Product modelling and model based product realisation

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Abstract
A vision of the future production methods and systems is given in this paper. The basic idea is a model based perspective to future product realisation. The basic aspects of modelling, such as the objects of models (structures, functions, manufacturing systems, etc.), the reasons of modelling (to design, to learn, to explain, etc.) and the types of models (mathematical, physical, logical, etc.) are discussed together with model definitions. Product and production models are analysed taking into account human and computer based information processing and intelligence. Finally distributed artificial intelligence, object oriented distributed systems, virtual reality and virtual manufacturing are detailed as means and tools of future model based production.

Keywords
Product model, modelling, computer intelligence, human intelligence, production

1 INTRODUCTION

A way to achieve a more rapid product realisation is through people working together in cross functional teams effectively supported by IT modelling of

The original version of this chapter was revised: The copyright line was incorrect. This has been corrected. The Erratum to this chapter is available at DOI: 10.1007/978-0-387-35357-9_22
A. B. Baskin et al. (eds.), *Cooperative Knowledge Processing for Engineering Design*

products, processes etc. in a data driven and information integrated product realisation system.

Model based product realisation and life cycle support processes must in the future have a more theoretically sound foundation. Design synthesis, analysis and modelling theories and theories of problem solving, collaboration and communication, etc., are therefore of utmost importance to study, develop, and apply. The Axiomatic Design Approach, (Suh, 1990) and Altschuller Theory of inventive problem solving (Altschuller, 1988) gives an important theoretical base for design.

2 VISION OF PRODUCT REALISATION

A tentative vision of tomorrow's product realisation in a highly competitive and global business environment can be stated as follows. Main product value will be added through human information processing amplified by IT modelling of products, processes and manufacturing resources etc. in stead of processing physical materials.

The goal of creating a model and simulation based Product Realisation Process, PRP, from customer requirements, is to effectively support a cross functional development team to realise:

- early product requirement specification;
- early product specification and work of innovative creation;
- doing right from beginning to end by focusing on the right issues in the right phase of development and by closed loop direct verification feed back;
- having a transparent and complete picture of the development process with developments and status directly available for all team members in a communicable and directly useful format for interaction, contributions and further detailing;
- a cost effective and fast product realisation process based on all team members' involvement and contributions;
- a value adding product with defined life cycle design and support system.

The goal is then to be able to design an effective product realisation process based on the concept of modelling and be able to:

- design needed processes
- design needed resources
- set and achieve PRP goals
- predict and control the overall product realisation and life cycle processes.

Modelling of product realisation process and life cycle processes aims at modelling the processes to be - to model the processes we want to realise!

The quality and effectiveness of our PRP and life cycle process we want to be able to measure based on our modelling and simulation, before we realise the processes.

The quality and effectiveness of a Product Realisation Process, PRP, can be measured as the ability

- to do the right things - to realise products which are value adding to the customers;
- to do things right the first time, from beginning to end and verify that it is right;
- to use minimum resources for product realisation, product life and retirement;
- to make minimum environmental influence through the product realisation and product life cycle.

The ability to build relevant models in computer - which are computable - in an interactive and integrated synthesis and analysis process will be of utmost importance for a successful PRP. The computable models should compute and give correct answers to the asked questions, within given tolerances for the model, and answer the questions for which the model has been developed.

3 THE MODELLING AND MODEL FOUNDATION

Building models have since a long time been a very important tool for designers. Leonardo da Vinci built numerous models to verify, visualise and communicate his designs. Today we are more or less able to build models in computer from early stages of design to fine detailing.

A very important argument for working and communicating using models is that it structures data into relevant information units for a number of tasks in the Product Realisation Process. Models will help man to filter our relevant information for different tasks from an overwhelming flow of information and in searching for the right information. "Survival goes to the best informed", (Miller, 1990).

Model comes from the Italian word **modello** which stands for **representation**
Image " " " Latin " **modulus** " " " **small measure**

In a technical context a model often stands for a three dimensional reproduction, often in a smaller scale. Models are as everybody knows used in architectural design, in ship building and in the manufacturing industry for visualisation or testing purposes as well as for hydrodynamic tests of scaled ship hulls, turbines or in wind tunnel tests. In the scientific field models are used to give a deliberately simplified description of a phenomena.

