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Evaluation of Process Computers

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1969

Document Version:
Publisher's PDF, also known as Version of record

Link to publication

Citation for published version (APA):
Olsson, G., & Wieslander, J. (1969). *Evaluation of Process Computers*. (Technical Reports TFRT-7176). Department of Automatic Control, Lund Institute of Technology (LTH).

Total number of authors:
2

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EVALUATION OF PROCESS COMPUTERS

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AND
JOHAN WIESLANDER

REPORT 6912 DECEMBER 1969
LUND INSTITUTE OF TECHNOLOGY
DIVISION OF AUTOMATIC CONTROL

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PREFACE

The reason for publishing this report is that there is not much detailed information available on the evaluation, comparison and selection of process computers.

Since a rather careful job was done when selecting a computer for the Division of Automatic Control at the Lund Institute of Technology for the taxpayers money we thought it reasonable to make all the detailed information available.

The reader should observe that the specifications are not necessarily typical and that they can not immediately be applied to industrial applications. For example the main motivation for a mass storage is ease of compilation and program preparation. The need to have many students working on the system dictates the requirement for high level language and removable discs or magnetic tapes. These and other specifications naturally limit the selection considerably.

Thus we do not in any way consider the final choice significant. The manner in which the work was done and the comparison of some of the features of the different machines considered might, however, be interesting.

I would also take this opportunity to thank Utrustningsnämnden för Universitet och Högskolor and in particular Mr Tell and Mr Gyllsdorf who handled the economic negotiations very competently and who are formally responsible for the purchase.

1. THE COMPUTER CONTROL PROGRAM.

1.1. INTRODUCTION.

The process computer system, which is the subject matter of this report, is to be installed at the Division of Automatic Control, Lund Institute of Technology, Lund, in 1970. The report is a summary of the evaluation work, which has been carried out at the Division. The system specifications which have been formulated are accounted for and comparisons between interesting machine systems have been made.

The evaluation has been accomplished as a teamwork at the Division, and several people have been engaged in it more or less. Professor K.J. Åström has all the time given new ideas, and has stimulated the work with his interest and engagement. Karl Eklund, Per Hagander, Sture Lindahl and Björn Wittenmark have given valuable help at test runs of different computer systems as well as manual studies.

Mr. Jonas Agerberg at the Research Institute of National Defense (FOA) has contributed with test runs of two computers as well as with stimulating discussions. The test runs for PDP 9 have been performed partly at FOA, partly by Nikolas Schuch at AB Atomenergi, Studsvik. IBM Svenska AB has kindly provided computer time at an IBM 1800 computer at the Stockholm University for testing purposes.

Honeywell and Hewlett - Packard have also helped with computer tests of the computers DDP 516 and HP 2115, 2116 respectively. It has been possible to test the Varian computer at Lunds Lasarett, Docent David Ingvar, which is gratefully acknowledged.

The evaluation works have been carried out during two periods. The first one took place in 1966, but as no computer could satisfy the specifications within the available sum of money, a new evaluation started in 1968. Some half a year's evaluation was made before the invitation for tender was sent out on December 16, 1968. The quotations returned on March 5, 1969. For several reasons, mainly that several firms introduced new systems during the spring of

1969, the final decision could not be made until June 1, 1969. The decision has been, that a PDP 15 model 30 system should be delivered to the Division in the spring of 1970.

Some of the specifications are possibly of special character, and all of them are probably not relevant for industrial purposes. The great difference is caused by the large number of users and different applications for the computer system. These facts will make great demands on software and hardware flexibility, easy handling as well as fast execution times.

The software flexibility is considered to be very essential for the system. A fast handling of programs and data is necessary, and therefore a disk monitor system is desired. The actual system can make editing, compilation, testing of routines, loading of programs, communication with peripheral units very simple and easily understandable for new users.

It is desirable to store all system programs on fast memories, such as disk or magnet tape. User's program will be stored on removable disk packs or on magnet tapes in order to make this handling simple.

The software languages are also essential parts of the flexibility. It is considered necessary to use Fortran, and the compiler should have certain minimal specifications for the language and for the diagnostics. Utility programs for all peripheral units are also necessary in order to make all handling as easy as possible.

Interrupts handling of processes should be made in a simple way on priority basis, and use of peripherals should be simple in real time.

It is an advantage, if Fortran programs can be ordered on a priority basis by high level programming.

In many future applications the internal speed is essential. Matrix handling should be simple and fast, and this means that addressing and floating point arithmetic should be fast. Also the communication speed between peripherals and the central processing unit is essential. A disk memory is necessary to get the desired properties for such applications as nonlinear op-

timizations. Table search and intermediate storing of data should be fast in order to get realistic control.

Several different processes will be used for the computer. Therefore also flexibility in hardware is essential. It should be possible either to move the computer inside the building or to control it from other rooms in the house by moving only the teletype.

The evaluation has taken place in several steps. In the first part of the work, a great number of computers were briefly examined. Some elementary specifications were set up, such as cycle time, disk, Fortran system, and service representation. After that evaluation some twelve computers remained. It may be noticed that Swedish service representation was considered essential.

After the invitation for tender, some computers could be eliminated directly due to their prices, and some specifications were not satisfactory. After that a strict comparison has been made between the computers and between the specifications and the real performance. A great number of elementary characteristics has been put up. The emphasis of the evaluation, however, has been put on the software systems and the test runs of the computers.

The central process unit speed has been tested for all computers, which have been possible to test. This has been made in order to get a better feeling of the effectiveness of the compilers for the type of computations, that will be common in future applications. Fast matrix handling and floating multiplications are therefore essential.

Not only the internal speed but also the memory requirements for the programs are essential for a process computer. However, it appeared, that it is very difficult to get reasonable comparison of the memory figures, so they have been omitted from the tables. The reason is, that most computers print the memory for user's program, formatter, mathematical library etc. but different parts are included in the figures. The libraries are often loaded in groups, and all parts of the loaded library are not necessary for the certain program, which have been loaded. The only reasonable comparison therefore may be total memory for some process control applications.

Many of the figures and facts in the reports are very strongly time dependent, and may change very rapidly. Therefore the report may not be generally applicable, but is just a report of a certain evaluation work. However, some of the ideas of the evaluation may be generally applicable for other types of process computer systems.

1.2. OUTLINE OF THE REPORT

Chapter 1 is a description of the purpose of the computer control project at the Division and gives briefly the consequences for the specifications of the system.

The specifications are given in chapter 2.

As the computer market has grown enourmously the last years, it was necessary to eliminate a number of computers at the very beginning. Chapter 3 gives a brief summary of the computer market

in 1969 and of the computers that remained for further studies.

Chapter 4 describes the quotations. The technical specifications are briefly outlined. On the basis of the quotations some computers were eliminated at this second stage of evaluation, mainly because of their prices.

Chapter 5 is a technical comparison between the different hardware systems.

The program systems are compared briefly in chapter 6, and the comparison is made out of manuals and technical descriptions.

It has been possible to run some computers directly, and the experiences of these computers are shown in chapter 7. Both handling and speed of the central processors have been tested. Some experience of real time monitors has been gained.

In chapter 8 some ideas concerning the trends of the computer market are outlined. The sources of the predictions are given in different articles.

Since the computer market is rapidly changing, the examination is valid only for computers on the market before June 1, 1969. The manuals are valid at least until July 1, 1969.

1.3. PURPOSE OF THE SYSTEM.

The computer system is to be installed in the laboratory at the Division of Automatic Control. It will be used primarily in research but also in education. It will be used to control different physical processes, and also to control an analog computer, PACE 231R.

The main purpose of the system is to implement modern control theories in a process computer for control purposes. Experience of the construction of algorithm for process computers for such problems as identification, linear and nonlinear optimization of multivariable systems, filtering and adaptive control has to be gained.

We intend to work with some pilot processes, mainly a thermal rod system, the analog computer, PACE 231R, a hydraulic servo, a flow system and a mechanical device. With the help of these rather general processes it is possible to make real time identification and multivariable control laws. The experience of these laboratory processes can later be used for a large number of industrial applications ref. [1, 2].

The first projects include:

- implementation of Kalman filtering in a distributed thermal system,
- realization of linear-quadratic control laws for the same system,
- real time identification of systems, simulated on the analog computer,
- real time identification of the mechanical device,
- adaptive control of a flow process,
- nonlinear optimal control of the mechanical device.

A large number of questions concerning numerical problems, such as accuracy, speed and convergence, have to be answered. Even programming difficulties must be tackled. A systematic study of the choice of programming language in different applications as well as memory and hardware requirements for different control purposes must be made.

Questions concerning signal handling are very important and different ideas about filtering outside or inside the computer must be numerically checked.

Many people will use the computer very often in different applications. This means that our demands on software as well as hardware flexibility must be high. Thus the high level languages are very important.

In some applications there is an extremely great demand on the speed and capacity of the computer, e.g. in nonlinear optimization problems. Since it is economically impossible for us to buy a sys-

tem, satisfying these demands, we want to have a data transfer facility between the process computer and the Data Center in Lund. At certain times the process computer may start an updating program on the big computer in order to get new control laws.

It is impossible to solve certain problems on the computer system, because of their complexity. As before we intend to use other systems, e.g. the EAI hybrid computer 640 at the Research Institute of National Defense (FOA) in Stockholm.

1.4. PREVIOUS INVITATION FOR TENDER.

In 1966 an invitation for tender for a computer system was sent out. The system had briefly the following specifications:

a) central processor unit with a core memory of 8 k words of at least 12 bit and a cycle time of less than 5 μs,

b) peripheral disk memory of at least 64 k words,

c) teletype, paper tape reader and punch (or cards),

d) analog inputs and outputs, 8 of each,

e) digital inputs and outputs, 16 bits each,

f) Fortran and Algol 60 compilers.

The following firms replied:

Control Data, Stockholm	CD 1700
Electronic Associates, Solna	EAI
Elliot Automation, Stockholm	ARCH
Foxboro Instruments, Stockholm	PDP 8 (PRODAC)
General Electric, Solna	GEPAC 4020
Honeywell AB, Stockholm	H 21, DDP 116
IBM Svenska AB, Stockholm	IBM 1800
L M Ericsson, Stockholm	UAC 1601
Remington Rand, Stockholm	

Scantele AB, Stockholm	GEC S2, 90-2, 90-25
Svenska Radio AB, Stockholm	Telefunken
Svenska Siemens, Stockholm	Siemens 304
Telare AB, Stockholm	PDP 8, PDP 9

Among the offered systems no computer could satisfy the specifications at an acceptable price. PDP, for example, could not offer disks for any of their computers, so they suggested DEC tape instead.

1.5. DEVELOPMENT DURING THE LAST FEW YEARS.

Since 1966 the small computer market has undergone a tremendous development, and the Division has continuously followed up what has happened [ref. 3, 4, 5]. We have also cooperated with the Swedish "Statskontoret" and Teleutredningar AB, Solna and Research Institute of National Defence (FOA).

One of the most important features of the recent development has been the introduction of integrated circuits, and these have brought with them cheaper systems with better reliability. There has been a great increase in the number of computers equipped with Fortran or Algol compilers and utility programs for external units, such as disks.

This trend has made it possible to increase the demands on the system. The most important changes are faster cycle time and bigger word length and bigger disk memory. Moreover, we have higher demands on software, since the system will be used in a number of different applications.

2. SPECIFICATIONS OF THE SYSTEM

2.1. INTRODUCTION.

In the previous chapter 1.3 a number of problems which have to be solved by the computer system are outlined. There are a number of specifications which are quite clear directly from these very short statements.

The flexibility of hardware and software is very important. Many different people are going to use the system for quite different applications, and this fact makes it necessary to use a high level program language.

In order to make many optimization calculations possible, it is necessary to use a random access memory, e.g. a disk. In several applications it is necessary to have a nominal control law stored in a disk memory, and a large part of the control consists of table look-up. These applications demand a disk capacity of more than some 200 k and furthermore a rapid access time.

A software package consisting of utility routines for the disk is desirable.

Because of the many users the handling of programs during compilation, editing and loading has to be as simple as possible. With a paper tape system, all the system programs must be loaded from paper tape, and it will take a very long time to compile, edit and load even a small program. Therefore it is desirable to store all the system programs on a mass storage in the computer. Thus a disk monitor system for batch processing is a very valuable feature of the system.

In many of the applications complicated algorithms are used. The internal speed of the computer is thus a very important quality. Since matrix handling is very common, hardware fixed point multiplication is necessary.

Utility routines for all the external units must be delivered.

In some applications, e.g. nonlinear optimal control problems, it is necessary to use the very high speed of the computer at the Lund Data Center. At certain times during the control of a process, it

is desirable to update a nominal strategy, and this can be calculated by the big computer. The process computer will then just start the execution of the big one, and it will get a new control law in return. Thus it is required to have a communication line between the computers. The capacity of the line may be rather modest.

The choice of computer for the Data Center was not made before this evaluation, so it was meaningless to specify the type of connection more closely. However, we regarded the demands on the connection to be very modest. Our demands were included in the specifications of the Data Center Computer. Now we know that a Univac 1108 will be installed in the Data Center. It will satisfy these specifications.

In the near future it might be essential to expand the system. Therefore the specifications include two alternatives, systems A and B. The main differences are core memory requirement and monitor specifications.

2.2. INSTRUCTION TO TENDERERS.

Each tender shall consist of a specific computer system, and shall describe in detail the following items:

- hardware,
- software,
- instruction manuals,
- training of computer users,
- technical assistance and maintenance,
- equipment warranties.

Alternative systems having different technical capabilities may be proposed, if desired.

Tenderers are encouraged to optionally include any additional item which in their opinion may be desirable for the planned program, but which is not required by the specifications.

The possibilities of future expansion of the system at a reasonable cost is a prime requirement. Each tender shall discuss the ability to accommodate additional inputs, outputs, auxiliary storage and other peripheral equipment, and give specific prices of the hardware required.

Each tender must include a specific list of exceptions to the specifications (if any). Minor exceptions will not cause rejection of the proposal, provided that the intent of the specifications is met.

Each tender must include sufficiently detailed information to permit a thorough evaluation.

In the prices university discount shall be included, if any.

The computer system shall consist of the following units:

- central processor,
- mass storage,
- teletype and fast paper tape reader and punch, or equivalent,
- input and output units for analog and digital signals,
- standard software routines including test routines.

2.3. GENERAL REQUIREMENTS.

2.3.1. Environmental Conditions.

The computer system will be operated in laboratory atmosphere, and its performance must be unaffected by room air temperature between +10°C and +35°C, and relative humidity up to 95%.

Temperatures up to +45°C should not damage the components of the system.

2.3.2. Power Source.

All units shall be supplied with 220 VAC, 50 cps unregulated line power. Voltage variations of ±10% and frequency variations of ±1 cps must not influence system performance.

The power required for the computer system shall be stated.

In the estimation of the total cost of the system will be considered if any special arrangements must be made to cool the air or to humidify it.

2.3.3. Communication with External Processes.

It must be possible to connect the computer system to the telephone network. It should be pointed out how to solve the communication problem with a big computer via the telephone network.

2.3.4. Service.

A service warranty shall be included in the tender. Service shall be available during normal working-hours (40 hours/week) within 24 hours from calling. Price and conditions for service shall be stated.

2.3.5. Delivery Time.

It is desirable that delivery is made within 6 months from receipt of order.

2.3.6. Test Runs.

During the evaluation it may be desirable to make some test computations. In the tender shall be stated the possibilities to do this.

2.4. COMPONENT REQUIREMENTS.

2.4.1. Central Processor.

Word length 16 bits or longer. Memory cycle time 2 μs or less.

2.4.2. Speed of Arithmetic Functions.

No specific limits have been established. However, the planned program requires periodic performance of several elaborate calculations, so that high-speed computations are essential. Hardware fixed point multiplication and division is a minimum requirement.

2.4.3. Core Memory.

8 k words or more in alternative A and 16 k words or more in alternative B. The memory shall be expandable to 32 k words.

2.4.4. Clock.

A digital clock is required.

2.4.5. Disk Memory.

A disk with a capacity of 200 k words (16 bits) or more. Access time and transfer rate shall be stated. If the disk is exchangeable the price for the detachable disk assembly shall be stated. The maximum number of disk units for one disk control unit shall be stated.

It shall be stated whether it is necessary to use direct memory access (DMA) in order to run the disk, and also if other peripheral units can use the same DMA channel.

The software, available for the disk, shall be described. If the software can use the flexibility of the DMA channel it shall also be stated.

2.4.6. Interrupt System.

A priority system shall be provided and it should automatically search an interrupt register. The number of priority levels shall be 8 or more. The possibilities of expanding the interrupt system shall be described.

Even different ways of shifting priority levels with hardware or software shall be specified.

Is it possible to make a new interrupt configuration without shifting hardware components in the system?

The use of the different levels is not specified here.

2.4.7. Input-Output (minimum speed requirements stated below).

A 10 ch/sec teletype, a 250 ch/sec paper tape reader and a 50 ch/sec paper tape punch. An equivalent card equipment may be offered.

