors are types of joints between different parts.
6. The Lanner method (Lanner matrix) (1996), based on PAD. Enables to get a proper modular system structure on the basis of TTS. Based on the idea that all technical parts can be observed as systems which are connected with the environment via inputs and outputs. Disadvantage: evaluating intermodular connection surfaces is a too complicated process for robotics system [71].
7. The Witter method (1995). Uses the method of QFD, focuses mainly on recycling and the consequential modular systems. An environment-friendly method – presumes the recycling of the system. The robotics system cannot usually be recycled [83].
8. The Meyer method (1997) is market-oriented and suitable to use when attempting to create a better product than the competitors. The method does not enable to evaluate the modular system's efficiency using direct calculations. Is suitable for product families, for creating series. The method is unsuitable for complex products [72].

In a nutshell: Proceedings from the 2nd seminar on Development of Modular Products. December 13-14, 2004, Campus Framtidsdalen, Dalarna University, Sweden [73, 74, 76, 77, 84, 85, 86].

4.2 Unification tasks

The aim of unification is to achieve the objects' unity using optimisation principles and to minimise a variety of the details and elements of a technical object, to improve the quality, guarantee the safety of products, enable production specialisation and production automation. Unification shall assure the technical level and high quality the product requires while there are minimum losses during development, project work, and production and by application [44]. The main tasks of unification for medium size producers are the following:

- Shortening the time required for product development, production preparation, production operations, supporting service, repair and maintenance procedures.

Those shall allow quicker technical progress:

- Assuring such conditions for the development works and production which guarantee high-quality production and the high level of interchange ability;
- Obtaining economical effect through minimising expenses by development works and using specialised production processes;
- Assuring better safety of products and compliance with the legal requirements.

4.3 Unification works and objects

For medium-sized production plants it is fatal to find the right way for unification work as there is lack of personnel and material, and development resources. Unification work involves the following general stages:

- finding and compiling an object list suitable for unification activity;
- sampling the service data of the unification object and its statistical analyse;
- making the unification's practical development work;
- the estimation of the development results;
- practical application of results and an analysis of data received from product users.

The unification activity shall be specified and can be done in medium-sized production plants under the following directions:

- finding the basic parts or details in existing production and the use of them;
- developing the basic parts and details for new production;
- separating objects to various groups and determination of the best unification level;
- finding grounds for new basic object development;
- finding the basic product;
- unification object development work;

- an analysis of results and determination of optimum unification level;
- finding and developing the parametrical rows for object;
- finding the limitations for the parametrical row, taking account of special technical and legal requirements, for example proceeding from the requirements of EU directives.

Unification object selection stage shall take account of the following specific moments:

- the general tasks and field of application of the object;
- importance and advances of the object;
- production volume and type of production of the object;
- existence of similar production units and the importance of those units in common production volume;
- general development trends of the object.

4.4 Basic product selection

The basic object is the specified product, the fundamental part of which is mandatory to be used in all products incorporated to the parametrical row. The basic object is crucial for the development of modified objects and has been assigned to maximum utilisation in product rows as an essential part.

The basic construction is the product construction given in consisting details, in figures and also in requirements, which determine the constructional solution and is mandatory for building up the product row. The basic construction is selected through works for unification of similar products constructions. The basic construction shall assure the maximum optimal fullness of parameters in range with developed production.

The basic construction is characterised through the general data of basic parts, with its task and data of its relationship and correlation with others. Basic construction shall give the numerical values and quality characteristics for the product row. This involves measures, figures, materials, pair parts and its connections.

The basic object shall have possibilities for application in the future and allows developing new modifications required in the future. The basic object shall satisfy all requirements, which are given by clients, in general rules or in specific requirements. The basic object shall include the maximum quantity of the basic structural parts which are suitable for using in modifications and shall assure the development of modifications through complementary connection of details.

For the basic object or its basic parts higher requirements shall be presented than to the modifications. This fact allows better basic potency for the modification.

The selection of the basic object is carried out taking account of the existing requirements for them and comparing the analysis of results at the following extent:

- The object's characteristics and basic and essential parameters, where the parameters the criterion is at its maximum compliance with the product's general quality parameters;
- functionality, where the criterion is at its maximum quantity of basic parts which are functionally working and has importance as row permanent component;
- quantity of functions, where the criterion include the basic and supplementary functions carried out by the product;
- dominant conditions, where the criterion is the quantitative estimation of general features (material quantity, expenses, quickly wearing details, etc.).

The basic product and construction selection works usually involve the following tasks:

- research and data analysis of similar technical products and constructions;
- product and constructions analysis and finding from them similar points, which are suitable for building up the parametrical row as the basis for unification;
- calculation works;
- the estimation of possibilities of the unification of constructional elements;
- carrying out works, also experimental, for finding the weak points of the product or construction and improving them;
- making and testing prototypes;
- the experimental samples production, research and testing of the product;
- the standardisation of the developed product, See Figures 4.1 and 4.2.

The unification object shall be identified by using quantity characteristics which enable to classify the object and develop the mathematical algorithm. The most essential shall be chosen as characteristics and statistical methods can be used for finding it but also the already existing analogous product data.

The object characteristic p_i can have different values M_i, which are given as figural values or as quality data. The quality characteristic can be given by different features like colour scale. The quantity value can be given as an interval or a discrete figural row. Each characteristic m the element of which is M_i ($m \in M_i$) gives features p_i grade and characterises the object's essential quantitative feature.

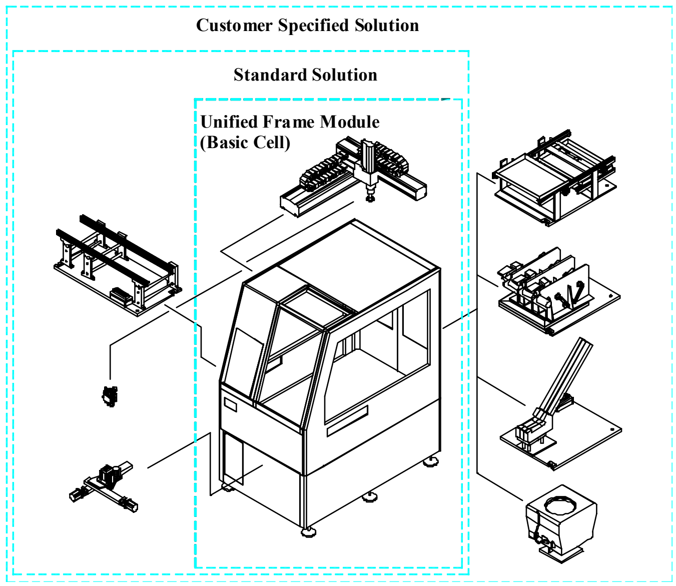

Figure 4.1 Unified basic robot cell and unified modules concept

Quantitative features are divided by taking account of different feature stages (levels). Numerical values are measured using interval or relations scales and numerical features can be coded to qualitative features. It can be converted to level features by using intervals and according to them the feature is divided into various levels.

Features are established as shown next:

- forming the features' initial groups, where the elementary way is to divide objects into two classes (groups);
- features supplementary grouping, where independent features shall be chosen for the each group. In the initial stage, the features connection matrix shall be found. The crossings of the matrix element *xij*, which is situated in row *i* and in column *j*, are characterised by the relation of features *i* and *j*. The relation can be characterised by the correlation coefficient;
- features arrangement, where the features "weight" is determined, depending on the importance of the influence to unification, and an order is given to the rows.

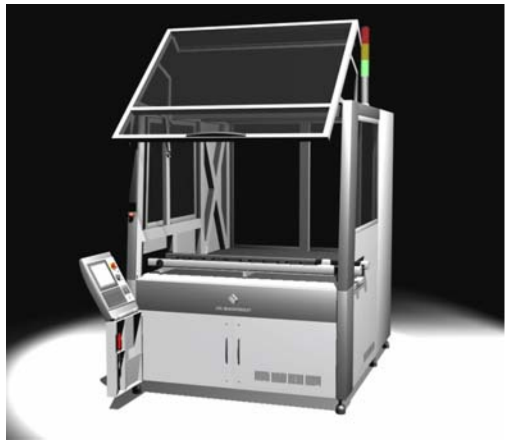

Figure 4.2 Example: Unified standard frame module (JOT Automation)

4.5 Unification model

The mathematical model of unification consists of the determining function and the limits conditions. The determining function is the situation's mathematical description depending on he aims and concrete unification of the object features and time particularities. First of all, the optimisation principles, where the object parameters and time relationship have the primary place in the model, are applicable to unification. The model shall allow to find this relationship's minimum and maximum values.

Various limitations shall be taken account when building up the model. Those limitations can serve as a connection between various parameters, time limitations, resources limitations, environmental limitations and safety requirements, especially deriving from the European directives and international treatments and also formal limitations which can't be expressed directly mathematically like ethical limitations.

The aforementioned limitations shall be used in model sensitive coefficients c as shown in the equation (4.1) and they can be founded mainly through experience, M_i is the feature parameter:

$$M = \sum_{i=1}^{n} cM_i \qquad (4.1)$$

It is complicated to find an exactly real unification mathematical model, so as rule a simplified model is used. The validity of the composed simplified models shall be estimated. The estimation shall include at least:

- the control of the limitations' applicability;
- the correctness of parameters used as constants;

- the estimation of aborted limitations' correctness by simplification.

Estimation can be carried out using the step by step principle and, if required, the model shall be corrected.

4.6 Formation of the parametrical row for products

Applying linear measures parametrical row is suitable for the formation of the model of product unification. The formation of parametrical row shall be taken into account as well as the interests of the producers and customers, and the final result shall be economically optimal.

The parametrical row consists of nominal values Y_i, where i is the member number of rows and can have values $i = 1, 2, 3, \ldots, N$, where N is the quantity of rows' members in the range ($b - a$). The parametrical row shall have compliance with some standardised parametrical row.

As rule, proposition Y_i given by the composer, does not exactly comply with the requirement X_i given by the standardised row and this causes losses to both the producer and the customer. Losses are described by economical equation $M(x, y)$. When demands are satisfied in the best way, then there are no losses ($x_i = y_i$), but in most cases this is different from 0 value. The situation is shown in equations:

$$M(x, y) = 0, \text{ if } x_i = y_i \text{ or } M(x, y) > 0, \text{ if } x_i \neq y_i \qquad (4.2)$$

When the distribution rule of demands parameters is known, then losses can be found using the so-called statistical game theory, according to equation (4.3):

$$E(f, y) = \sum_{i=1}^{N} \int_{x_{i-1}}^{x_i} f(x) M(x, y_i) dx, \qquad (4.3)$$

Optimal parametrical row is found from equation (4.3), taking account of the minimisation requirement. For this case, the parametrical row of demands distribution shall be established using previous research. This can be normal distribution or normal distribution which has systematic deviation from the central line.

If the distribution rule of customer demands is not known, the parametrical row shall be found which complies with all distribution rules. This gives general minimum losses.

Such feature is the least affected by the statistical game theory and can be expressed by equation:

$$E(f^*, y^*) = \frac{\min}{y} \cdot \frac{\max}{f} \; E(f, y), \qquad (4.4)$$

where $E(f^*, y^*)$ are losses, which are achieved using optimal row y^* and the worst distribution rule is f^*. This gives the best results for the worst distribution case and presents the game with two parts where the game's end result has zero sum of losses and where a concrete number of strategies exist.

If loss $M(x, y)$ is given for each proposition and demands pare (X, Y), then one part tried to maximise $M(x, y)$ the value through the suitable selection of x, this is usually the worst case. But at same time, the second part tried to minimise function $M(x, y)$ through selecting the suitable value of y.

Equal condition apply for pair x', y' which has compliance according to equation:

$$\frac{\max}{x} M(x, y') = M(x', y') = \frac{\min}{y}(x', y) \tag{4.5}$$

Condition (4.5) is valid if:

suitable pairs exist;

equation members can be changed as $\frac{\min}{y} \Leftrightarrow \frac{\max}{x}$

then

$$V_i \equiv \frac{\max}{x} \cdot \frac{\min}{y} M(x, y) = \frac{\min}{y} \cdot \frac{\max}{x} M(x, y) \equiv V_2$$

wins or loses value and a strategy for finding wins or losses exist.

Taking account of the above-named value $E(f^*, y^*)$ can express as given in equation:

$$E(f^*, y^*) = = \frac{\max}{f} \cdot \frac{\min}{y_i} \cdot \frac{\min}{x_i} \sum_{i=0}^{N} \int_{x_{i-1}}^{x_i} f(x) M(x, y_i) dx \tag{4.6}$$

Maximal losses are on the limits maximum values and the probability function has been formed as given in equation:

$$f^*(x) = \sum_{i=0}^{N} P_i \delta(x - x_i), \tag{4.7}$$

where P_i is demand probability and $\delta(x\text{-}x_i)$ is equation.

The result can be found by using a step by step procedure.

4.7 The practical use of unification principles in an Estonian machinery firm

An Estonian machinery products development firm has been given as a practical example of unification work. The following main points are included in the practice.

In order to be successful, the development firm will modify old products but previous solutions will also survive. It is necessary to know which modification was sent to the customer and, if required, to carry out required change or modification works there. This is the reason why all changes are documented and traceable. All the information – documents, orders from client, complexity and dates – have been gathered in the database.

The task is to carry out maintenance work of the database in the required periodicity. This maintenance work will update the database and remove all old components, modules and solutions. Only components, modules and components that have quality, novelty and or that are universal and best will be maintained. During the unification process the database is also renewed and old solutions are destroyed. This assures the products and production a permanent improvement.

Versions, i.e. the basic product, the task of which is to be basic for the object row, will be chosen during the development stage. The versions serve as the basis for unification. This basic product shall diminish a variety of the versions and produce universal versions which satisfy all the products in the row. The variations of the basic version allow getting the maximum quantity of solutions from a minimised database for a variety of demands.

For construction units versions product and modules models will be available. Through computerised techniques aid such models are used easily for the new constructions. Example: for Assembly Line design different Cells = Different Frame modules are used, Figure 4.3.

Figure 4.3 With standard module frames composed assembly line

One basic principle for unification is the requirement to minimise various producers and the quantity of products. Minimised products from minimised producers may be useful for grouping the different classes on the basis of criteria of use, for example A − preferable selection, B − limited selection, C − undesirable components. The basis for selections may be also special cases or clients' requirements and demands. If a new component is chosen, the data of producers will be documented. This data will be given to the development unit and to the servicing unit databases.

