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Patient data management systems in intensive care – the situation in Europe

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Abstract *Objective:* Computerized Patient Data Management Systems (PDMS) have been developed for handling the enormous increase in data collection in ICUs. This study tries to evaluate the functionality of such systems installed in Europe.
Design: Criteria reflecting usefulness and practicality formed the basis of a questionaire to be answered accurately by the vendors. We then examined functions provided and their implementation in European ICUs. Next, an "Information Delivery Test" evaluated variations in performance, taking questions arising from daily routine work and measured time of information delivery.
Setting: ICUs located in Vienna (Austria), Antwerp (Belgium), Dortmund (Germany), Kuopio (Finland).
Participants: 5 PDMS were selected on the basis of our inclusion criteria: commercial availability with at least one installation in Europe, bedside-based design, realization of international standards and a prescribed minimum of functionality.
Results: The "Table of Functions" shows an overview of functions and their implementation. "System Analyses" indicates predominant differences in properties and functions found between the systems. Results of the "Information Delivery Tests" are shown in the graphic charts.
Conclusions: Systems with graphical data presentation have advantages over systems presenting data mainly in numeric format. Time has come to form a medical establishment powerful enough to set standards and thus communicate with the industrial partners as well as with hospital management responsible for planning, purchasing and implementing PDMS. Overall, communication between clinicians, nurses, computer scientists and PDMS vendors must be enhanced to achieve the common goal: useful and practical data management systems at ICUs.

Key words Intensive care · Critical care · Patient data management Computer systems · Care documentation · Hospital information systems

Introduction

The development of new technology for diagnostic and therapeutic purposes in intensive care, combined with the introduction of microprocessor technology has led to an enormous increase in data collection in ICUs [1–3]. We have already reached a point where the manual handling of these large amounts of data is very difficult to manage [4, 5]. For almost a decade, computerized systems have been claimed to be the solution for handling such data. Recent technological innovations – influenced primarily by the development of more sophisticated, faster and cheaper computer systems – have also permitted the evolution of more affordable systems for Patient Data Management, the so-called PDM-Systems. Many arguments point out the various advantages of a PDMS. However, since every coin has two sides, PDMS also have disadvantages. Here are some of the pros and cons which are foccused in discussion.

● On line data aquisition ensures actuality of the collected data which, together with the possibility of combining corresponding data (which have been collected at different sites and times) and displaying it in a problem-oriented manner, opens up both new possibilities of data presentation and new aspects for treatment [6].

● The phrase "time-saving" when using a PDMS is an argument widely used by vendors. Charting in an ICU constitutes up to 20% of the staff's time [7] and can be reduced by up to 50% through computerized charting systems [8–10]. Various studies comparing manual and computerized documentation have been done (primarily in the USA) and have found a clear possibility of reducing charting time [7–11, 13]. Not all studies came to the same conclusion; a comparison between manual and computerized documentation at the Latter Days Saint Hospital (Utah, USA) showed an increase in nurses charting time [12]. Although the authors held the degree of severity of patients's illness responsible, the increased amount of data documented through PDMS could also be a contributing factor. The amount of time saved varies from study to study; most authors, however, agree on cost saving with PDMS. Not only does time saving occur through minimized charting time, but also the productivity of ICUs can be enhanced by using planning strategies combined with computerized scores. Reduced average length of stay could be the result of these optimized bed-occupancy strategies [8].

● Human errors are common in handwritten documentation and may include arithmetic errors or data omission. They are often due to excessive work load and can result in iatrogenic complications. A study of human errors in an ICU demonstrated the importance of these events: 22 out of 180 errors in manual documentation led directly to a clinical deterioration of the patient's state [13]. The authors found errors in at least 25% of the handwritten documentation which could be avoided by computerized documentation. A higher frequency of data documentation, for example vital signs or blood gas analyses, is also achieved which improves documentation quality. With manual record keeping methods up to 30% of the documentation gets lost; another part remains incomplete and therefore not legally usable. Generally, computerized documentation is said to provide complete and readable documentation [5, 12]. However, our experience shows a lot of chances for data errors in PDMS, too.

