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Computerized design analysis in machine construction

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COMPUTER AIDED DESIGN - CAD

Computerized design analysis in machine construction

by

Maciej Bossak

There are four main fields of CAD: geometric modelling, analysis, testing and drafting.

Computerized design analysis, which is performed mostly with the aid of computer based analysis techniques such as the finite elements method, simulation or optimization runs parallel with prototype build and testing and its results form the grounds for design evaluation. The results of such CAD activity are among the most effective and beneficial ones. If the selection where to concentrate CAD efforts have to be made, the computerized design analysis should be the first choice.

Differencies between conventional design and CAD.

For decades the design process of machines has been based primarily on a prototype build and test cycle utilized to verify the adequacy of the product. If some problems were encountered during prototype evaluation or after the product was in the field, design "fixes" based on past experience were implemented in order eventually to eliminate or minimize these problems. There are many reasons why now this "evolutionary" design methodology is not sufficient and why many manufacturers are utilizing new techniques in mechanical design. (Fig.1)

These reasons are primarily related to the greatly increased pressures being exerted upon the engineering function:

- users are continually demending more productive machines. The design specifications for these new machines often exceed the experience base of today's engineering organizations and may require revolutionary rather than evolutionary concepts,
- government regulations and standards impose to reduce noise and pollution as well as to increase safety and comfort of operators,
- energy saving requires to develop an optimal design from a weight-efficiency standpoint,
- the changing competitive nature of market is beginning to exert a greater presure on getting a new product into the customer's hands as quickly as possible in order to counter the introduction of superior new machines by competitors.

In recent years, [illegible] and analysis techniques has made it possible to respond to [illegible] pressures by allowing design engineers to:

- process massive amounts of experimental data and extract the desired useful information to obtain practical design solution,
- evaluate the structural performance and reliability of new machines in the concept stage prior to initial prototype build or delivery of initial production machines.

In doing so, manufacturers have realized significant reduction in overall engineering costs per design as well as compression of the overall design cycle time through elimination of several iterations in the costly build and try process. Utilization of these techniques has also led to new machines which exhibit superior performance characteristics and reliability.

The quality of the product can be estimated by the set of characteristisc such as: reliability, stability, weight, strength, cost etc. The necessary condition for estimating, in quantitive manner, these characteristics during the design phase is elaboration of adequate
Fig.2 design criteria. The design criteria are estabilished upon the data taken from experience, analyses, tests as well as competition, and describe what and how should be calculated (how - means method and accuracy).

As a consequence at the heart of computer aided design is the mathematical model of the product, created in the computer, according to the design criteria.

The model simulates product performance in the computer in contrast to the traditional prototype build and test method. The model is exercised to determine [illegible] of the product as a whole and loads on components during operations. Next, individual components designs are refined and evaluated based on these loads.

Later, a prototype is built to verify the design. In each of these
Fig.3 steps, the model is refined in an iterative procedure to include increasingly precise design informations. Finally, the optimum design is released to manufacturing.

In computer aided design, each analysis is connected with the following correlation:

OBJECT → PROBLEM → DISCIPLINE

Figure [illegible] shows, for example, the objects, problem areas and scienti-
Fig.1 fic disciplines engaged in today s automotive analysis.

There are three types of work connected with CAD activity, namely: research, implementation and applications. Their relationship and aims are as follows:

Research	Theory -> Model ↓	Methods
Fig.5 Impementations	Problem -> Model -> Software ↓	Tools
Applications	Data -> Software -> Results	Analyses

For estabilishing successful CAD activity the following elements are necessary:

1. Properly elaborated design criteria (methods),
2. Adequately oriented software,
3. Reliable hardware,
4. Highly educated and trained personell,
5. Apprioprate organization.

Methods.

Computer aided design in mechanical engineering depends primarily on two disciplines:

Computational mechanics, and

Computer graphics.

Fig.6 The first one is responsible for elaborating methods and associated
Fig.7 application software necessary for solwing encountered problems.

The second one is responsible for developing methods and associated basic software for efficient utilization, in engineering practice, methods and application software.

A variety of engineering problems can be managed in a standard mathematical manner on the basis of physics once the uniform differential or integral relationship has been found. This is the case with method
Fig.8 oriented analysis systems such as, for example, finite element systems or boundary element systems,

A uniform mathematical methodology is applied to such widely differ-
Fig.9 ent problems as mechanics of solids (elasticity, plasticit), heat conduction, mechanics of fluids, lubricating film problems etc.

Modern computer aided design activity is based on the information processing approach which can be interpreted as integration of methods.
Fig.10 All CAD-related methods are assembled in the method bank. Standarized basic software serves for controlling the method bank components and handling communications with the data base, including its management. It serves also for integrating all functions including graphics and dialoque. The method bank programs are capable of being executed on peripheral devices (screens, plotters, digitizers) of any type.

Software.

It must be realized that software is the greatest CAD dilemma of thes days and will be for the next, at least, five years. The progress in technology (LSI and VLSI) has drastically reduces the price of computer

Fig.11 hardware and rise , at the same time, its perfectness.