A mathematical model is a mathematical structure of expressions and operations representing an abstraction of a real world phenomena, process or object behaviour. Models often fill very important pedagogical functions. They are also a very important means for communication among people to understand a proposed development or phenomena.

WHAT do we want to model for example?

- Structure
- Function
- Principles of a solution
- Shape and dimension
- Behaviour
- Phenomena

WHAT is the purpose of building models? - A tool for

- Creation and Innovation
- Design and Detailing
- Learning, Teaching
- Explanation
- Presentation, Visualisation
- Communication
- Prediction
- Verification - Analysis and Simulation

WHAT types of models can we create for example?

- Mental models - thoughts
- Physical - Scale-, arrangements-, clay- and work-models, mock-ups etc.
- Mathematical
- Logical
- Geometrical - graphs, surface models, solids
- Structural
- Topological
- Behavioural
- Heuristic
- Descriptive - these models will describe, classify or order
- Prescriptive

First of all we can say that mental models as we understand and define them are the core for information and knowledge development. It is important to notice that a model of something is not the same as this something in reality. In reality it is something, (An object or phenomena) which we want to abstract information about and describe in a simplified way. The purpose might be better understanding. communication or predicting behaviour etc.

It is important also to notice (stated by Douglas Ross among others)

- the purpose of a model - what question do I want to get answers on, from a certain model;
- the view points from which the object or phenomena to be modelled is observed;
- to which detail the model is made and should be relevant.

How can we define what a model is?
How can we characterise a model?
How can we validate a model?
How can we use a model for different purposes?
It is important to be able to know how useful a model is and can be.

4 DEFINITIONS OF MODEL

- A model is an analogy of an object or phenomena which we want to study.
- A model is an abstraction of a real object or phenomena or thought of object.
- The model represents the limited information which has been abstracted from reality - the real object.

The value of a model can best be defined as how well the model can give correct answers to the questions we want to put and how well it can give correct predictions. The value of a model is, so to say, defined by how well the model responds with correct output for different input. That is how well the model mirrors the relation between cause and reaction of the studied object, using models.

With rapid prototyping or Free Form Fabrication we are now able to more quickly study the relation between models and real world objects and their behaviour. Being able to quickly build prototypes for practical testing makes it possible to verify capabilities of different models for analysis and simulation etc.

5 DEFINITION OF PRODUCT MODEL IN COMPUTER

A model of a product is a product model. When talking about models in computer we have to represent the abstracted information as a model in the computer. The product model in the computer (digital product model) is then a representation of a number of relevant properties of a product or thought of product. Properties which are represented in a structured, integrated and consistent way. A "complete" product model is a model or a set of models which represent "all" relevant properties of the product in a structured, integrated and consistent way.

Citation marks are used here because a model never will be "complete" only complete enough in relation to its purpose. A model will never model "all" relevant properties of a product.

Each product model should give answers to the relevant questions for which the model has been developed. A communication of models should give answers to the combined set of questions.

6 HUMAN INFORMATION PROCESSING - A COGNITIVE FOUNDATION

Man can be regarded as an information processing system according to Newell & Simon (Newell & Simon, 1972). The information processing system is placed within an external problem situation. The information processing system has input and output organs, an information processing unit with a control system and an internal memory. The internal memory can be divided into a short term memory and a long term memory. Investigations done by Miller (Miller, 1956) have showed that seven (plus/minus two) information units or symbols can be presented in the short term memory. The long term memory can be regarded as unlimited. The information processing system can be amplified through "extending" its short term memory by using an external memory like paper, or for instance in our case a graphics screen.

Long term memory

In the long term memory is stored information of more long term nature like knowledge. The information is stored in form a symbols or symbol structures. A symbol structure can be replaced by a new symbol by which we have one information unit that represents the whole structure - a chunk. Through this mechanism different abstractions can be handled. The symbol of a car can replace the symbols of engine, chassi (body), gear box, transmission and body etc. and on thê higher level we can have a symbol for vehicles. Reading out information from the long term memory takes about a couple of hundred milli-seconds for fresh information but for old it will take much longer time.