● Collected data may easily be electronically processed for scientific analyses or quality control purposes [14, 15]. A comparison between different ICUs can for example be made by comparing scores (e.g. APACHE or SAPS) which is very time consuming when done manually but can be automated in a PDMS. Gardner demonstrated that his hospital could dramatically reduce the use of packed red cells with computerized quality control within one year [16]. Another possibility is calculation of patients costs, which is quite important since ICUs are mostly underfunded [17]. Costs of Intensive Care are difficult to determine with manual documentation, but are estimated to be 15–20% of a hospital's budget [18]. PDMS data, already in digital format, could form the basis of an automated accounting system for an ICU.

● Medical computer systems are still expensive and the decision upon which system is to be purchased needs to be made carefully. Many secondary considerations are necessary before making a decision; do the existing devices, such as ventilators, have declared interfaces? Is it possible to connect the PDMS with the hospital's laboratory or administrative computer system? An appropriate decision can only be based on accurate information which is not yet standard. One the one hand, most of the information presented comes from public relation departments, not from technicians. On the other hand only few clinicians are familiar with the limitations and problems of computer systems. Altogether, the communication between clinicians, informatic specialists and hospital management is a problematic issue. Normally, neither clinicians nor managing directors are experts in medical informatics, but they often have to make the decisions.

● Sophisticated computer systems like PDMS are prone to technical errors and need maintenance by specialized personnel, which may increase hospital costs.

● Implementation of a PDMS needs much time and resources and may decrease the productivity of an ICU during this period. Hard- and software installation, system configuration, device interfacing, personnel training are as important as establishing a good communication between vendor, hospital and system administrators. Starting time of a PDMS may be affected by many first-time faults and is surely a burden for the staff. If a system fails to satisfy customer's needs after implementation, it is hard to change to another one.

The University Clinics of Vienna have purchased PDMS for all ICUs, which were installed in 1991. Since that time we have had many experiences, mostly during routine work. We learned about problems of implementation and use of a PDMS. Concrete information about practicality and possible enhancements before implementation would have helped us a lot before starting the computerization. This was the basis of our study: to provide concrete material for decision making, which should – from our point of view – contain accurate and detailed information as well as a report of systems practicality and usefulness.

In this paper the definition of "Patient Data Management Systems" is restricted to a computer system which collects and presents medical data from patients in an ICU. Computer systems which manage primarily administrative data are not included. This is done in accordance with the international usage, where the term characterizes a system for managing patient data in ICUs. Although this provides some selectivity, there are still many different system designs. Principally, PDMS can be divided into three different classes, based on their development and marketing.

First, "self-made systems": there are very innovative Clinics with their own informatic specialists, working in the field of hospital communication and computing, presenting interesting applications. The range goes from simple text-based DOS applications to complex, Graphical User Interface-based Windows®, UNIX® or Apple® applications. Most of them are adapted to local needs and can hardly be transferred to other ICUs [19, 20].

Second, some "minimal PDMS" are commercially available: often PC-based systems, which collect information from different devices (e.g. the SDN-net or laboratory). We call them "minimal" because most of them don't support bedside workstations. They are easy to handle and cheap solutions for small ICUs or Intermediate Care Units which don't need (or can't afford) large systems for data management [21].

Third, commercially available "bedside-based" PDMS: the most powerful systems available today, however, are not enough to cover demands of information management in an ICU. Database systems used need enough resources as the transactions done in an ICU's database may well exceed the limits of a business database. A fast database response time is necessary, but hard to achieve, especially when the amount of stored data grows constantly. Further applications, such as bedside display of X-rays will need even more computer power than that provided by today's systems [3].

Materials and methods

According to the needs of data management in ICUs, the future of ICU computing is not to be found in the first two groups. We therefore selected and compared only bedside based PDMS. They had to satisfy the following inclusion criteria:
Commercial availability with at least one installation in Europe; Bedside-based design; Realization of international standards in terms of hardware, e.g. with IBM compatible PCs or UNIX workstations and on the software side, e.g. on a DOS®, UNIX® or similar standard operating system and application environment; Minimum of functionality with the ability to fulfill at least the following functions:

- on-line acquisition of data (HR, ABP, SaO_2, CVP)
- management of medical patient data, e.g. laboratory or blood gas data
- display of administered data on screen in tabular or graphical format
- report functions and printout of the managed data
- calculations e.g. hemodynamics.