Due to the need for engineer-programmer with a strong background in the field of applications (in our case mechanics), numerical methods

Fig.12 and software engineering the cost of labour has gone up. The increased effectivness of system software has made possible the cost per instruction remained nearly constant (at about 10 $) for the past two decades. At the same time the users are attempting applications which are increasingly ambitious, the number of instructions goes up drastically (e.g. NASTRAN has doubled the source instructions in about eight years from 200.000 to 400.000 statements) and hence increase of developing time

Fig.13 and cost of computer software (as a rule 10 is the average number of program lines written by programmer each working day). Experiences in CAD activity show that it is more effective if programming is performed by staff members involved in the problem.

Fig.14 Figure 14 illustrates graphically the trends in relative-costs betwee hardware and software during the last 30 years.

Software for CAD can be divided into three groups:

1. System software. Programs that are tools for the user to generate programs, debug and test them, modify them and finally execute them (operating system, machine language, assembler language, compilers, editor, loader, linkage editor, testing, debugging and diagnostic programs). They are generally written and delivered by the computer manufacturer for one specific computer.

2. Basic software. Programs that are tools for the user to perform general tasks (data base management system, graphical system, library of mathematical subroutines). They are generally written and delivered by specialized software groups connected or not with computer manufacturer.

3. Application software. Programs for specific, well defined tasks for a particular applications in a particular field. They are divided into two groups: method oriented and product oriented depending on whether the methods are offered with or without reference to specific objects of analysis. Typical examples of first group are the finite element or boundary element systems. Typical examples of second group are progr sets for crankshaft or gearbox designing.

Very important role plays software dokumentation. Without good documentation it is practically impossible to utilize programs effectivelly.

Before buying the software it is necessary to recognize it carefully from the efficiency and compatibility points of view.

Hardware.

At the present time the availability of small computer syytems causes
Fig.15 that computational power is no longer restricted to large organizations.
Fig.16 Small computer systems which vary from personal computer to mini computer can act separately or as a terminal to other computers.

The small computer system is relatively slow for floating point (arithmetical) operations and relatively fast for logical operations.

Therefore, a cost effective approach is to transfer the interactive processing to the small computers and to use mainframe computers for batch processing only. Interactive processing is very important for CAD since it can increase the productivity of engineer. The largest cost of a computer analysis is the engineer cost associated with model gene-
Fig.17 ration and results interpretation. Interactive processing can make a significant reduction in the costs.

The use of interactive terminals on small computer systems, coupled to mainframe computer for batch solutions, is called distributed proce-
Fig.18 ssing. It is atractive for the following reasons:

- capital and maintenance costs are lower,
- the user can have direct access to the computer,
- interactive processing can be removed from mainframes,
- most analyses (80% or more) can be performed on small computer systems.

Today's interactive terminals has usually form of the so called work-
Fig.19 stations. This term is used for a set of graphics hardware components, enhanced by some local computing power, and arranged with special attention to ergonomic aspects. Commen parts of workstations are: a large work table with digitizing tablet, two screens with different characteristics, off-screen hard-copy, plotter etc. The two screens are frequently either an alphanumeric screen for command echoing and system messages plus a graphic screen for the graphic interaction, or a black-and-white vector refresh display for fast interaction plus a color raster display for the presentation of several more slowly changing views of the object being worked on.

Superminicomputers with 32-bit wordlength and virtual memory are capable of performing entire CAD analyses using even very large programs (systems).

On the other hand there is also a great need for faster and faster mainframe computers (supercomputers) particularly for the comprehensive analyses which involve detailed simulation of the behaviour of structures under a wide variety of operating conditions. An extension of the analysis phase involves the activity of computer aided engineering (CAE), which encompasses not only analysis, but comprehensive geometric modelling, design, drafting and testing. All of these activities are dependent o sufficient computer power.

Personnel.

Efficient applications of CAD methods need highly qualified engineers with a strong background in the field of applications, numerical methods and software engineering.

Experinces show that at least two years of continuous education and training are necessary for preparing independant workers in CAD.

That is why the education in, and hence correct usage of, CAD techniques is a topic that has just recently received wider publicity (education and training are very often recognized as a kind of CAD activity).

Economical aspects of CAD.

Several authors have investigated methods for the economical evaluation of CAD. It is vitally important that the analysis and evaluation should not only consider the design process itself, but also the consequencies of using CAD for the minimization of costs in such areas as: material savings, improved job planning, greater efficiency of experimental investigations, enhanced potential for product validation, shorter lead time, improved product quality etc. Fig.20

Tendencies in CAD.

The future of CAD is CAE. CAE is a product design and development philosophy integrating key engineering design, analysis, test, drafting/ documentation and related manufacturing functions into each phase of the mechanical product development process. The essential elements of CAE are Fig.21

- integrated application software,
- integrated computer hardware for each engineering functions,
- integrated data base for overall project and product control.

The CAE approach is extremly flexible since it relies on information from each component as well as how components connect a sytem. A change in one or more components can be evaluated easily by modifying the mathematical description of those components, and re-running the system model. Fig.22

References.