The processing time for fixating an information unit can be estimated to about five to ten seconds. An interesting observation is that learning new symbols can be speeded up about 100% if they in a meaningful way can be associated with already overlearnt symbols (Newell & Simon, 1972).

Short term memory:

The short term memory can be characterised by that it contains a number of symbols that are immediately available for the information processing system. In the short term memory are stored partial results from the information processing together with input/output symbols. The information in the short term memory declines with time. In order to keep information in the short term memory the human is forced to repetition.

Human thinking:
In the human thought process the mental model of the problem is being changed and updated through thinking operations. In very moment of the problem situation the mental model is defined by special symbols in a well defined structure. This state of the mental model is called a knowledge state.

Problem space:
The problem space is a theoretical conception and means the knowledge space within which the information processing system is seeking a solution out from the presented problem situation. Every problem space is an abstraction of the external objective problem situation according to Newell & Simon. The problem space can then be defined by:

- A mental model of the problem
- Knowledge about the goal and guidelines for the problem solving - a goal state
- All operations that can change a knowledge state from start to goal
- All knowledge states which are theoretically possible as a consequence of all possible operations on all knowledge states from the initial mental model to the final goal.

Perception
For the problem solver it is important to be able to perceive relevant data from a scene or a picture. The goal is to perceive the relevant information from the objective problem situation according to the goals for the problem to be solved. If for instance spatial relations and dimensions are important these must be possible to judge on the basis of perceived information.

A main thesis is that external scenes and pictures from reality which are well known to the human eye use the correspondent internal symbols in the short terms memory. The same is relevant for familiar and well-known symbols. Picture of parts, assemblies or manufacturing systems, familiar to the designers or planners,. generate symbols in the short time memory

The external memory:
A human information processing system equipped with an external memory will show quite other properties and performance than an information processing system that has to rely only on the short term and the long term memory. A piece of paper to write on is an effective external memory. Even if the external memory is only available for observation the problem solving process will be amplified.

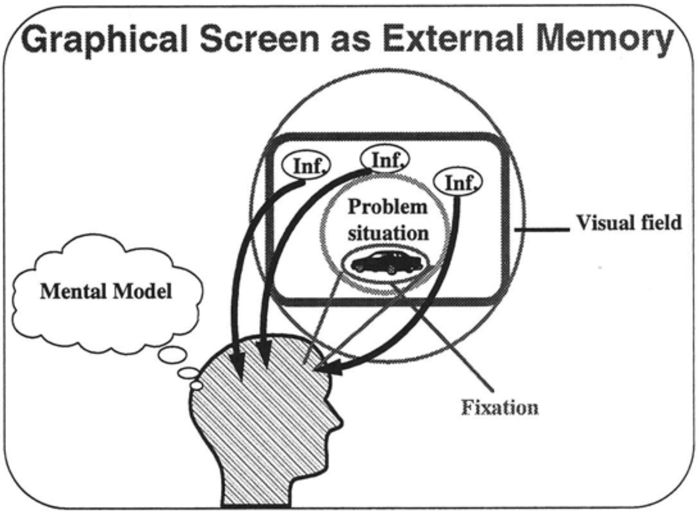

Figure 1: The graphical screen as an external memory for problem solving in design, etc.

According to Newell & Simon (Newell & Simon, 1972) it goes a hundred time faster to multiply two four figured numbers using papers and pen compared with no external memory at all.

The focusing area of the visual field is really a way of "expanding" the short term memory in problem solving, Figure 1.

It is important that it is easy to "write" into the external memory and that the "writing" is quick. With an overlearnt "writing" procedure into the external memory the load on the information processing system for this activity will be rather minimal and the concentration can be focused on the problem solving.

7 A MODEL BASED PERSPECTIVE ON FUTURE PRODUCT REALISATION

From the reasoning above we have developed our perspective on the development of future product realisation systems based on modelling to effectively support man.