Table 1 Bedside based PDMS, matching the inclusion criteria

Name	Vendor
Atlantis	Hospitronics
Carevue 9000	Hewlett Packard
Chartmaster	SpaceLabs
Clinicomp	Marquette
Clinisoft Inf. System	Clinisoft Corp.
Emtek System 2000	Siemens

The systems listed in Table 1 were available (also as demo- or test-systems) at the beginning of our study and were in accordance with these demands. The Buyer's Guide To Bedside Computer Systems of the National Report on Computers & Health 1993 [23] reported some more PDMS for Intensive Care Data Management (ACT/PC: ARGUS 2000; QMI: Quantitative Sentinel) at the time of our investigation; however, neither an installation nor a distributor of those systems could be found in Europe.

To compare the systems, we first defined criteria which could determine the usefulness and practicability of a PDMS. A questionaire, so designed, we sent to the vendors who had to answer it as accurately as possible to be included in the study. Next we looked at functionality, be evaluating the functions provided by the different systems together with their usage and implementation in clinical use. The comparison was made of systems already in clinical use in European ICUs at the following locations: ICU 13H1, Dep. of Internal Medicine, Univ. of Vienna, Austria; ICU B200, Dep. of Cardiothoracic Anaesthesia, Univ. of Vienna, Austria; Surgical ICU, Städtische Kliniken Dortmund, Germany; General ICU, Dep. of Anaesthesia and Intensive Care, Univ. Hosp. of Kuopio, Finland; Medical ICU, Dep. of Intensive Care, Univ. Hosp. of Antwerp, Belgium. Results of this evaluation are presented in the "Table of Functions". The section "System Analyses" points out predominant differences in functionality.

During the investigation of this study, we recognized big differences in the speed of information delivery. Based on the assumption that measuring the time needed for delivery of information – via a sequence of interrogations – could point out those differences in performance, we designed an "Information Delivery Test". We chose some questions which should cover most parts of the tested systems. They are listed in Table 2 and have been taken straight from routine work – questions which have indeed been asked during shifts in our unit.

The Information Delivery tests were carried out at the locations listed above. All tests were conducted by the same person. We tried to locate a person who seemed to be most familar with the system in every unit. Each question was explained in detail before execution. Starting from a "standard screen", we measured the time required to extract the complete information. To make people executing the tests familiar with this kind of test, we created a preliminary set before performing the final tests. We documented the time of beginning as well as the end of information delivery. Data series in the charts which are not filled with a bar were questions not answered by the participants, mostly because they had not been implemented in the specific installation at the test site. We obtained two values with our regimen: 1) the starting point of information delivery describes the time the probationer needed to assess the data. This gives an indication of how quickly important data can be assessed, which depends mainly on the quality of data arrangement and configuration of available data displays. Systems with

Table 2 Summary of questions used in the information delivery tests

1	Date of insertion of the central venous catheter;
2	Fluid balance of the last 5 days;
3	Sedation: dose per hour, since what time and which dose did you apply before?
4	Changes of creatinine clearance and free water clearance of the last 3 days;
5	Blood pressure and cardiocirculatory therapy 8 h ago: MAP, HR, CVP, medication;
6	Adjustments of the mechanical ventilator and bloodgas analysis of the last 4 hours: FIO_2, type of ventilation, I:E, P_{max}, expiratoral tidal volume, PO_2, PCO_2, pH;
7	How often did the patient have a temperature over 38 °C in the last 4 days?
8	Extracorporal therapy: adjustments of the last 24 h: Flow, TMP, Heparin;
9	How often did you take bronchial specimens for culture in the last 3 days?
10	How often did the patient produce stool in the last 4 days?

good review screens should have better results in this respect; 2) the end-point of information delivery defines the time needed to extract the entire information and is determined by two variables: First, the performance of the computer system which depends on the hardware used. The speed of PC-based PDMS can vary by up to 5 fold. Second, the type of data display, that is, whether graphic or numeric presentation is used.

Results

System analyses

Technical data presented in this section presents the answers obtained from the different corporations. As systems are constantly developing, some data may have changed during the publication of this paper although we tried to update the information as much as possible.