2.4.8. Analog Inputs.

The system shall be able to receive at least 8 analog signals, which shall pass a multiplexer and a AD converter. The multiplexer speed shall be more than 10 kHz. The AD conversion must take place in less than 200 μs with 10 bits accuracy including sign bit. Drift and linearity shall be stated. It shall be possible to expand the system up to 64 channels. In the proposal shall be described, what hardware is necessary for the expansion. The signals have levels ±10 V.

2.4.9. Analog Outputs.

8 DA converters with 10 bits including sign bit with a settling time less than 100 μs. The signal level must be ±10 V.

Output current shall be stated.

2.4.10. Digital Inputs.

A buffer register of 16 bits or more. The register shall be able to store contact settings.

2.4.11. Digital Outputs.

A buffer register of 16 bits or more. All 16 bits shall be sent out parallel from the accumulator.

2.4.12. Earthing.

In the system proposal shall be described how to solve the problem of connecting analog signals to processes with separate earthing system.

2.5. PROGRAM SYSTEMS.

2.5.1. Assembler.

A symbolic assembler with subroutines for all input and output units, including disk memory and analog and digital input-outputs, must be available.

A program library for floating point arithmetic and mathematical standard routines shall be delivered. Especially, a list of all mathematical standard routines shall be included. In this list shall be stated execution times and memory requirements of the routines. It shall be pointed out, if the software uses the available hardware such as the hardware multiplication unit.

2.5.2. Compilers.

An Algol 60 compiler (defined in CACM, May, 1960) with procedures for all input and output units, including disk, analog and digital units.

A Fortran compiler (FORTRAN X.3.9 ASA FORTRAN) with routines as required for Algol. Especially the disk shall be used as a logical unit in READ and WRITE statements.

The core storage required during compilation as well as execution shall be stated.

A conversational language of type BASIC.

2.5.3. Debug and Editing Programs.

If a paper tape system is proposed, an editing program for tape corrections shall be supplied.

A program system for debugging of Fortran and Assembly programs is required. The program shall have breakpoint facilities, and it shall be possible to use both symbolic and absolute addresses as breakpoints.

2.5.4. Disk Operating System (both systems A and B)

- The disk operating system shall provide possibilites of storing all system programs on disk. It must be possible to call these programs by their names from the teletype. The programs include:

  - compilers,
  - assemblers,
  - symbolic editor,
  - relocating loader,
  - Fortran library,
  - disk file management programs,
  - I/O drivers for all the peripheral units,
  - batch processor.

- The system shall include a batch processor. All orders are to be given alternatively from card,paper tape or teletype. A Fortran program, Algol or assembly program shall be run without operator from loading of the source program to the execution.
- The compiler shall fetch the source program (in ASCII) from disk or from paper tape.
- The binary relocatable program, which is the result of compilation, shall be stored directly on disk or on paper tape.
- The system shall be provided with a symbolic editor. The editor shall read or write on disk as well as paper tape.
- The system shall be provided with disk editing routines which can:

  - delete a program from disk with its program name,
  - store relocatable binary programs on disk in reserved areas,
  - store source code directly from paper tape or disk,
  - reserve a disk area for data before an execution,
  - dump files from the disk on to other peripherals.

- The monitor shall be provided with interrupt routines, which can use a hardware priority system.
- The monitor shall permit device independent programming, i.e. permit a shift of logical units.
- If any more hardware than the specified is necessary to make the monitor run, and if this hardware is not delivered initially, the tenderer shall provide this hardware without any cost.
- The necessary memory requirement in core and on disk for minimum and maximum core layout shall be specified.
- The monitor shall use the hardware multiplication unit.
- It shall be specified if any disk areas can be memory protected (hardware or software).

2.5.5. Real Time Monitor (System B).

A monitor of the foreground-background type shall be supplied.

In order to use the processor more effectively, it shall be possible to use it for background jobs, when there is a pause in the on line execution.

It shall be possible to link programs with the monitor in a determined sequence, and to store programs, which are not executed, on disk.

Programs and external interrupts shall be treated on a priority basis.

Structure, flexibility and changeability shall be described in detail.

It is an advantage, if Fortran programs can be ordered on a priority basis by high level programming.

The memory requirements on disk and in core shall be specified. Also the time for system generation shall be specified.

2.5.6. Hardware Diagnostics Programs.

In the quotation shall be stated which test programs are available for testing the CPU and peripherals.

2.6. BASIC DESCRIPTION OF THE SYSTEM.

In the quotation we want the following information explicitly summarized in a short table:

- total price of systems A and B,
- service price,
- physical data, such as dimensions, weight and total power consumption,
- word length and cycle time,

- speed of fixed point and floating point calculations of:

  A+B, A-B, A/B
  C = A+B, C = A*B, C = A/B
  C(I) = A(I) + B(J)
  B(J) = A(I) + B(J)
  C = C + A(I)*B(J)
  C = A(I)*B(J)
  as well as A+B, A-B, A/B in fixed and floating point double precision,

- data representation in single and double precision,
- core memory, max. and min. as well as module size,
- disk memory size, access time (min.,average and max.), transfer rate, max. and min. size of one control unit,
- paper tape system speed,
- multiplexer size, and its maximum size,
- A/D converter, speed and accuracy,
- D/A converter, speed and accuracy

3. FIRST EVALUATION AND PREPARATION FOR INVITATION FOR TENDER.

3.1. THE PRESENT COMPUTER MARKET.

Since 1966 an examination of new computers has been successively made at the Division. We have discussed with users of computers and representatives of computer manufacturers in order to obtain a better understanding of the type of computer system, which will be required for the program, outlined in chapter 1.

In March, 1968, we spent two so called contact days with users from the industry. A number of computer systems were then discussed.

The main information about the computer market, besides personal contacts and firms, was found in technical magazines, such as Control Engineering, Control and Datamation [6 - 9].

Before the invitation for tender was made, we listed most of the available computers in the market (table 3.1).

It may be difficult to make the difference clear between small and big computers. Some computers which may be regarded as big computers are therefore listed in the table.

We define small computers as those having short word length (8, 12, 16 or 18 bit). In some cases computers with 24 bit word length are listed. Computers without any external equipment are excluded at this stage.

It is important to note that the computers with 8 bit and e.g. 4 k memory have half the number of bits in the core compared with a 16 bit computer.

We have had very bad information on some computers. Unknown answers are denoted by question-mark.

We regard the disk available only if it is adapted to the computer system from the beginning.

The term "disk operating system" is used in a wide sense here. We define it as utility programs for the use of the disk.

Table 3.1 - Available computers in the small computer market 1969.

Computer	Swedish representative	Manufacturer	Cycle time	Word length	Compilers	Disk available	Disk oper. system available	Comments
1. AEI 4020		AEI Automation Ltd. GB	1.6	24	Fortran	yes	yes	
2. Argus 400, 500	?	Ferranti Ltd., GB	0.5 - 2.0	24	Fortran, Astrol April	"	"	
3. ARCH	Elliot Automation, Stockholm	Elliot Aut. Comp., GB	2/6	24	Fortran, Algol	"	"	
4. BIT 480/482		Business Inform. Techn., USA	3.0	8	Fortran	"	no	
5. CD 1700	ASEA, Västerås	Control Data	1.1	18	Fortran	"	yes	
6. Decade 70		?	0.86	18	Ftn IV	"	no	
7. Data Mate - 16	-	Gamco Industries Inc., USA	1.0	16	none	"	"	
8. Digiac, Micro 16	-	Digico Ltd., GB	?	?	?	?	?	
9. DT 1600	-	Decade Comp. Corp., USA	8.0	8	none	yes	yes	
10. EAI 640	Electronic Ass., Solna	Electronic Ass. Inc. USA	1.65	16	Ftn IV	"	"	
11. EMR Advance 6130	Schlumberger Sv.AB Lidingö	EMR, USA	0.775	18	Ftn IV	"	"	
12a. GEC S2, 90-2	Scantele AB, Stockholm	GEC Comp. & Aut. Ltd., GB	0.9	16	Ftn IV	"	"	
b.			1.75	12	Ftn IV	"	"	

Table 3.1 Contd.

Computer	Swedish representative	Manufacturer	Cycle time	Word length	Compilers	Disk available	Disk oper. system available	Comments
13. GEC 90-25	Scantele AB, Stockholm	GEC Comp. & Aut. Ltd., GB	1.75	24	Ftn IV	yes	yes	
14. GEPAC 4020	General Electric, Solna	General Electric, USA	1.6	24	Fortran	"	"	
15. Honeywell H 316	Honeywell, Sthlm	Honeywell Comp. Ltd., GB	1.6	16	Fortran	"	"	
16. DDP 416	- " -	- " -	0.96	16	none	"	"	
17. DDP 516	- " -	- " -	0.96	16	Fortran	"	"	
18. HP 2114	HP Instrument, Solna	Hewlett-Packard, USA	2.0	16	Algol Fortran	"	no	
19. 2115	- " -	- " -	2.0	16	Algol Fortran	"	yes	
20. 2116 B	- " -	- " -	1.6	16	Algol Fortran	"	"	
21. IBM 1800	Svenska IBM, Stlm	IBM, USA	2/4	16	Fortran	"	"	
22. Interdata, mod. 3		Interdata, USA	0.980/1.5	16	Fortran	"	no	
23. mod. 4		- " -	0.980/1.5	16	Fortran	"	"	
24. ITI 4900/20		Information Techn. Inc., USA	0.975/1.75	16	Ftn IV	?	"	
25. M-2140	Sv. Radio AB, Stockholm	English Electric, GB	1.0	16	Fortran	yes	?	
26. MAC-16		Lockheed Electronics	1.0	16	Fortran	no	no	
27. MDP 1000		Motorola, USA	2.16	8	none	yes	"	
28. Micro Linc		Spear Comp. Inc., USA	1.0	12	none	"	"	

Table 3.1 Contd.

Computer	Swedish representative	Manufacturer	Cycle time	Word length	Compilers	Disk available	Disk oper. system available	Comments
29. Mincal 4E		H. Dietz, Mühlheim, W. Germany	20.0	18	none	no	no	
30. " 4N		- " -	20.0	18	none	"	"	
31. " 513		- " -	1.5	18	none	"	"	
32. Modular One		Computer Technology, G.B.	0.75	16	none	yes	yes	
33. Multi 8	Nanoteknik, Solna	Intertechnique, France	1.1	8	none	no	no	
34. Myriad II	Sv. Radio AB, Stockholm	Marconi Co. Ltd., GB	1.2	24	Algol Fortran	yes	yes	
36. Nova		Data General, USA	2.6	16	none	"	no	
37. PDC 808		Computer Aut. Inc., USA	8.0	8	none	"	"	
38. " 816		- " -	8.0	16	none	"	"	
39. PDP 8I	Digital AB, Solna	Digital Eq. Corp., USA	1.5	12	Fortran	"	yes	
40. " 9	- " -	- " -	1.0	18	Fortran	"	"	
41. " 9L	- " -	- " -	1.5	18	Fortran	"	"	
42. Philips P 9202	Sv. Philips, Stockholm	Philips, Holland	0.96	16	Fortran	"	"	Compare (17)
43. Raytheon 703	Scandiametric, Stockholm	Raytheon Comp., USA	1.75	16	Fortran	"	"	
44. " 706	- " -	- " -	0.9	16	Fortran	"	"	
45. RC 4000		Regnecentralen, Denmark	2	24+2	Algol 60	"	?	

Table 3.1 Contd.

Computer	Swedish representative	Manufacturer	Cycle time	Word length	Compilers	Disk available	Disk oper. system available	Comments
46. SCC 4700		Scientific Control Corp., USA	0.92	16	Fortran	yes	yes	
47. SEL 810 A, B		Systems Eng. Lab., USA	0.75/1.75	16	Fortran	"	"	
48. Siemens 304	Sv. Siemens, Stockholm		1.5	24	Fortran Algol	"	"	
49. SPC 8		General Automation, USA	2.0	8	none	"	no	
50. 12		- " -	2.0	8	none	"	no	
51. Telefunken	Sv. Radio AB, Stockholm	Telefunken, W. Germany						
52. Tempo 1		Tempo Comp. Inc., USA	0.9	16	Fortran	no	yes	
53. UAC 1601	L.M. Ericsson, Stockholm	L.M. Ericsson, Sweden	6	16	none	"	no	
54. Univac 494/418	Univac Scandinavia, Stockholm	Sperry Rand, USA	?/2	18	Fortran	yes	yes	
55. Varian 520I	Varian AB, Solna and	Varian Computers, USA	1.5	8	none	"	no	
56. 620I	SAAB AB, Linköping	- " -	1.8	16/18	Fortran	"	"	

Table 3.1 Contd.

Computer	Swedish representative	Manufacturer	Cycle time	Word length	Compilers	Disk available	Disk oper. system available	Comments
After the invitation for tender:								
57. BIT 483		Business Inform. Technology, USA	1.0	8	Fortran	yes	yes	New model of (4)
58. CA 208		Comp. Automation Inc. USA	2.0	8	none	"	no	Compare (37, 38)
59. 216		- " -	2.0	16	none	"	"	
60. Computa Trol		Machine Control Corp., Mass., USA	1.6	?	?	?	?	
61. GA 18/30		General Automation Inc., USA	0.96	16	Fortran[1]	yes[1]	yes[1]	Compare (49, 50)
62. Micro 800		Micro Systems Inc., USA	1.1[2]	8	none	no	no	
63. PDP 15 model 10	Digital AB, Solna	Digital Equip. Corp., USA	0.8	18	Fortran	yes	yes	
64. model 20	- " -	- " -	0.8	18	Fortran	"	"	
65. model 30	- " -	- " -	0.8	18	Fortran	"	"	
66. model 40	- " -	- " -	0.8	18	Fortran	"	"	
67. Philco Ford model 1212		Philco Ford Corp., USA	1.5/3.4	12	Fortran	?	?	
68. model 1216		- " -	1.5/3.4	16	Fortran	?	?	
69. model 1220		- " -	1.5/3.4	20	Fortran	?	?	

1) Software compatible with IBM 1130/1800

2) 0.2 for RO

Table 3.1 Contd.

Computer	Swedish representative	Manufacturer	Cycle time	Word length	Compilers	Disk available	Disk oper. system available	Comments
70. Prodac P-2000		Westinghouse Electric Corp.USA	0.5	16	Progen[1)]	yes	yes	
71. Redcor 70		Redcor Corp. USA	0.86	16	Fortran	no	no	Modified version of (6)
72. SDS CE 16, CF 16		Scientific Data Syst., USA	8.0/2.67	16	Fortran	yes	?	
73. SPIRAS -65		IRA Systems Inc., USA	1.8	16	Fortran	yes	yes	

1) Augmented Fortran

3.2. PRELIMINARY EVALUATION.

From the specifications we selected five important demands on the computer systems, that had to be satisfied. In table 3.1 is examined how these demands were satisfied by a number of computers. The computers, that did not satisfy the first four demands were excluded from further detailed examination.

The rest of the computers were compared on the basis of list prices, where they were available.

A number of computers had to be excluded directly for economic reasons.

The next demand was Swedish service representation. This demand was a strong one, but we did not want to exclude directly those computers, which seemed to be attractive for economic or technical reasons. Therefore we wanted to invite these firms for tender in order to be able to determine later.

3.3. INVITATION FOR TENDER.

The invitation for tender was sent out on December 16, 1968. The following firms were invited for quotation:

	Firm	Computer
1.	ASEA, Västerås	CD 1700
2.	Digital AB, Solna	PDP 9
3.	Honeywell AB, Stockholm	DDP 516, H 316
4.	HP Instrument (Hewlett-Packard), Solna	HP 2115, 2116B
5.	IBM Svenska AB, Stockholm	IBM 1800
6.	Philips Svenska AB, Stockholm	Philips P 9200
7.	SAAB AB, Linköping	Varian 620 I
8.	Schlumberger Svenska AB, Lidingö	EMR Advance 6130
9.	Svenska Radio AB, Stockholm	M-2140, Myriad II
10.	Svenska Siemens AB, Stockholm	Siemens 304, 305
11.	Univac Scandinavia AB, Solna	Univac 9000
12.	Varian AB, Solna	Varian 620 I

The quotations returned on March 5, 1969.

The following firms did not want to give any quotation at that moment:

Philips
SAAB AB
Svenska Radio AB
Univac

As shown in table 3.1 new computers appeared during the spring, 1969, and some of them were interesting to us. DEC introduced a new whole system PDP 15 with integrated circuits, to replace the PDP 9. Raytheon and their Swedish representative introduced the new Raytheon 706. Both these new systems were taken into account, so the decision could not be made until the end of May, 1969.

4. THE QUOTATIONS.

4.1. PRESENTATION OF OFFERED SYSTEMS.

A short presentation of the different tenders is given in table 4.1, where the most important hardware and software features are listed.

4.2. METHOD OF EVALUATION OF BIDS.

All tenders received were evaluated on a technical basis by comparing the different features of the computers and peripheral equipment to the extent this was possible. About a hundred different items, like floating point multiply time, divide time, interrupt systems, register features, etc., were compared for each computer.