- A theoretical frame work for future engineering environment
- Software kernel tools for future Product Realisation System
    - the product modelling tools;
    - process modelling tools;
    - manufacturing resource modelling;

- product life cycle modelling;
- tools for man model communication /interaction;
- framework of product model and data driven applications for product realisation;
- archive repositories for product, process and manufacturing resource model data and knowledge etc.

- To amplify human intelligence and capability in
  - problem solving
  - communication
  - collaboration
  - competence build up and
  - continued life long education.

In order to better understand the demands on tools for human problem solving, communication and collaboration we can elaborate a little bit on the human behaviour. In communication with other people we know that, what you hear you only remember 10% of. What you see, you will be able to remember about 30-40% of, but what you are being able to do you will understand more deeply and thereby get even better remembrance of 60 - 70%. From this verified perspective we can draw the conclusion that computer tools for human problem solving, communication and collaboration towards a common goal of developing complete solutions should emphasise that the documentation of work results should be

- automatically captured in the design and development process in the computer;
- made in such a way that it can be of direct use for the further development in the computer;
- related to the actual product requirements, specifications and problem areas;
- easy to comprehend and understand;
- stored according to reflective learning principles (a meaningful wholeness).

We will then be able to support and amplify man as an individual and the collaboration of whole groups by supporting

- the memory of what has been told, showed and discussed;
- the understanding of what has been heard and seen;
- the easiness of applying and further develop what has been heard, seen and already done;
- the easiness of doing it yourself to achieve learning by doing.

All of it will be supported through a problem related and model based documentation. Then it must also be easy to find, understand and apply known facts. This puts a lot of demands on future tools for natural interaction, like tools for handwriting, input, handdrawing / sketching and decoding of voice information by the computer. We want to achieve as wide "band width" as possible for communication between man and computer.

Sketching has long been an important tool for thinking. R. H. McKim (McKim, 1980) recognised eight different types of thinking operations which can be amplified and supported by sketching

- Abstraction for generalisation and classification
- Concretising for detailing., focusing and clarification
- Modification through exaggeration or caricature
- Transformation of picture identity through for instance metaphors
- Manipulation to rearrange or make separation
- Time scanning of a sequence in mind or through successive sketching
- To express, study and develop
- Testing to find inconsistencies

Sketching, hand drawing and writing in a mixed combination in a modelling world in computer will probably considerably increase the problem solving capacity of engineers. All the different inputs demand a lot of the interpretation, matching the input with what has been achieved and deducting what should be done. Input should through a general interface be clearly separated from the representation of information in the computer. It all puts a lot of demands on information presentation. Graphical presentation tools for product model information, both geometrical and technical has to be presented in a consistent and coherent way.

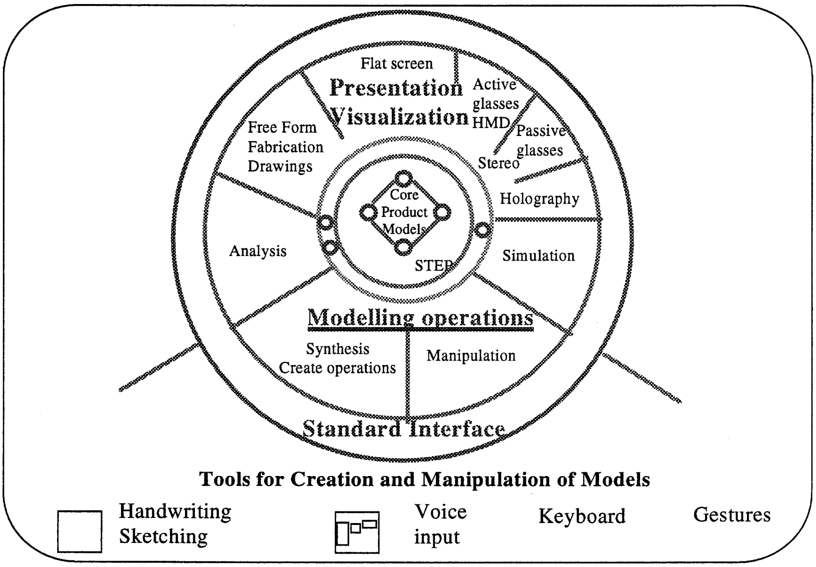

Figure 2: Tools in human interaction with IT.