All this system is based on the proper order. Unification works is carried out through the standardisation group. The group will determine the principles of the selection of components to the database and set up the limits for new components. The group shall give its approval to the application of new mechanics, electrical, electronics, pneumatics, robots and control equipment and systems as well as management programs [45, 46, 47].

4.8 Description of the patent

Task description (Initial Data List):

The aim of this project is to define and evaluate the core adapter for most of the product programs for customers.

- Projects have to develop only the PSPHW part and factories use the same core adapter mechanics for several products.
- PSPHW will use separate blocks like in usual Test adapters. Those parts are mounted on POM plate.
- The area for test contacts must be the same as in case of the existing solutions.

Targets for IFA concept:

- decrease in PSPHW cost;
- short delivery time;
- easy IFA PSPHW change without tools, product change over remains as it is now one adapter is in stock in factories;
- the task was to decrease the percentage of product specific parts or in other words to increase the unification of the standard module.

A summary of the invention

- IF Adapter will be an addition to the tester slide and customers will pay only once for that. In the future, customers will only buy product specific modules (SP Adapter).
- IF Adapter is a module of standard movements and its task is to assure main movements for product testing, such as locking, connecting to the power supply, connecting to the electro-, pneumatic- and I/O interfaces.
- IF Adapter is thought to be an addition to the tester, adding all required components-elements-modules for achieving all necessary movements without removing the tester from line or working place.

Description of the problems which the invention overcomes

- reducing the price of customer's product functional test adapter;

- inefficient use of components, products and modules;
- request for reusing components, products and modules.

Earlier solution

Earlier customer bought a new adapter for every new product, which consisted of standard assemblies and product specific parts, and all this makes the product a functional testing adapter. New adapters were designed for new products and new parts were ordered. Parts from old adapters were not used, however its resource allowed that (for example standard parts like cylinders and sensors).

Invention improvements for earlier solutions, advantages of the invention

Advantages:

Compact design. Design can be used also as a replacement for current drawer solutions. Allows to use the adapters of previous generation in the tester – positioning and locking system on tester slide will not change. Reducing the new price of the adapter, IF adapter parts will not be included. Reducing the delivery-, design-, project time and supporting competitiveness.

Functionality and Control:

Pneumatic pipes are duplicated by an upper plate – gives us addition ports.

Every adapter's chip includes certain I/O-s

Ecology:

Addition will be made only once, when a new generation adapter, which consists of product specific parts, will be ordered.

Reusing components, products and modules

More effective use of components, products and modules

Economy of materials, resources and energy while IF adapter is ordered – single addition to the tester.

Economical aspects – reducing the product price, after IF adapter has been added to the tester the adapter price will only include the PS adapter's price.

Patented solution

The new product's functionality testing adapter is ready to be used with the present test systems.

The adapter consists of two modules:

1. A tester update kit IF Adapter (InterFace Adapter), by which tester is improved (See Figure 4.4) and
2. PS Adapter which is connected with IF Adapter, See Figure 4.6.

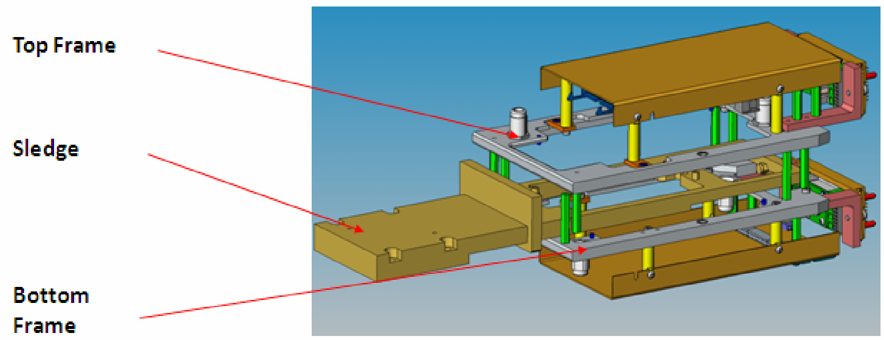

Figure 4.4 Tester Update kit IFA

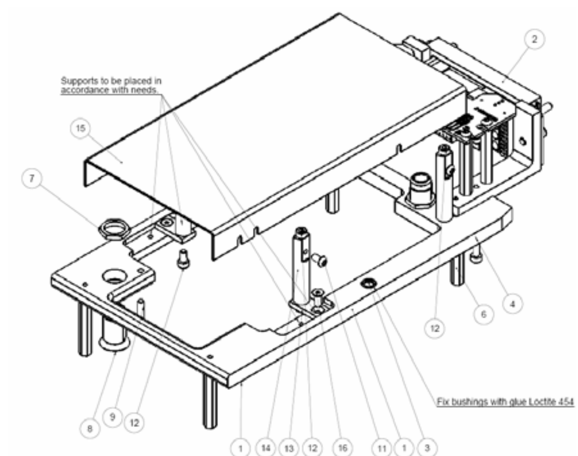

Figure 4.5 IFA module

With the new system, a lower price is achieved for the adapter and components, modules and parts reuse. The reuse of components, modules and parts enables us to use the adapter's resources more effectively, by which the economic and ecologic aspect of resources and materials use is implemented (supports ISO14001).

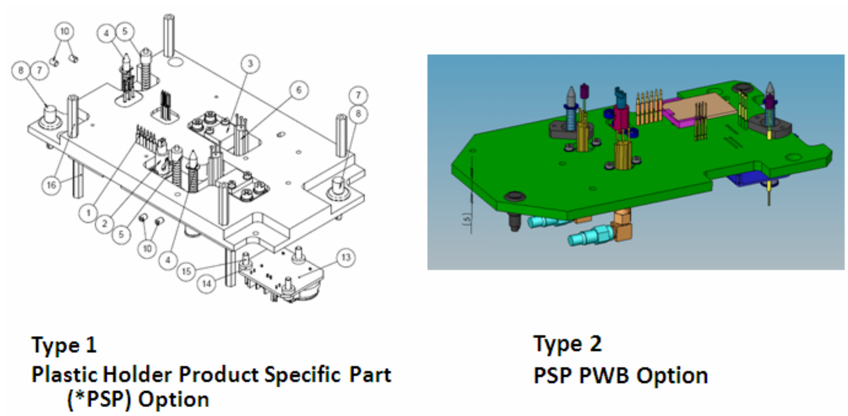

Figure 4.6 different PSP module solutions

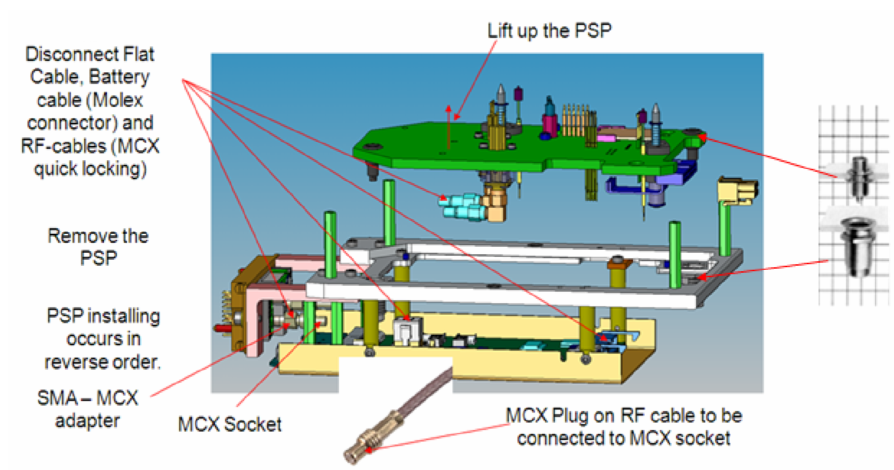

Figure 4.7 Implemented technical solution (Patent No.: FI119529B1)

4.9 Summary of unification task

The aim of the unification task is to achieve the objects' unity using optimisation principles. A product, process or service can be an object of unification. Optimisation principles and common procedures for unification were developed for the needs of large industries. The 1970 – 1980 Soviet Union planned economy had an especially high interest for unification of machinery and apparatus products. Nowadays there is a need for the use of unification principles in medium-sized or even in small industrial plants. The main reason for this is to have a more economical production process while not degrading the quality of production. In

Estonia, this problem is more complicated because industrial plants are usually small and they are mainly involved as subcontractor. Subcontractors take account of the requirements of various clients, make various types of products but have low production costs and good quality.

The reason for this study has been given above. The thesis gives a short review of the unification principles used earlier and analyses unification possibilities in medium sized production plants. The objective of the unification work in medium-sized plants is to choose a suitable basic model as a product, optimise the product series and the servicing process. Unification principles can be used also for improving management procedures. The paper gives a theoretical basis and conclusions of the unification principles which can be used in conditions were the main task is to produce products as a subcontractor and the producer is not big. An example of a concrete Estonian machinery firm has been given.

Unification principles can be successfully applied in medium-sized production plants.

The main task is to achieve economical gain which can be done if unification works are properly organised. In case of medium-sized production plants it is essential to find a suitable unification object, form the mathematical model and estimate the success of unification's results. In order to survive it is essential to correctly estimate the losses or gains of the unification. If necessary, corrections will be made. It is not easy to carry out unification procedure in medium sized production plants and without a high level specialist this is cannot be realised.

A new scientifically grounded unification methodology and model have been developed, allowing greater flexibility for the company in using standard frames, since the unified standard frame is suitable for moulding, assembly, marking and welding robots, and is (20–30) % less expensive.

Restrictions to the variety of different components used, decreased the list of components up to 40 % [47].

Unification effects:

1. As a result of the given research, a new unification methodology and unification scheme principles were developed, suitable to be used in smaller manufacturing companies.
2. Using the newly developed unification methodology, a catalogue of systemic standard modules of robot grippers was prepared, as result of which the design time of the modelling robot gripper is reduced from one week to one day, including the preparation of the required documentation.
3. The newly developed unification methodology allows engaging standard modules already at the beginning of the project and focus on developing relevant solutions in accordance with the client's specific requirements, which makes it possible to reduce the time gap between design and finished product from 6 weeks to 4 weeks. Using this new unification methodology, a new catalogue of unified test system modules (ADB) was

prepared and created, as a result of which the construction time of test adapters was considerably reduced.

4. The results of the research proved to be at the level of inventions and a patent protection is being sought in Finland.

4.10 Conclusion to chapter 4

1. The developed standardization method and the research results of this model enable to:
   a. Increase the enterprise's flexibility at actual usage;
   b. Decrease the nomenclature of components at product development;
   c. Develop a systematic catalogue of standard modules;
   d. Shorten the time necessary for design;
   e. Quicken the project's throughput time.
2. As a result of applying the standardization method, a new technical solution was developed, the essence of which is that the proportion of product-specific parts was minimized and the level of standard module standardization was increased. As the mentioned technical solution met the criteria of patentability with respect to its novelty and technical standard, the Finnish patent number FI000119529B was applied for the solution.

5 IMPROVEMENT OF CIRCUIT BOARDS THROUGH MEASUREMENT UNCERTAINTY EVALUATION BY TESTING

The first chapter of the research gives an overview of the problems that arise in manual testing of printing plates, and how automatic procedure can radically improve the testing quality. Removing these two sources of faults – Bad Contact and Operator Caused – means more capacity on the production line and major cost savings.

The next step is to create a mathematical model for solving that problem, including model inputs and uncertainties of those inputs, whereas that model must be prepared for a specific stage of product development. In the model development phase, (main) inputs need to be determined and mapped.

Main inputs must be mapped according to the quality management principles, i.e. the tree structured fishbone diagram analysis with its branching. The mapping of input components in the shape of a tree (main branch with sub-branches and their inputs) means indicating the input components of the relevant branch, determining their values with uncertainties assessments, on the basis of which the uncertainties tree is formed.

Two new definitions are introduced: **inputs tree** and **uncertainties tree**.

The third concept – **Uncertainty budget** – suits best as a term that expresses a set of inputs to be involved in the model. The term is used by GUM methods [24], in metrological literature, instructions [58, 59] and is a really suitable term/concept to be used and covered also with the proposed method.

It is easier to collect inputs into a model from companies who have aligned their processes with quality management principles (ISO 9001; 6σ, CS, ... etc.), i.e. their processes are mapped, operations and operating rules analyzed, and rules of the game established and approved for all parties involved. It is important that the agreed rules of the game are indeed followed in everyday operations. This can be verified by checking the relevant materials during audits. Additional information can be obtained from claims, audit materials, score cards, survey results, etc. Assessment must be on equal basis, unbiased, without emotions, i.e. the engineer must rely upon concrete facts.

Yet it is possible that a very important point – the issue of testing accuracy – has been left aside. It is a problem for manufacturers, which they don’t wish to acknowledge: “At what price was that result actually obtained? “

5.1 Problem setting

The biggest problem in testing printing plates is the catch accuracy of testing areas in situations where the equipment is old, worn or when there is not enough information about the accuracy of the test device, the number of measuring links of the measuring circuit is too high (more than 4 or 5, depending on the accuracy of the links), and the tested test areas approach diminutive: μBGA, LFBGA, PGA test areas and micro cuttings contacts.

The problem in this case lies also in how to increase the catch accuracy of the test device's contact points (test peak, test module) that have contact with the product in the following cases:

a) older and worn equipment where catch accuracy of the given test areas cannot be guaranteed;
b) it is impossible to reach the given catch accuracy due to the test points measuring circuit;
c) the miniature μBGA test areas and measuring circuit calculation do not allow optimizing the accuracy of the links or it is technically difficult to ensure the accuracy (large number of links) and the solution is not economically feasible (rigorous requirements on processing accuracy: the 5^{th} and 6^{th} quality in calculations).

5.2 Action plan

In the process of fit calculation or selection, it's necessary to take into consideration the real work situation of fit calculation. What makes it possible is the real product with all the processes with tolerances and the proposed mathematical model modulation method.

Modern ideology is used for uncertainties calculation which is given by GUM (Guide to the Expression of Uncertainty in Measurements) [48].

The main goal of this work is to introduce the modified (new) method for the calculation of fit dimension tolerance and value. The PWB design and production tolerances and uncertainties have been focused on in this article. In this method the single element measurements of fit (dimension chain) are considered as random variables with characteristic uncertainty.