The speed of the computer was stated in the cycle time for the computer. It is very difficult to quantitatively specify the speed of the computer in any other way. As the computers are getting faster and faster, it seems obvious to demand a relatively high speed. To compare costs of similar equipment with different speeds is also difficult, as new equipment always have additional features.

The physical size of the system was interesting but not a decisive question. Integrated circuits are getting more and more common, and this will make the computer hardware more reliable. Likewise, many computers are easily movable, and this is very attractive, even though the computer will not be moved from the laboratory in the near future. The reliability of an integrated circuit computer ought to be higher. The power requirement is important, as a big system demands cooling equipment in the room.

The most important peripheral is the disk, and much attention was paid to this detail. An ideal computer system should have a fast and cheap disk unit with interchangeable disk packs.

The analog systems were quite different for the different quotations.

The software package was very important. A special chapter is devoted to these questions.

Table 4.1 - Summary of the hardware and software of the proposed systems.

	CD 1700	EMR 6130	H 316	DDP 516	HP 2115	HP 2116	IBM 1800 (2 µs)	PDP 9	PDP 9L	PDP 15 mod 30	Ray-theon 703	Ray-theon 706	Sie-mens 304	Varian 620 I
MEMORY														
Memory cycle time µs	1.1	0.775	1.6	0.96	2.0	1.6	2	1.0	1.5	0.8	1.75	0.9	1.5	1.8
Memory word length	16+2	18	16	16	16	16	16+2	18	18	18	16	16	24	16/18
Min. memory size	4 k	8 k	4 k	4 k	4 k	8 k	4 k	8 k	4 k	16 k	4 k	4 k	8 k	4 k
Mem. increment size	4 k	8 k	4 k	4 k	4 k	8 k	4 k	8 k	4 k	4 k	4 k	4 k	8 k	4 k
Max. memory size	32 k	32 k	16 k	32 k	8 k	32 k	64 k	32 k	16 k	128 k	32 k	32 k	16 k	32 k
Parity check	std	std	opt	opt	opt	opt	std	opt	opt	opt	no	opt	no	opt
Memory protect	std	std	opt	opt	opt	opt	std	opt	opt	std	no	opt	opt	opt
INTEGRATED CIRCUITS	no	yes	yes	yes	yes	yes	no	no	no	yes	yes	yes	yes	yes
CPU FEATURES														
Instr. word length	16/32	16/32	16/32	16/32	16	16	16/32	18	18	18	16	16	24	16/32
Number of accumulators (or gen. purpose reg. that can be used as accum.)	1	2	1	1	2	2	1	1	1	1	1	1	2	2
Number of index registers	1 hardw 1 mem.	3 hardw	1 hardw	1 hardw	none	none	3 hardw	7 (auto ind. mem. reg.)	7 (auto ind. mem. reg.)	1 hardw 7 (auto ind. mem. reg.)	1 hardw	1 hardw	none	2 hardw
Bits for operation code	4	5	4	4	4	4	5	4	4	4	4	4	4	4
Bits for adress modes	4	3	2	2	2	2	2	1	1	2	1	1	1	3

Table 4.1 Contd.

	CD 1700	EMR 6130	H 316	DDP 516	HP 2115	HP 2116	IBM 1800 (2 µs)	PDP 9	PDP 9L	PDP 15 mod 30	Ray-theon 703	Ray-theon 706	Sie-mens 304	Varian 620 I
Number of addr. modes	7	7	4	4	4	4	3	2	2	4	2	2	2	4
Bit for address	8/15	8/15	9/14	9/14	10	10	9/16	13	13	12/13	11	11	14	9/11
In this machine one can:														
address ... words in	32 k	32 k	16 k	32 k	2 k	2 k	32 k	8 k	4 k	32 k	32 k	32 k	16 k	2 k
... µs	2.2	1.5	3.2	1.9	4.0	3.2	4.0	2.0	3.0	1.6	3.5	1.8	3.0	3.6
and indir. address:														
... words in	32 k	32 k	16 k	32 k	8 k	32 k	32 k	32 k	16 k	32 k	-	-	16 k	32 k
... µs	3.3	2.2	4.8	3.0	6.0	4.8	6.0	3.0	4.5	2.4	-	-	4.5	5.4
Indirect addressing (multi or single level)	Multi	Multi	Multi	Multi	Multi	Multi	Single	Single	Single	Single	No	No		Multi
ARITMETHIC OPERATIONS														
Add time full word µs	2.2	1.9	3.2	1.92	4.0	3.2	4.25	2.0	3.0	1.6	3.5	1.8	3.0	3.6
Fixed point hardw. mul/div (std or opt) (EAU)	std	std	opt	opt	opt	opt	std	opt	opt	std	opt	opt	std	opt
mul time µs (with EAU)	7-9	4.5-8.3	9	5.3	24.0	19.2	15.25	3-11	4.5-16.5	2.5-7.0	12.25--17.5	6.3-9	19.5	10-18
div time µs (with EAU)	9-11	7.9--11.4	16.5	10	26.0	20.8	42.75	3-12	4.5--18	2.5-7.5	24	9	19.5	10-24
Fix multiply time software	-	-	260	155	187	150	-	281 max	421 max	-	147	75	-	200
Fix divide time software µs	-	-	370	221	387	310	-	352 max	528 max	-	299	154	-	200
Fix double precision add/sub µs(with EAU)		10	5	2.9			7	255	393				90	54
mul/div µs(with EAU)		?	230/340	136/205				272,352	422,482				200/ /1100	128/ /258-310

Table 4.1 Contd.

	CD 1700	EMR 6130	H 316	DDP 516	HP 2115	HP 2116	IBM 1800 (2 μs)	PDP 9	PDP 9L	PDP 15 mod 30	Ray-theon 703	Ray-theon 706	Sie-mens 304	Varian 620 I
Floating point add/sub μs (with EAU)	150	74-92	396	238	1150	700	160	280	385				730 (26 hw)	403
mul/div μs (with EAU)	217,262	107-141/815 /107-168		489	950, 1500 (450, 569 w EAU)	900, 1100 (344, 448 w EAU)	322,424 (nonre-entr.)	264,324	411,471				660,660 (28, 26 in hw)	426/602
INSTRUCTIONS														
Memory reference	14	31	14	14	14	14	31	14	14	14	15	15	40	14
DATA REPRESENTATION														
Floating(mantissa+exp)	23+8	23+8	23+8	23+8	23+8	23+8	23+8	26+9	26+9	26+9	23+8	23+8	24+12 2 words	22+8
I/O CAPABILITY														
DMA channel or data channel, max transfer rate	std 900 kc	std/ 1.26 Mc	opt/ 1 Mc	opt/ 1 Mc	opt/ 500 kc	opt/ 625 kc	std/ 500 kc	opt/ 1 Mc	no/-	std/ 1 Mc	opt/ 571 kc	opt/ 1.1 Mc	std/ 660 kc	opt/ 200 kc
External priority interrupt levels standard/max.	16/16	0/126	16/64	2/48	8/40	16/48	12/384	1/256	1/256	4/4	1/16	1/16	24/?	0/64
REAL TIME CLOCK	opt	opt	opt	opt	opt	opt	std	std	opt	std	opt	opt	opt	opt
SOFTWARE														
Assembler (1 pass, 2 pass, etc)	2 pass	both	both	both	2 pass	2 pass	2 pass	2 pass	2 pass	2 pass	both	both	PROSA	2 - 3 pass
Relocatable assembler core size necessary	yes/ 4 k	yes/ 8 k	yes/ 4 k	yes/ 4 k	yes/ 4 k	yes/ 4 k	yes/ 4 k	yes/ 8 k	yes/ 4 k	yes/ ?	yes/ 8 k	yes/ 8 k	yes/	yes/ 8 k
Macro assembler capability	yes	yes	no	no	no	no	yes	yes	yes	yes	yes	yes	yes	no

Table 4.1 Contd.

	CD 1700	EMR 6130	H 316	DDP 516	HP 2115	HP 2116	IBM 1800 (2 μs)	PDP 9	PDP 9L	PDP 15 mod 30	Ray-theon 703	Ray-theon 706	Sie-mens 304	Varian 620 I
Compilers available (Ftn II, IV, Algol, ASA Basic Ftn ...)	Asa Basic Ftn	Ftn II, IV, Asa Basic	Ftn IV	Ftn IV	Asa Basic Ftn Algol		Asa Basic Ext.Ftn	Ftn IV	Ftn IV	Ftn IV	Ftn IV, Asa Basic Ftn	Ftn IV, Asa Basic Ftn	Algol Ftn IV	Ftn IV
Conversational language	none	none	Desc top sim.	Desc top sim.	Basic		none	Focal	none	Focal	none	none	none	Desc top sim.
Disk oper. system available	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	no
Foreground-background monitors available	yes	yes	yes	yes	no	yes	yes	yes	yes	yes	yes	yes	yes	no
PERIPHERALS AVAILABLE														
Teletype, power	ASR 33 35 kg/ 230 W	ASR 33	ASR 33	ASR 33	ASR 33	ASR 33	TT, 15 ch/sec	KSR 35	KSR 35	KSR 35+ KSR 33	ASR 33	ASR 33	ASR 33	ASR 33
Paper tape reader speed/weight kg/power	400/-/-	300/	500-1000/ /15/-	500-1000/ /15/-	300/7/ /40 W	300/7/ /40 W	cards	300/-/-	300/-/-	300/-/-	300/-/-	300/-/-	400/-/-	300/12/-
Paper tape punch speed/weight kg/power	120/-/-	60/	150/ /14/-	150/ /14/-	120/ /14/-	120/ /14/-	cards	60/-/-	60/-/-	60/-/-	110/-/-	110/-/-	100/-/-	60-120/ /20/-
Disk min size/max size for 1 contr.	1.5 M/ 6 M	1 M/ 1 M	196 k/ 196 k	196 k/ 196 k	800 k/ 6.4 M	174 k/ 348 k	512 k/	256 k/ 8*256 k	256 k/ 8*256 k	256 k/ 8*256 k	400 k/ 1.6 M	400 k/ 1.6 M	800 k/ 1.6 M	221 k/
Disk fix or moving head	mov.	fix	fix	fix	mov. or fix		mov	fix	fix	fix	fix	fix	mov	fix
Access time min/mean/max ms	30/70/ /170	-/17/34	-/10/21	-/10/21	16/70/ /120	or -/8.5/ /17	-/520/-	-/20/40	-/20/40	-/20/40	-/17/33	-/17/33	20/320/ /1000	-/10/20
Transfer rate		145 kc	25 kc	25 kc	41 kc	176 kc	36 kc	50 kc	50 kc	50 kc	187 kc	187 kc	40 kc	95 kc
ADC: bits/speed kc/ /min-max ch	several	12/60/ /8-128	10/50/ /8-256	10/50/ /8-256	12/35/ /1-64	12/35/ /1-64	23-35 kc 8-14 bit	10/50/ /4-16	10/50/ /4-16	10/50/ /4-16	10/?/ /8-16	10/?/ /8-16	12/30/ /8-16	12/

Table 4.1 Contd.

	CD 1700	EMR 6130	H 316	DDP 516	HP 2115	HP 2116	IBM 1800 (2 μs)	PDP 9	PDP 9L	PDP 15 mod 30	Ray-theon 703	Ray-theon 706	Sie-mens 304	Varian 620 I
DAC: bits/speed kc/ /min-max ch	several	12/500	10/125	10/125	8-10/ /250	8-10/ /250	several	10/100/ /8	10/100/ /8	10/100/ /8	10/?	10/?	8/?	12/
SIZE OF THE SYSTEM														
length × width × × height (cm)	460×91× ×190	280× ×120× ×180	200-300 ×100× ×110	200-300 ×100× ×110	106×50× ×163	106×50× ×163		230-370 ×70×180	230-370 ×70×180	230-370 ×70×180			490×55× ×180	
WEIGHT, whole syst. kg		1000	∿275	275				900-1200	900-1200	900-1200			3500	35+I/O
POWER, whole syst. kW	3	10	∿2.6	2.6	2-3	2-3	5.2	?	?	?			7.5	340W+ +I/O

After the technical comparison a price comparison was made. As most of the bids varied considerably, we tried to make the price comparison for a "standard system" just meeting the specifications. It should, however, be kept in mind, that several firms could only offer a system, which was well above our requirements.

We also took into account programming assistance, hardware maintenance, system warranty and delivery etc.

In the price comparison was therefore stated also the system price after five years service.

4.3. ELIMINATION OF COMPUTER BIDS.

Siemens, Schlumberger and Honeywell DDP 516 (system B) offered complete systems, which met our specifications. In order to satisfy the requirements, these systems were too expensive, and no technical way of reducing their prices sufficiently, in order to make them competitive, could be found. Later Honeywell introduced a new and cheaper system H 316. The system can use exactly the same program system as the 516 computer, and was therefore carefully examined.

IBM 1800 and CD 1700 are quite big computer systems, and it was soon found, that, due to their large capacities, these systems are not well designed for alternative A, but only for alternative B. For example, in order to run the Fortran compiler a 12 k core memory on CD is required. Thus the price difference between systems A and B becomes rather small.

The Varian computer could not offer any real time monitor system, but since the system price was rather low, the computer remained for further evaluation.

The following tenderers were chosen for a further and closer evaluation:

1. CD 1700
2. Honeywell DDP 516 (A)
3. HP 2116 B
4. IBM 1800

5. PDP 9 and 9L
6. Varian 620 I

Besides the quoted systems we also evaluated the following ones:

1. Honeywell H 316
2. PDP 15
3. Raytheon 703 and 706

5. COMPARISON BETWEEN OFFERED HARDWARE SYSTEMS.

This chapter is devoted to a closer examination of some features of the hardware, which are considered important.

In 4.3 we have motivated the fact, that only the following computers are discussed in this chapter:

CD 1700
Honeywell 316 and 516 (DDP)
HP 2115 and 2116 B
IBM 1800
PDP 9, 9L and 15
Raytheon 703 and 706
Varian 620 I

The DDP, HP, PDP and Raytheon computers have more than one model, that interests us. The models have many common features, and therefore we often refer only to the first name.

From table 4.1 several comments can be made, and the figures of the table are referred to several times in this chapter.

The central processor and the core memory are commented on in 5.1.

The instruction features and the addressing facilities are also examined. The input-output organization of a process computer is important, and some comments are made in 5.3.

After that a further examination of the peripherals is made. In 5.4 we summarize the facilities of the disk systems. We regard the disk systems as almost decisive for the choice of our computer. The paper tape and card systems are examined in 5.5. There are small differences between the paper tape systems. It is worth noting, that only IBM offered a card system.

The analog and digital I/O systems are discussed in 5.6. The physical sizes are commented on in 5.7. After the service and maintenance organization has been discussed in 5.8, the chapter is summarized in 5.9.

5.1. CORE MEMORY AND INTERNAL SPEED.

5.1.1. Word Length.

The PDP computers have 18 bit word length, while CD and IBM have 16 bit plus parity check and memory protect bits.

Varian can be delivered optionally with 18 bits. All the other computers have 16 bits.

5.1.2. Memory.

The memory modules are 4 k with the exception of HP and PDP 9, which have 8 k modules. PDP 15 has 4 k modules.

All computers except PDP 9L are expandable to 32 k or more. IBM and CD have memory protect. HP, DDP and PDP 15 has a somewhat simpler memory protect system.

5.1.3. Cycle Time.

The following computers have cycle times below 1 μs:

DDP 516
PDP 9
PDP 15
Raytheon 706

The rest of the computers have cycle times between 1 and 2 μs.

DDP 516 and PDP 15 have the fastest multiplication times for fix numbers (see table 4.1).

5.1.4. Circuits.

CD, IBM and PDP 9 and 9L have discrete components in the central processor. All the other computers have integrated circuits. The power consumption of the different central processors vary a lot.

However, if the whole systems are taken into account, the variation is smaller, as the peripherals will have a great power consumption.

5.1.5. Registers.

All the systems are delivered with 2 accumulators, as a hardware multiply unit is offered. However, the two accumulators are not equivalent on all the computers (see 5.2).

HP has no index register, but has a rather big page size, 1024 words.

PDP 9 and 9L have no index register either, but the page size is 8 k words, because of the 18 bit word length.

Raytheon has no indirect addressing facility, but has instead an index register.

CD, IBM, PDP 15 and Varian have the best register configurations. This will make the addressing facilities of these computers very good.

5.1.6. Data Representation.

The data representation of floating point numbers is the same for all 16 bit computers. PDP has a more accurate data representation, because of 18 bits word length. Varian can optionally be provided with 18 bits.

5.2. INSTRUCTIONS.

The instruction repertoire is dependent on the disposition of the word in the computer. There must be bits reserved for the operation code, the address and the addressing modes. In all computers it is necessary to make a compromize between the number of basic instructions, the addressing facilities and the page size.

The instructions may be divided into the following groups:

memory reference
register
input-output
shift
skip instructions

Many of the instructions are available on all the computers. We have listed the most important differences in table 5.1.

The IBM computer has five operation code bits, and therefore it has a large number of basic instructions, e.g. double precision instructions (see table 5.1).