The same goes for different types of underlays like standards, design rules for dimensioning or manufacturing like assembly or parts manufacturing etc. The interactive tools and the representation in the product model, see Figure 2 should provide the possibility for the designer and planner etc. to really express new thoughts and relate them to achieved knowledge and applied standards etc..

These tools should make it possible to stepwise refine and to build further on achieved results. They should allow for focusing on primary functionality to fulfil the requirements and letting other minor details be left open for detailing later on

The product modelling tool is really a tool for the product realisation process. It is a problem solving tool for the development, testing and verification of different solution concepts from idea to final product.

The product modelling system should really be in the form of an external memory to man and the collaborating team. It should help in keeping the team updated and goal oriented. The goal of AI research was in the beginning at least, to develop thinking machines, our goal is to apply advanced programming techniques, also from AI, to develop computer support for thinking individuals and groups.

The computing environment should support the retrieval and search for all kinds of available knowledge and necessary underlays, represented in the computing network within or outside the company. It should support collaboration between different individuals and competence groups within and outside the company.

The system environment should have the functionality to present different underlays in a consistent way related to its context and presented in a way easy to understand and in a transparent structure and form

Effective tools for human interaction - Conclusions

- What you see is what you get

  The perception of easy recognisable symbols and objects with characteristic shapes, colours and other attributes and behaviour

- You see what you can do

  It should be intuitively evident what is possible to do with a system

- You see how you can do it

  Easy recognisable tool symbols for different operations. Generic tools which behaves in accordance with what is expected and the established functionality. Application specific tools, with the same operational semantics, consistent with expectations

- The system behaves as you expect

  Like in "Virtual Reality" for instance

- Expressiveness

It should be possible to as directly as possible express what you think and intend to do in the system. There should be a close correspondence between mental operations and operations in the system

- The system is transparent to you

You see the complete system, how you can work with it and all aspects of achieved results

- The system supports your information navigation and filtering

8 FUTURE STEP BASED AND MODEL SHARING PRP SYSTEMS

Information tools for acquisition, representation, storage, distribution and change management will be very important to acquire and apply effectively in an PRP organisation.

Conceptual analysis of Engineering Concepts, Terms and definitions in PRP will be needed to build and create shareable representations of information contents capable of supporting logical integration and interaction between diverse functions from product requirements through conceptual design and detailing to conceptual design of processes and manufacturing systems and to manufacturing. The STEP development is an important contribution in this direction.

Data sharing systems for the product realisation process must in the future take advantage of and build on the STEP standard. STEP application Protocols and STEP Standard Data Access Interface, SDAI, in order to be cost/performance realistic. Open data must exist independent of the applications or systems that create them and be accessible to and usable by any other applications, systems or tools that need to use them.

Application vendors will then be able to sell their systems to any end user who is having a STEP data integrated engineering environment.

Data integrated systems must be further developed to information integrated systems. Models must then have a semantic representation. The engineering elements of the product model must then be represented. A semantic layer for "intelligent" product models can be built on top of STEP product models with a clear well defined interface. It is then possible to introduce a semantic representation piece by piece to industrial applications while waiting for the STEP further enhancement in this direction with features etc.

It is important to distribute models and data bases in a company to those who are responsible for the information and keeps it up to date. Figure 3 illustrates the principles of using STEP's Standard Data Access Interface, SDAI, and/or CORBA (CORBA Common Object Request Broker) for separate applications to read and write data into a number of commonly available object-oriented data bases in the company.