Siemens Emtek System 2000

Specific for the Emtek System 2000 is its network configuration, which is based on an Ethernet with ring topology. There exists no specific data server. Patient data is stored on the bedside-workstations and mirrored in the network for proper data security. The system includes a micro-organism resistance table, which can be updated automatically when connected to the bacteriological lab. The Siemens Emtek PDMS includes a case-oriented care plan: after medical and nursing diagnosis have been made, there is a (configurable) set of care activities generated. They include daily goals which have to be achieved and thus provide control over the development of the patient's state. Graphic features include the possibility of displaying any variable in graphical trend format, providing tools for easy scrolling and zooming across the duration of the patient's stay. Balance display features bar graphs for intake and output categories. Unfortunately device drivers for peripheral devices from vendors other than Siemens have to be purchased separately for each device, which can be very expensive.

Marquette CliniComp

The CliniComp system is the only one in this comparison which uses centralized computer power. It is based on two mirrored Sequent servers, which are built up as multiprocessor systems with Intel i486 CPUs. The so called "Intelligent Display Stations" are terminals which are connected via Ethernet and use X-Windows as a graphical user interface. Configuration of the system can only be done by the vendor and is done via a continous connected phone line. Although the company claims the system to be completely secured against unauthorized access of the system, the continous phone connection may be a weak point for security. Online connection to the vendor may result in fast response times for service and maintenance purposes but also increase phone costs markedly. A very useful feature is the possibility of moving from one screen to another via shortcuts without the necessity of using pulldown menus. The system covers complete critical care documentation and is intended as a clinical information system which combines different units rather than separate them. Users must get used to the Graphical User Interface where manual data entry is only possible via keyboard. The monochrome high-resolution monitor used at the test site also didn't fit today's standards for sharp displays.

Hospitronics Atlantis

The company Hospitronics was dissolved shortly after testing and renamed to Medisoft. The system was newly released and is now running under MS Windows® and MS Windows NT®. It generally provides the same functions as before and includes some enhancements.

Advantage of the Atlantis (PICIS) system is its PC-based, open philosophy. PCs or components can be purchased according to the customer's needs and be upgraded at any time. The system is shipped with device drivers for some eighty peripheral devices (monitors, ventilators, labs, etc.) which makes it economical to connect peripherals. The PDMS comes already preconfigured but provides only limited features for configuring and adapting to local needs. On the one hand, this is a limitation of its usefulness, on the other hand, its implementation is as fast as the installation and the system can be used almost instantly. Trend displays are available for almost all measured variables, balance included. The program is built up from different modules (basic, care printing etc.) which

Table 3 Functions of compared PDMS

System	Emtek-release 3.A	Clinicomp	Atlantis	CareVue-rel. F	Clinisoft
Admission display	yes	yes	yes	yes	yes
Patient data	yes	yes	yes	yes	yes
Display configurable	yes	yes	no	yes	yes
Graphical patient chart	yes	yes	yes[a]	yes	no such display[b]
Display configurable	yes	yes	yes	no	XX
Vital parameter/quick look screen	yes	yes	yes	yes	not in tabular form
Respiratory screen	yes	yes	yes	yes	yes
Display configurable	yes	yes	yes	yes	yes
Laboratory values display	yes	yes	yes	yes	yes
Microbiological tests	yes	*	no	*	*
Microbiological table of resistance	yes	no	no	no	no
Drug levels	yes	yes	yes	yes	yes
Display configurable	no	yes	no	yes	yes
Medications screen	no separate display currently	yes	no separate display[c]	yes	yes
Calculation of dose[d]	yes	yes	no	yes	yes
Calculation of rate[e]	yes	yes	no	yes	yes
Standard doses given	no	yes	no	yes	yes
Maximum dose alarms	yes	yes	no	yes	24-h maximum
Display configurable	XX	yes	no	yes	no
Balance screen	yes	yes	yes	yes	yes
Blood	yes	yes	yes	yes	yes
Crystalloid solutions	yes	yes	yes	yes	yes
Perfusors	yes	yes	yes	yes	yes
Infusions	yes	yes	yes	yes	yes
Enteral nutrition	yes	yes	yes	yes	yes
Parenteral nutrition	yes	yes	yes	yes	yes
Urine	yes	yes	yes	yes	yes
Input/output	yes	yes	yes	yes	yes
Netto balance	yes	yes	yes	yes	yes
Graphical display of balance	yes	at trend analyses	yes	no	yes
Display configurable	yes	yes	no	yes	yes
Trend analyses – graphical	yes, all parameters available for display	yes, all parameters available for display	yes, all parameters available for display	yes, all parameters available for display	yes, all parameters available for display
HR	yes	yes	yes	yes	yes
ABP	yes	yes	yes	yes	yes
SaO_2	yes	yes	yes	yes	yes
RR	yes	yes	yes	yes	yes
$ETCO_2$	yes	yes	yes	yes	yes
Temperature	yes	yes	yes	yes	yes
Hemodynamics	yes	yes	yes	yes	yes
Renal function	*	yes	yes	yes	yes
Laboratory values	*	yes	yes	yes	yes
Balance	yes	yes	yes	no	yes
Scores	yes	yes	yes	yes	yes
Which time interval to display at once	any	any	any	maximum 96 h	any
Display configurable	yes	yes	yes	yes	yes
Dialysis/extracorp. therapy	configurable, but not included at this site	configurable, but not included at this site	configurable, but no included at this site	yes	configurable, but not included at this site
Display configurable	*	*	*	yes	*
Hemodynamics	yes	yes	yes	yes	yes
Display configurable	yes	yes	yes	yes	yes
Pulmonary function	configurable, but not included at this site	yes	configurable, but not included at this site	yes	yes