5.3 Improvement of circuit boards through measurement uncertainty evaluation by testing

Test plates for mobile telephone printing plates are used as callipers to assure the proper work of mobile telephone. Printing plates shall have concrete measures so that it is possible to carry out later assembling with required quality. Assembling takes a short time, is accurate, is carried out by automated equipment, but should have as low cost as possible.

One possible way to assure a better assembling process is to make testing plates with higher accuracy, this means with less tolerance of linear measures.

The uncertainties of the testing process need to be evaluated more exactly, some components influents of uncertainties need to be found and reduced with the task not to increase the cost of the whole control process.

This research work introduces a theoretical base for the calculation method of the measurement chain for the control set of the mobile phone circuit boards taking into account the uncertainty evaluation and estimation principles used by measurements. Such approximation is novel in this field and enables to achieve a better quality of the end product, but not causing an increase in the price.

Main task is to build up the model of dimensional chain calculation, describing specific conditions in producing and calibration of the control set.

This was the base for this research and the results were used or will be used in practical work in companies producing mobile phones.

The end task is to have a concrete testing plate with higher accuracy parameters but with the same price as before.

The use of mobile phones is widened progressively over the entire world. For users it is important to have a product with high quality and assured liability of work during its lifetime. The correctness of the production process is one of the most important factors in assuring the required quality of the end product. Measurements, testing and inspection operations are important in the inspection of the production process.

One of the main parts of mobile phones is the circuit board. The exactness of the measures of the circuit board is an important quality parameter. The parameters' exactness will be optimized but cannot be exaggerated. Too much exactness causes the high price of mobile phones which is the reason for the low competitiveness of the end product.

The control set of the mobile phone circuit board is used as a calliper to inspect measures and it tolerances. Circuit boards shall have concrete measures so that it is possible to carry out later assembling with required quality. Assembling takes a short time, is accurate, is carried out by automated equipment, but should have as low cost as possible.

For the control set it is important to design its main parameters and tolerances by using the dimensional chain calculation. The main goal for the dimension chain calculation is to fix its tolerances and limits to all measured parameters in chain which must be optimized. Up to now, the calculation of the measurement chain was based on the mathematical and probability theorems. There was no place for the uncertainty estimation principles which are used for measurements, testing and metrology. The use of uncertainty principles allows estimating the factors influenced in the practice far more appropriately.

This research introduces a theoretical base for the calculation method of the measurement chain for the control set of the mobile phone circuit boards, taking into account the uncertainty evaluation and estimation principles used for measurements. Such approximation is novel in this field and allows achieving a better quality of the end product, but not causing an increase in price.

The main task is to build up the model of dimensional chain calculation describing specific conditions in the production and calibration of the control set. The objective is to reduce the chain dependent link's nominal value, tolerance and limit deviations.

The results of this research are used in practice for testing and calibration the control set in an Estonian plant.

5.4 Testing principles of circuit boards

The conformity of circuit boards to the requirements and norms are controlled in the testing operation. The main equipment used in testing is a testing set as a testing plate with pins.

Usually the problems comes from the test pin catching the fringe area of the test pad and therefore not obtaining the contact and resulting in false transmitted signal or the lack of it. This causes the test to fail and the high-quality product has to be considered as not compatible.

The control process influences all the devices and its components. The main tasks of the testing process are prescribed as follows:

- quality assurance for the whole working life cycle of the device;
- price;
- assuring simply the accuracy by assembling;
- testing equipment calibration and maintenance without distortions.

One of the simplest but most reliable ways is a thorough evaluation of uncertainty – easy to improve production without increasing the cost.

The main model and ingredients of the Test Chain are shown in Figure 5.1 and given as follows:

- PWB, beginning (started) at design, manufacturing, ... to handling the finished product;
- Testing Jig (Adjustment Jig) for calibration;
- Interface Adapter (Test adapter);
- Test Box with calibration procedures;
- Work Environments – concrete working conditions (temperature, humidity, etc.) must always be taken into consideration in particular

process segment as they may affect the overall results in different ways.

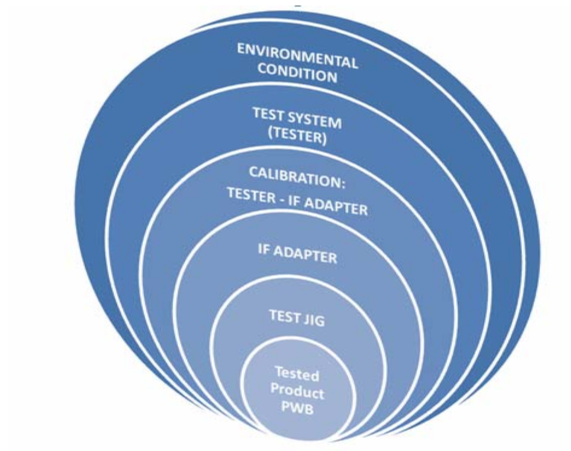

Figure 5.1 Test system General Model

Depends on production volumes selected for the testing system (test device) – manual, semi-automated or full-automated handling and Test Principle is shown in Figure 5.2.

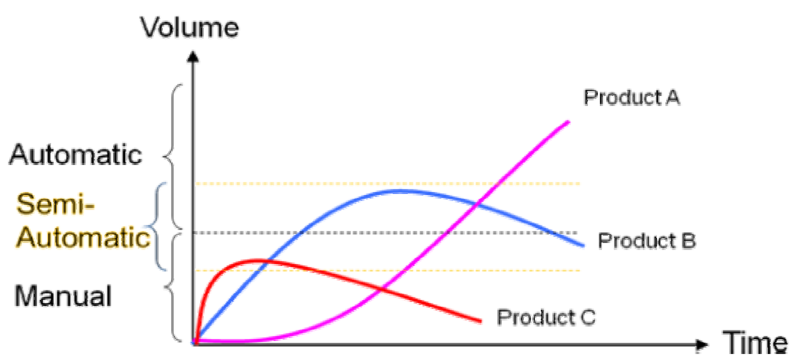

Figure 5.2 Expected volume changes

Manually handled PWB Level Testers (Test Box) are used for low volumes, shown in Figure 5.3

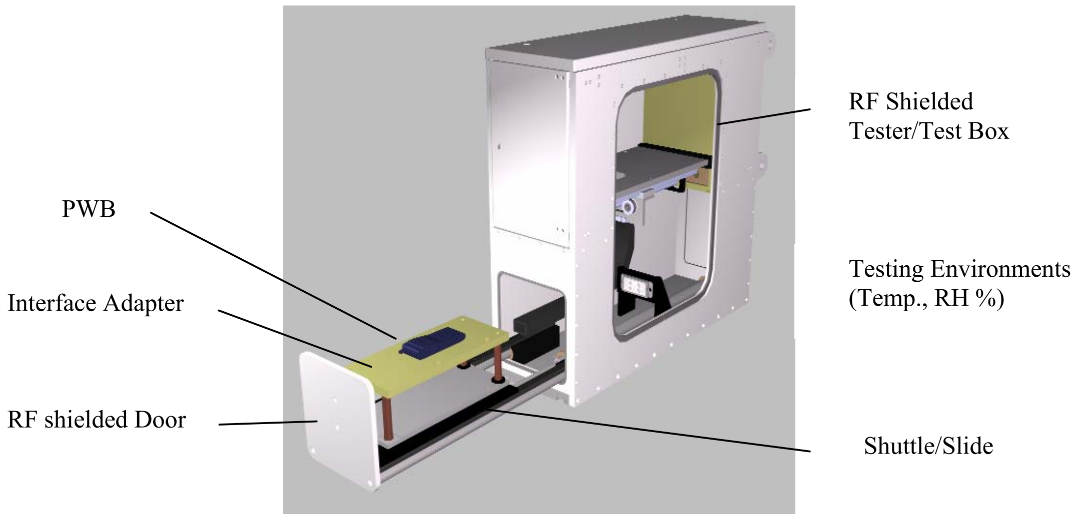

Figure 5.3 PWB Level Tester for manual and semi-automated test

Test terminals, like shown in Figure 5.4, are used for high volume automated tests and sophisticated in-circuit testing

Figure 5.4 ICT Tester

5.5 Automate test

Removing two sources of faults – Bad Contact and Operator Caused – enables more capacity on the production line and major cost savings (see Chapters 1.2.1 and 1.2.2). The main points of taking the automated test system-handler into use include:

- Time: Faster Beat Rates & Faster Test Speeds.
- Profits: Lower Labour Rates & Increased Machine Utilization.
- People: Improving Ergonomics & Decreasing Variance.
- Significant cost savings: can be gained by improving the test cell performance with test automation (Hering E. et al.) [49].
- Globalization of production, "Copy-Paste-Factory"

With automated testing: Process quality improves, Production throughput increases, Material flow integrates. Difficulties that arose were some systematic deviations which will be estimated and included in the uncertainty budget.

Significant cost savings will be gained with test automation.

5.6 Elementary testing module

The test set for mobile telephone circuit boards are used as callipers to assure the proper work by the users of mobile phones. Circuit boards will have concrete measures that enable the later assembling to be carried out with required quality. Assembling takes a short time, is accurate, is carried out by automated equipment, but will have as low cost as possible.

One possible way to a better assembling process is to make test sets with higher accuracy, this means with less tolerance of linear measures.

The uncertainties of the testing process need to be evaluated more exactly, some components influents of uncertainties need to be found and reduced with task not to increase the cost of the whole control process.

Above was ground for this research work and result were used or will be used in practical work in companies producing mobile phones.

The final goal is to have a concrete test set with higher accuracy parameters, but with the same price as before.

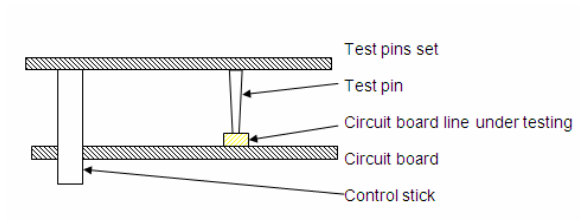

Figure 5.5 Simple control set for testing the circuit boards of mobile phones

5.7 Main parameters of testing procedure

The main aim of testing is to carry out the inspection of testing point tolerances of the circuit board. An example is given in Figure 5.6.

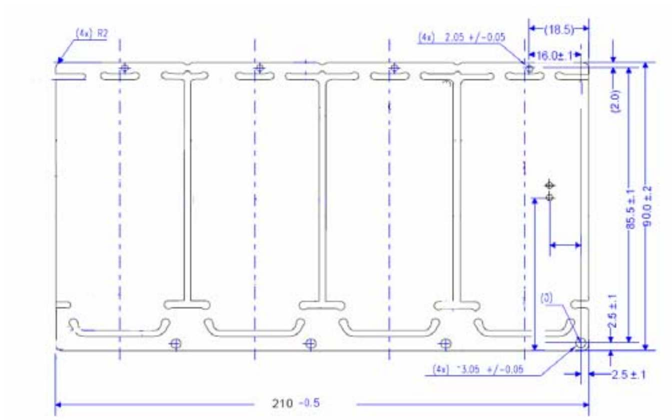

Figure 5.6 Placement and main parameters of test points on the test plate in PWB panel (PWB contour only for illustrative example)

Testing procedure of circuit boards involve various influence factors. Influence factors of the testing as fishbone structure are shown in Figure 5.7.

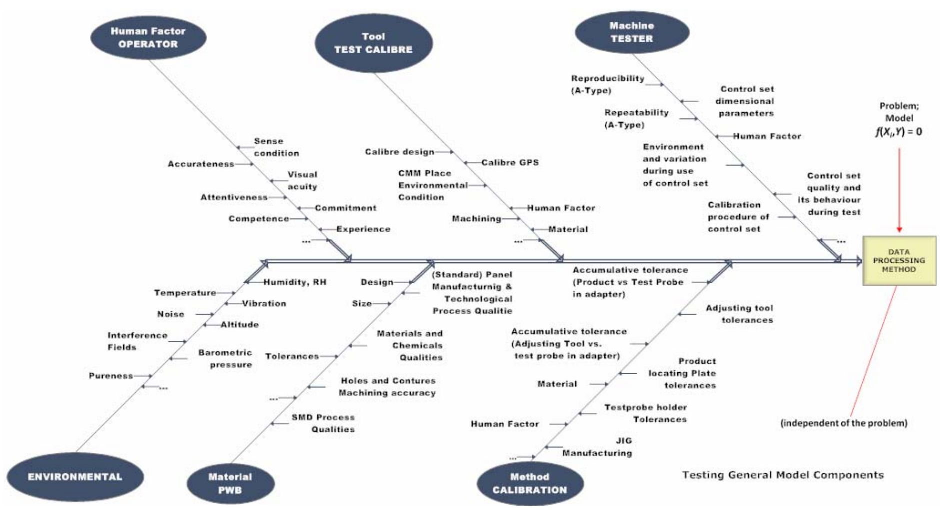

Figure 5.7 Mechanical Test System General Model – Inputs Tree

Main parameters for testing are based on the main influence factors:

- tester: control set dimensional parameters; environment and its variation during the use of control set; calibration procedure of control set; control set specificity and its behaviour the during test; control set sensitivity and stability;
- test calibre: calibre design, geometrical and measure tolerances of the calibre, environment, material, machining;
- calibration: accumulative tolerance, product vs. test probe in the adapter, adjusting tool tolerances, accumulative tolerance, adjusting tool vs. test probe in the adapter, product locating plate tolerances, material, test probe holder tolerances, JIG manufacturing;
- material PWB: design; manufacturing and technological process quality; size; materials and chemical quantities; tolerances; machining accuracy of holes and contours; SMD process quality;
- environment: humidity; temperature; vibrations; noise; altitude; interference fields; barometric pressure; pureness;
- human factor, operator: sense conditions; competence; experience; commitment.