The addressing facilities are satisfactory on all the computers, which have an index register. However, CD is superior with its seven addressing modes. IBM and Varian are also very good, because they have three and two index registers respectively.

HP, PDP 9 and Raytheon are a bit limited. However, PDP 9 has a 8 k page size, while Raytheon has a hardware index register. DDP and PDP 15 are satisfactory with four address modes, although relative addressing is not available.

Double word instructions are available on CD, DDP, IBM and Varian.

Table 5.1 shows some interesting instructions. Although all computers have two accumulators, called A and B, they do not use them in the same manner. The table shows, that only HP and Varian have direct communication between the memory and the second (B) accumulator. PDP 15 must communicate with its index register (X) via the A accumulator. This is probably due to historical reasons.

The three "interchange" instructions on DDP are very useful and attractive.

The "compare" instructions on DDP, HP and IBM are also useful.

Only CD and HP can add a number directly into the B accumulator.

As mentioned previously, only IBM has double precision instructions.

To summarize, the instruction feature is less flexible on PDP 9, PDP 15 and Raytheon than on the rest of the computers. HP is considered somewhat better because of its B accumulator.

Table 5.1 - Brief comparison of the instructions.

	CD	DDP	HP	IBM	PDP 9	PDP 15	Ray-theon	Varian
Bits for operation code	4	4	4	5	4	4	4	4
Bits for addressing modes	4	2	2	2	1	2	1	3
Number of addressing modes	7	4	4	3	2	4	2	4
Hardware index reg.	1	1	0	3	0	1	1	2
Relative addressing	yes	no	no	no	no	no	no	yes
Indirect addressing multi/single level	multi	multi	multi	single	single	single	no	multi
Double word instructions	yes	yes	no	yes	no	no	no	yes
Instructions								
Load/Store B	no	no	yes	no	no	no	no	yes
" / " X	yes	yes	-	yes	-	no	yes	yes
Double load/store A	no	no	yes	yes	no	no	no	no
Double add/sub A	no	no	yes	yes	no	no	no	no
Add B	yes	no	yes	no	no	no	no	no
Interchange (A) and memory	no	yes	no	no	no	no	no	no
Compare memory to (A), skip if unequal	no	yes	yes	yes	yes	yes	no	no
Compare memory to (B), skip if unequal	no	no	yes	no	no	no	no	no
Interchange (A) and (B)	no	yes	no	no	no	no	no	no
Interchange halves of (A)	no	yes	no	no	no	yes	no	no
Load/Store byte	no	no	no	no	no	no	yes	no

5.3. INPUT-OUTPUT ORGANISATIONS AND INTERRUPT SYSTEMS.

5.3.1. Input-Output Channels.

The input-output capability is a very important feature. The width of the I/O channel is typically the word length of the computer. For an application with analog inputs of 10 bits, there is no difference between the offered computers, as all of them have 16 or 18 bits word length.

There are two basic types of I/O channels:

a) I/O transfer is under direct program control of the CPU, where the data path is through the CPU registers (e.g. programmed data channel, party line I/O);

b) The I/O transfer is led directly from the controller of the external device to the memory, independent of program control, once the transfer has been initiated (e.g. DMA, direct memory channel).

Some machines provide the programmer with one single instruction to execute I/O automatically while on other machines more programming is required, such as testing program loops to see if the channel is busy.

System b) is standard on CD, IBM and PDP 9 and PDP 15.

PDP 9 is provided with a DMA channel, while PDP 15 has a separate I/O processor. This means that the CPU and the I/O processor are separated, and both these devices have access to the core memory. The I/O processor has a higher priority than the CPU during data transfer.

DDP, HP, Raytheon and Varian can be supplied optionally with DMA channels, which are included in the prices.

A DMA channel is necessary for all disks with fixed heads.

5.3.2. Interrupt Systems.

The interrupt systems are quite different. It is not intended to describe all the differences within this report.

Generally speaking, it is possible to solve our problems with all the proposed systems. However, it is difficult to make a relevant comparison between the different interrupt systems. The documentation is sometimes very bad. Later contacts with the vendors have not given us complete information in some cases.

A typical interrupt system consists of a single interrupt line, to which multiple interrupt sources can be connected. The priorities in a multi level priority system can be evaluated in software or hardware. The hardware approach costs more but results in much shorter response times and reduced storage requirements.

The different firms offer quite different interrupt facilities. The number of priority levels are as follows:

CD	14
Honeywell DDP	8
HP	16
IBM	12
PDP 9	8
PDP 15	8
Raytheon	8
Varian	8

The PDP computers have an attractive feature in the Incremental and Add-to-memory capability. This facility is very useful in pulse counting applications, and will be used with digital transducers from a process.

In summary, no computer may be excluded from the list on account of I/O organisation. PDP 15 is attractive when its price is regarded.

5.4. DISK SYSTEMS.

As mentioned in the specifications, the application of the system requires a fast disk of a capacity of more than 200 k words. It is necessary to make a compromize between the speed of a fixed head disk and the flexibility of a moving head disk.

The capacities and access times of the different systems vary a lot (see table 4.1). Therefore it is very difficult to make a fair comparison.

Moving head disks were offered by CD, HP and IBM. Their characteristics are outlined in table 4.1. Their capacities vary from 1.5 M words for CD through 800 k words for HP to 500 k for IBM. The access times of CD and HP are quite short. IBM is slower, but the firm can offer a faster disk. Because of its price the HP disk was very attractive. The rather fast access time is the result of 8 moving heads. A detachable disk assembly was quite cheap for HP and IBM and somewhat more expensive for CD.

In the first quotation HP promised delivery during summer, 1969. Because of some delay of the development work, the delivery time was later told to be not before summer 1970. HP also offered a fixed head disk, but this one is much more expensive, and the flexibility becomes comparable to several other computers'.

Fixed head disks were offered for the DDP, HP, PDP, Raytheon and Varian computers. The differences of access times are not very great, at most a factor of two, but HP has the shortest access time. The transfer rate of the Raytheon disk is the greatest, about the same as that of HP. The Honeywell disk could not be expanded above 196 k, which is a disadvantage. Varian suggested a drum in order to get a fast access time.

The HP fixed head disk had low capacity, only 176 k in the quotation, but can be expanded to the double size. The PDP disk size is 256 k and is expandable to 8*256 k, while Raytheon offered the greatest fixed head memory, 400 k, expandable to 1.6 M words.

PDP could offer a DEC tape system together with the disk. The PDP 9 became too expensive with this facility. PDP 15, however, was found to be cheaper than the previous one, and included a DEC tape system

in the basic configuration. The fixed head disk will give a fast access time. The transfer rate is not the highest one, but was estimated to be satisfactory. The DEC tape system will give good flexibility. Since all programs and data can be transferred from DEC tape to disk and in opposite direction, all the users' programs can be stored on the tape. Even data from users or from experiments can be stored simply. One DEC tape wheel will cost about 7 dollars.

To sum up, HP had a very attractive moving head disk, which was fast and cheap. The alternative to HP was PDP with a fixed head disk, combined with DEC tape.

5.5. PAPER TAPE AND CARD SYSTEMS.

All the vendors have offered a paper tape system, except IBM who offered a card system.

In general, a card system is superior, but in most cases it is too expensive. IBM has a great advantage here.

Among other quotations, the capacities are quite comparable. Table 5.2 shows some more details about the reader, punch and teletype for the systems.

Table 5.2 - Summary of the capacity of the paper tape systems.

	Reader		Punch		Teletype	
	type	ch/sec	type	ch/sec	type	ch/sec
CD	1721	400	1723	120	1711	10
Honeywell	Facit	500/1000	Facit	150	ASR 33	10
HP	HP2737	250	Facit	75	ASR 33	10
IBM (cards)	1442	300 c/min	1442	1 c/sec	1816	15
PDP	PDP	300	PDP	60	KSR 35 KSR 33	10 10
Raytheon	75601	300	75602	110	ASR 33	10
Varian	-	300	-	60	ASR 33	10

All the quotations satisfy the specifications. CD and Honeywell offered the best paper tape systems. However, if a good disk system is offered, the paper tape system is not so important.

It shall be noted that the PDP 15 system has a good complement in the DEC tape system.

IBM has the fastest typewriter, but PDP offered two teletypes, both a heavy duty one and the smaller KSR 33 model. The KSR model has no punch.

5.6. ANALOG AND DIGITAL I/O SYSTEM.

Table 5.3 shows a summary of the specifications of the offered analog systems.

All the systems satisfy the requirements in the specifications, except Varian, which has a 5 volt analog output instead of 10 volts. In the specifications was required, that the system should be expandable to 64, but this figure was later changed to 16.

HP first offered a too expensive analog output, but changed this one to a Raytheon DAC 60, which is shown in table 5.3.

CD and IBM can offer a big number of analog systems, and their proposals are not the best ones in the table, but they satisfy the specifications.

The PDP proposal was expensive, but the vendor could offer modules and a complete drawing for converters and digital registers. This alternative decreased the PDP price for the analog-digital system considerably. It was possible to build the analog systems before the delivery of the computer, as the modules could be delivered in advance.

Table 5.3 - Summary of figures for the analog and digital I/O systems.

	CD	DDP 516	HP	IBM	PDP 9 PDP 15	Raytheon 703, 706	Varian
Multiplexer							
No. of channels	8	8	16	16	12	8	16
expandable to ... channels	64	256	16	256	16	8	16
Conversion rate (kc)	20	50	100	10	30-100	50	20
A/D Converter							
Accuracy bits	10	10	10	8, 11, 14	10	10	12
Conversion time μs	10	-	10	29, 36, 44	16	20	50
D/A Converter							
Accuracy bits	12	10	10	13	10	10	12
Conversion time μs	8	8	25	10	5-10	25	unknown
Max. load (amp.)	0.01	0.01	0.005	-	0.01	0.005	unknown

5.7. PHYSICAL SIZE.

It is, of course, very attractive to have a small system, in order to make it movable. Now, it is not necessary to move more than the teletype, if the computer is to control different processes in the laboratory.

The biggest systems will make an air cooling system necessary, i.e. the CD and IBM systems and perhaps PDP 9.

The physical sizes are shown in table 4.1.

5.8. SERVICE AND MAINTENANCE ORGANIZATIONS.

CD, Honeywell, HP, IBM, PDP have well-established service organizations in Sweden.

Raytheon and Varian have smaller organizations, and have not been able to increase them yet.

The nearest service offices are situated in:

CD	Västerås
Honeywell	Stockholm
HP	Stockholm
IBM	Malmö
PDP	Copenhagen and Stockholm

IBM could offer cheap service, compared to all other vendors.

Most of the firms have available computers at their offices, to make test runs possible, such as:

CD	Västerås
Honeywell	Stockholm
HP	Stockholm
IBM	Stockholm

PDP has no computer at their office, but there are several possibilities to use PDP 9 computers at AB Atomenergi, Studsvik, and FOA, Studsvik. Varian has installed a computer at Lund central hos-

pital, while Raytheon has no computer available in Sweden.

The service organization of Raytheon in Sweden was considered unsatisfactory to the Division. It was not possible to get enough information in time about the program systems. Therefore Raytheon has not been examined completely in the next chapter, only in some detail.

5.9. SUMMARY AND COMMENTS.

An evaluation of process computers has to be carried out on the basis of technical specifications as well as prices. This fact will influence the judging and the choice of computer.

From the information of the central processors, 5.1, it is not possible to exclude any computer. The instruction repertoire, 5.2, is especially attractive on DDP, HP, IBM and Varian, and CD has superior addressing facilities. The input-output organization of PDP 15 is very good (see 5.3).

We have emphasized in 5.4 that the disk system is very important, and PDP 15 and HP have offered interesting systems with prices, which are advantageous. The delivery time of the HP disk is somewhat uncertain.

In 5.5 is presented the input-output systems.

The IBM card system is superior. PDP 15 offered a heavy duty teletype besides the common teletype.

All systems can deliver analog-digital I/O subsystems, which satisfy the specifications (see 5.6). The choice has to be made out of prices.

The physical sizes of CD, IBM, PDP 9 and PDP 15 are big and uncomfortable. In this respect the DDP, HP and Varian computers are advantageous.

The Raytheon and Varian service organizations are considered not satisfactory today.

We exclude the Raytheon 703 and 706 systems from further evaluation, mainly due to the small service organization. Varian is discussed further because of its attractive price.

6. COMPARISON BETWEEN PROGRAM SYSTEMS.

6.1. VENDORS' EXPERIENCES OF THE SYSTEMS AND THEIR PROGRAMMING SERVICE.

We consider the programming service of CD, IBM, PDP, and Honeywell the best.

CD, DDP and IBM have developed their executive software for process control, and the systems have proved to work satisfactorily. The firms have a long experience of the systems. These monitor systems are the most flexible ones, and in several respects they are better than the specifications. A large number of application programs are also available.

PDP have also long experience and we regard their programming service satisfactory. It has not been possible to test the PDP 15 system, but it has the same software as PDP 9. The monitor has been available since December, 1968.

The HP monitor is developed for a fixed head disk, but it has not yet been introduced for the new moving head disk.

Varian has no real time monitor, and the disk operating system is quite new. It has not yet been delivered to any customer (Phase II software).

Raytheon has also a quite new real time monitor.

We regard the programming service in 1969 of HP, Raytheon and Varian not as good as the service of the other computers.

6.2. ASSEMBLERS.

The computer hardware organization determines the features of the assemblers to a high degree (see 5.2). The addressing modes depend on available registers as well as the word bit disposition. An important feature of the assemblers is the facility to mix Fortran and Assembly routines. Even the Macro order facility will be discussed in this section.

The list of orders is determined by the word organization. However, the addressing ought to be made in symbolic form, so the user need

not worry about page sizes and memory absolute locations. On HP and DDP it is possible to do page free programming. This means, that the assembler will put in indirect addresses in order to solve the communication problem between different pages. PDP 9 has neither page free programming nor hardware index register, but has a large page size, 8 k. If the user writes his program and addresses in the "right" address mode, e.g. relative or index register addressing, he needs not worry about the pages either. All the other computers, including DDP, have index registers and programming work is rather simple.

It is desirable to use the library of elementary functions, I/O functions and floating point package. It is not possible to communicate with the library on all the examined computers.

The simplicity of the orders differs a little. On

CD, DDP, IBM, PDP

it is possible to make a call to a library routine just with a pseudo operation or a user defined macro. With

HP

it is necessary to do some more assembly programming, e.g. load the arguments and reserve storage for the output. This disadvantage is not very important, as the procedure is standardized. With Varian, however, the Fortran library is not accessible from the assembler. This depends on, that different loaders are used for assembly and Fortran programs. In the Phase II software, this will be changed.

On CD and PDP the Macro programming facility is available. It is an advantage to have this facility, but it is also simple to write subprograms without Macros.

6.3. COMPILERS AND THEIR SUBROUTINE LIBRARIES.

All the computers are supplied with Fortran compilers of different complexity. Only HP has also an Algol compiler (similar to Algol 60, defined in CACM, Jan., 63) which has been tested at the Division.

In this section we make a brief comparison between the Fortran compilers and Fortran languages.

We emphasize the difference between:

a) the language (e.g. USASI Fortran)

and

b) the compiler: the implementation on a certain computer.

There is a great confusion about these two words, and it is very important to define, what one is considering at the moment. A very general and complex language may be ineffective in a certain computer. On the other hand, a simple language may have a very effective binary code as a result of compilation.

We have tried to find out, how different compilers use the computer hardware, such as hardware multiplication unit, index registers, interrupt system, accumulators and other registers. However, we have almost failed, because of bad information, and the only way to find out the compiler efficiency has been execution of test programs, which is described in chapter 7.

In table 6.1 we have listed the most interesting features of the different Fortran versions of the computers and have concentrated upon the main differences to a standard Fortran IV.

Debugging aids are very important. We want to know if it is easy to work with the program test package. Is it necessary to know machine language or octal numbers to use the system?

We have also tried to learn the age of the compilers. A compiler, not older than 2 - 3 years,may have several errors in it. Some errors have been found in the tests. Likewise, we considered it interesting, if new versions of the compilers had appeared during the last year. This information is also difficult to obtain.

Some comments on table 6.1 have to be made:

CD and DDP have the most flexible Fortran. The former demands 12 k core memory. The latter also includes complex variables. It is more difficult to perform logical operations on HP, IBM and Varian.

PDP and DDP can use scale factors in FORMAT statements.

Varian uses two words to store integers in Fortran. One of these words is not used.

The number of compilation passes is an important indication of the compiler performance. Varian and DDP have one pass compilers, which never can give as effective binary code as a two pass compiler. Forward references cannot be addressed directly, so the compiler has to put in either indirect addresses or a number of jumps. The binary program becomes both more time and memory consuming.

The Fortran subroutine library of DDP is superior, as this compiler includes both double precision and complex variables. Thus double precision as well as complex intrinsic and elementary functions are included in the DDP library.

IBM, PDP 9 and 15 as well as Varian include double precision functions in the Fortran library. CD and HP have no double precision functions in the library.