Table 3 (continued)

System	Emtek-release 3.A	Clinicomp	Atlantis	CareVue-rel. F	Clinisoft
Display configurable	yes	yes	yes	yes	yes
Renal function	configurable, but not included at this site	configurable, but not included at this site	configurable, but not included at this site	yes	yes
Display configurable	yes	yes	yes	yes	yes
Scores	yes	yes	no	yes	yes
Apache II	*	yes	no	yes	yes
Apache III	*	*	no	yes	*
Child	*	*	no	yes	*
GCS	*	yes	no	yes	yes
TISS	*	*	no	*	yes
Care activities display	yes	configurable, but not included at this site	see I.N.C.A.	yes	yes
Prescriptions	no	*	no	no	yes
Medical diagnoses	yes	yes	at admission display	yes	yes
Care diagnoses	yes	yes	no	no	yes
Automatic configuration[f]	*	*	no	no	yes
Tick off already done activities	yes	no	no	no	yes
Alarm when not handled	no	no	no	no	yes
Graphical display of the body[g]	no	no	no	no	yes
Notes possible	yes	yes	yes	yes	yes
Display configurable	*	yes	no	yes	yes
Nutrition	*	yes	no	no	no
Fluid account	*	yes	no	no	yes
Accounting of calories	no	yes	no	no	yes
Accounting of electrolytes	yes	no	no	no	yes
Documentation	*	configurable, but not included at this site	no	yes	yes
Anamnesis report function	yes	*	no	yes	*
Transfer report function	yes	*	no	no	yes
Automatic take over of patient data[h]	yes	*	no	no	no
Diagnoses database	yes	*	no	no	yes
Notes	yes	yes	yes	yes	yes
Notes per worksheet cell	yes	no	no	yes	yes
Overview for notes	yes	yes	no	no	yes
Sorting notes for different criteria	yes	yes	no	no	yes
Printed reports	all trends configurable as reports	any report configurable	only with module Hospiprint[i]	any report configurable	any report configurable
Interval changeable?	yes	24 h maximum	XX	yes	yes
Data acquisition	yes	yes	yes	yes	yes
Ward sided laboratories	yes	yes	yes	yes	yes
Laboratory information systems	yes	yes	yes	*	yes
X-ray systems	from SIEMENS	no	yes[j]	no	no
On-line data acquisition	yes	yes	yes	yes	yes
Monitors	yes	yes	yes	yes	yes
Ventilators	yes	yes	yes	yes	yes
Pulsoximeters	from monitor	yes	yes	yes	yes
Perfusors	yes	yes	yes	no	yes
Dialysis/filtration devices	*	*	*	yes	*
IABP	*	yes	*	*	*
Mechanism of data import into PDMS	validation/ automatic	validation	automatic	validation/ automatic	automatic

Table 3 (continued)