Tables 5.1 to 5.6 give the testing process parameters of circuit boards for an average electronic device which has the following values:

Table 5.1 Testing process parameters: Tester and movements

Tester and movements			
Factor/Parameter	Parameter Range	Deviations	Distribution and Specificity
Control set dimensional parameters	(1 − 210) mm	min 0,01 mm	Normal, given by designer as tolerances
Environment and its variation during the use of the control set	(10 − 60) ^{o}C (10 − 80) % rel	max 10 ^{o}C max 15 % rel	Triangular
Calibration procedure of control set	(10 − 300) mm	0,0003 mm	Rectangular
Control set specificity and its behaviour during test	fitting to the rigs and movement 0,01 mm	0,001 mm	Rectangular
Control set sensitivity and stability (during the use)	change of parameters 0,05 mm/100 mm	0,001 mm	Rectangular, often raising
Changes (reactions) speed	0,05 mm	0,01 mm	Rectangular
Electric or magnetic fields gravity	0,02 mm	0,01 mm	Rectangular
Force and dynamics	0,05 mm	0,01 mm	Rectangular

Remarks: * included in dimensional chain calculation; ** by experts' estimated value.

Table 5.2 Testing process parameters: Test calibre

Test calibre			
Factor/Parameter	Parameters range	Deviations	Distribution and specificity
Calibre design	(1 − 210) mm	(0,001 – 0,05) mm	Normal
Calibre geometrical and measure tolerances	(0,001 – 0,05) mm	0,001	Normal, 95 % probability level
Environment	(10 − 60) ^{o}C (10 − 80) %rel	max 10 ^{o}C max 15 %rel	Rectangular, often raising
Material, structural change (stability), armature and armature orientation, homogeneity	(1 − 210) mm	0,005 mm	Rectangular
Machining	(1 − 210) mm	0,01 mm	Rectangular

Table 5.3 Testing process parameters: Human factor, operator

Human factor, operator			
Factor/Parameter	Parameters range	Deviations	Distribution and specificity
Attentiveness		±0,0025 mm	Rectangular
Sense conditions		±0,005 mm	Rectangular
Competence		±0,0005 mm	Rectangular
Experience		±0,0005 mm	Rectangular
Commitment		±0,001 mm	Rectangular

Table 5.4 Testing process parameters: Calibration

Calibration			
Factor/Parameter	Parameters range	Deviations	Distribution and specificity
Accumulative tolerance	+0,02 −0,01	0,01 mm	Rectangular
Product vs. test probe in adapter	±0,036	0,02 mm	Rectangular
Adjusting tool tolerances	+0.042 −0.016	0,005 mm	Rectangular
Accumulative tolerance	±0,101	0,01 mm	Rectangular
Adjusting tool vs. test probe in adapter	±0,063	0,01 mm	Rectangular
Product locating plate tolerances	±0,02	0,005 mm	Rectangular
Test probe holder tolerances	±0,01	0,002 mm	Rectangular
JIG manufacturing		0.005 mm	0,0075 mm

Table 5.5 Testing process parameters: Design

Design			
Factor/Parameter	Range	Deviations	Distribution and specificity
Material, hygroscopicity, structural change (stability), armature and armature orientation (armature), homogeneity, mm		0,0046	Rectangular
Manufacturing and technological process quality, mm	±0,0175	0,004	Rectangular
Size and mass	max 8 g		Rectangular
Chemical and surface quantities		0,004	Rectangular
Tolerances, mm	±0,05	0,0289	Rectangular
Holes and contours machining accuracy, mm	±0,025	0,050	Rectangular
SMD process quality, (Replacement), mm	±0,18		Rectangular

Table 5.6 Testing process parameters: Environment

Environment			
Factor/Parameter	Range	Deviations	Distribution and specificity
Humidity RH, %	(20 – 60)	max 15 % rel	Rectangular
Temperature, ºC	(23 ± 5)	max 10 ºC	Triangular
* Vibrations, Hz			
* Noise, dB	60 ± 15		Rectangular
* Altitude, m	5 ± 2		
* Interference fields, T			
* Barometric pressure, bar	1,08 ± 0,01		Rectangular
* Pureness [1]			

- These factors don't affect testing process much, so we will not take them into consideration. However these parameters will play significant part in testing environment if we test such devices as the pressure sensor, etc.

[1] Clean room conditions according to ISO.

5.8 Uncertainty components for the testing procedure of circuit boards

Testing parameters (See Figure 5.7) give components which have an influence on the uncertainty budget. Parameter deviations values are used for the estimation of uncertainty.

Furthermore, some of these influences may have little effect as long as they remain constant, but could affect measurement results when they start changing. The changing rate of temperature can be particularly important.

Combined uncertainty u_B is found through the estimation of standard uncertainties caused by individual factors i. Combined uncertainty u_B is calculated by the equation:

$$u = \sqrt{u^2_{TC} + u^2_{HF} + u^2_{TB} + u^2_{CB} + u^2_{EC} + u^2_{MAT}} \tag{5.1}$$

The equation (5.1) gives main grouped factors, where u_{TC} is the uncertainty from the test calibre (calibration instrument), u_{HF} is the uncertainty from the operator = Human Factor; u_{TB} is the uncertainty from the specific conditions of the test box (tester), u_{CB} is the uncertainty from the calibration of the tester (equipment and method), u_{EC} is the uncertainty from the environmental conditions and u_{MAT} is the uncertainty from the object = material under test. PWB general testing model is shown in Figure 5.8.

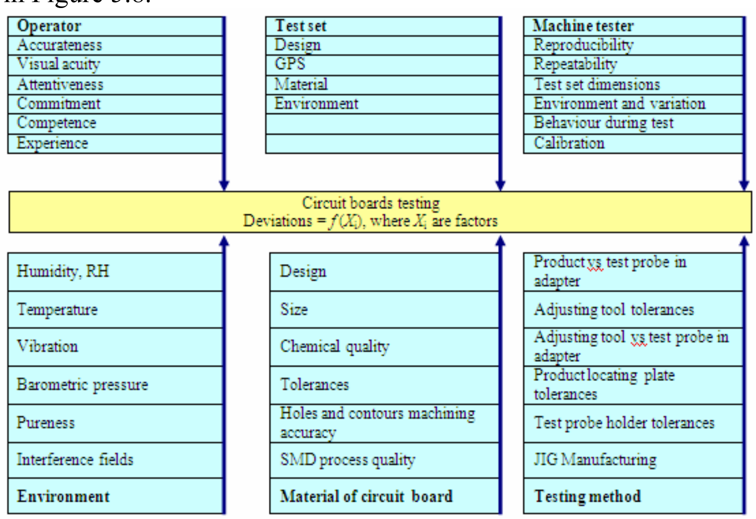

Figure 5.8 Circuit boards testing general model - Uncertainty Tree

Each uncertainty has a concrete sensitivity coefficient. In equation (5.1) sensitivity coefficients are shown as 1, i.e. uncertainty components are estimated at the same influence level. Expanded uncertainty U must be found using coverage factor k = 2, which gives a probability level of ca 95 % for the estimated uncertainty [47, 48, 50, 51, 52].

5.8.1 Test calibre (calibration instrument) influence, u_{TC}

Table 5.7 gives a summary of uncertainty components caused by environmental conditions at the standard level.

Table 5.7 Uncertainty from calibre condition

Parameter	Distribution	Standard uncertainty, mm
Accumulative tolerance	Rectangular	0,0170
Product vs. test probe in adapter	Rectangular	0,0416
Adjusting tool tolerances	Rectangular	0,0335
Adjusting tool vs. test probe in adapter	Rectangular	0,0727
Product locating plate tolerances	Rectangular	0,0231
Material	Rectangular	0,0046
Test probe holder tolerances	Rectangular	0,0115
JIG manufacturing accuracy	Rectangular	0,0750
Human factor	Rectangular	0,0070
Combined uncertainty u_{TC}, mm		0,0972

5.8.2 Human factor influence, u_{HF}

Table 5.8 gives a summary of uncertainty components caused by the human factor (line operator) on the standard level.

Table 5.8 Uncertainty from manufacturing

Parameter	Distribution	Standard uncertainty, mm
Sense conditions	Rectangular	0,0115
Competence	Rectangular	0,0115
Experience	Rectangular	0,0231
Commitment	Rectangular	0,0115
Combined uncertainty u_{HF}, mm		0,0305

5.8.3 The influence of the specific conditions of the tester, u_{TB}

Table 5.9 gives a summary of uncertainty components caused by the specific conditions of the tester at the standard level.

Table 5. 9 Uncertainties from the Specific Conditions of the Tester

Parameter	Distribution	Standard uncertainty, mm
Test set dimensional parameters	Normal, given by designer as tolerances	0,0115
Environment and its variation during the use of test set, detractions	Rectangular, often raising	0,2122
Calibration procedure of test set	Normal	0,0003
Test set specificity and its behaviour during test	Rectangular	0,0012
Test set sensitivity and stability	Rectangular, often raising	0,0012
Changes (reactions) to the speed	Rectangular	0,0173
Electric or magnetic fields, gravity	Rectangular	0,0012
Force and dynamic	Rectangular	0,0173
Combined uncertainty u_{TB}, mm		0,2135

5.8.4 Testing process (equipment and method) influence, u_{CB}

Table 5.10 gives a summary of uncertainty components caused by the testing process at the standard level.

In order to achieve an accurate contact between the probe and test point, the test point's area should be narrowed off. This guarantees contact also in a situation where probe hits the test point on the edge that was narrowed off by us. There will be enough force for contact at high speed. Fixing is used in the tester adapter.

Table 5.10 Uncertainty from testing

Parameter	Distribution	Standard uncertainty, mm
Product vs. test probe in the adapter	Rectangular	0,0115
Adjusting tool tolerances	Normal	0,0058
Adjusting tool vs. test probe in the adapter	Rectangular	0,0115
Product locating plate and tolerances	Rectangular	0,0115
Material stability	Rectangular	0,0115
Test probe holder and tolerances	Rectangular	0,0115
JIG manufacturing	Rectangular	0,0095
Combined uncertainty u_{CB}, mm		0,0281

5.8.5 Environmental influence, u_{EC}

Table 5.11 gives a summary of the uncertainty components caused by environmental conditions at the standard level.

Better control of environmental conditions is one point which enables an easy way to increase the accuracy of testing operations. Special importance can be attributed to temperature.

Table 5.11 Uncertainty from Environmental Conditions

Parameter	Distribution	Standard uncertainty, mm
Tester in work: (70 ± 10) ºC, (60 ± 10)% RH	Triangular	0,0592
Test calibration run: (23 ± 5) ºC, (60 ± 10)% RH	Triangular	0,0020
Tester calibre: (23 ± 5) ºC, (60 ± 10)% RH	Triangular	0,0061
Calibration: (23 ± 5) ºC, (60 ± 10)% RH	Triangular	0,0004
Circuit board: (23 ± 5) ºC, (60 ± 10)% RH	Triangular	0,0061
Human factor	Rectangular	0,0070
Combined uncertainty u_{EC}, mm		0,0610

5.8.6 Components from circuit board characteristics, u_{MAT}

Table 5.12 gives a summary of the uncertainty components caused by the manufacturing of the circuit board and circuit board material at the standard level.

The designer has given large value tolerances and testing has given requirements with a high accuracy for tipping. This is a case where realistic values are needed for optimization and uncertainty estimation is of great help. It allows to give importance order to factors. Manufacturing possibilities, handling by robots, composing, and measurement chain possibilities will also be estimated.

The circuit board is usually made from plastics, which has a big thermal expansion coefficient.

Table 5.12 Uncertainty from circuit board as a testing object

Parameter	Distribution	Standard uncertainty, mm
Design, tolerances	Rectangular	0,0506
Boards material, hygroscopicity, structural change (stability), armature and armature orientation (armature), homogeneity	Rectangular	0,0078
Mechanical manufacturing process	Normal	0,0164
Size and mass	Normal	0,0156
Chemical and surface quantities	Rectangular	0,0060
Holes and contours machining accuracy	Normal	0,0164
SMD process quality (Replacement)	Rectangular	0,0000
Combined uncertainty u_{MAT}, mm		0,0587

5.8.7 Combined and Expended uncertainty for the circuit board test

Combined uncertainty u_B is calculated by equation 1. The results have been summarised in Table 5.13.

Table 5.13 Combined and Expended uncertainty from circuit board as a testing object

Parameter	Combined uncertainty, mm
Test calibre (calibration instrument) influence, u_{TC}	0,0972
Human factor influence, u_{HF}	0,0305
The influence of the specific conditions of the tester, u_{TB}	0,2135
Testing process (equipment and method) influence, u_{CB}	0,0281
Environmental influence, u_{EC}	0,0610
Components from circuit board characteristics, u_{MAT}	0,0587
Combined uncertainty in test u_B, mm	**0,253**
Coverage factor *k*, probability level ca 95 %	**2**
Expended uncertainty *U*, mm	**0,506**

5.8.8 Report the result

In accordance with generally accepted international practice, it is recommended that a coverage factor of $k = 2$ is used to calculate the expanded uncertainty. This value of k will give a coverage probability of approximately 95%, assuming a normal distribution

Tester specified parameter: ±0,251 mm.

Tester accurate parameter is: **0,502 ± 0,506 mm,** in probability level ca 95 %.

5.9 Possibilities of minimizing component values

The main task is: to eliminate the accumulative tolerance of the test system and total tolerance in tester. New design concepts are necessary for that purpose – a flouting interface system (Adapter) or self-adjusting system, that enables free movements for positioning the contacting module or test probes (adapter) and making contact with the product's (PWB) contact pads.

5.10 Solutions in practice

A comparative analysis showed that catch accuracy of test areas of older equipment could be increased with new design solutions that eliminate factors associated with wear and inaccuracy of equipment.

Three possible novel solutions are suggested:

1. Mutually floating product module and test module, where on the basis of the developed methodology the choice of positioning and technological base are changed and the measuring circuits are optimized. In such a

case it is possible to position the product and the test module first in respect of each other, where the test module is in contact with the determined product testing areas. This is a universal solution suitable for testing diminutive products.

2. Positioning of the floating test module according to the product. In this case measuring circuits are optimal. The tested product is placed according to pointers, whereas the placement's accuracy is can be estimated by expanded uncertainty ±0,5 mm and fixed on the module. A point is chosen on the product as a base for positioning and technological (a precisely determined and processed opening or treenail on the product). The test module has a guaranteed float range of ±0,6 mm, the test module adjusts to the product by additional fixation and test movements. This solution is suitable for using with diminutive test modules that float into position according to the product, or for testing massive products, where the test module adjusts to the product.
3. Positioning according to the test module, where the product floats according to the test module's positioning point. In this case, measuring circuits are optimal as well. The tested product is freely orientated according to the points, depending on the floatability of the test module. When the work position of the test module moves, the pointer of the test module points the tested product to the test module's basing element. The product is positioned, then fixed, and only after fixing the product, the test movement is initiated. The order of operations is important here both in the test module contacting and in releasing it from contact. This ensures smooth running of the test module and spares both the product and the test module from damage. This solution is suitable for using with products that can be positioned according to the test module and where there is no risk of damaging the product or product surface (micro relief) or shape (geometry). This solution is suitable also when the product is too light to position itself according to the test module or in case of a massive test module, which cannot be floated or which cannot move because of the measuring method.
4. As a new development, a solution is offered, in which case product floating can be combined with (specific) product base, where the product is placed and fixed. This solution is suitable in situations where the product cannot be dragged. The product adjusts to the test module together with the product base.