The diagnostics have been tested only on HP, PDP and IBM, and is reported in chapter 7.2. The number of error diagnostics is also a measure of performance (see table 6.1).

The speed of the binary programs is reflected in table 6.2 for the mathematical routines. It is, however, difficult to find out whether the execution time, stated in the manual, is maximum, average or minimum. For some computers there is a sizable difference between the "theoretical" and practical execution times (see also 7.3).

Table 6.1 - Summary of Fortran facilities

	CD	DDP 316,516	HP	IBM	PDP	Varian
Type	ASA Basic (extended)	Fortran IV x3.4.3	Extended ASA	ASA Basic	Fortran IV	ASA Basic
Memory requirement for compiler	7.3 k + 200 k	?	9 k	3.7 k	6 k	6 k
Minimal configuration	12 k + TT	8 k + TT	8 k + TT	8 k + TT	8 k + TT	8 k + TT
No. of passes (paper tape)	-	1	2	-	2	1
DATA TYPES						
Floating (words)	2	2	2	2 or 3	2	2
Double prec. (words)	no	yes (3)	no	no	yes (3)	yes (4)
Complex variables (words)	no	yes (4)	no	no	no	no
Logical operations	yes	yes	yes	no	yes	no
Logical variables	no	yes	no	no	yes	no
Relational operators ≤ ≥ = ≠ > <	yes	yes	no	no	yes	no
Max. number of index	3	3	2	3	3	3
EXPRESSIONS						
Mixed mode (A + I)	no	no	no	yes	no	no
STATEMENTS						
Logical IF	yes	yes	no	yes	yes	no
Assigned GOTO	yes	yes	no	yes	yes	no
Scale factors in FORMAT	no	yes	no	no	yes	no

Table 6.1 Contd.

	CD	DDP 316,516	HP	IBM	PDP	Varian
Labelled COMMON	yes	yes	no	no	yes	no
Number of error diagnostics						
compiler	90	∿50	17	83	13	24
object program	13	11	7	?	8	10
Change of logical number	?	yes	no	?	yes	no
Segmenting	yes	yes	no	yes	yes	no
Assembler can be written inside a Fortran subroutine	no	no	no		no	no
Assembler subroutines can be combined with Fortran subroutines	yes	yes	yes		yes	yes

Special features.

Varian: A program map is listed after every compilation, which is unnecessary and time consuming.

HP: Has simple Hollerith FORMATS.

IBM: Extended precision can be declared instead of double precision.

Table 6.2 - Comparison of subroutine libraries of different Fortran systems.[1)]

	CD 1700 reentr.	DDP 516 EAU	HP 2115 not EAU	HP 2116 w. EAU	IBM 1800 reentr.	IBM 1800 non-reentr.	PDP 9 EAU	PDP 9 not EAU	Varian EAU	Varian not EAU
FADD	0.150 – –	0.238 – –	0.50 94 –	0.7 ? – –	0.548 158 –	0.269 168 –	0.280 – –	0.280 – –	0.400 – –	
FMUL	0.217 – –	0.489 – –	0.7 51 –	0.34 – –	0.519 65 –	0.322 83 –	0.264 – –	2.05 – –	0.430 – –	
FDIV	0.262 – –	0.489 – –	1.3 70 –	0.45 – –	0.748 106 –	0.424 130 –	0.324 – –	1.54 – –	0.600 – –	
SIN	– – 3.6	– – 2.4	13.8 66 16.0		2.93 148 3.3	1.97 159 2.0	4.09 – 4.2	10.37 – 11.4	2.4 – 4.4	– – 25.7
ATAN	– – 5.5	1.06 36 2.2	20.9 87 23.0		4.55 170 6.1	2.62 172 3.6	5.63 – 5.5	16.35 – 14.2	5.2 – 7.4	– – 16.2
SQRT		– – 0.8	4.8 77 –		5.58 86 –	2.24 117 2.7	3.58 – 8.3	6.66 – –	0.6 – 1.1	– – –

1) The figures show for every function:

- Time in ms from manual,
- Memory requirement,
- Time in ms from test run.

6.4. CONVERSATIONAL LANGUAGES.

Two types of conversational languages are offered, viz. BASIC and FOCAL. The languages are presently available in the following systems:

CD	-
DDP 316, 516	-
HP	BASIC
IBM	-
PDP 9, 15	FOCAL
Raytheon	-
Varian	-

There are many similarities between BASIC and FOCAL. The main difference is matrix handling.

BASIC can handle 2-dim. matrices while FOCAL can handle only vectors. In this respect BASIC is better. BASIC has matrix statements, so it is possible to treat matrices as scalars.

Both languages have a library of mathematical routines. FOCAL has 10 and BASIC 8.

DDP and Varian have a type of desc top simulator system, which can make the common desc top calculator operations.

6.5. DISK OPERATING SYSTEM.

In this section we will discuss the Varian, HP, DDP and PDP 8 k monitor systems. We do not discuss the CD and IBM systems. In 4.4 we explain, that we regard these systems interesting only in the B version. Therefore, they are compared with the other computers in the next section. Generally speaking, the CD and IBM software include all the features, which are discussed in this section.

Table 6.3 - Disk operating systems. A short comparison.

	DDP	HP	PDP
Name	BOS	DOS	Keyboard
Delivery		1969	Dec., 1967
System programs, stored on disk, which can be called from TT:			
Assembler	yes	yes	yes
Compilers	"	"	"
Editor	"	"	"
Relocating loader	"	"	"
Fortran library	"	"	"
Disk editing programs	"	"	"
Batch processor	"	"	"
I/O drivers for peripherals	"	"	"
Batch processor. It is possible to do all system control inputs such as:			
- JOB initiate			
- compilation			
- execution orders			
from TT as well as paper from tape, i.e.			
a Fortran program can be run without any human operator from JOB start to execution	yes	yes	yes (see 6.5.4)
Possible to do linking (overlay)	yes	yes	yes
Compilation			
The compiler can fetch the source program from disk as well as from PTR.	yes	yes	yes
Possible to store the binary relocatable program directly on disk after compilation.	yes	yes	yes
Editing			
The editor can fetch the source program from disk and write it back again on disk. (See also 7.1.2.)	yes	yes	yes

Table 6.3 Contd.

	DDP (BOS)	HP (DOS)	PDP (Keyboard)
Disk editing			
Possible to delete a program from disk with a CALL NAME.	yes	yes	yes
Possible to store a binary relocatable program on disk directly from paper tape.	yes	?	yes
Possible to store a source code (Fortran, Algol or Assembler) directly from paper tape to disk.	yes	?	yes
Dumping of disk files on other peripherals.	yes	yes	yes
Fortran execution			
Read and write data from reserved disk files with READ and WRITE statements.	yes	yes	yes
Possible to change logical numbers of peripherals.	yes	yes	yes
Possible to measure execution time with the monitor.	?	yes	no
Hardware			
Core resident area	300	2 k	1 k
Disk memory requirement	?	?	100 k
Hardware memory protect of the system on disk.	?	yes	yes
Software memory protect of disk possible.	?	yes	no
The monitor uses the hardware multiply unit.	?	yes	yes
The monitor uses hardware priority interrupts.	?	yes	yes

6.5.1. Varian 620 I

There is no operating system available today, but a Master Operating System is under development. It is called the Phase II software. However, no monitor can be shown today, but it will be available late 1969 or early 1970. A monitor system is very seldom perfect just after the introduction. Even if the firm has told us the time of introduction, we consider the system non-existing.

6.5.2. H 316 - DDP 516

The DDP Batch Operating System (BOS) operates with 8 k core memory and alternatively with a fixed head or a moving head disk. No information has been obtained about the age of the system.

6.5.3. HP 2116 B

HP has presently a Disk Operating System, DOS, which is presently working with the fixed head disk. The system will be changed to the new disk. However, as the disk is not delivered, the system is not available today.

The DOS is compared to the PDP disk operating system (keyboard monitor) in table 6.3.

Some special features of the HP monitor will be emphasized. About 2 k is residently in core. This fact makes it possible to execute more system operations with the disk during an execution. A smaller area than for PDP is available to the user. However, an I/O driver can be disk resident. It is read into core only at request. Only one I/O driver has to be resident in the core memory at a certain moment.

A "floating boundary" exists between the system and user areas on the HP disk. This advantage makes it possible to use the disk more effectively. On the moving head disk with 800 k, however, this advantage is not as obvious as for a smaller disk unit.

6.5.4. PDP 9 - 15

The keyboard monitor system has been available since December, 1967. It was originally written for DEC tape and not for disk. Later the disk has been included in the system. It is in the first part simulated as DEC tape with named files. The monitor will be updated in November, 1969.

The keyboard monitor, including all other system programs and library, occupies about 100 k on the disk.

The core resident area is 960 words. Contrary to HP, PDP does not permit disk resident I/O drivers, so all drivers, which are used, must occupy the core memory.

The Peripheral Interchange Program (PIP) is used for all data transfer between different files and peripherals.

We define batch processing as the whole sequence of operations from read in source tape, through compilation, loading, execution to stop. It is possible to punch all monitor orders on paper tape, so all this work can be done automatically. However, the definition of JOB is different at DDP and HP. The latter defines the whole sequence mentioned as a JOB. PDP divide this sequence into a number of JOBS, such as compilation, loading, etc. From the user's point of view the difference occurs when an error is detected.

Contrary to HP, PDP has no floating boundary on the disk between the system area and user's area. The disk area is sometimes not effectively used. This is not a great disadvantage, because of the DEC tape. The DEC tape can always be used as a spare memory.

6.5.5. Summary and Comparison.

There are quite small differences between the DDP, HP and PDP disk operating systems. However, some comments can be made.

The information about the DDP system is not as good as the information about HP and PDP. All the systems seem to satisfy the requirements. The HP monitor is probably the most flexible one, but the differences between the systems are not decisive.

In order to compare the systems, one also must take the hardware into account. The disk flexibility and size are very important (see 5.4).

The HP monitor is presently not working with the moving head disk, and the system has been demonstrated only with the fixed head disk in USA. DDP has a working system. However, the fixed head disk has only 196 k memory and cannot be expanded. A moving head disk is more expensive. PDP has experiences with the DEC tape system and has also a working disk system. The great advantage of PDP is the flexibility when both disk and DEC tape (see 5.4) are used.

It has not been possible to test the HP and DDP systems in Sweden. We have tested a PDP 9 supplied with DEC tape (see chapter 7).

6.6. REAL TIME MONITORS.

In this section we will compare the different advanced "16 k monitors", or those with some type of foreground-background programming facility.

CD, DDP, HP, IBM and PDP 9 and 15 computers are compared.

In the previous section was discussed the disk operating systems, but not those for CD and IBM.

Varian is discussed separately in 6.6.2.

All the monitors which are mentioned here can work with a 16 k core memory, even if a very small area is left for the user in some cases. Therefore some of the vendors have suggested a bigger core memory in order to have a better configurated system.

CD offered a 16 k memory, but suggested 20 k as an option, since the system will get faster.

DDP offered directly a 24 k memory, although the manual states 12 k as a minimum configuration for the OLERT 2 monitor.

IBM offered 16 k, but experiences from other users indicate, that substantially higher speed and flexibility is obtained with a bigger memory.

In the following sections we will compare the most interesting features of the monitors, and the comparison is summarized in table 6.4.

Table 6.4 - A short comparison between different real time monitors.

	CD	DDP	HP	IBM	PDP
PROGRAM SCHEDULING.					
Segmenting possible?	yes	yes	yes	yes	yes
Fortran programs can be run on priority basis in the core memory?	yes	yes	yes	yes	no
The queue of priority programs in Fortran can reside both in core and on disk?	yes	yes	yes	yes	no
Program priority can be changed on-line (Fortran programs)?	yes	yes	yes	yes	no
Number of priority levels.	16	-/8		24	4 + 4
Several programs may have the same priority.	yes	?		yes	
PROGRAM TYPES.					
Real time programs can be stored in absolute form on disk?	no	yes	yes	yes	yes
Re-entrant math. subroutines	yes	yes	yes	yes	no
Real time programs can be dynamically incorporated on-line?	?	no	no	yes	no
MEMORY ORGANIZATION.					
Hardware protection of foreground program area in core?	yes	yes	yes	yes	yes
Floating boundary between protected and nonprotected areas in core?	yes	yes	no	yes	yes
Size of core resident monitor.	8-12 k	8-12 k		7-11 k	
Possible to get a buffer for I/O for slow peripherals in Fortran program?	yes	?	yes	yes	no

6.6.1. Vendors' Experiences of the Monitors.

The monitors MSOS2 (CD), OLERT 2 (DDP) and TSX (IBM) have been used in several applications, and they have been tried during rather a long time. We regard them satisfactory.

The HP monitor is quite new and is presently written only for a fixed head disk. The company has not yet released any information about the performance of the monitor.

The PDP monitor was released in December, 1968, and is therefore fairly new. At that occation it was written for DEC tape, and it has not yet been demonstrated together with the PDP 15 system and a disk, although the monitor is quite the same.

6.6.2. Varian 620 I.

In the quotation a "time sharing system" was mentioned. This was not the real time monitor, described in the specifications.

Some routines of the monitor might be valuable for us, but we cannot get a complete system. No disk drivers are available, as the system is tape oriented.

At later contacts with Varian we found, that no real time monitor was presently planned.

6.6.3. Interesting Features of the Monitors.

We will not try to describe the general facilities, which may be included in the real time monitors. However, when examining the computers we have looked at some special features, which we consider especially interesting for our purposes.

Programming Language.

In order to get good flexibility it is valuable to be able to write all Monitor orders in Fortran. The orders include such as segmenting, different types of priority handling, disk routines, and clock interrupts. At some computers several of these orders can be given in a macro language or assembly language, but this is not as flexible as Fortran. The problem is often to schedule Fortran programs on a priority basis.

Program Scheduling.

There are two different types of programs, which will be run at the computer, viz. foreground and background programs. The background programs are executed when the central processor is not occupied by a real time program. The background programs include compilers, assemblers and editor as well as ordinary user programs, which are not run in real time. In the background we will execute all the things, which are defined in previous section, for the disk operating system.

The real time programs may be ordered in two different ways. The first is segmenting or chaining. This means that one program is executed after the other in a pre-determined way. The next program is read in from the disk and is read over the old program. Common data are saved in a resident register area.

The other type of ordering is on a priority basis. In order to achieve this, we must have some features of the computer.

The real time programs, which are to be executed, must be ordered in a queue, and a number of priority levels must be defined. Several programs may have the same priority.

The currently executed program retains control until it terminates or is suspended by the monitor. An interrupt may occur for several reasons, viz. by an I/O operation or other system function, by a higher priority program, by a clock interrupt or by another internal or external interrupt. When an interrupt occurs, the monitor has to identify the source of interrupt.

From the user's point of view it is insignificant, if the priority levels are hardware or software. The identification is made either by hardware or by the monitor itself. If any disk operation is necessary due to the interrupt, the difference in handling time between the hardware and software system may be neglected. It is generally very difficult to find out the response time, that is the time between the interrupt occurs and the initiating of the service routine begins. We have only been able to test the IBM system (see 7.5).

When the interrupt source is identified, the monitor has to bring over the control to another program, which presently has the highest priority.

If the core memory were very big, all the programs in the priority queue could be placed in the core permanently. The monitor only has to save the registers from the old program and switch over to another entry point in the core memory. No advanced disk handling is necessary in this case.

Now the core is seldom big enough and there may be a need to use the disk in a more advanced way. The interrupt service program may be placed in disk, and therefore the working program has to be saved on disk in order to get space enough for the new program in the core. The old program is thus saved in a special area on disk, and the new program is read in (swapping).

It is possible to do this kind of interrupt service by swapping on all computers except PDP by using a Fortran language. In order to do the same things with PDP, it is necessary either to change the compiler (which is difficult) or to use machine language.

If the programs on disk are stored in absolute format together with all necessary subroutines and library routines, the loading will be as fast as possible. On CD the programs are stored in relocatable form, so the loading procedure is more flexible but a bit slower. (Naturally the hardware speed of the disk is also important!)

In advanced monitor systems it is possible to incorporate new real time programs dynamically when the computer runs. Only CD and IBM have this facility.

Re-Entrant Subroutines.

With re-entrant subroutines, e.g. the mathematical library routines, it is possible to avoid loading of one routine several times. The subroutines can be interrupted and started again for higher priority programs.

All monitors except PDP have re-entrant subroutines available. This fact makes PDP disadvantageous. It is presently impossible to run Fortran programs on a priority basis in the core, as they cannot share the same routines. For example, the floating point package has a unique name and therefore it is possible to load it only once. As it is not re-entrant it cannot be shared. Thus only one main program in Fortran may be in the core at one moment. In assembly language there are several ways to overcome this problem. In Fortran it could be possible to change the compiler to include several copies of the library but with different names. However, it is also very memory consuming to load several copies of one library routine. A smarter solution may be to give the mathematical library highest priority. Then it cannot be interrupted by another program and need not be made re-entrant.

Memory Organization.