System	Emtek-release 3.A	Clinicomp	Atlantis	CareVue-rel. F	Clinisoft
Manual validation	yes	yes	no	yes	no
Automatic validation	yes	no	yes	yes	yes
Artefact recognition	yes	no	no	no	median-filtering
Automatic validation all ...min	1 min	no	10 – 60 min	15 – 120 min.	2 or 5 min
Storage without validation	48 h storage	no	no	no[k]	patient stay
Data acquisition from CIS	*	yes	*	*	*
Data transfer to CIS	*	yes	*	*	*
Data storage	yes	yes	yes, in ASCII-format	currently no permanent storage	yes
In the main database	no limitation	minimum 25 years	no	around 12 weeks[l]	patient stay
Archiving possible?	automatic	automatic	yes, from the user	available with ver. G	yes
Database					
Scientific use of the data possible?	not installed in Europe	not installed in Europe	yes[m]	yes	yes
Database	SYBASE	CCIDB	WATCOM	ALLBASE	MS SQL Server
Data access	via SQL queries	via CCIDB queries	ASCII export	ASCII export	ASCII export, SQL access planned
Display					
Associative displays[n]	no	no	at the balance display	no	yes
Time interval of display configurable	yes	no	yes	yes	yes
Minimum interval between columns	1 min	XX	1 min	1 min	1 min
Maximum interval between columns	patient stay	patient stay	patient stay	8 h	patient stay
Configuration: done by vendor or user?	both possible	at the moment only from Marquette	user	both possible	user

yes = this function was included in the tested system;
no = this function was not included in the tested system;
* = it is possible to configure this function, but it was not done for the tested system;
X = a special display is not available for that item; therefore the single parameters can not be shown as yes or no for that display;
Display configurable = this option means that the display can be configured by the user; e.g., new parameters; can be added, unnecessary ones deleted

[a] This system provides limited possibility to display sections in graphic format: it is possible to configure six different screens with any combination of measured values

[b] In this system, all value displays are graphical displays

[c] To document medications, care activities etc., you must buy the module INCA

[d] At entering a medication

[e] At entering a medication

[f] Usual in American systems: after selecting a care-diagnose there is a set of care-activities automatically generated, a so called care-plan; it can be edited if needed

[g] Graphical display of the human body, which gives the nurses the possibility to select and mark different points with an input device, e.g. a mouse, and to describe the condition of the patient; this should simulate the situation as given in written documentation

[h] When producing a transfer report e.g.

[i] At this ward an external reporting-program was configured; if you don't have programming-engineers available it is recommendable to buy the module "Hospiprint", which acts as a print-server module. With this module you can configure any report you need

[j] With module Hospiimage

[k] But 24-h storage at HP-Merlin monitors; from there, the data can be taken

[l] Until the database becomes full; then the oldest patient data are deleted

[m] You can convert the ASCII-data-sets into any database

[n] This marks the possibility to display some valuable information during recording data; e.g. as you enter the prescribed cardiovascular medications, you would maybe like to see the trend of the HR and MAP of the last hours; systems with a "yes" have the ability to display such additional information in a window

Table 4 Technical data: Siemens EMTEK system 2000

1. Hardware	
1.1. Server	SUN SPARCstation 2 with 32 MB Ram and 2×600 MB hard disks;
1.2. Workstations	SUN Microsystems Workstation SPARCstation IPC; 24 MB Ram, 207 MB harddisk;
1.3. Displays/resolution	SUN-19″, monochrome or color, 1192×900 pixel;
1.4. Network specifications	Ethernet; ring topology;
2. Software	
2.1. Operating system	SUN/OS (UNIX) release 4.1.2;
2.2. Applications environment	Openlook/X11;
2.3. Database	SYBASE;
2.4. Network specifications	TCP/IP protocol/NFS;
3. Interfaces	
3.1. Implemented interfaces	HL-7 for connection onto lab devices and CIS systems;
3.2. Planned interfaces	Eventually EDIFACT;
3.3. Device drivers	Monitoring: Siemens, Marquette, HP, SpaceLabs, Nihon Koden; Ventilators: Siemens Servo 900 C/D, Dräger Evita, Puritan Bennett, Pumps: Imed, Ivac in preparation