Depending on the technological level of manufacturing, some details must be made of several parts. It is clear from the above that combining alternative technologies and materials allows optimizing the existing solutions:

5. Rapid prototyping (3D printing) enables to:
    a. Print out different details or the whole sub-content as one detail, sorting out the model, if necessary (retouching before printing), where the combination of the mentioned solutions

allows to quickly make prototypes during development, in case the functionality of the device or the system need to be tested. The number of links and the tolerance value of geometric measurements of the test adapter and the uncertainty of contacting test points measurements values can be decreased. According to the accuracy or surface roughness requirements, it is possible to reprocess a detail manufactured with the RP method.

   b. Saves time spent on designing blueprints, by defining basic surfaces and accuracy and technical requirements on a model and/or a simplified drawing (processing guidelines).

5.11 Conclusions to chapter 5

The developed calculation method of measuring circuits which involves uncertainty enables to:

1. Specify the value of the closing measurement with greater accuracy:
   a. Consider the values characterizing the working environment and the alteration of the values;
   b. Minimize the number of measurements forming the measuring circuit;
   c. Point out problematic places in the measuring circuits in a clear and reliable manner;
   d. Increase or decrease the values of production tolerances of the measuring circuit's measurements with good reason.
2. The developed product engineering method, terms and the model are covered with a protected trade mark AIKON.

6 UNCERTAINTY FOCUSED DIMENSIONAL CHAIN CALCULATION

Competition today is determined by speed, quality and price. This is the key how to best solve contradicting requirements – manufacturing requirements, the choice of technology – the required accuracy and quality at the best possible price – what tolerance requirements are determined by the client, and which conditions to feed to the systems, knots, details in order to ensure the above?

The following is based on the 6σ principle. The biggest flaw of the last chapter was supposedly that the accuracy of the device is poorly presented in the specification or missing altogether. At the same time, the final accuracy of the product depends on the tolerance requirements of the measurements and on how the specific tolerances are chosen. Thus, a task to be solved is: How to solve accuracy issues, and how and what to take into account in accuracy calculations? The problems of the above task are considered in solving the following measuring circuit prepared respective of the product's geometrical measurements or control measurements.

A short summary of the research of the aforementioned schools:

Balakshin's work [64] is based on research into the processes that concur with mechanical engineering technology; random values and variances have been given for technological measuring circuits.

The method created by Dunajev and others [54] is based on the conditions showed in the figure and on the static state, taking into account the variance, based on normal distribution (series and mass production).

The present doctoral thesis elaborates on the calculation method. In order to describe the situation, a mathematical model is created for a specific situation; as inputs, factors have been included and also their evaluation on uncertainty which is based on experience, manuals, standards, experiments, also involving the environment, materials and other factors, i.e. novelty. Type B uncertainty have been included.

The problem to solve:

1. Process uncertainty evaluation;
2. Uncertainty calculation method;
3. Dimensional chain calculation by modified method;
4. Environmental conditions;
5. Materials and stability of material structure;
6. Risk components;
7. Subcontractor evaluation;
8. Create a simple method for estimating dimension chain that relates to the above points;
9. Consider the solution when preparing a mathematical model, find a suitable way to present (visualize) the uncertainty components.

6.1 Theoretical base

Although dimensional chain calculations are being made, and min-max or probability method is used, the latter do not take into account directly the variations of parameters which are caused by either the calibration and exploitation conditions, or by time and structural changes of the materials of the gadget details. Especially influential are the environment, temperature, moisture and pollution and also mechanical vibration and shocks, which can cause variation of parameter values during practical use of the control set.

The standardized values of tolerances are found as random values and factors from main components are summarized as shown in Figure 6.1.

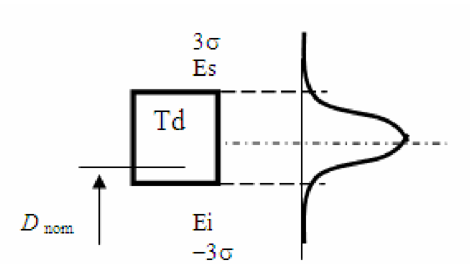

Figure 6.1 Tolerance structure allowing the use of normal distribution statistics

The main components causing the tolerance between its limit values Es and Ei:

1. Technological process.
2. Control instrument.
3. Change of environmental conditions.
4. Object behaviour.

The probability theory confirms that if there exist at least four random values, their summary is more or less normally distributed (as shown in Figure 6.1) which, in its turn, also allows for the use of the probability method for the calculation of the dimensional chain and summarizing uncertainties of factors to the tolerance value.

The value of the dependent link, in general expressed as Y, can be found through functional dependence on the dimensional chain of other link parameters or input values X_i ($i = 1, 2,..., N$) with their tolerances in equation (6.1):

$$Y = f(X_1, X_2,.., X_N) \tag{6.1}$$

But input values X_i on which the output value Y depends, can be observed as values, which can depend on other values including corrections causing systematic effects. This forms a complicated functional dependency f, which is impossible to be described correctly.

Functional dependence *f* can be observed as a combined function including values and corrections of dimensional chain links, which can add an essential part to dependent link value and, therefore, to uncertainty formation.

The Figure 6.2 shows dependent link movement through the influence of systematic factors.

In Figure 6.2, the following terms and symbols are used:

→ – initial parameter

⇢ – parameter having a systematic factor

Es1, Es2, Ei1 and Ei2 – upper and lower deviation limits of dimensional chain links,

Es and Ei – upper and lower deviation limits of dimensional chain dependent link.

In Figure 6.3 shows dependent link tolerance and uncertainty of systematic factors which are to be added.

Es_{sys} and Ei_{sys} are used as tolerance (uncertainty) limits of systematic factors.

6.2 Estimates of values of parameters of dependent link and input

As input parameters are included, dimensional chain links are included. Their values and uncertainties can be found directly in the technical figure through solving the dimensional chain.

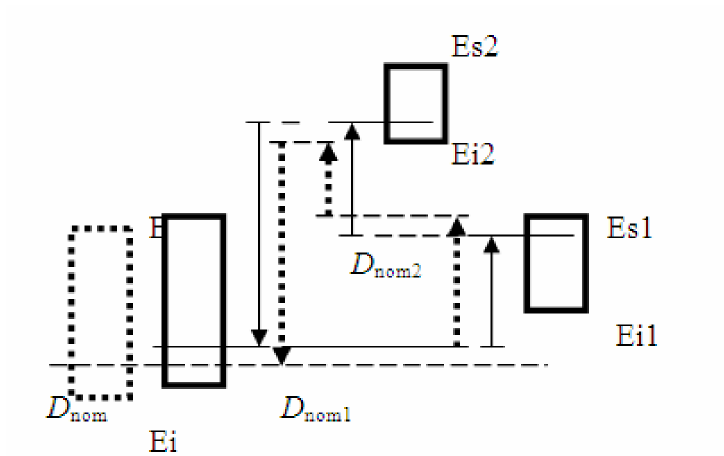

Figure 6.2 Dimensional chain movement (shift) caused by systematic factors

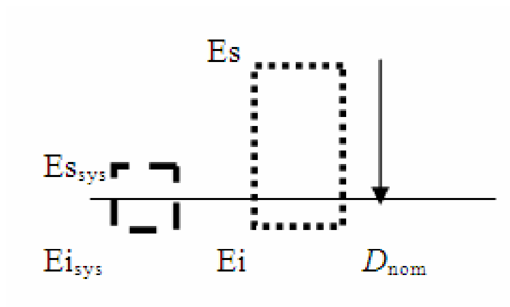

Figure 6.3 Dependent link tolerance (Es and Ei) and uncertainty of systematic factors (index sys)

Those values and uncertainties can also include estimation of correction factors for nominal parameters of dimensional chain links depending on:

- medium deviation position of tolerance relating to the nominal parameter,
- arithmetical average placement (changes) of parameter measurements in relation to their nominal value in the production process,
- change in parameter value through changes in temperature,
- elastic deformation of construction detail,
- wearing during use,
- changes of parameter through time influence, etc.

Since the values of X_i are not exactly known and their values change at random, the values of its estimate x_i can be used as input.

The depending link is characterized by the estimate of output Y, which can be marked as y and its values can be found through equation (6.1). Its values in equation (6.1) are N measures forming the dimensional chain and can be used for input values $X_1, X_2,..., X_i,..., X_N$ its estimates $x_1, x_2,..., x_i,..., x_N$.

In this case, estimate y is the value of the dependent link of dimensional chain and can be found using equation (6.2)

$$y = f(x_1, x_2,..., x_i,..., x_N) \tag{6.2}$$

Estimates of input values for the dimensional chain can be presented as given in equation (6.3)

$$x_i = A_i + \delta_1 A_i + \delta_2 A_i + \dots + \delta_j A_i + \dots + \delta_M A_i \tag{6.3}$$

where A_i – nominal value of the dimensional chain link,

$\delta_j A_i$ – correction for the measures A_i depending on influence factor j,

M – quantity of influence factors.

Thus, equation (6.3) can be presented for min-max method of dimensional chain calculation as follows

$$A_\Delta = \sum_{i=1}^{N} \xi_i (A_i + \delta_1 A_i + \delta_2 A_i + ... + \delta_j A_i + ... + \delta_M A_i) \quad (6.4)$$

where A_Δ – depending link nominal value,

ξ_i – direction factor for dimensional chain link.

Correction factors $\delta_j A_i$ in equations (6.3) and (6.4) can be calculated, if concrete initial data are known, such as deviation of tolerance field TA_i for measure relating to the nominal value of parameter A_i, or information about the technological process is used to assure that there exists link value. This can be given as an arithmetical mean of size $\bar{x}_{Ai}$ relating to A_i.

Correction factors can also be found on the basis of other concrete data, such as correction from temperature in exploitation which is caused by thermal expansion of measures depending on the temperature or on the load of construction (elastic deformation).

The reason for the necessity of correction is the density of material of construction parts, which often depends on humidity, and the resulting expansion makes the measures change.

Depending on the concrete factors of the object, more types of influence can be found. All those corrections must be taken into account for calculating the value of dependent link, using equation (6.3). Corrections may have the value near to zero, but always have some uncertainty.

Using equation (6.3) as a concrete calculation model of dimensional chain the standard uncertainty of the dependent link correction of the dimensional chain, depending on dimensional corrections of standard uncertainties of measure corrections of other link measures, ($\delta_j A_i$).

Usually all measures A_i of chain links are random values and for dependent link A_Δ correction, caused by systematic factors, combined uncertainty can be found through summarizing $A_i + \delta_1 A_i + \delta_2 A_i + \ldots + \delta_j A_i + \ldots + \delta_M A_i$ combined uncertainties of estimates by equation (6.5)

$$u(A_\Delta) = \sqrt{\sum_{i=1}^{N} c_i^2 u^2 (A_i)} \quad (6.5)$$

where c_i is a coefficient of sensitivity of corrections.

In some cases can input estimates $A_i \equiv A_i + \delta_1 A_i + \delta_2 A_i + \ldots + \delta_j A_i + \ldots + \delta_M A_i$ and $A_k \equiv A_k + \delta_1 A_k + \delta_2 A_k + \ldots + \delta_j A_k + \ldots + \delta_M A_k$ an have a correlation between each other, then, according to [59] equation (6.6)

$$u(A_\Delta) = \sqrt{\sum_{i=1}^{N} c_i^2 u^2 (A_i) + 2 \sum_{i=1}^{N-1} \sum_{k=i+1}^{N} c_i c_k \, u(A_i, A_k)} \quad (6.6)$$

is valid, where A_i and A_k are estimates for X_i and X_k and $u(A_i, A_k) = u(A_k, A_i)$ are co-variations estimates of A_i and A_k.

Exceptional is the case when all the estimates of measures of the dimensional chain are in a complete correlation, $r(A_i, A_k) = +1$, then equation (6.5)can be obtained from (6.7)

$$u(A_\Delta) = \sum_{i=1}^{N} c_i u(A_i) \qquad (6.7)$$

Correlation factor can be calculated by equation (6.8):

$$r(A_i, A_k) = \frac{u(A_i, A_k)}{u(A_i)u(A_k)} \qquad (6.8)$$

where $r(A_i, A_k) = r(A_k, A_i)$,
$-1 \le r(A_i, A_k) \le +1$.

Equation (6.7) shows that combined uncertainty is a sum of linear values. Correlation must be taken into account if it exists, but usually dimensional chain links are independent.

6.3 Standard uncertainties of size correction of dimensional chain links

Information for standard uncertainty of correction can be found in the technical figure and in manuals of details (drawings).

If the size is given with the tolerance, and assuming its normal distribution, the standard uncertainty can be given by equation (6.9)

$$u(\delta_{\mathrm{T}} A_i) = \frac{\mathrm{T}A_i}{6} = \frac{\mathrm{Es}A_i - \mathrm{Ei}A_i}{6} \qquad (6.9)$$

where $\mathrm{T}A_i$ – size A_i tolerance with probability 95 %,
$\mathrm{Es}A_i$ ja $\mathrm{Ei}A_i$ – size A_i upper and lower limit deviation.

Other standard uncertainties of corrections can be expressed using equation (6.10)

$$u(\delta_t A_i) = \frac{\Delta_{ti\,\max} - \Delta_{ti\,\min}}{2\sqrt{3}} \qquad (6.10)$$

where $\Delta_{ti\max}$ and $\Delta_{ti\min}$ are limit deviations of change of nominal size A_i ,for example, after having been influenced by temperature. It is assumed that that change distribution is taken according to rectangular deviation.