The core memory has to be divided into two parts, one for foreground programs and one for background programs. As it is desirable to use the core memory as effectively as possible, we want to have a flexible boundary between these areas.

The real time program area is memory protected, and the boundary has to be set just over the program area. If a big background program is to be run when the computer is free, we want to move the boundary for the protected area. The boundary is made "floating" at all computers except HP, where the boundary is established when the configurated system is created. Both HP and PDP use a fence register and associated logic circuits to protect memory addresses less than the one specified in the register.

The smallest unit of protection is only one word for CD and IBM. For the other computer the unit is 512 or 1 k words. If the boundary has to be moved on PDP for example, the free area between the upper part of the foreground program and the boundary can be used for dynamic data storage via a software protect feature.

I/O Buffers.

A program is placed in a suspended state during its I/O transfers. Output directed to high-speed devices should not cause excessive delays in the overall program execution. However, delays could become excessive and cause sizable delays when directing output to low speed devices. Therefore an automatic output buffering is very valuable. This type of buffering cannot be done in Fortran on PDP. It is, however, still possible to have buffers in machine language.

6.6.4. Summary.

The PDP monitor is not as advanced as the other monitors, which are examined. It does not include swapping facilities. It is also impossible to execute priority programs in Fortran, but the monitor has mainly the foreground-background facility.

The HP monitor is more flexible than the PDP one, but is not so flexible as the rest of the monitors. For example, the protection boundary is fixed, so new programs cannot be incorporated on-line. Also the disk utility routines are simpler than the IBM and CD ones. In order to pack program on the disk, one must specify every stored program. However, due to a clever logical structure of the HP disk system, the system does not need a packing routine as much as other systems.

Both DDP, CD and IBM have very advanced monitors. As a consequence they will occupy a bigger resident area, and 16 k is often a small core memory, as the user has only about 4 - 7 k available in the core. In order to use these systems effectively, it is therefore often necessary to buy more core memory, and this would be too ex-

pensive for us.

We consider it possible to carry out the tasks, which are specified at the beginning (1.3) on all the computers, which are discussed here. The PDP monitor, however, is less flexible than the other ones.

6.7. SUMMARY AND COMPARISONS.

It is impossible to give a unique measure of performance of the different software systems. Therefore we choose to divide the computers into different classes, depending on their software flexibility.

Generally speaking there are three computers with great flexibility as regards both compilers and monitor systems, viz. CD, DDP and IBM. The software systems have been tested in real applications and are regarded reliable.

HP and PDP will be placed in the second class. Their compilers are somewhat smaller, especially they have not so good diagnostics. However, PDP has a reduced Fortran IV language, which seems to be satisfactory. Their disk monitor systems are comparable, but because of the hardware configuration the PDP system is superior since HP can presently offer only a fixed head disk.

The HP real time monitor is more flexible than the PDP foreground-background monitor. However, the HP monitor is fairly new, and we do not know anything about its reliability. It is not yet written for the moving head disk. The PDP monitor is quite new, Dec., 1968, and was written for DEC tape. The disk files are organized as DEC tape files. Even if the real time monitors in this second class are not as good as those in the first class, we may not exclude the computers HP and PDP due to the monitor systems.

The Varian software, however, is placed in a third class. The "Phase II software" has not been introduced yet. Neither a disk operating system nor a real time monitor are available. Varian has to be excluded from the list, due to its software system.

7. TEST RUNS AND EXPERIENCES OF THE COMPUTERS.

As it is impossible to learn all the facilities of a system from manuals only, it has been desirable to test the systems in reality. However, it is impossible to test all the systems, especially in the right environment.

We have direct experience from test runs on HP 2115, IBM 1800, PDP 9 and Varian 620 I. Moreover, we have had test programs run at HP 2116 B, CD 1700 and DDP 516. For comparison we have tested an EAI 640 computer. In the following sections we will discuss different results from these test runs.

In 7.1 we report experiences with different paper tape systems. We have run the computers HP 2115, PDP 9 and Varian. Paper tape handling and editor work are discussed.

We have studied the compiler diagnostics on HP, IBM and PDP 9 and the results are discussed in 7.2.

In 7.3 a test program is discussed, which has been run on all the above-mentioned computers. The test run has given very valuable information about compiler and run time library effectiveness. The difference between the compilers is very great, and these results have had a decisive influence on our choice of computer.

In the tests we have not used any general "scientific mix" in order to get an average operation time.

Gibson has suggested one mix for "scientific purposes". Another mix for real time applications is suggested by Collins. We have not regarded these types of mixes. The first reason is that it is very difficult to estimate the frequency of different operations. Another reason is that the mixes have not regarded I/O and data transfer.

The mix divide the operations in four main classes, floating point arithmetic, multiplication and division in fixed point, jump operations and finally such operations as shift, comparison etc. We regard the frequency for the first class to be underestimated.

In the tests we have tried to find out some representative application program.

It must be emphasized, that this test run is only a test of the central processor. The total effectiveness of a system may be quite different. However, from the tests we have found operations, which are unsatisfactory. We have also got a tool to estimate the quality of the programs in general.

Only one "disk" operating system has been run, the PDP 9 system. Instead of disk, the computer was supplied with DEC tape, which changed the handling speed but not the user's orders. The experiences are discussed in 7.4.

Finally it has been possible to test some features of the time sharing system TSX at an IBM 1800 computer. The speed of some monitor operations was measured and the results are given in 7.5.

7.1. HANDLING THE PAPER TAPE SYSTEMS.

We consider card systems superior paper tape systems. Only IBM could offer a card system at a reasonable price. In this section we compare HP, PDP 9 and Varian, which have been run in different tests.

7.1.1. Compiling and Loading Procedure.

We consider the case when all the system programs are stored on paper tape. This implies several things:

- long reading time,
- hugh amounts of paper tape spool,
- long punching time,
- errors due to dust on paper tape, when it happens to fall on the floor.

PDP has folded tape which is considered better than the spooled tape of HP and Varian. There is no need to rewind it and the tape is collected in a certain tape receiver. However, for long tapes, problems may arise.

The punch should be turned off automaticly, when it is not used. This was not the case for the Tally punch, of HP and Varian, but the Facit and PDP punches worked satisfactorily.

7.1.2. Editing.

The editors of HP and PDP have been tested and compared. Generally the HP editor is less advanced than the PDP editor. Some comments are given below.

Varian has no editor program as the other computers. The program, that is available, is a program for controlling the teletype. All the editing is made manually at the teletype.

The HP editor works very well and it is simple to use. The command "Edit file" can be read in from the teletype. There are a couple of disadvantages:

- all changes have to be specified at the beginning,
- the changes have to be specified with line number and the character number within the line,
- a check of the editing can only be done if the whole program is listed.

The PDP editor was stored on DEC tape. It is more advanced than the HP editor, especially with respect to the following items:

- an arbitrary string of characters of the source program can be specified and located by the editor,
- the changed line is always written out,
- an arbitrary part of the program can always be listed,
- new statements and strings of characters can be incorporated from the paper tape reader.

7.2. COMPILER DIAGNOSTICS.

From table 6.1 we will get a feeling of the diagnostic facilities of the compilers, when looking at the number of error messages. CD, DDP and IBM have better error lists than the other three computers, HP, PDP and Varian.

We have been able to test only the HP, IBM, PDP 9 and Varian compilers.

For HP about half of the error messages have been tested and they worked in most cases. Sometimes they were difficult to understand, and many errors followed after one single error. The I/O operations and Format statements are rather bad or described badly, but this is a common feature on several small computers.

The Algol compiler worked satisfactorily, and the diagnostics was correct apart from a couple of cases.

IBM has not been tested as carefully as HP, but in all cases the diagnostics worked very well. The compiler seems to be very reliable.

The PDP computer has a compiler with rather bad diagnostics. It is difficult to understand the messages. However, the manual describes rather good, what happens if an error occurs.

The Varian compiler diagnostics is comparable to HP and PDP.

A general desire is better diagnostics. This facility will probably cause longer compilation times and bigger compilers. However, from the user's point of view, long compilation time is not serious. It is more important to reduce the handling time by better diagnostics. Of course, an effective binary code is essential.

7.3. TEST OF THE CENTRAL PROCESSOR SPEED FOR FORTRAN PROGRAMS.

7.3.1. Type of Test Programs.

The research program will have a great demand on the internal speed of the computer system. Out of this fact a number of test programs have been defined.

First some typical mathematical library functions are run, and their speeds are compared to the speeds given in the manuals.

Then a number of arithmetic operations are measured. Floating point addition and multiplication are programmed for indexed and non-indexed variables.

In order to get better accuracy of the time measurements, the programs were repeated in DO-loops, until some minute had elapsed. In order to get the single test program time, we then subtracted the time for a DO statement.

Matrix multiplication is a very important part of the programs which are planned. The speed depends on basic multiplication time, run time library and indexing flexibility. The computing time increases in different ways for different computers, when the dimension of the matrix increases.

The precision has been measured rather simply with an inversion of a small matrix. The matrix (2 x 2) was inverted 10^4 times, and the result was compared to the initial matrix. The maximum deviation is written in table 7.1.

As a typical application program a Kalman filter was executed. Two systems of order 2 and 5 with one output signal were calculated.

A Kalman filter execution consists mainly of matrix multiplications. The order between the computers was therefore just the same as for single matrix multiplications.

The programs are listed in the appendix.

In these tests the execution times for Fortran programs and floating point arithmetic calculations have been emphasized. In many applications of process control the memory occupation is almost more crucial than the execution times. Therefore the memory requirement of the monitors and system programs have been studied, where it was possible.

In the computer test it was very difficult to get unique measures of the memory occupations. The mathematical libraries are often loaded in modules, which include more than the necessary parts for a specific user's program. The size of these modules may differ very much between the computers, and it is difficult to get the relevant information. The formatters are also different and include different facilities.

In our opinion, the most relevant memory comparison should be the total memory requirement for a whole application program.

Table 7.1 - Results from test runs with different computers.
The program names refer to the listing in appendix 1.

MANUAL FIGURES		CD 1700	DDP 516		HP 2115	HP 2116	IBM 1800		PDP 9		Varian 620 I		EAI
		reentr.	EAU	not EAU	not EAU	EAU	reentr.	non-reentr.	EAU	not EAU	EAU	not EAU	640
Cycle time µs		1.1	0.96	0.96	2.0	1.6	2.0	2.0	1.0	1.0	1.8	1.8	1.65
Word length	fix	16	16	16	16	16	16	16	18	18	16	16	16
	float	23+8	23+8	23+8	23+8	23+8	23+8	23+8	26+9	26+9	22+8	22+8	23+8
	fix DP	31	31	31	31	31	31	31	35	35	31	31	31
A+B	fix µs	2.2	1.9	1.9	4.0	3.2	4.25	4.25	2.0	2.0	3.6	3.6	3.3
	DP fix "	?	2.9				7	7	255		54		
	float "	150	238		500	700 ?	548	269	~280		400		
AxB	fix "	7	5.3	155	187	19.2	15.25	15.25	12	<281	10	200	18.15
	DP fix "	?	136						272		128		
	float "	217	489		700	344	519	322	~264	2050	430		
A/B	fix "	9	10	221	387	20.8	42.75	42.75	12	<352	10-14	200	18.98
	DP fix "	?	205						352		275		
	float	262	489		1300	448	748	424	~324	1540	600		
SQRT (from manual) ms					4.8		5.58	2.24	3.58	6.66	0.6		
SIN (" ") "					13.8		2.93	1.97	4.09	10.37	2.4		
ATAN (" ") "			1.057		20.9		4.55	2.62	5.63	16.35	5.2		
TEST RUNS													
SQRT ms			0.8					2.7	3.0		1.1		4.03
SIN "		3.6	2.4		16		3.3	2.0	3.0	11.4	4.4	25.7	4.68
ATAN "		5.5	2.2		22.8		6.1	3.6	5.5	14.2	7.4	16.2	5.9

Table 7.1 - Results from test runs with different computers.
The program names refer to the listing in appendix 1.

MANUAL FIGURES		SIEMENS 301	SIEMENS 305 Hardw. float.p.	PDP 9 times 0.8	PDP 15-30 (July, -70)
Cycle time µs		1.5	1.5	0.8	0.8
Word length	fix	24	24	18	18
	float	24+12	24+12	26+9	26+9
	fix DP				
A+B	fix µs				
	DP fix "				
	float "				
AxB	fix "				
	DP fix "				
	float "				
A/B	fix "				
	DP fix "				
	float				
SQRT (from manual) ms					
SIN (" ") "					
ATAN (" ") "					
TEST RUNS					
SQRT ms		22.27	0.74	2.4	2.7
SIN "		16.9	0.62	2.4	3.0
ATAN "		19.1	0.76	4.4	3.84

Table 7.1 Contd.

	CD 1700	DDP 516		HP 2115	HP 2116	IBM 1800		PDP 9		Varian 620 I		EAI
	reentr.	EAU	not EAU	not EAU	EAU	reentr.	non-reentr.	EAU	not EAU	EAU	not EAU	640
DO LOOP 1 µs	11	14.2			20		29	14.2	15	240		33.8
DO LOOP 2 µs	11	15.8			17.5		33.5	19.2	20	235		53
R = R + S x T ms	0.75	0.450		1.7	0.6	1.68	1.0	0.775	1.82	1.48	4.1	0.75
R = R + S(I) x T(J) ms	0.75	0.480		1.7	0.8	1.84	1.4	0.950	2.20	1.53	4.2	0.85
R = R + S(2I+3) x x T(3J+4) ms		0.550			0.85		1.4	1.050		1.75		0.90
CALL PAUL µs		25			100		60 ?	25		270	240	80
CALL LAUP (1.,2., 3.,4.,5.) µs		180			200		690 ?	150		490	490	256
MATMULT 5 x 5 ms	153	86		300	120	390	200	140	213	266	937	138
10 x 10 sec	1.23	0.655		2.4	0.910	3.04	2.1	1.09	1.73	2.04	5.95	1.06
15 x 15 sec	4.16	2.2			2.0	7.02	5.0	3.65	6.2	6.8	22.5	3.55
20 x 20 sec	9.9	5.18		19.4	7.3	16.5	11.7	8.5	14.8	16.1	60	8.45
MATINV 2 msec	3.2	2.95		11.9		8.4	5.1	3.2	9.4		18.3	3.28
PRECISION max. deviation				10×10^{-6}		$110\ 10^{-6}$		13×10^{-6}	13×10^{-6}			19×10^{-6}
KALMAN 2x2 sec				0.152		0.17	0.12	0.085	0.138	0.115		0.079
5x5 sec				4.14		3.58	2.35	1.91	3.48	2.8		1.92
PRECISION 2x2 (max.rel.				5×10^{-5}		3×10^{-5}						
5x5 error)				3×10^{-7}		$20\ 10^{-7}$						
STORAGE I/O												~2800
MATH library												540
program			2492									1312
dimension			1140									1820
Total						9195						6497

Table 7.1 Contd.

	SIEMENS 301 nonreentr.	SIEMENS 305 Hardw. float.p. nonreentrant	PDP 9 times 0.8	PDP 15-30 (July, -70)
DO LOOP 1 μs	755	21	11.4	11.0
DO LOOP 2 μs	870	24	15.4	16.5
R = R + S x T ms	2.7	0.070	0.620	0.535
R = R + S(I) x T(J) ms	7.44	0.335	0.760	0.635
R = R + S(2I+3) x x T(3J+4) ms	9.95	0.375	0.840	0.700
CALL PAUL μs	1591	136	20	25
CALL LAUP (1.,2., 3.,4.,5.) μs	10430	722	120	138
MATMULT 5 x 5 ms	1434	53.8	112	86
10 x 10 sec	11.04	0.404	0.870	0.680
15 x 15 sec	36.8	1.34	2.92	2.34
20 x 20 sec	86.7	3.14	6.80	5.5
MATINV 2 msec	15.17	0.31	2.56	2.2
PRECISION max. deviation	1.0×10^{-3}	1.0×10^{-3}	1.4×10^{-5}	1.3×10^{-5}
KALMAN 2x2 sec	0.81	0.036	0.068	0.052
5x5 sec	19.81	0.82	1.53	1.15
PRECISION 2x2 (max rel.	6×10^{-7}	6×10^{-7}		1×10^{-7}
5x5 error)	7×10^{-7}	7×10^{-7}		0.8×10^{-7}
STORAGE I/O				
MATH library	2356	2356		
program	3705	3705		
dimension				
Total				

7.3.2. Comments on the Test Results.

The first part of table 7.1 shows the computing times, stated in the manuals. It is often impossible to find out, if the figures are maximum, average or minimum execution times. This problem is clearly demonstrated when the "theoretical" figures are compared to practical test runs.

In order to get a feeling of the effectiveness of the Fortran compiler and the run time library, we define a performance index as the ratio of the calculation time and the cycle time.

Library Functions.

We have chosen three functions of the mathematical library, which will demonstrate the speed of the library functions.