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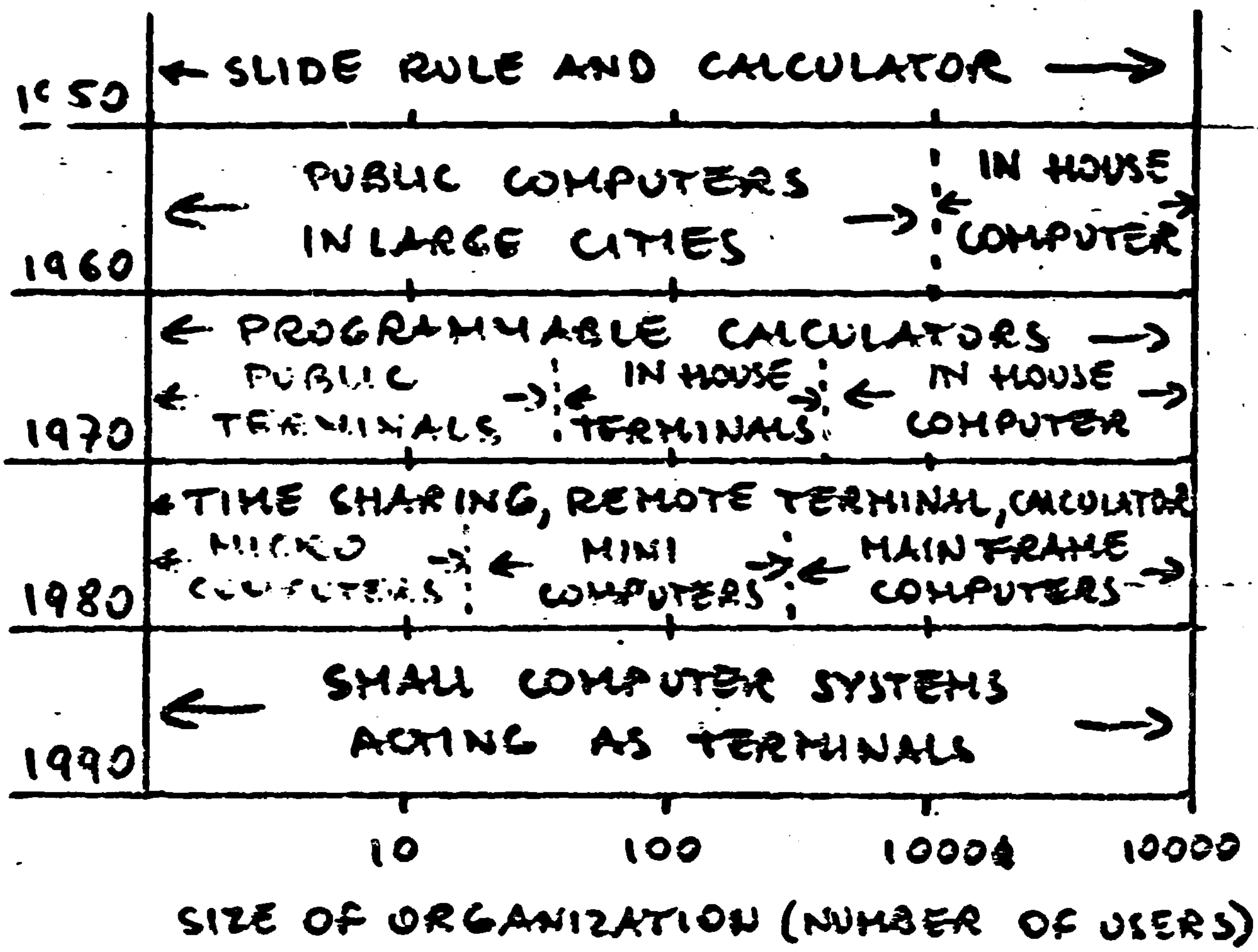
2. Radaj D., "Integration of analysis methods in the context of industrial requirements", Proceedings of the 10th International FEM Congress 16-17 Nov. 1981, Baden-Baden.

3. Zielinski R., "The role of industrial engineering research and development centres in developing countries", UNIDO, 1985.