All standard uncertainties can be summarised to have a combined uncertainty by equation (6.11)

$$u(A_i) = \sqrt{\sum_{j=1}^{M} u^2(\delta_j A_i)} \qquad (6.11)$$

6.4 Calculation of tolerance of dependent link

The combined uncertainty of correction of dimensional chain dependent link A_Δ is presented as standard uncertainty.

To calculate the final deviations of the dependent link A_Δ, EsA_Δ and EiA_Δ or the change interval of measures values, expanded uncertainty of tolerance correction of a dependent link must be added, with a coverage factor k = 3. If systematic influence corrections cannot be calculated, those correction estimates are also added to EsA_Δ and EiA_Δ (see Figure 6.3).

The coverage factor k = 3 gives a probability level of 99 %, if normal distribution is under consideration, which is needed for standard tolerance calculations. For specific cases, other coverage factor values can be used.

In the worst case, the corrected limit deviations of dependent link can be calculated by equation (See also Figure 6.4)

$$Es_{cor} = Es + T_{sys}/2 \text{ and } Ei_{cor} = Ei - T_{sys}/2 \quad (6.12)$$

where $T_{sys} = Es_{sys} - Ei_{sys}$.

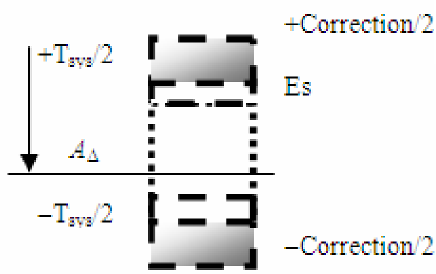

Figure 6.4 Dependent link summary tolerance scheme including systematic factor uncertainty and corrections if those can't be exactly estimated

The uncertainty estimation principles given above can be used in all calculations of the dimensional chain.

In this case, standardised tolerances of the size of the dimensional chain are not used but calculated, and standard uncertainties of the links are estimated by users themselves.

In Figure 6.2, a simple dimensional chain scheme for the control set is shown. Chain links have tolerances assigned by the designer and prescribed in the technical specification.

The parameters of links are calculated using the following well-known formulas. The dependent link dimension A_D is calculated through other link dimensions A_i by equation (6.13):

$$A_D = \sum_{i=1}^{n} \xi_i \cdot A_i \,, \quad (6.13)$$

where ξ_i is direction coefficient.

The dependent link tolerance T_D is calculated, using min-max method through other link tolerances T_i by equation (6.14):

$$T_D = \sum_{i=1}^{n} |Q_i| \cdot T_i \ , \qquad (6.14)$$

where Q_i is the sensitivity coefficient.

The mean value ME_D of the dependent link tolerance T_D is calculated through mean values of other link tolerances ME_i by equation (6.15):

$$ME_D = \sum_{i=1}^{n} \xi_i \cdot ME_i \ . \qquad (6.15)$$

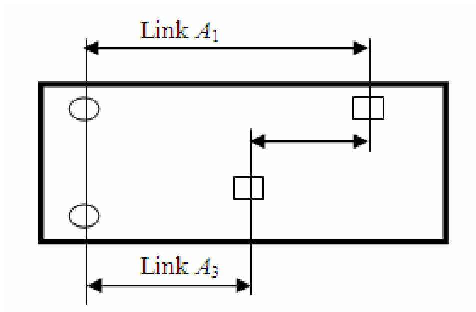

Figure 6.5 Dimensional chain for the elementary control set of mobile phone circuit boards.

In the Figure 6.5 the symbols shown are:

○ - guide bars, at least two pieces;

□ - needles as contact elements for the control of circuit board elements.

6.5 An illustration from practice

Example: Dimensional chain has links (all with ζ_i = +1) with following values: A_1 = 100h6 (0; –0,022 mm); A_2 = (100 ± 0,15) mm; A_3 = 100H8 (0; +0,054 mm) and dependent link A_Δ = ?

Environmental conditions: working temperature (70 ± 10) °C and humidity ca (20 − 60) % RH. According to the dimensional chain calculation by min-max method the dependent link is as follows: $A_\Delta = A_1 + A_2 + A_3$ = 100 + 100 + 100 = 300 mm.

The tolerance for dependent link T_Δ can be found by equation (6.16)

$$T_\Delta = t_\Delta \sqrt{\sum_{i=1}^{m-1} \xi_i^2 \lambda_i^2 T_i^2} \qquad (6.16)$$

where t is risk factor, ξ is link direction factor, λ is relative standard deviation, i is tolerance unit and n the quantity of links.

$T_\Delta = 3\sqrt{10377{,}8} = 305{,}6$ μm ≅ 0,306 mm. The mean deviation of T_Δ would be Ec_Δ = 0 and limit deviation of the dependent link are:

$Es_\Delta = Ec_\Delta + T/2 = 0 + 0{,}306/2 = 153$ mm

$Ei_\Delta = Ec_\Delta - T/2 = 0 - 0{,}306/2 = -0{,}153$ mm

The dependent link measures obtained are: $A_\Delta = 300^{+0{,}153}_{-0{,}153}$ mm.

The modified method adds corrections, which take into account the changes in sizes depending on temperature and moisture influence and their uncertainty. The correction factors, in the meaning of link change depending on temperature, can be calculated using equation (6.17)

$$\Delta_t A_i = \alpha\,(20\ ^\circ\mathrm{C} - t_\mathrm{w})\,A_i \qquad (6.17)$$

where α is temperature factor for linear expansion and t_w working temperature ºC.

The results of calculation are given in Table 6.1.

Factory 1:

The combined uncertainty of linear size change depending on temperature and linear correction factor, using equation (14) and partial derivations for link, is:

$$u(\Delta_t A_i) = \sqrt{u^2(\alpha)\cdot\left(20^0\mathrm{C} - t\right)^2\cdot A_i^2 + u^2(t)\cdot\alpha_i^2\cdot A_i^2 + u^2(A_i)\cdot\alpha_i^2\cdot\left(20^0\mathrm{C} - t\right)^2} =$$

$$\sqrt{(1{,}1\cdot10^{-6})^2\cdot(20-23)^2\cdot100^2 + (3{,}2)^2\cdot(1{,}1\cdot10^{-5})^2\cdot100^2 + \ldots} = \sqrt{4{,}0\cdot10^{-3}} = 0{,}06 \text{ mm.}$$

If analogically calculated, the results of calculations for all the links are as follow:

$u(\Delta_t A_1)$ = 0,060 mm,

$u(\Delta_t A_2)$ = 0,007 mm,

$u(\Delta_t A_3)$ = 0,075 mm.

The correction of moisture influence to the link material is the following: (only the third link is influenced): $\delta RHA_3 = \Delta d_3 = 0{,}0035 d_3 = 0{,}0035\cdot100 = 0{,}35$ mm with standard uncertainty $u(\delta RHA_3) = 0{,}05/\sqrt{3} = 0{,}03$ mm (trapeze distribution).

The combined uncertainty for dependent link 3, owing to the influence of temperature and moisture is:

$$u(A_{\Delta3}) = \sqrt{u^2(\Delta_t A_\Delta) + u^2(\delta_{RH} A_3)} = \sqrt{75^2 + 0{,}2^2} = 0{,}075 \text{ mm.}$$

The standard summary uncertainty for links is:

$$u(\Delta_{SYS}) = \sqrt{u^2(A_{\Delta1}) + u^2(A_{\Delta2}) + u^2(A_{\Delta3})} = 0{,}044 \text{ mm.}$$

The maximum total movement of the Dependent link, at the average temperature of 23 ºC ,taking into account the systematic factors:

$$\Delta_{SYS} = 0{,}003 + 0{,}007 + 0{,}075 + 0{,}03 = 0{,}115 \text{ mm.}$$

The corrected value of the dependent link is now:

$A_{\Delta COR} = A_{\Delta} + \Delta_{SYS} = 300 + 0{,}115 = 300{,}115$ mm.

a) The expanded uncertainty is (on the probability level of 95 %, $k = 2$, assuming normal distribution)

$U(\Delta_{SYS}) = k \cdot u(\Delta_{SYS}) = 2 \cdot 0{,}044 = 0{,}088$ mm.

The total corrected tolerance $T\Delta_{COR}$ for dependent link is:

$T_{\Delta COR} = T_{\Delta} + U(\Delta_{SYS}) = 0{,}306 + 0{,}088 = 0{,}394$ mm.

Correction of tolerances:

$ES_{\Delta COR} = ES_{\Delta} + U(\Delta_{SYS})/2 = 0{,}153 + 0{,}088/2 = 0{,}279$ mm

$EI_{\Delta COR} = EI_{\Delta} - U(\Delta_{SYS})/2 = -0{,}153 - 0{,}088/2 = -0{,}203$ mm.

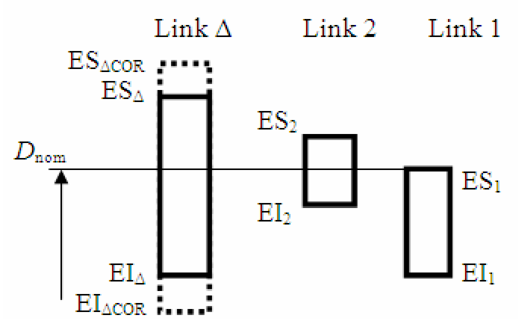

Figure 6.6 Movement of dimensional chain links through the influence of factors:
——— - tolerances of measures from the technical specification;
▪▪▪▪▪▪▪ - tolerances of measures including influences caused by factors.

Table 6.1 Dependent link parameters at temperature 23 ºC, RH 60 %

PWB link value without corrected limit derivations, mm	$A_{\Delta\ PWB}$	300	±0,200
Dependent link value without corrected limit derivations, mm	A_{Δ}	300	0,191 −0,115
Corrected value of dependent link with corrected limit derivations (23 °C), mm	$\boldsymbol{A_{\Delta\ COR}}$	**300,115**	**0,279** **−0,203**
PWB link corrected value with corrected limit derivations, mm	$A_{\Delta\ PWB\ COR}$	300*	±0,200

*) the maximum movement at an average temperature 23 ºC, taking into account the systematic factors is $\Delta_{SYS\ PWB} = 0{,}008$ mm and the expanded uncertainty is (on 95 % probability level, $k = 2$, assuming normal distribution) is 0,017 mm. Uncertainty for link parameter $A_{\Delta\ PWB\ COR}$ is close to 0, because the parameter acts in this case as a constant (is assumed to be right).

6.6 Solutions to the chapter 6

The dependent link can be corrected by taking into account the uncertainties of systematic factors. The systematic factors can be estimated as a possible maximum and calculated by their uncertainty estimation. To get a systematic factor estimate of the corrected dependent link size its expanded uncertainty on probability level 99 %, must be added to the nominal value of the dependent link.

The parameter tolerances of the control set of the mobile telephone circuit plate can be corrected taking into account influence factors as uncertainties. Excluding the influence of factors by deep analysis, dependent link tolerance can be minimized up to 20 % without raising economic expenses.

The above analysis showed that for increasing manufacturing accuracy there is no need to obtain expensive and equipment or measuring devices with a high level of accuracy, it is just necessary to control and manage environmental conditions.

Using the floating adapter solution enables to eliminate tester measuring circuit links and their uncertainty in older test devices, as a result of which the number of measuring links can be minimized.

It is not reasonable to give more accurate measurement values to plastic details than the ones determined by the 8^{th} quality tolerance values, since the allowed deviations of environmental conditions do allow ensuring the given accuracy requirements. Comparison of the results obtained on the basis of the new developed methodology concurred with the result of the practical test (deviation within the 3 % limit).

The analysis conducted showed that:

1. The client/co-operation partner needs to be guided and helped to find the best solution to reach his/her goal (help in considering automatic handling and testing solutions in product planning and design);
2. In co-operation with specialists, decisions need to be based on technical facts and laws of physics; compromises need to be made both on the part of the client as well as the solution provider;
3. The virtual work room should be used as a communication channel. Constant feedback is very important in finding solutions, this excludes the possibility of misunderstanding, misinterpretation or miscomprehension – the more specific and defined the wishes, the less uncertainty.
4. The developed model of measuring circuit solution, which takes into account the value of every link with its uncertainty, gives the clearest and most unambiguous perception of the problem at hand and its background (the uncertainty). Visualization of uncertainty makes it easier and clearer to explain things to people in different sectors and brings out the parts and the field of the problem.
5. This methodology enables to decide for the desired result prior to subcontracting, which work (at which complexity level) to provide certain subcontractors with, or to which specific subcontractor, depending on the

situation, the finished tolerances (requirements) of product measurements can be restricted.

6. The product development methodology based on the uncertainty concept allows mapping the background (global events, local events, increase or decrease in economy, changes in the political situation, movement of workers, change of owners, changes in energy prices, changes in raw material prices, logistics, etc.) of manufacturing capability changes, changes in uncertainty in the final product depending on input values and changes of their uncertainties in the given model.
7. The use of input values with uncertainties in the given product development model allows for stimulating and analyzing engineering solutions in accordance with a new method and its scientific bases, i.e. a virtual model, which enables to prepare proactive action plans and manage the possible risks.

6.7 Conclusions to chapter 6

The developed calculation method of measuring circuits which involves uncertainty enables to:

1. Specify the value of the closing measurement with greater accuracy;
2. Consider the values characterizing the working environment and alteration of the values;
3. Minimize the number of measurements forming the measuring circuit;
4. Point out problematic places in the measuring circuits in a clear and reliable manner;
5. Increase or decrease the values of production tolerances of measurements of the measuring circuits with good reason.

The developed product engineering method, the terms and the model are covered with a protected trade mark AIKON.

CONCLUSIONS

The novelty of the present research lies in the following:

A new method for dimension chain calculation involving measurement uncertainty has been developed.

In order to describe specific situation a mathematical model has to be developed underlie by experience, handbooks, standards and experimental data. The model inputs are variables and influence factors together with their uncertainty values, including environmental, material and other influences based on B-type uncertainty estimation.