Comparing the SINE and ATAN functions, we see that DDP, IBM and PDP 15 are the fastest computers. The performance index of IBM is superior. IBM has evidently very fast mathematical library functions, especially the elementary functions. Without the EAU unit both HP and PDP 9 are quite slow. PDP 15 has about the same performance index as PDP 9. Siemens 305 has hardware floating point, which explains the fast execution times. Varian has a rather fast square root routine.

If the test times of the library functions are compared with the figures from the manuals, IBM, HP and PDP 9 show good agreement, while DDP and Varian have greater differences.

DO-Loops.

For the DO-loop 1 we can see that CD and PDP 15 are fastest. CD has a better performance index. Varian and Siemens 301 have very bad DO-loops and the numbers of cycles are 13 times greater for Varian and 50 times greater for Siemens 301, compared with CD. The bad data representation of Varian in Fortran might partly explain the long execution time. Fixed numbers are stored in two words. One of the words is not used at all (see 6.3), so addressing may be quite complicated.

Another explanation may be, that DO-loops in Varian are made by special subroutines. The compiler output indicated this fact.

Another computer, EAI, which generally has a very good performance index, has slower DO-loops. The explanation here is, that it has a rather complex Fortran IV language. Consequently it takes a longer time to order a DO-loop, as the entry is more flexible.

The same arguments may be valid for Siemens.

The rest of the computers have a speed of the same order as CD.

As DO statements will take a small part of the execution, the speed here is not very crucial.

R = R + ST.

Here DDP is the fastest computer. However, looking at the cycle time, the HP 2116 computer is superior. HP needs 375 cycles while EAI needs 455, DDP 470, CD 680, IBM (nonreentrant) 500, PDP 15 670 cycles, PDP 9 (EAU)775, Varian (EAU) 820, Siemens 301 1800 cycles, Siemens 305 47 cycles (hardware floating point).

In table 7.2 we compare the measured times with the "theoretical" times for floating addition and multiplication.

Table 7.2 - Comparison between execution times given in manuals and practical calculations for add and mul (times in μs).

	R=R+ST	Add	Mult	ADD+MULT
CD	750	150	217	367
DDP with EAU	450	238	489	727
HP 2115	1700	500	700	1200
HP 2116 w. EAU	600	700(?)	344	1044
IBM reentr.	1680	548	519	1067
IBM nonreentr.	1000	269	322	591
PDP 9 w. EAU	775	280	264	544
Varian w. EAU	1480	400	430	830

The figures in the rightmost column may confirm the statements above, that these figures might be any value between max. and min.

The figure for DDP seems curious, but may be right. The test run was made by Honeywell. The Add time for HP 2116, given by the firm, is probably too big, and should be about the half.

Matrix Handling and Kalman Filters.

Also here DDP, HP, and PDP 15 are very fast computers. The HP computer gives binary programs which are very effective.

PDP 9 needs twice as many cycles as HP, while PDP 15 needs 40 - 50% more cycles as HP in the matrix multiplications.

If we take the ratio between the computing times for the big matrices and the small matrices, we can get a feeling of the addressing facilities. In this respect IBM is the best computer, probably because of its index registers. The ratio for IBM between the 20x20 matrix and the 5x5 matrix execution times is 42. For the other computers this ratio is about 60 to 70.

A single matrix multiplication subroutine ought to give about the same test result as a Kalman filter execution.

IBM is flexible in the addressing, but the difference to the other computers is not so great here.

The Kalman filter has not been run for all computers. It is interesting to note, however, that the code in PDP 15 is more effective than in PDP 9.

The Siemens 305 times are fast all the time. However, considering the hardware floating point unit, the times are not impressive. The precision of the computations ought to be mentioned.

Because of the longer mantissa in the PDP computers, their precision both in the matrix inversion example and in the Kalman filters are very good. The Kalman filters have been compared to the 48 bit CDC 3600. It is interesting to note that Siemens has not so good precision. This depends on the floating point data representation. Half a word is unused, and the mantissa has only 24 bits, two less than in PDP.

It should also be observed, that the IBM precision is not very good, compared with PDP. However, the comparison between HP and IBM shows, that the matrix inversion and Kalman examples are not enough to get unique precision measures.

Effect of the Hardware Multiplication Unit.

On three computers, HP, PDP 9, and Varian, it has been possible to measure the increase of speed when the hardware multiplication unit is included. For PDP the decrease in time was 15 - 40%, while HP decreased about 50% and Varian as much as 70%.

Re-Entrant Subroutines.

Theoretically the computing times for re-entrant subroutines are about twice compared to non-reentrant subroutines. The times of the tested IBM non-reentrant subroutines are about 50 - 60% of those of the re-entrant routines.

For the matrix multiplication and the Kalman filter, the decrease of computing time is shown to be 29 - 34%. Most of the calculations need the floating point routines, which can be made re-entrant, and as these operations are dominating, the decrease in time is quite near that of floating operations.

7.3.3. Summary of the Test Runs.

It is impossible to give a unique measure of performance of the computers, as it is necessary to know the frequency of the different operations in the planned programs. Therefore we just divide the computers in a couple of classes, depending on the speed.

As the specifications include hardware multiplication, computers without this facility are not considered in this summary.

In the high speed class we have DDP 516, EAI 640, HP 2116, PDP 15, Siemens 305, and CD 1700. PDP 9 is just a bit slower than these computers.

The PDP 15 has been proved to be more effective than the PDP 9. The hardware configuration, e.g. registers and extended arithmetic unit are better, and parts of the run time library have been speeded up. E.g. the matrix multiplications and the Kalman filters are 35 - 40% faster on PDP 15, while the cycle time is 20% smaller.

The test results have shown that several computers have rather a bad Fortran run time library. The floating point package is a very important part of the library in the calculations. A correction of the package may be very profitable. On some computers this change is rather easily done.

IBM 1800 is quite fast with non-reentrant subroutines, but is slower with reentrant ones.

Varian seems to have rather an ineffective compiler, as its calculation times are quite great, although the cycle time is rather short.

The instruction list may influence the compiler effectiveness. Both HP and DDP have flexible machine instructions, 5.2, and they have evidently been used by the compilers. Probably the flexible accumulator and index register operations are important.

The addressing is another interesting feature. One explanation of the small HP test times may be, that the compiler uses page zero effectively as a communication area.

Finally we emphasize, that a compromize has to be done in several cases between speed and language flexibility.

7.4. THE DISK OPERATING SYSTEMS AND THE BATH OPERATING SYSTEMS.

At the Division we have gained direct experiences from test runs with the IBM 1800 TSX monitor system and the PDP 9 keyboard monitor system.

In order to learn more about CD we have asked other users. The rest of the computers have not had monitor systems available in Sweden.

7.4.1. The PDP 9 Keyboard Monitor.

A PDP 9 keyboard monitor system, placed at the Research Institute of National Defence (FOA) in Stockholm, has been tested. The computer has an 8 k memory, DEC tape system and no disk. As no disk was available the access times were very long. Thus we have no experiences of any work with the disk system. The memory is occupied rather much because of the monitor, about 3.5 k. This fact implies, that only small Fortran programs can be executed in the core memory, as the formatter and the Fortran library occupies a sizable area. A 16 k memory is quite more realistic configuration.

It may be more difficult to sit at the teletype and give orders instead of giving them on control cards.

Editing takes very long time due to the DEC tape handling. This disadvantage will hopefully be eliminated with a disk.

The orders, which are described in the manuals,work satisfactorily.

7.4.2. Batch Processing.

The problems with batch processing are quite the same for CD and PDP 9 and PDP 15, equipped with paper tape system.

Orders have to be given either from the teletype or from the paper tape directly. No test run has been made with paper tape orders. Thus it was necessary to give several orders from the teletype of PDP in order to read in the compiler, load the program, and so on.

IBM has been tested with nonprocess as well as process programs. The TSX system was run at a 16 k computer at the University of Stockholm. The batch processing is quite simple to manage, both because of card system and the reliable TSX system.

7.5. REAL TIME MONITORS. The IBM TSX System.

This test intended to show the speed of some common orders of the IBM TSX monitor system.

The computer, that was used, is installed at the University of Stockholm at the Chemical center and has

16 k memory with 2 µs cycle time
Card reader/punch
Line printer 1443
2 disks 2310 (mean access time 520 ms)

Our specific questions were:

- How long does it take to get an interrupt core load swapped?
- What time does it take to call LOCAL subroutines from the disk?
- What time does it take to do CALL CHAIN (load in a program from the disk)?

7.5.1. Test of Segmenting.

The order CHAIN is used to segment large programs. With this order a program A, which is placed in core memory can call a program B from the disk, and A is read over by the program B.

Program 1. One Disk and Big Dimensions.

Case 1.

A sequence of 3 core loads are tied together with CALL CHAIN (see fig. 7.1). Every core load will occupy about 3 cylinders of the disk and are placed after each other.

Every jump took 460 ms (92 sec. for the whole sequence).

```
//JOB                    (CORE LOAD A)
//FOR A
      EXTERNAL B
      COMMON/INSKEL/ I
      I = 1
      PAUSE 1
10    CALL CHAIN (B)
      END


//FOR B                  (CORE LOAD B)
      EXTERNAL C
      DIMENSION IB(6000)
      COMMON/INSKEL/I
      I = I + 1
      IB(1) = 1
      IF(I - 100) 10,20,10
20    PAUSE 7070
10    CALL CHAIN (C)
      END


//FOR C                  (CORE LOAD C)
      EXTERNAL B
      DIMENSION IC(6000)
      IC(1) = 1
10    CALL CHAIN (B)
      END
```

Figure 7.1. Program 1 of 7.5.1, demonstrating CHAIN.

Case 2. Two Disks and the Same Program.

We will examine if it is possible to get a faster system, when using two disks. The most time consuming sequence is the moving of the disk heads, and therefore we wanted to see if this movement can be made smaller.

Program B is placed on disk 0 and program C on disk 1. It took 88 sec. for the whole sequence, 440 ms for every jump. The following will happen:

(1) CALL CHAIN (C)
    The head is moved to track (c) (see fig. 7.2).
(2) During the execution of C the head is at (d).
(3) CALL CHAIN (B)
    The head on disk 0 is moved from (b) to (a) and is moved to (b) again during the reading of B.

The accumulated moving of the heads during the execution is quite the same in case 1 as in case 2.

There is no monitor order to move the heads in advance in order to save time.

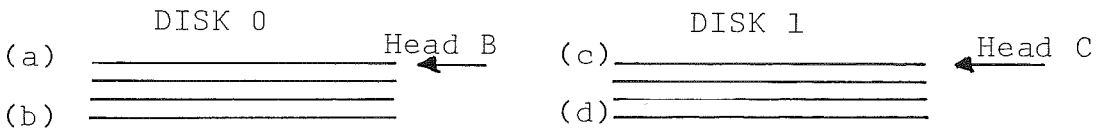

Figure 7.2. The figure illustrates the disk head movements in case 2.

Program 2. One Disk and Small Program Dimensions.

Instead of the dimensions 6000 in core load B and C we have now only 2 (see figure 7.1). The moving of the head is now completely avoided, and the access time should be determined by the disk rotation time.

The total time was 8 sec or 40 ms per jump.

We thus observe that the disk has to make one revolution for every jump. The core loads B and C are placed on the same track (see figure 7.3). It is, however, impossible to read B and C directly after each other. Some ms administration has to be done at every CALL and during this time the disk has rotated too much, so it has to make another revolution in order to find C.

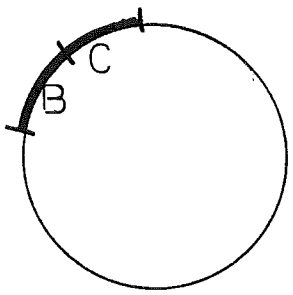

Figure 7.3. Illustration of the position of the programs on one disk track.

7.5.2. Test of Interrupts.

At the order CALL LEVEL the following sequence takes place:

The core load that presently is executed in the core is saved to the Interrupt Save Area on the disk. After that, the disk head is moved to the Interrupt Core Load. Even if this program is quite small, rather a long time has to be spent to move the disk head to the entry point of the area. The influence of the size of the program is not great. At an average it takes about 2 sec to load an interrupt core load. With 2 disks the time can be decreased to about 1 sec. Interrupt programs which can be expected rather often thus have to be placed residently in the core.

Program 1. Big Program Size.

Core load A

```
CALL LEVEL
```

Interrupt core load (core load B)

```
DIMENSION 6000
```

200 interrupt core loads took 367 sec or 1.83 sec per jump.

Program 2. Small Program Size.

The programs are changed, and B has only a small size this time. This time it took 392 sec or 1.96 sec per revolution. The time is longer than before and this is due to the fact that the core loads now are situated outside the core loads of the previous example, as they are loaded after the previous ones. The core loads are:

(Core load A)

```
//JOB
//FOR A
      CALL UNMK(-1,-1)
      PAUSE 1
      I = 1
      CALL LEVEL (6)
10    I = I + 1
      IF(I-200) 10,20,10
20    PAUSE 7070
      CALL VIAQ
      END
```

(Core load B)

```
//FOR B
      CALL INTEX
      END
```

Program 3. 2 Disks.

The heads will be moved a small bit only as one disk is used for the Save AREA and the other one for the interrupt core load. The time is comparable to twice the time for CALL CHAIN, as one program has to be saved and one is to be loaded.

The whole sequence of 200 procedures took 208 sec or 1.04 sec per interrupt core load.

7.5.3. Test of LOCAL Subroutines.

A LOCAL ought to take the same time as a CALL CHAIN, as no program is saved from the core memory at these orders. This statement was shown to be true.

(1) A CALL ROL (I,J) in the core memory takes 660 µs.

(2) A LOCAL, where the dimension is small takes 40 ms (only one revolution of the disk for every call).

(3) A LOCAL, where the subroutine occupies 6000 cells or about 3 cylinders, takes 430 ms (compare CHAIN).

7.6. FINAL CHOICE OF COMPUTER SYSTEM.

After the detailed evaluation of hardware and of software seven computers remained: CD, H 316, DDP 516, HP 2116 B, IBM 1800, PDP 9, PDP 15.

At first we compare the computers from the same firm. H 316 and DDP 516 have the same software, and the difference between the computers is mainly the internal speed. DDP 516 had to be excluded due to its price, and H 316 remained.

PDP 15 is superior to PDP 9 both in price and capcity, so PDP 15 model 30 remained.

CD 1700 and IBM 1800 had to be excluded due to their prices.

After this elimination only H 316, HP 2116 B and PDP 15/30 remained. HP had to be excluded primarily due to the disk. The moving head disk could not be delivered, and therefore the system became less attractive for technical as well as economic reasons.

PDP 15 was the cheapest computer left and it was also regarded to be a more flexible system than H 316. The H 316 software system was considered better, but the PDP hardware was superior. The PDP disk-DEC tape system will give better flexibility than the H 316 fixed head disk. The PDP 15 cycle time is shorter. PDP has also a very flexible hardware system. The firm has modules and description for all kinds of logic modules, and therefore it is possible to have the analog and digital I/O system tailor-made.

It was possible to choose the system B directly, so the system will consist of the following parts:

Central Processor PDP 15 model 30

with 16 k words of 18 bit
cycle time 0.8 µs
hardware fixpoint multiplication
real time clock
paper tape reader (300 ch/s)
paper tape punch (50 ch/s)
interrupt system with 8 priority levels
three DEC tape units, expandable to eight units
one KSR-35 and one KSR-33 teletype

Disk memory RS09 (average access time 20 ms)
(storage 262 144 words)
with control unit RF 15

A/D converter 10 bit
Multiplexer for 16 channels
8 D/A converters for ±10 V
One 18 bit input buffer
One 18 bit output buffer

8. EXPECTED AND DESIRED FUTURE TRENDS IN COMPUTER CONTROL SYSTEMS.

This section will give a brief summary of the present development of the computer industry, and what may happen within 2 - 5 years.

During the last few years a tremendous development has taken place and this has been demonstrated during the evaluation work. All the time new computers have been introduced.

Hardware has developed tremendously fast and integrated circuits have become common. Although software has been developed very fast during the last 2 or 3 years, there is a hope that the future software systems will be more standardized.

We will consider some major parts of a process control system in the discussion: sensors and transducers, central processor and core memory, input/output, program systems as well as overall systems performance.

8.1. SENSORS.

A control engineer always want to have better sensors in order to get a more exact control of the process. There are several sources of failures today: wrong linearization, dead zones of the sensors, noise, and lack of calibration of the transducers. These errors will also cause wrong control strategies.

Probably one will try to eliminate several of the components in the long chain from process to central processor. The use of remote digitization can reduce the inherent errors in a transducer. A non-linear digital computer-based conversion of the digital representation of the sensor's output to a representative set of units can eliminate the errors due to linearization as well as much of the drift of analog conversion and recording units. With digital transducers the rather expensive analog to digital conversion is unnecessary. The computers have to build in facilities for direct access to the memory for digital pulses. PDP has already such a facility in its add-to-the-memory unit.

8.2. RELIABILITY.

By the far most important factor today from the user's point of view is the overall system reliability. That is, what percentage of the total time can the computer control system be counted upon to carry out its task. This is a combination of a long mean time between failure, MTBF, and a short average repair time. A figure of 99.95% availability seems to be normal figure of what the industry considers desirable today.