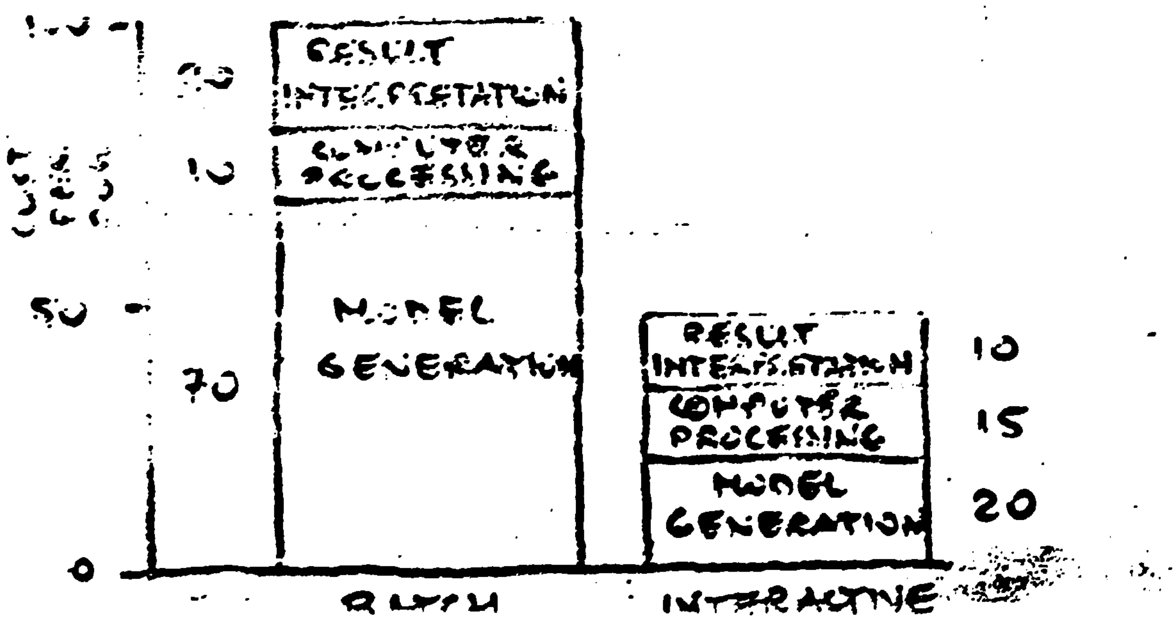
4. Bossak M. "Trends in the finite element method applications", Proceedings of International Conference COMPCONTROL 83, 13-15 Sept. 1983, Bratislava.

Examples.