As a result of the conducted research:

1. A new idea of organizational culture was developed; it gave a novel vision for an effective functioning of an organization on the bases of virtual workplace (e-Business). An idea of a new organizational culture, e-Business, was developed, which gives a new inner vision for a company.
2. The standardization method and principles have been developed further; this enables to:
   - Increase the flexibility of product development at actual usage;
   - Decrease the nomenclature of components at product development;
   - Develop a systematic catalogue of standard modules.
3. Computer-aided engineering for products was developed, which:
   - Proved the necessity of using uncertainty with computer-aided engineering;
   - Enabled to develop four versions of engineering solutions during the research;
   - Enabled to simulate and analyze the computer-aided engineering situations in the product development model and test them virtually.
4. A new calculation method for measuring circuits that includes uncertainty was developed; it enables to:
   - Consider the values characterizing the working environment and the alteration of the values;
   - Minimize the number of measurements forming the measuring circuit;
   - Increase or decrease the tolerance values of the measuring circuit's measurements with good reason.
5. A new technical solution was created, which met the criteria of patentability with respect to its novelty and technical standard and it is protected with the Finnish patent number FI000119529B.

KOKKUVÕTE

Doktoritöös on esitatud läbilõige 21. sajandi alguseks muutunud tööstusmaastikust ja globaliseerunud turu mõjutustest firma uurimus- ja arendustöö ühele olulisele osale, mis seisneb efektiivsusel ja kiirusel ning teiselt poolt kogu tootmestamisahela optimeerimisel ja hinna alandamisel. Kusjuures võtmesõnadeks on konkurents, kvaliteet, tootmestamine, inseneri arvutused, alternatiivsete tootmismeetodite, tehnoloogiate ja materjalide kasutamise kombineerimine.

Tootearendusprotsess toimub ülimalt lühikese aja jooksul. Tihti on tootest olemas ainult visioon, toodet hakatakse alles kujundama ja samaaegselt kavandatakse juba sellele nn. olematule tootele tootmisliini. Toote kavandamise etapi käigus võib tekkida ühe toote kohta eri mudeleid/versioone, mis ei pruugi olla lisaks programmilistele võimalustele ning kõikvõimalikele lisafunktsioonidele, üldsegi mitte identsed. Toote testisüsteemis on baseerimise ja opereerimise sõlmed-süsteemid kardinaalselt erinevad, kuid peab olema võimalus neid tootmisliinis, tootmisliini seiskamata, jooksvalt ja lihtsalt häälestuseta vahetada ja asendada. Niisugused tingimused esitavad projekteerimisel kõrgeid nõudmisi testisüsteemide loojatele. Tuleb järgida erinevaid standardeid, arvestada standardimise ja unifitseerimise põhimõtteid, modulaarset struktuuri, ergonoomikat. Teostada korrektseid inseneri- ja täpsusarvutusi, planeerida vajalikud eeltestid ning koondada eri kompetentsid, tagamaks vastavused ning kvaliteeti ja pakkudes konkurentidest odavamaid süsteemilahendusi. Kliendi tegelikele vajadustele sobivaima lahenduse pakkumine, teenuse kiirus, kvaliteet ja hind annavad eelise turul. See on omakorda impulsiks valmistajatele leidmaks uusi tootmislahendusi e-Business, e-Commerce ning tehnoloogiate ja materjalide kasutamise kombineerimist prototüüpide- ja seeriatootmiseks. Seejuures 3D mudel tootest saadetakse koostööpartneri 3D printerisse või kiirtöötlemise keskusesse (High Speed Machining Centre). Kiiruse ja säästu annab materjali logistika optimeerimine info siirdamisega.

Reeglina kliendi vajaduste ja plaanide infost saavad osa väljavalitud potentsiaalsed koostööpartnerid-tarnijad, kes on valmis kliendi plaanide (ennustuste) ja visioonide teostamise riskid enda kanda võtma.

Tingimused muutuvad karmimaks ja tempo kiiremaks, võitlus käib turu (pea)võidu nimel, võitja võtab kõik ja selle nimel on allhanget ja koostööd pakkuvad firmad nõus tingimustega kaasa minema. Uued ideed ja nende edukast realiseerimisest oodatava võidu tulusus kaalub üles sellele eelnenud etappide miinused. See on mootor, mis innustab täistulemi nimel kõiki süsteemi osalisi mõtestatult tegutsema. Möödapanek selles ei pruugi võimaldada jätkamist tulevikus. Ülalnimetatu on reaalne keskkond selgete tingimustega, milles osalemine on firma eksistentsi küsimus. Firma peab olema suuteline määratlema tulemit mõjutavad faktorid, ka neid mida ei oska ette näha, ja nende mõju piirid ning nende usaldatavuse. Äris ja inseneerias tähendab see oskust määramatusi ja riske ohjata.

Doktoritöö eesmärgiks oli edasi arendada ja täiendada inseneriarvutuste valdkonda mõõtemääramatuse kontseptsioonist lähtudes. Põhjalikumalt oli vaatluse all mõõteahelate arvutusmetoodika.

Probleem on selles, et inseneriarvutustes toote plaanimisel ja arendusel ei piisa ainult üldiste inseneriprobleemide lahendamisest, vaid tuleb lahendada konkreetsed tulemit andvad pisiprobleemid, ja tegeleda inseneriarvutuste nüanssidega.

Antud uurimustöös on võetud uurimise alla elektroonikatööstuse sektorile (telekom, autoelektroonikatööstus, arvutitööstus) tootmislahendusi pakkuva ettevõtete toimimise eripära ja sealt tulenevad probleemid.

Uute toodete väljatöötamisel on oluline infovahetus, mängureeglid uue toote kavandamisprotsessi algfaasist alates. Oluliseks osaks on siin organisatsiooni (firma) sisekultuuri- ja väliskultuuri tundmine, nende vastastikune toimimine ja toimemehhanismid uues virtuaalruumis, mis loovad uued võimalused firmakultuuri edasiarendamiseks.

Ühe olulise haruna lahenduste väljatöötamisel on unifitseerimine ja standardimine, mis annab efekti pikemaajaliselt ja mõõdikuks on efekt rahalises vääringus kui ka ajalises vääringus. Unifitseerimine annab paindlikkust, kiirust, võimaluse kombineerida olemas-olevatest moodulitest optimaalseid lahendusi, mis on konkurentsivõimelised. Unifitseerimine ja standardimine on firma jaoks üks võtmeoskusi edu saavutamisel.

Uudsed tehnoloogiad ja materjalid võimaldavad loodavad konstruktsiooni-lahendused realiseerida uudsel viisil, paindlikumalt, odavamalt, kiiremini ja säästlikumalt, kui seda võimaldasid tänaseni laialt kasutuses olevad tehnoloogiad ja materjalid.

Tulles toote parameetrite juurde on oluliseks osaks lahenduste komponentide valikul insenerilahenduste väljatöötamise arvutuste osal. Uurimuse alla on võetud tolerantside arvutus, millest sõltub läbi täpsusnõuete, k.a. suuresti tulevase lahenduse maksumus: seadme/liini paigaldamise, käsitlus- ning hoolduskulud ja utiliseerimine. Milline on „rauda valatud“ osa täpsus jm. omadused ja mida sellest tulenevalt tuleb arvesse võtta juhtimise ja programmeerimise poolelt või vastupidi.

Kuna eelpool toodud punktid on olulised uute toodete väljatöötamisel koostöös eri firmade vahel, on neid teemasid, peatükkide kaupa, käsitletud doktoritöös:

Töö esimeses peatükis antakse ülevaade elektroonika tootmissektoris tegutseva ettevõtte peamistest probleemidest ja soovidest ning sellest tulenevatest nõudmistest. Uurimuse alusmaterjalideks on võetud müügiinseneride ja kliendi tugiisikute poolt koostatud materjalid ja esitlusmaterjalid. Tõstatatud probleemi lahendamisel ilmnes rida alamprobleeme, mis toodi selles peatükis välja edasiseks põhjalikumaks uurimiseks. Esimese peatüki lõpus on formuleeritud doktoritöö ülesanne.

Töö teises peatükis on keskendutud ettevõtte (firma) sisese organisat-sioonikultuuri uurimisele. Kokku on võetud toote kvaliteedi kavandamise osa oma uurimuste, katsetamiste ja järeldustega, mis on väga aktuaalne ka tänapäeval. Vaatluse alla on võetud toote kavandamisega seotud probleemid toote väljatöötamise ja tootearenduse algetapist tootmestamiseni, kaasates samaaegselt koostööle toote tootmis- ja testisüsteemide lahenduse pakkuja. Uurimustöö tulemusena on välja pakutud koostöö uued suunad ning selle realiseerimise võimalused. Ettevõtte sisemise toimimise efektiivsemaks muutmisel arendati välja uus organisatsioonikultuur, mis andis firmale uue nägemuse organisatsiooni toimeks seespidiselt ja tõi kaasa vajaduse tootmise efektiivsuse tõstmiseks. Kombineerides virtuaalruumis omavahel erinevaid tootmispõhimõtteid oli võimalik saavutada vajalik sünergia, mis annab märgatavat efekti tootmises.

Töö kolmandas peatükis on keskendutud ettevõtte (firma) välise organisatsioonikultuuri uurimisele – koostöö ja teenused. Käsitletud on kliendile pakutavaid lahendusi ja teenuseid, mis võimaldavad kõrvaldada puudusi seadmete dokumentatsiooni osas ning testi raportites. Uudse organisatsioonisüsteemi nägemuse edasiarendus kliendi suunas andis võimaluse viia koostöö uuele tasandile, st e-ROOM-i, seniseid teenuseid pakkuda toodete ja teenuste osas virtuaalselt ja seda 24h/7d, teostada virtuaalset varuosade müüki, kliendituge, koolitust ja programmitäiendusi. Analüüsi tulemusena töötati välja korrektsed nõuded testipõhjale ja loodi uued testidokumendid.

Töö neljandas peatükis on käsitletud toote unifitseerimist läbi standardimise ja modulariseerimise. Protsessi sisendiks on selles probleemilahenduses kliendi hinnatundlikkus ja kiirus. Edasi on arendatud unifitseerimise metoodika ja selle mudel väikeettevõtetele, arvestades Eesti mastaape ning kasutades suurseeria tootmise põhimõtteid prototüüpide väljatöötamisel varieeruva väikeseeria tootmise tingimustes. Täiendatud on unifitseerimis- ning standardimispõhine tootearenduses rakendatav inseneriarvutuste metoodikat. Unifitseerimismetoodika realiseerimise tulemusel arendati välja uus tehniline lahendus, mis on ülevaatlikult esitletud antud peatüki all.

Töö viiendas peatükis on käsitletud väljaarendatud tootearendusmudeli kohaseid inseneriarvutusi, kaasates arvutustesse sisendsuuruste väärtuste ja nende määramatuse hinnangud. Kasutusse on võetud kolm põhilist mõistet. Uudsed terminid: sisendite puu ja määramatuste puu. Kolmanda terminina: määramatuse büdžett - termin, mis väljendab sisendite kogumit, mida mudelisse kaasata. Termin on kasutuses GUM metoodikates [24], metroloogiaalases kirjanduses, juhistes [58, 59] ja on igati sobiv termin-mõiste, kasutamiseks-käsitlemiseks ka väljapakutavas metoodikas. Mudelipõhilised arvutused võimaldasid tulemina esitada kolm põhilist inseneraarvutuste suunda, millele üks insenerifirma võib heitlikul turul kindlalt toetuda ja läbi mille võib ta olla arvestatav koostööpartner klientidele.

Töö kuuendas peatükis on koostatud uus konkreetsele tootele suunatud insenerlahenduse mudel, kus esimeses etapis on mudelisse kaasatud toote geomeetriliste mõõtmete mõõtahelad ja nende tolerantsid, järgneva etapina on sellesse mudelisse kaasatud töökeskkonda ja materjalide omadusi iseloomustavad suurused. Edasi on mudelis kirjeldatud toote testisüsteem tervikuna, koos tulenevate määramatuste komponentidega. Ülalkirjeldatud probleemi lahenduse lõpus on koostatud määramatuse büdžett, kaasates mudelisse lisaks toote valmistamismeetoditest ja käsitlemisest tingitud määramatuse komponendid.

Doktoritöö uudsus:

Loodud on uus määramatust kaasav mõõtahelate arvutusmetoodika. Iga konkreetse olukorra kirjeldamiseks luuakse matemaatiline mudel, kus sisenditeks on suurused ja mõjurid koos nende määramatuse hinnangutega, mis tuginevad kogemustele, käsiraamatute, standardite ja katsete andmetele, kaasates lisaks keskkonna, materjali jt mõjurite mõju, mis on määratletud B-tüüpi määramatuste hinnangute abil.

Läbiviidud uurimistöö tulemusena:

1. Arendati välja uus organisatsioonikultuuri idee, mis andis uudse nägemuse organisatsiooni toimeks virtuaaltööruum (e-Business) baasil.
2. On edasi arendatud unifitseerimise metoodikat ja unifitseerimisskeemi põhimõtteid, mis võimaldavad:
   - reaalsel kasutamisel suurendada tootearenduse paindlikkust;
   - vähendada tootearendusel koostekomponentide nomenklatuuri;
   - välja arendada standardmoodulite süsteemse kataloogi.
3. Arendati välja toote inseneriarvutuste mudel, mis:
   - tõestas määramatuse kasutamise vajadust inseneriarvutustes;
   - võimaldas uurimustöös välja arendada neli insenerilahenduse versiooni;
   - võimaldas tootearenduse mudelis inseneriarvutuse situatsioone simuleerida, analüüsida ja virtuaalselt läbi mängida.
4. Arendati välja uus määramatust kaasav mõõteahelate arvutusmetoodika, mis võimaldab:
   - arvesse võtta töökeskkonda iseloomustavaid suurusi ja nende muutust;
   - minimeerida mõõteahelat moodustavate mõõtmete arvu;
   - põhjendatult suurendada või vähendada mõõteahela tolerantside väärtusi.
5. Loodi uus tehniline lahendus, mis uudsuse ja tehnilise taseme poolest vastas patentsuse kriteeriumidele ja on kaitstud patendi nr. FI000119529B alusel Soomes.

ABSTRACT

This thesis studies the nature and operational problems of a company offering manufacturing solutions in electronics sector (telecoms, vehicle electronics and computer industry).

Communication and game rules are important in developing new products already at the primary stage of the development process. A significant part here is to know the organization's (company's) internal and external culture, their mutual functioning and functioning mechanisms in a new virtual space, which creates new opportunities for the further development of organizational culture.

One of the important branches in developing solutions is unification and standardization which produce a longstanding effect that can be measured in monetary as well as temporal value. Unification provides flexibility, speed, an opportunity to combine the existing modules into optimal solutions that are competitive. For a company, unification and standardization are part of the key factors in achieving success.