The MTBF for aerospace systems has grown from about 50 hours in 1952 to more than 10.000 hours today. Recently U.S. Air Force requested 20.000 hours MTBF for tenders on guidance computers.

For civilian process control computer systems the development has come some 3 years later.

The problem of short repair time can probably be solved by the use of sophisticated diagnostic techniques by the computer itself. "Swapping" of faulty major units seems to become common in the future. Ferranti Ltd. has already instituted such an advanced procedure for maintenance of their Argus 500 systems.

The low cost minicomputer is ideally suited for "backing itself up". In industries or plants, requiring more than one computer, it is of course easier to justify a spare computer.

8.3. COMPUTER ORGANIZATION.

The computer organization will probably change very much due to cheaper hardware. Then it is possible to build in more registers and accumulators and get a more flexible instruction set. Already today not all computers have parallel binary organization, and not all parallel binary machines follow the usual pattern. Interdata models 2 and 3, for example, have made microprogramming facilities which will make a compromize between processing speed and flexibility in programming. Interdata model 4 uses another pattern for the same compromize.

The byte oriented computer is an interesting blend of serial and parallel machines characteristics. The computer does not use fixed word length, but treats data in standard blocks, usually 8 bits, and these blocks can be combined to form multiple words. These features, e.g. in Varian 620 I, will create a greater flexibility and a more effective use of the memory. This form of processing is slower than that for fixed words, as the computer will process one byte at a time. However, the word length is not limited by hardware in the computer. The programmer is free to define his word length. In BIT 480 and 483, e.g., this is accomplished by setting a word mark bit in the last byte of each data word.

The problem with all these computers is to get a standardized software. We have seen during the evaluation, that Varian 620 I, although having flexible machine organization, has no software which can use the very fine hardware flexibility. Therefore there is a strong need for software development.

Hardware floating point arithmetic will probably become standard on small computers. Today it is available e.g. on CD 1700, IBM 1800 and Siemens 305.

Computer memories will probably be developed very much during the next years. Memories are very expensive, and therefore the manufacturers work very hard in order to find better and cheaper systems.

If solid state circuits can replace the common core memories, the cycle time may decrease five or tenfold. Read-only memories are already used, and probably they will be more and more common for standardized programs because of their price, speed and reliability.

Before 1975, the following development may take place:

- A five fold increase in basic computer speed is achieved over the third generation hardware. With solid state circuits in the memory the cycle times may be some 0.1 - 0.4 µs.
- A four fold increase in reliability is achieved (now 2000 - 4000 hours MTBF for all electronic equipment).

- A five fold decrease in computer system costs below the third generation equipment.

8.4. INPUT-OUTPUT SYSTEMS.

A trend toward card oriented rather than paper tape oriented program systems is foreseen, although card handling equipment is more expensive. The ease of handling, greater durability and ease in modification of programs is superior in a card based system.

In the man-machine communication field there will probably be a tremendous development. This has been a large cost area and systems for alarm devices, logging printers, typewriters, panels and displays are often very elaborate. Cathode ray tubes with disk memories and "minicomputer" directors can eliminate most of the need for the previously mentioned equipment.

8.5. SOFTWARE.

In early applications the effort necessary to make the programs work was often underestimated. These computers also lacked the aid of monitors and utility programs which are now available with most manufacturers' equipment.

While programming aids such as compilers and special process control languages have recently simplified the programming task very much, this has been almost compensated for by the much increased size and complexity of recent overall software packages required for the new and more sophisticated control systems.

Today there is thus a need to reduce this total programming load by developing new and more universal programming aids, by standardizing them for easier personnel training and use. We have also seen, that the effectiveness of the compilers and the run time libraries have to be made much better.

The description of monitors and program system is often very inadequate. A standard vocabulary is highly desirable.

There is requested to get some standardized system configuration

for different kinds of control tasks in order to make the choice easier for the customers.

Finally we may list a summary of the desirable requirements for software standardization:

1. A high level language should be available, e.g. a language which includes USASI Fortran (X3.9-1966) as a subset.
2. The high level process control programming should include orders, which are common in industrial applications, such as bit manipulation, bit handling, process interrupt handling, parallel task execution and file handling.
3. The language should be as independent as possible of the certain computer available.
4. The language should permit on-line addition of inputs, control algorithms, outputs and changes of coefficients without recompilation.
5. The software should preserve as much compatibility as possible with older installations of analog equipment.
6. Modular fashion of the software systems.
7. The compiler should make use of the flexible computer hardware organization.
8. Better software descriptions.

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Varian 620 I Systems Computer Manual

Technical Proposal

APPENDIX LISTING OF TEST PROGRAMS

```
C       INTEGRATION OF KALMAN EQUATIONS
C       THE PROGRAM EXECUTES SYSTEMS OF ORDER 2 AND 5
C       TIME SHALL BE BETWEEN PAUSE 1 AND PAUSE 10 TWICE
C       AUTOMATIC CONTROL, LUND
C
        DIMENSION A(20,20),B(20,20),C1(5),R1(5,5),R12(5),XP(5),P(5,5)
        JMP=-1
        N=2
        NN=100
        Y=0.5
        R2=1.0
        A(1,1)=0.5
        A(1,2)=1.0
        A(2,1)=0.0
        A(2,2)=0.8
        B(1,1)=1.0
        B(1,2)=2.0
        B(2,1)=0.0
        B(2,2)=2.0
        C1(1)=1.0
        C1(2)=0.0
        GO TO 30
   20   N=5
        JMP=1
        NN=100
        Y=1.0
        R2=1.0
        A(1,1)=-0.00870
        A(1,2)=-0.28070
        A(1,3)=-3.15800
        A(1,4)=-14.04000
        A(1,5)=-16.67000
        A(2,1)=0.00530
        A(2,2)=0.12470
        A(2,3)=1.05300
        A(2,4)=3.50900
        A(2,5)=2.63200
        A(3,1)=-0.00080
        A(3,2)=-0.01570
        A(3,3)=-0.08590
        A(3,4)=0.00000
        A(3,5)=0.87730
        A(4,1)=-0.00030
        A(4,2)=-0.00790
        A(4,3)=-0.08590
        A(4,4)=-0.43680
        A(4,5)=-0.87330
        A(5,1)=0.00030
        A(5,2)=0.00670
        A(5,3)=0.06230
        A(5,4)=0.26490
        A(5,5)=0.44050
        DO 21 I=1,5
        DO 21 J=1,5
   21   B(I,J)=0.0
        B(1,1)=1.0
        B(2,2)=1.0
        B(3,3)=1.0
```

```
      B(3,4)=1.0
      B(4,3)=1.0
      B(5,2)=1.0
      B(5,4)=1.0
      C1(1)=1.0
      C1(2)=0.0
      C1(3)=2.0
      C1(4)=0.0
      C1(5)=0.0
   30 DO 31 I=1,N
      DO 31 J=1,N
      R1(I,J)=0.0
   31 P(I,J)=0.0
      DO 32 I=1,N
      R1(I,I)=1.0
      P(I,I)=50.0
   32 R12(I)=0.0
      DO 33 I=1,N
   33 XP(I)=4.0+FLOAT(I)


C     TIME TO PAUSE 10
C
       CONTINUE
      DO 100 II=1,NN
  100 CALL KALM(A,B,C1,R1,R2,R12,N,Y,XP,P)
C
       CONTINUE
C
       PRINT 500,   N,NN
  500 FORMAT(////10X,10HKALMANTEST/1X,16HORDER OF SYSTEM=,I2/1X,21HNUMBE
     *R OF TIME STEPS=,I4)
       PRINT 501
  501 FORMAT(//1X,9HXP-MATRIX/)
       PRINT 502,  (XP(I),I=1,N)
  502 FORMAT(1X,5F15.8)
       PRINT 503
  503 FORMAT(///1X,8HP-MATRIX/)
      DO 34 I=1,N
34     PRINT 502,  (P(I,J),J=1,N)
      IF (JMP) 20,20,900
  900 CONTINUE
       STOP
      END
```

```
      SUBROUTINE KALM(A,B,C,R1,R2,R12,N,Y,XP,P)
      DIMENSION A(20,20),B(20,20),C(5),R1(5,5),R12(5),XP(5),P(5,5),XP1(5
     *),GAIN(5),PC(5),BR(5),S(5,5)
C
C     COMPUTE GAIN
C
      DO 10 I=1,N
      Q1=0.0
      Q2=0.0
      DO 9 J=1,N
      Q1=Q1+P(I,J)*C(J)
    9 Q2=Q2+B(I,J)*R12(J)
      PC(I)=Q1
   10 BR(I)=Q2
      R=0.0
      DO 11 I=1,N
   11 R=R+PC(I)*C(I)
      R=1.0/(R+R2)
      DO 13 I=1,N
      Q=0.0
      DO 12 J=1,N
   12 Q=Q+A(I,J)*PC(J)+B(I,J)*R12(J)
   13 GAIN(I)=Q*R
C
C     COMPUTE NEW STATE-VARIABLES



C
      E=0.0
      DO 14 I=1,N
   14 E=E+C(I)*XP(I)
      E=Y-E
      DO 16 I=1,N
      Q=0.0
      DO 15 J=1,N
   15 Q=Q+A(I,J)*XP(J)
   16 XP1(I)=Q+GAIN(I)*E
C
C     COMPUTE NEW VARIANCE MATRIX
C
      DO 18 I=1,N
      DO 18 J=1,N
      Q=0.0
      DO 17 L=1,N
      DO 17 K=1,N
   17 Q=Q+A(I,K)*P(K,L)*A(J,L)+B(I,K)*R1(K,L)*B(J,L)
   18 S(I,J)=Q-GAIN(I)*GAIN(J)/R
C
C     NEW VALUES TO XP AND P
C
      DO 19 I=1,N
      XP(I)=XP1(I)
      DO 19 J=1,N
   19 P(I,J)=S(I,J)
      RETURN
      END
```

```
      PROGRAM TESTS
C     TEST OF PROCESS COMPUTERS
C     AUTOMATIC CONTROL, LUND
C
      DIMENSION A(20,20),B(20,20),C(20,20)
      DIMENSION D(20),E(20)
      I=5
      J=4
      R=0.0
      S=3.141593
      T=0.3210987
      DO 5 K=1,20
      D(K)=3.141593
    5 E(K)=0.3210987
C
C     TEST OF DO LOOP, TIME TO PAUSE 2
C
      PAUSE 1
C
      DO 10 K=1,30
      DO 10 L=1,20000
   10 CONTINUE
C
      PAUSE 2
C
C     TEST OF DO LOOP, TIME TO PAUSE 3
C
      DO 15 K=1,15
      DO 15 L=1,20000
      DO 15 M=1,1
   15 CONTINUE
C
      PAUSE 3
C
C     TEST OF FLOATING ARITMETIC
C
      DO 20 K=1,20000
   20 R=R+S*T
C
      PAUSE 4
C
C     TEST OF INDEXED VARIABLES, TIME TO PAUSE 5
C
      DO 25 K=1,20000
   25 R=R+D(I)*E(J)
C
      PAUSE 5
C
C     TEST OF INDEXED VARIABLES, TIME TO PAUSE 6
C
      DO 30 K=1,20000
   30 R=R+D(2*I+3)*E(3*J+4)
C
      PAUSE 6
C
C     DATA
```

```
C
      DO 35 K=1,20
      DO 35 L=1,20
      A(K,L)=20*(L-1)+K
   35 B(L,K)=A(K,L)
C
      PAUSE 7
C
C     MATRIX MULTIPLICATION ORDER 5, TIME TO PAUSE 10
C
      DO 40 K=1,500
   40 CALL MMULT(A,B,C,5)
C
      PAUSE 10
C
C    MATRIX MULTIPLICATION ORDER 10, TIME TO PAUSE 11
C
      DO 45 K=1,100
   45 CALL MMULT(A,B,C,10)
C
      PAUSE 11
C
C     MATRIX MULTIPLICATION ORDER 15, TIME TO PAUSE 12
C
      DO 50 K=1,20
   50 CALL MMULT(A,B,C,15)
C
      PAUSE 12
C
C     MATRIX MULTIPLICATION ORDER 20, TIME TO PAUSE 13
C
      DO 55 K=1,10
   55 CALL MMULT(A,B,C,20)
C
      PAUSE 13
C
C     TIME FOR A CALL STATMENT, TIME TO PAUSE 14
C
      DO 60 L=1,10
      DO 60 K=1,10000
   60 CALL PAUL
C
      PAUSE 14
C
C     TIME FOR A CALL STATMENT, TIME TO PAUSE 15
C
      DO 65 L=1,10
      DO 65 K=1,10000
   65 CALL LAUP(1.0,2.0,3.0,4.0,5.0)
C
      PAUSE 15
C
C     TIME FOR LIBRARY FUNCTIONS, TIME TO PAUSE 16
C
      DO 70 K=1,5000
C
```

```
   70 R=ATAN(T)
C
      PAUSE 16
C
C     TIME FOR LIBRARY FUNCTIONS, TIME TO PAUSE 17
C
      DO 75 K=1,5000
   75 R=SIN(T)
C
      PAUSE 17
C
C     TIME FOR LIBRARY FUNCTIONS, TIME TO PAUSE 20
C
      DO 80 K=1,10000
   80 R=SQRT(S)
C
      PAUSE 20
C
C     INVERSION OF A 2*2 MATRIX, PRECISION IS MEASURED
C     TIME BETWEEN PAUSE 21 AND PAUSE 22
C
      U=3.012345
      V=1.987654
      X=7.112233
      Y=4.998877
      JMP=-1
      GO TO 90
   83 JMP=1
C
      PAUSE 21
C
      DO 85 K=1,10000
      DET=U*Y-V*X
      SL=U
      U=Y/DET
      Y=SL/DET
      V=-V/DET
   85 X=-X/DET
C
   91 PAUSE 22
C
   90 WRITE(01,95) U,V
      WRITE(01,95) X,Y
      IF (JMP) 83,96,96
   96 CONTINUE
   95 FORMAT(2F12.7)
      STOP
      END
```

```
      SUBROUTINE PAUL
      I=1
      RETURN
      END
```

```
      SUBROUTINE LAUP(A,B,C,D,E)
      I=1
      RETURN
      END
```

```
      SUBROUTINE MMULT(A,B,C,N)
      DIMENSION A(20,20),B(20,20),C(20,20)
C     MATRIX MULTIPLICATION
      DO 10 I=1,N
      DO 10 J=1,N
      SL=0.0
      DO 5 L=1,N
    5 SL=SL+A(I,L)*B(L,J)
   10 C(I,J)=SL
      RETURN
      END
```

Summary of the quotations. Prices in Sw.kr. (*1000)	CPU 8 k with TT	CPU 16 k with TT	Paper tape (card) I/O	Analog input	Analog output	Digital I/O	Disk	Total A incl. freight	Total B incl. freight	Service per year (1 yr./ later)	Total A after 5 years	Total B after 5 years	Differences from quotation	Comments
Varian 620 I	149	215	28	20.7	26	9	76	313	379	21.9 26.5	416	503	Clock +5.6, freight +4 - 5% discount	1 $ = 5.18 kr
HP 2116 B	193	249	23	22	25	4	58	323	381	24.8 25.9	437	500	Raytheon ADC +21 - 3% discount	
PDP 9	269	387	-	29	43	30	84	455	573	23.3 28.0	551	688	API +28 k, DMA +22.4 k	
PDP 9L	214	319	27	29	43	30	84	427	532	21.0 26.3	513	638	API +28 k DMA +22.4 k	
IBM 1800	297	375	63	42	60	22	59	554	632	14.4 14.8	626	706	Freight +10 k - 20% discount	Card punch must be hired. Air conditioning necess.
CD 1700								678 (12k)	722	20.0	778	822	4 k memory added in A	Air conditioning necess.
								495 (12k)	540	20.0	595	640	4 k memory added in A	Disk is borrowed.
Siemens 304, 305								854	898	28.8	998	1042	Installation +7	Air conditioning necess.
Advance 6130	280	378	44	107	34	26	145	646	744	30.0	796	894	Freight +10	Air conditioning necess. 1 $ = 5.18 kr.
Honeywell DDP 516								456	684 (24k) ~560 (16k)	31.1 36.7	611	871		

Summary of the quotations. Prices in Sw.kr. (*1000)	CPU 8 k with TT	CPU 16 k with TT	Paper tape (card) I/O	Analog input	Analog output	Digital I/O	Disk	Total (A) incl. freight	Total (B) incl. freight	Service per year (1 yr./ later)	Total (A) after 5 years	Total (B) after 5 years	Differences from quotation	Comments
PDP 15-30	-	278[x)]	-		58.5[xx)]		72	-	408	30.4	-	560		[x)] Includes tape I/O and 3 DEC tapes
- " -	-	278	-	26	38	27	72	-	442	30.4	-	594		[xx)] Modules
LIST PRICES														
Raytheon 703	183	218	43	12	25	13	104	380	415					
Raytheon 706	192	239	43	12	25	13	104	389	436					