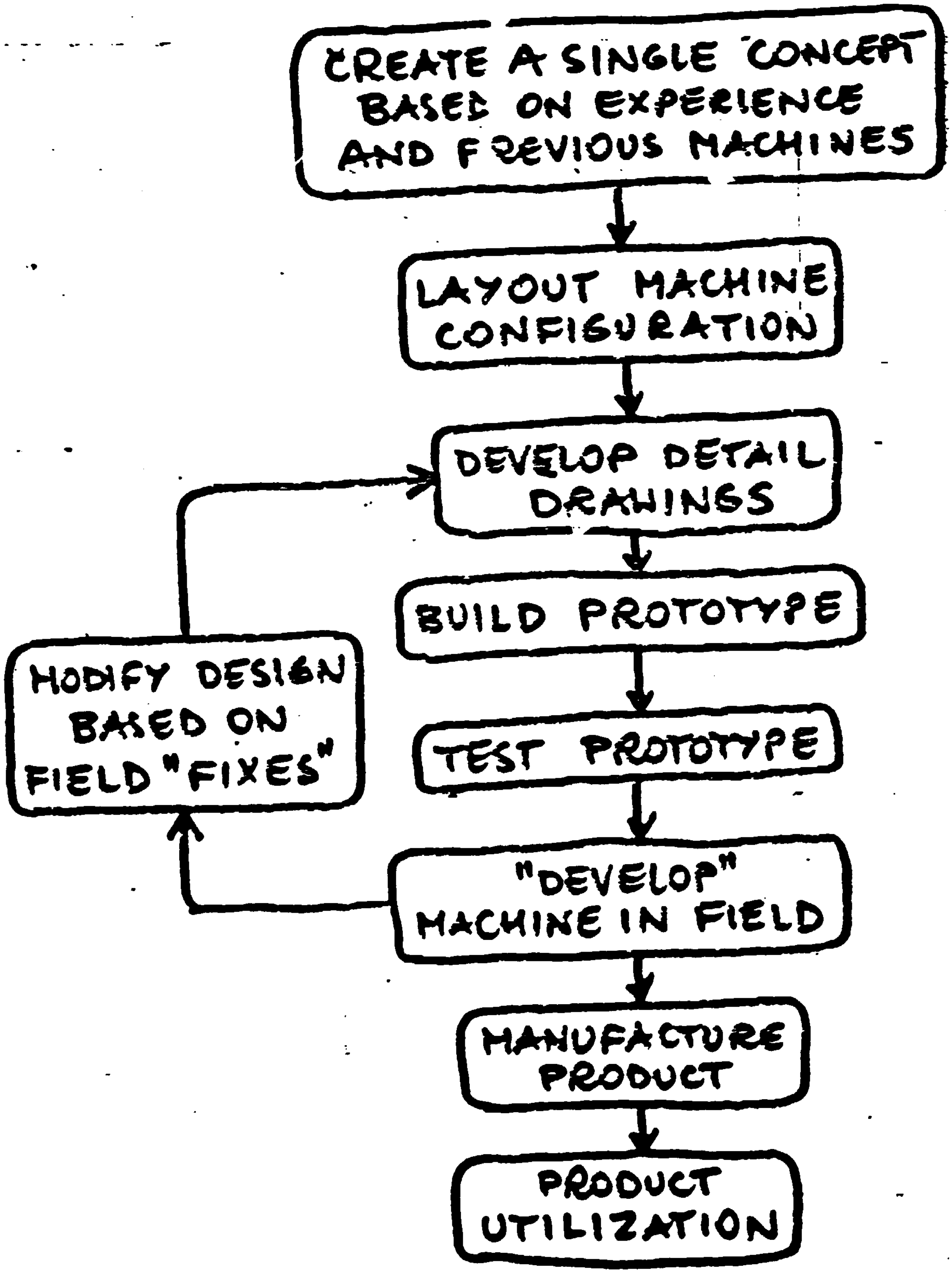
TREND IN COMPUTER USE BY ENGINEERS



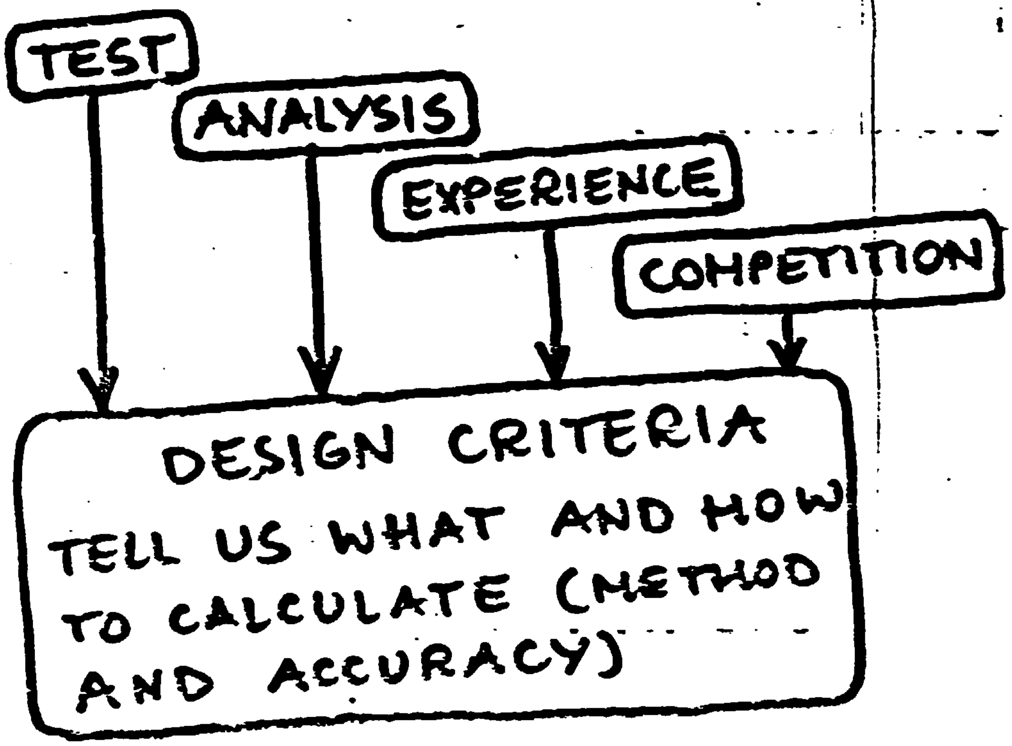
BATCH VERSUS INTERACTIVE COSTS



CONVENTIONAL PRODUCT DEVELOPMENT PROCESS



DESIGN CRITERIA



TYPES OF CAD ACTIVITY

RESEARCH	THEORY → MODEL ↓	METHODS
IMPLEMENTATION	PROBLEM → MODEL → SOFTWARE	TOOLS
APPLICATION	DATA → SOFTWARE → RESULTS	ANALYSIS

OBJECTS, PROBLEM AREAS AND DISCIPLINES IN AUTOMOTIVE ANALYSIS

OBJECTS

COMPLETE VEHICLE

....

DRIVE UNIT
TRANSMISSION
CAR BODY

....

ENGINE
GEAR BOX
DRIVE LINE
SUSPENSION
STEERING

....

WHEEL
AXLE
CRANKSHAFT
PISTON
CLUTH

....

BOLTS
WELDS
SPRINGS
GEARS
CHAINS
BEARINGS
DAMPERS

⋮

PROBLEMS

WEIGHT
STRENGTH
DURABILITY
RIGIDITY
STABILITY
VIBRATIONS
SHOCKS
MASS BALA-NCING
CRASHES, BEHAVIOUR IN ACCIDENTS
CYLINDER CHARGING
COMBUSTION PROCESS
HEAT
FRICTION, LUBRICATION