Novel technologies and materials enable to implement the structural solutions to be created in a more novel, flexible, cheap, fast and economical manner than it was enabled by the technologies and materials widely used up to now.

When talking about product parameters, the calculations made for developing engineering solutions have an important part in selecting solution components. Tolerance calculation is being studied here. When considering the requirements for precision, the cost of the future solutions largely depends on this calculation: the installation of a device/line, treatment and maintenance costs, and utilization. It is also considered how precise is the “cast iron” part and what are other qualities, and, resulting from that or vice versa, what has to be taken into account in terms of management and programming.

As the aforementioned matters are important in developing new products in cooperation with different companies, these topics have been included in the doctoral thesis in separate chapters:

The first chapter of the thesis gives an overview of the problems and wishes of that company operating in electronics sector, and its relevant requirements. The thesis is based on materials and presentation kits prepared by sales engineers and customer account representatives. Solving this problem resulted in emergence of several sub-problems, which are identified in the paper for later research. The thesis of this doctoral thesis is formulated at the end of the chapter.

Then the thesis summarizes the product quality planning phase and the relevant research, testing and conclusions, which is very up-to-date also today. The paper focuses on product development problems from the initial phase of product planning and development up to production, engaging simultaneously also the service provider of the product manufacturing and test systems. The thesis paper has led to propositions on new co-operation avenues and ways to deliver. Upon making the company's internal operations of more effective, a new organizational culture was developed that gave a new inner vision for the company and the need

to increase productivity. Combining different manufacturing principles in virtual space enabled to achieve the required synergy for a significant effect in production.

The third chapter of the thesis covers the solutions offered to customers and the service of removing defects from device documentation and test reports. The customer orientation in the vision of the novel organizational system enabled to take co-operation to a new level – e-ROOM – constantly providing existing products and services electronically, selling spare parts, providing customer service, training and program updates via e-Business. The analysis produced new test documents and proper requirements for the test base.

The fourth chapter of the thesis covers product unification through standardization and modularization. Inputs are customer's price sensitivity and speed. A new unification methodology and a corresponding model for small enterprises was developed, taking into account Estonian proportions and using mass production principles for developing prototypes in the variable conditions of small scale production. Additionally, engineering calculations methodology for small companies based on unification and standardization was developed and improved for the implementation in product development.

The fifth chapter of the thesis covers the engineering calculations of the new product development model and includes input values and uncertainty predictions. Model based calculations generated three main engineering avenues which can safely be used by an engineering company in today's fickle market environment, so that it could be a serious co-operation partner for its customers.

The sixth chapter of the thesis presents a new engineering solution model intended for a specific product, whereas the first stage of the model includes measurement chains of product geometric measures and tolerances and the next stage includes values related to work environment and the nature of the materials used. Then the model describes the entire product test system and its uncertainty components. At the end there is an uncertainty budget which includes uncertainty components of manufacturing methods and handling.

Keywords: Co-operation process, unification, virtual organization, tolerances, dimensional chain, mathematical model, random variable, uncertainty

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American National Standards Institute (ANSI): www.ansi.org
American Society for Testing and Materials (ASTM): www.astm.org
American Society of Mechanical Engineers (ASME): www.asme.org
Co-Operation on International Traceability in Analytical Chemistry (CITAC): www.citac.ws
Eurachem: www.eurachem.bam.de
European cooperation for Laboratory Accreditation (EA): www.european-accreditation.org
International Laboratory Accreditation Cooperation (ILAC): www.ilac.org/
International Organization for Standardization (ISO): www.iso.org
International vocabulary of basic and general terms in metrology (VIM): www.cornnet.nl/~mlbroens/vim.htm
National Conference of Standards Laboratories International (NCSLI, formerly known as NCSL, the National
Conference of Standards Laboratories): www.ncslinternational.org
National Institute of Standards and Technology (NIST): www.nist.gov
NIST-SEMATECH Engineering Statistics Internet Handbook: www.itl.nist.gov/div898/handbook/index.htm
Uncertainty Analysis: www.itl.nist.gov/div898/handbook/mpc/section5/mpc5.htm
United Kingdom Accreditation Service (UKAS): www.ukas.com

Electronic databases

Eesti Patendiamet: http://www.epa.ee
Eesti Patendiraamatukogu: http://www.patentlib.ee
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Patents

Invention: **Testing of electronic device** (in Finnish). Owner: JOT Automation OY (FI); Authors: Karl Raba, Toomas Tiismaa, Sten Lindvest; Patent number: FI 000119529 B – 15.12.2008, IPC: G01 R31/28.

Trademark: (**AIKON**); Owner: Karl Raba; Author: Karl Raba; Priority number: M200801491; Priority date: 17.10.2008.

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2005 – 2006	AS Metrosert-i: metroloogia erikursus
2005	TTÜ mõõtmestamisalane erikursus
2004	TRIZ ja loova töö tehnika, JOTE erikursus
2004	TJK Konsultatsioonid: Ettevõttesisised integreeritud juhtimissüsteemi auditid

2004	Mescuri International Eesti AS: JOTE Business School 2004
2002	Säästva Eesti Instituut, Keskkonnaalane koolitus OÜ JOT Eestis (JOTE ja ISO 14 000)
2002	Mescuri International Eesti AS: JOT Business School Training 2002
2001	FESTO DIDACTIC ja JusMATIX Oy
2000	Cristiansen Consulting: International Qualty Auditor Training
1999	Mescuri International Eesti AS: JOT Eesti ajaplaneerimise workshop

6. Teenistuskäik

2008	IPTE Automation OÜ	Tehnoloogia ja tootmestamise juht
2000 – 2008	JOT EESTI OÜ	Tehnoloogia ja tootmestamise juht; disainijuht; rühma juht
1999 – 2000	Seinäjoen ammattikorkeakoulu	Õppejõud-lektor
1997 – 1999	JOT EESTI OÜ	Konstrueerimisrühma juht
1996 – 1997	CAF	Spetsialist, vanemkonstruktor,
1996	AS Rocca-al-Mare Tivoli	Tehnikadirektor
1994 – 1996	AS Inrestauraator / AS Inrestauraator Ehitus	Tehniline konsultant, meister, tehniline konsultant,
1993 – 1994	Univier AS (Fleming)	Tehnikadirektor
1993	GrafimillAS	Müügijuht
1987 – 1992	TTMTK STANDARD	Tsehhi juhataja, vanemmeister, meister

7. Teadustöö põhisuunad

Tööstustehnoloogia, mehhatroonika- ja mõõtesüsteemide süntees: modelleerimine, optimeerimine ja kvaliteediohje.

CURRICULUM VITAE

1. Personal data

Name	Karl Raba
Date and place of birth	02.05.1968, Tallinn
Citizenship	Estonian
Children	Maria (born 06.09.2006)
	Marti (born 03.09.2007)

2. Contact information

Address	Järveotsa st 29-61, 13520 Tallinn
Phone	+372 67 00 466
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E-mail	Karl.Raba@gmail.com

3. Education

Tallinn University of Technology	2000 – 2009	Faculty of Mechanical Engineering, Doctor Studies, Ph. Student
Tallinn University of Technology	1995 – 1999	Faculty of Mechanical Engineering, Post grad. Stud. MSc (Eng.)
Tallinn University of Technology	1987 – 1993	Faculty of Mechanical Engineering, Engineer of Mechanics
Tallinn Technical School of Building and Mechanics	1983 – 1987	Faculty of Mechanics, Technican in Machine Engineering Cum Laude

4. Language competence/skills

Estonian	Mother tongue
Russian	Intermediate
Finnish	Intermediate
English	Intermediate
Greman	Elementary

5. Special Courses

2008	An Intruduction to Metrology and Uncertainty, Special Cource in JOT Estonia
2007	Cristiansen Consulting: Value Stream Mapping.
2006	EDU Training: Lean Manufacturing Cource
2005 - 2006	Metrosert Ltd.: Metrology Special Cources
2005	TUT special cource of dimensioning
2004	TRIZ and Creative Work Technics in JOT Estonia
2004	TJK Consultations: Company integrated management system audits
2004	Mescuri International Estonia Ltd.: JOTE Business School 2004 Prpgramm
2002	SEI Tallinn Centre, Environ-mental Ttraining (ISO 14 000 preparatory study)
2002	Mescuri International Estonia Ltd.: JOT Business School TP 2002: JOT Estonia and Virtual Organization; Thesis: How to use a virtual organization in customer offers
2001	FESTO DIDACTIC and JusMATIX Oy: Modern Pneumatics, Services. Programs: FluidSIM & FluidDraw in use.
2000	Cristiansen Consulting: International Qualty Auditor Training
1999	Mescuri International Estonia Ltd.: JOT Estonia Ltd.Time Planing workshop.

6. Professional Employments

2008	IPTE Automation Ltd.	Manager, Functional Engineering,
2000 – 2008	JOT Estonia Ltd.	Manager, Manufacturing Engineering, Design Manager, Group Manager
1999	Seinäjoki University of Applied Sciences	Lecturer
1987 – 1999	JOT Estonia Ltd	Design Team Leader,

1996 – 1997	CAF Ltd.	Expert; Senior Designer; Designer
1996	Rocca-al-Mare Tivoli Ltd.	Director of Technique
1996	Inrestaurator Ltd.	Technical Consultant,
1994 – 1996	Inrestaurator Building Ltd	Object Master , Technical Consultant
1993 – 1994	Univier Ltd. (Fleming)	Director of Technique
1993	Grafimill Ltd.	Sales Manager
1987 – 1992	TTMTK STANDARD	Chief (Manager), Senior Master, Master

9. Main areas of scientific work/Current research topics

Industrial technology, mechatronics-, and measurement systems synthesis: modelling, optimization and quality control.

DISSERTATIONS DEFENDED AT TALLINN UNIVERSITY OF TECHNOLOGY ON *MECHANICAL AND INSTRUMENTAL ENGINEERING*

1. **Jakob Kübarsepp**. Steel-bonded hardmetals. 1992.
2. **Jakub Kõo**. Determination of residual stresses in coatings & coated parts. 1994.
3. **Mart Tamre**. Tribocharacteristics of journal bearings unlocated axis. 1995.
4. **Paul Kallas**. Abrasive erosion of powder materials. 1996.
5. **Jüri Pirso**. Titanium and chromium carbide based cermets. 1996.
6. **Heinrich Reshetnyak**. Hard metals serviceability in sheet metal forming operations. 1996.
7. **Arvi Kruusing**. Magnetic microdevices and their fabrication methods. 1997.
8. **Roberto Carmona Davila**. Some contributions to the quality control in motor car industry. 1999.
9. **Harri Annuka**. Characterization and application of TiC-based iron alloys bonded cermets. 1999.
10. **Irina Hussainova**. Investigation of particle-wall collision and erosion prediction. 1999.
11. **Edi Kulderknup**. Reliability and uncertainty of quality measurement. 2000.
12. **Vitali Podgurski**. Laser ablation and thermal evaporation of thin films and structures. 2001.
13. **Igor Penkov**. Strength investigation of threaded joints under static and dynamic loading. 2001.
14. **Martin Eerme**. Structural modelling of engineering products and realisation of computer-based environment for product development. 2001.
15. **Toivo Tähemaa**. Assurance of synergy and competitive dependability at non-safety-critical mechatronics systems design. 2002.
16. **Jüri Resev**. Virtual differential as torque distribution control unit in automotive propulsion systems. 2002.
17. **Toomas Pihl**. Powder coatings for abrasive wear. 2002.
18. **Sergei Letunovitš**. Tribology of fine-grained cermets. 2003.
19. **Tatyana Karaulova**. Development of the modelling tool for the analysis of the production process and its entities for the SME. 2004.
20. **Grigori Nekrassov**. Development of an intelligent integrated environment for computer. 2004.
21. **Sergei Zimakov**. Novel wear resistant WC-based thermal sprayed coatings. 2004.
22. **Irina Preis**. Fatigue performance and mechanical reliability of cemented carbides. 2004.

23. **Medhat Hussainov**. Effect of solid particles on turbulence of gas in two-phase flows. 2005.

24. **Frid Kaljas**. Synergy-based approach to design of the interdisciplinary systems. 2005.

25. **Dmitri Neshumayev**. Experimental and numerical investigation of combined heat transfer enhancement technique in gas-heated channels. 2005.

26. **Renno Veinthal**. Characterization and modelling of erosion wear of powder composite materials and coatings. 2005.

27. **Sergei Tisler**. Deposition of solid particles from aerosol flow in laminar flat-plate boundary layer. 2006.

28. **Tauno Otto**. Models for monitoring of technological processes and production systems. 2006.

29. **Maksim Antonov**. Assessment of cermets performance in aggressive media. 2006.

30. **Tatjana Barashkova**. Research of the effect of correlation at the measurement of alternating voltage. 2006.

31. **Jaan Kers**. Recycling of composite plastics. 2006.

32. **Raivo Sell**. Model based mechatronic systems modeling methodology in conceptual design stage. 2007.

33. **Hans Rämmal**. Experimental methods for sound propagation studies in automotive duct systems. 2007.

34. **Meelis Pohlak**. Rapid prototyping of sheet metal components with incremental sheet forming technology. 2007.

35. **Priidu Peetsalu**. Microstructural aspects of thermal sprayed WC-Co coatings and Ni-Cr coated steels. 2007.

36. **Lauri Kollo**. Sinter/HIP technology of TiC-based cermets. 2007.

37. **Andrei Dedov**. Assessment of metal condition and remaining life of in-service power plant components operating at high temperature. 2007.

38. **Fjodor Sergejev**. Investigation of the fatigue mechanics aspects of PM hardmetals and cermets. 2007.

39. **Eduard Ševtšenko**. Intelligent decision support system for the network of collaborative SME-s. 2007.

40. **Rünno Lumiste**. Networks and innovation in machinery and electronics industry and enterprises (Estonian case studies). 2008.

41. **Kristo Karjust**. Integrated product development and production technology of large composite plastic products. 2008.

42. **Mart Saarna**. Fatigue characteristics of PM steels. 2008.

43. **Eduard Kimmari**. Exothermically synthesized B_4C-Al composites for dry sliding. 2008.

44. **Indrek Abiline**. Calibration methods of coating thickness gauges. 2008.

45. **Tiit Hindreus**. Synergy-based approach to quality assurance. 2009.