Table 5 Technical data: Marquette Clinicomp

1. Hardware	
1.1. Server	2 Sequent Symmetry 2000, 2 to 6 Intel i486 CPUs, 16–512 MB RAM, SCSI Interface, HD 316–1250 MB, optionally optical disks, Juke box or DAT;
1.2. Workstations	Terminals;
1.3. Displays/Resolution	19″ monitor, 1280×1024 pixels, monochrome or colour;
1.4. Network specifications	10Base T Unshielded Twisted Pair, 10Base 2 Thin LAN. Backbone: Thick LAN, Fibre Optic and ANSI X3T9.5 compliant FDDI;
2. Software	
2.1. Operating system	AT&T UNIX system V Release 3.2 (SVID) 3;
2.2. Applications environment	
2.3. Database	CCIDB (CLINICOMP Intel. Database) with CQL (Clinical Query Language) developed from LISP;
2.4. Network specifications	IEEE 802.E Ethernet;
3. Interfaces	
3.1. Implemented interfaces	Clinical Data Link (CDL) HL-7 Version 2.1, CIS Link Media: RS232, RS422, Ethernet;
3.2. Planned interfaces	MIB;
3.3. Device drivers	Marquette, Siemens, HP, SpaceLabs, Mennen, Ventilators, IV Pumps, Urimeter, Mass Spectrometer, gas monitors

need not be purchased together. Care plans can be created, where care activities can be checklisted and marked as done, to provide an overview. Installation and servicing needs an informatic engineer, since the vendor sells the system and provides interfaces (e.g. for programming of own modules) as well as problem support, but doesn't provide further services at the moment.

Hewlett Packard CareVue 9000

HP's CareVue 9000 is part of the company's vision of a hospital-wide clinical information system. The system is based on a very complex data structure, which provides useful data for further processing. Unfortunately, the database system is not able to store patients' data permanently. As the database fills up, the oldest patient records are deleted. At present the only possibility of accessing data later on is to export it in the form of ASCII files and import and reconstruct them into a scientific database system [23]. The system, although built upon HP's Apollo Series 700 workstation, shows a very slow response, although it's twice as fast than it's predecessor systems equipped with workstations from the Apollo 400 Series. The graphical features of the system lag behind those of other PDMS: trend graphs are limited to the same time scale and design as are the tables. The maximum displayable interval on one screen is 4 days. Automatic charting is possible in 15 minute intervals, which is not enough to provide continuous trends. Variables are freely configurable but displays are fixed to the basic screen design, which has a tabular-based outlook.

Clinisoft Clinisoft Inf. System

The Clinisoft PDMS is a PC-based PDMS. The basic review modules are freely configurable trend graphs of all available variables which can be grouped as needed. It is therefore possible to create problem-oriented displays, which contain any variables required. Accurate data can be displayed with a keystroke or mouseclick on the interesting part of the trend curve; tabular data display is also possible. A specific feature of the Clinisoft PDMS is the use of associative displays: small windows displaying associated data. For example, when entering cardiovascular medication it is possible to review hemodynamic variables in a separate window. The system's care plan includes a graph of the human body, where abnormalities can be drawn as on a paper chart.

Information delivery tests

The graphs plotted here are the results, drawn from the information delivery tests. The systems hardware and network configuration of the test sites were as follows:

Table 6 Technical data: Hospitronics Atlantis

1. Hardware		
1.1. Server	PC 386 or 486, 16 MB Ram, 210–650 MB harddisk;	
1.2 Workstations	PC 386 or 486, 8 MB Ram, 120–210 MB harddisk;	
1.3 Displays/Resolution	VGA;	
1.4 Network specifications	Ethernet or Token Ring;	
2. Software		
2.1. Operating system	MS DOS 5.0;	
2.2. Applications environment	QUEMM 386, Desqview;	
2.3. Database	Internal format as described in the documentation;	
2.4. Network specifications	Novell Netware 3.11 or higher;	
3. Interfaces		
3.1 Implemented interfaces	At the moment only communication via RS 232 and RS 422 is supported;	
3.2. Planned interfaces	HL-7, MEDIX;	
3.3. Device drivers	Biomed	Bioimpedance Cardiac Output
	Braun	Infusomat, Dianet/Perfusor
	CDI	Blood gas analysis for Bypass
	Cobe	Heart lung machine
	Critikon	Dinamaps
	Datex	Cardiocap, Capnomac, Multicap, Oscar, Satellite
	Dräger	Anemone, Evita, Cicero, Mondine, PM8010, Narkomed
	Engström	Elsa
	Hamilton	Veolar
	HP	Monitors series 78xxx
	Kontron	7210
	Marquette	monitors series 701, MBX, mass spectrometer
	Mennen	Horizon
	Nellcor	Pulsoximeter
	Ohmeda	Pulsoximeter, $EtCO_2$
	Physio-Control	Pulsoximeter
	Puritan-Bennet	7200 Ventilator
	Siemens	Data Bus (SCM 990, 1280, 960)
	SpaceLabs	PDMS monitors
	Spectramed	SvO_2
	Stockert Shiley	Heart lung machine
	Vitalmetrics	Urine monitor