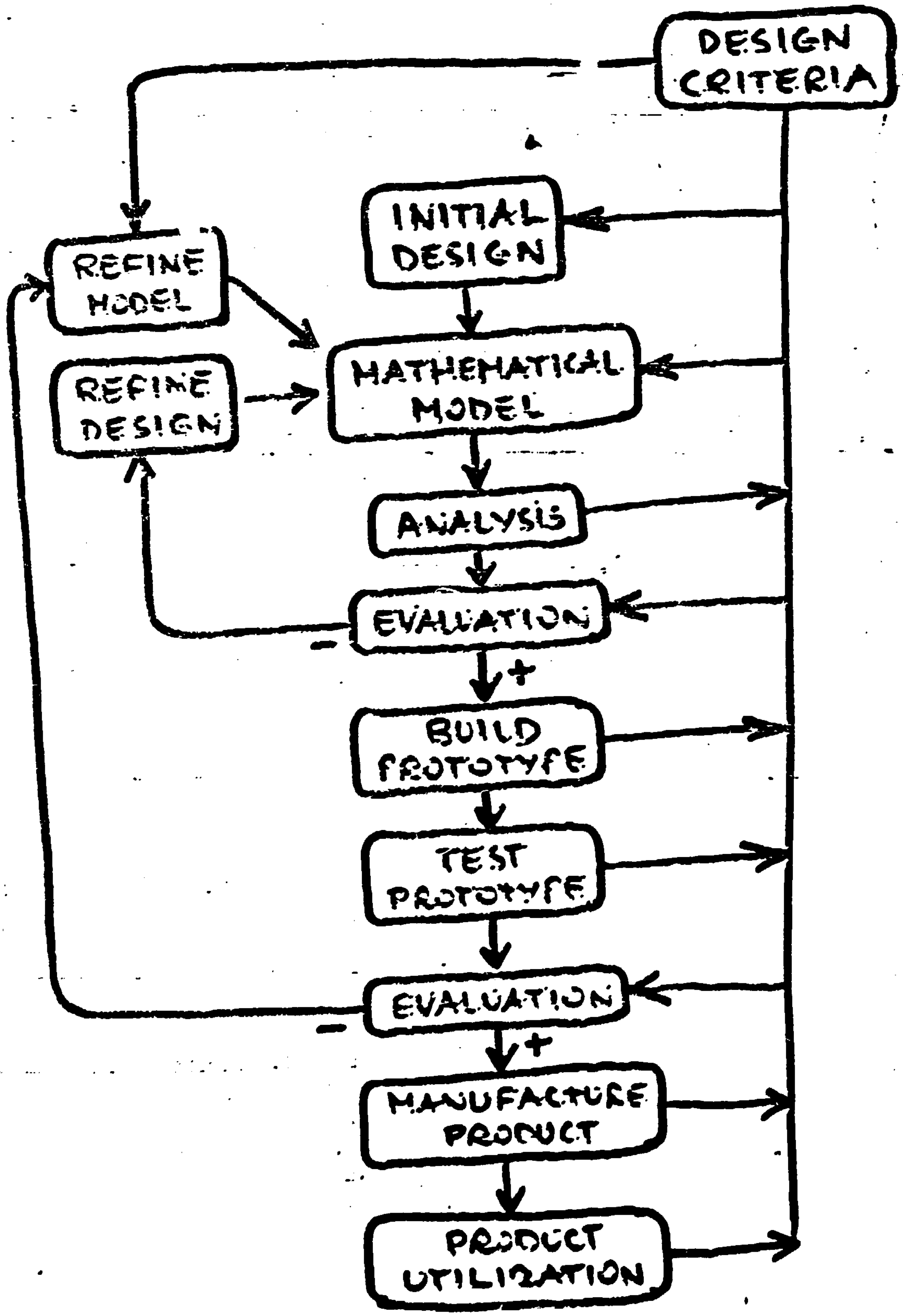
⋮

DISCIPLINES

MECHANICS OF DISCRETE SYSTEMS
SOLID MECHANICS
FLUID MECHANICS
GAS DYNAMICS
THERMODYNAMICS
MATERIAL SCIENCE
MATHEMATICS
COMPUTER SCIENCE
ACOUSTICS
TRIBOLOGY

⋮

PRODUCT DEVELOPMENT PROCESS USING CAD



THE MAIN COMPONENTS OF METHOD BANK

10

GEOMETRY DESCRIPTION METHODS: METHODS FOR THE REPRESENTATION OF GEOMETRICAL INFORMATION AND DIGITALIZATION

REPRESENTIONAL METHODS: METHODS RELATED TO GRAPHIC REPRESENTATION BY USE OF CLOSED PROGRAMS: HIDDEN LINES OR SURFACES, AREAS OF SHADOW, ANIMATED PICTURES, DIAGRAMS

EVALUATION METHODS: METHODS FOR EVALUATION OF EXPERIMENTAL DATA, ANALYSIS, SMOOTHING, INTERPOLATION, APPROXIMATION, STATISTICS, REGRESSION

REDUCTION METHODS: METHODS FOR REDUCING LARGE DATA SETS WITHOUT LOSS OF INFORMATION - CONDENSATION, TRANSFORMATION, MATRIX BANDWIDTH OPTIMIZATION

MODEL GENERATION METHODS: METHODS FOR GENERATION OF THE MATHEMATICAL MODEL, FINITE ELEMENT MESH GENERATION, LOAD GENERATION

ANALYSIS METHODS: METHODS FOR THE NUMERICAL EXECUTION OF THE MATHEMATICAL MODELS, ALGORITHMS

6

COMPUTATIONAL MECHANICS

THEORETICAL MECHANICS: THE THEORETICAL STUDY OF THE MECHANICAL BEHAVIOUR OF PHYSICAL SYSTEMS AND BODIES;

APPROXIMATION THEORY: THE FORMULATION OF DISCRETE MODELS, WHICH ARE APPROXIMATIONS OF THE EQUATIONS OF MECHANICS;

NUMERICAL ANALYSIS: THE DEVELOPMENT OF NUMERICAL METHODS TO ANALYZE THESE MODELS;

SOFTWARE ENGINEERING: THE DEVELOPMENT OF COMPUTER SOFTWARE TO IMPLEMENT THE NUMERICAL METHODS.