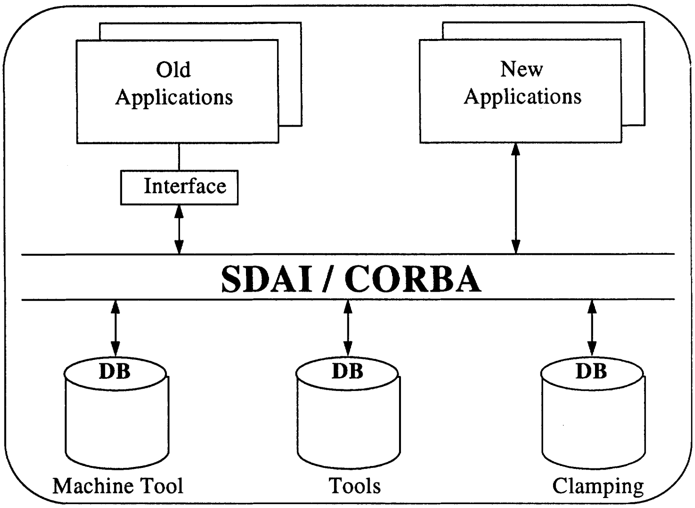

Figure 3: Future system architecture using SDAI and CORBA.

9 CONCLUSION - A TENTATIVE VISION OF FUTURE PRODUCT REALISATION

A tentative vision of tomorrow's product realisation can be stated as follows.

Main product value will be added through human information processing amplified by IT modelling of products, processes and manufacturing resources etc. in stead of processing physical materials.

A more rapid product realisation will be realised through people working together in cross functional teams effectively supported by IT modelling of products, processes etc. in a data driven and information integrated product realisation system.

In product realisation doing it right the first time and increasing quality is of main importance. The right competencies must be involved taking responsibility by also seeing the complete picture through computer analysis, simulation and optimisation based on IT modelling of products, processes etc.

Better market adaptation and customer satisfaction must be achieved through IT modelling of products, processes, material behaviour and life cycle issues etc. by increasing awareness of possibilities, constraints of a product in early development and market testing.

Information Processing, Communication and Information integration will be the future enabling tools in the Product Realisation Process, PRP.

Manufacturing Resources, process information for manufacturing feasibility studies and manufacturing planning will be represented in the form of Manufacturing Systems - resources - Models and Process Models to drive design for manufacture and planning for manufacture and final manufacturing.

Tools for Product Modelling and Process Planning (design and manufacturing plan synthesis) must be closely integrated with tools for engineering analysis and simulation, need for stepwise development and verification. Supporting the concept of doing right first time. Those tools should be targeted towards Global Optimisation (not towards Local Optimisation as of today)

Modelling products as well as manufacturing resources should take advantage of and be based on STEP development. Figure 4 shows a concurrent engineering schema built on AP(Application Protocol)214 for products within automotive industry, AP224 for manufacturing features, AP 213 for NC and the preliminary new work item Apxxx for Design and configuration of manufacturing systems.

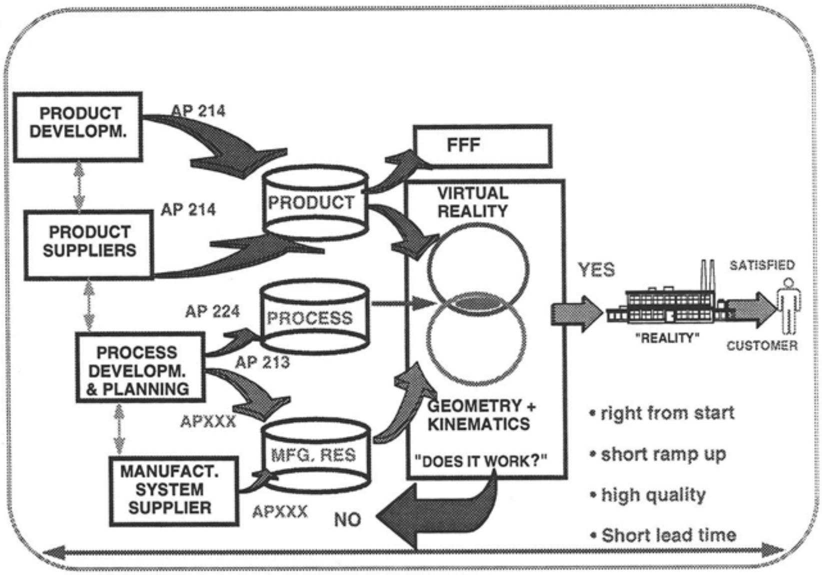

Figure 4: A concurrent engineering schema built on Aps.