7

COMPUTER GRAPHICS

TO PRESENT DATA TO THE DESIGNER: GRAPHICAL REPRESENTATION CAN BE PERCEIVED IN AN IMMEDIATE AND INTEGRATED WAY: "ONE PICTURE IS WORTH A THOUSAND WORDS"

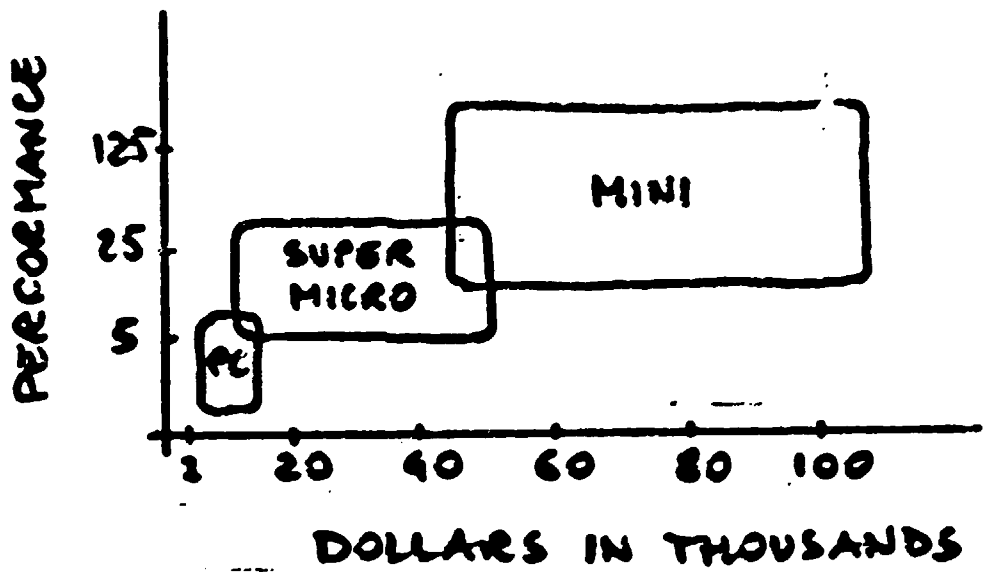
TO PROVIDE POSSIBILITIES FOR MANIPULATING DATA BY MEANS OF A COMPUTER GRAPHICS SYSTEMS.

PROGRAMMERS EFFICIENCY

NUMBER OF INSTRUCTIONS (NOI) PER TIME UNIT

DIFFICULTY DEGREE	DEVELOPING TIME (MONTHS) 6 ÷ 12	12 ÷ 24	OVER 24
	NOI/DAY	NOI/MONTH	NOI/YEAR
SMALL (SLIGHT CONNECTIONS)	20	500	10.000
AVERAGE (IMPORTANT CONNECTIONS)	10	250	5.000
BIG (STRONG CONNECTIONS)	5	125	1.500

RELATIVE PRICE/PERFORMANCE COMPARISON OF SMALL COMPUTER SYSTEMS



CHANGES OF HARDWARE CHARACTERISTICS.

E - ENERGY CONSUMPTION W/GATE

S - SPEED OPERATIONS/S/GATE

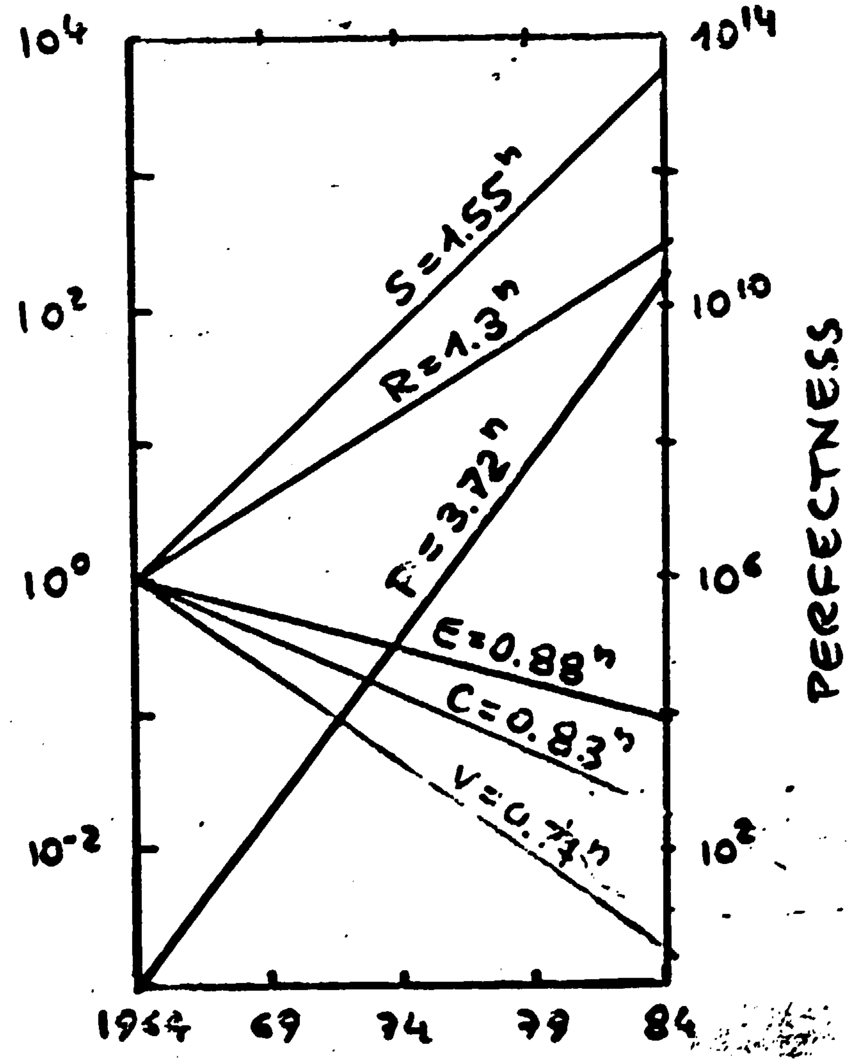
R - RELIABILITY HOURS/GATE

V - VOLUME dm^3/GATE

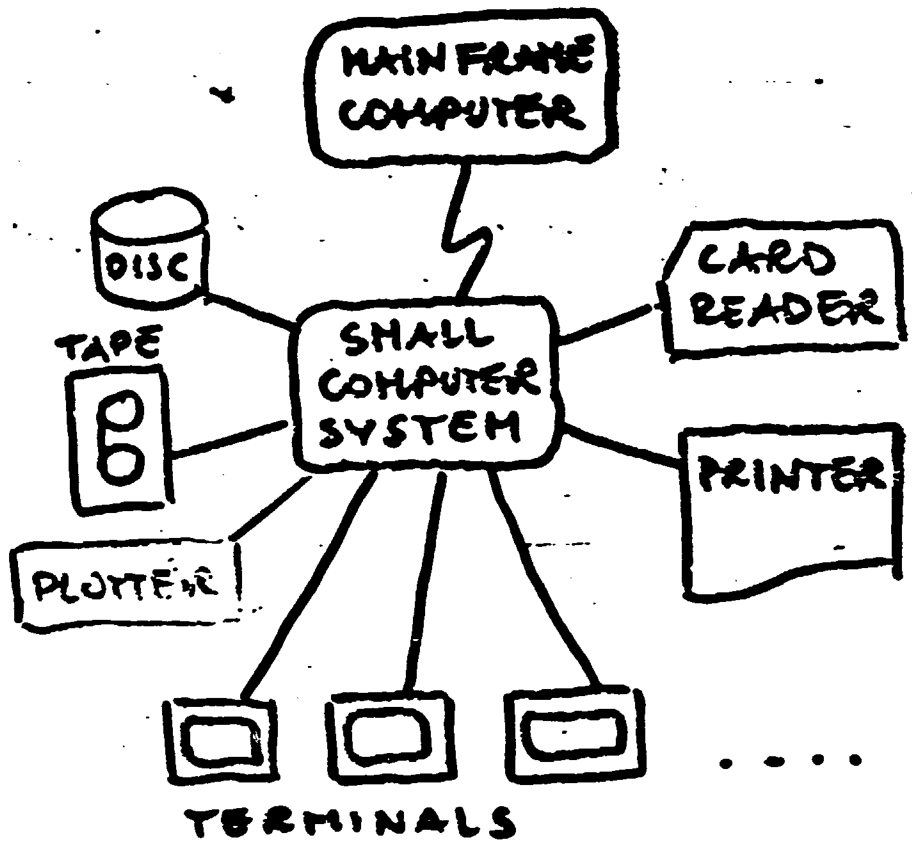
C - COST $/GATE

$$P - \text{PERFECTNESS} = \frac{S * R}{V * E * C}$$

(n - NUMBER OF YEARS; n = 0 FOR 1964)



DISTRIBUTED HARDWARE CONFIGURATION



CAD BENEFITS

DIRECT COST BENEFITS: COST REDUCTION
IMPROVED PRODUCTIVITY RATIO

INDIRECT COST BENEFITS:
INCREASE OF PRODUCT QUALITY,
SHORTER PROJECT DEVELOPMENT TIME,
BETTER INTERFACING OF PROGRAMS,
BETTER DESIGN,
RAPID ELIMINATION OF IMPRACTICAL APPROACHES,
MANPOWER AUGMENTATION