Product Modelling and Analysis Tools effectively supporting cross functional teams in Conceptual Design constitutes the greatest possibility for Value Added Product Realisation. 90% of the total life cycle cost of a product are defined in the conceptual design phase. Tools that effectively links and transforms consumer needs, for function and external perception, to product specification will be important in focusing idea creation and early conceptual design.

Information tools for acquisition, representation, storage, distribution and change management will be very important to acquire and apply effectively in an PRP organisation.

Conceptual analysis of Engineering Concepts, Terms and Definitions in PRP will be needed to build and create shareable representations of information contents capable of supporting logical integration and interaction between diverse functions from product requirements through conceptual design and detailing to conceptual design of processes and manufacturing systems and to manufacturing.

A holistic organisational, technological and human phychosocial environment will be needed and has to be developed to effectively support the cross functional teams. The advanced product realisation, manufacturing systems, computers and information systems will never work without knowledgeable and competent people that are able to collaborate and organise themselves into effective teams, as illustrated in Figure 5. (Kjellberg, 1996)

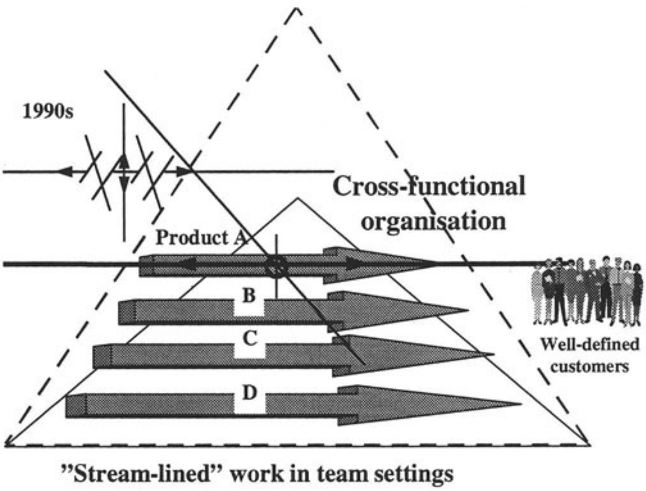

Figure 5: The process oriented, cross functional and flat organisation.

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11 BIOGRAPHY

Professor, Dr. Eng. Torsten J. A. **Kjellberg** was born in 1942, received a Master of Engineering and Doctor of Technology in Mechanical Engineering at the Royal Institute of Technology (KTH), Stockholm, Sweden. Project unit leader for the Research Unit on Computer Systems in Production, at the Swedish Institute for Production Engineering Research, IVF and KTH 1977-94. Dr Kjellberg have been project leader and Steering Committee member of many projects and also research programmes at KTH and IVF on Product Modelling, Process planning and modelling of also manufacturing systems. Docent (associate professor) in Computer Systems for Design and Manufacturing at KTH, Stockholm 1986. Head of the subject 1994 and professor 1996. Opponent at a number of Dr. dissertations in Norway and Sweden and member of Dr dissertation committees. Continuous Referee work for IFIP 5.3, IFIP 5.2 conferences and workshops and for Design sessions at CIRP General Assemblies 1991-94. Dr Kjellberg have received a number of personal invitations to make research presentations internationally. Member and Swedish representative and secretary of IFIP Working Group 5.3 since 1985. IFIP WG 5.2 Member since 1990. Chairman of the Technical Committee of Design, International Institution for Production Engineering Research, CIRP 1991 to 1994. Chairman of the CIRP Design Book editorial committee since 1994. Since Oct. 1996 ISO SC4 authorised project leader for an application protocol planning project on "Design and Configuration of Manufacturing Systems".