Hospitronics Atlantis (Fig. 1)

Network: Novell 3.11, Token Ring, 22 bedside stations. Server: IBM compatible PC-386 DX-33 MHz, 8 MB RAM, 320 MB HD. Workstations: IBM-PC-386 SX-20 MHz, 8 MB RAM, 120 MB HD. Operating System: MS DOS, QUEMM

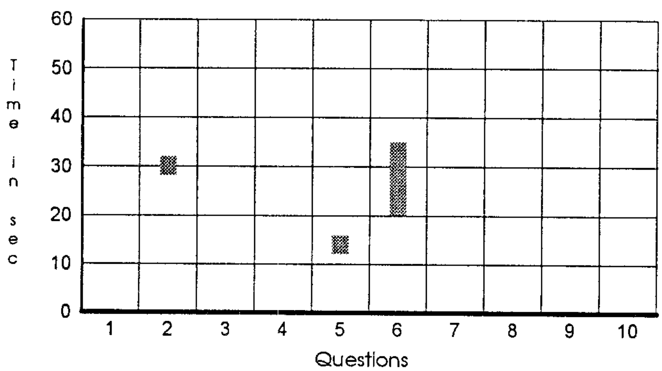

Fig. 1 Hospitronics Atlantis

Clinisoft Clinisoft Information System (Fig. 2)

Network: Novell 3.11, Token Ring, 16 bedside stations, Server: IBM PC-486 DX-33 MHz, 16 MB RAM, 600 MB HD, Workstations: IBM PC-486 SX-25 MHz, 8 MB RAM. Operating System: OS/2 1.3

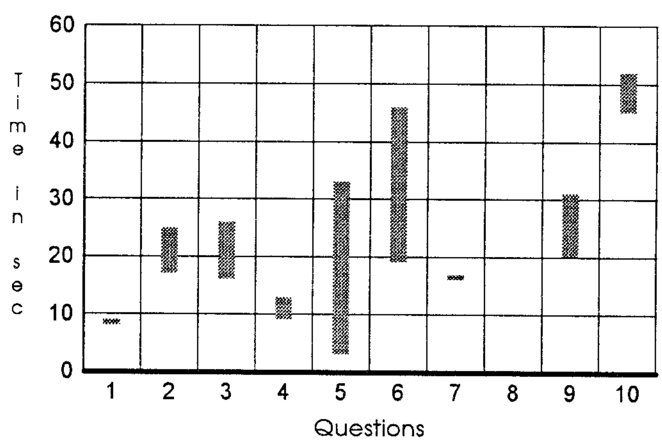

Fig. 2 Clinisoft Clinisoft information system

Table 7 Technical data: Hewlett Packard CareVue 9000

1. Hardware		
1.1. Server	HP Apollo Model 730; 66 MHz PA RISC CPU, 32 MB Ram, 2×440 MB SCSI hard disks and EISA slot; external 1350 MB SCSI harddisk;	
1.2. Workstations	HP Apollo Model 710; 50 MHz PA RISC CPU, 16 MB Ram: diskless stations;	
1.3. Displays/Resolution	16″ or 19″ monochrome or colour display with 1280×1024 pixel;	
1.4. Network specifications	Vendor installed LAN AUI configuration; External transceiver (MAU); Ethernet compatible; Star LAN topology;	
2. Software		
2.1. Operating system	HP-UX 8.07;	
2.2. Applications environment	X-Windows, OSF/Motif;	
2.3. Database	Allbase (object oriented queries on base of SQL);	
2.4. Network specifications	Protocol: TCP/IP;	
3. Interfaces		
3.1. Implemented interfaces	Monitor data from the SDN-net over Careport station; HL-7 is used as external data format; a gateway PC is needed;	
3.2. Planned interfaces	MEDIX;	
3.3. Device drivers	Drivers for all HP peripherals and compatible are included in the system;	
	Monitors:	HP CMS patient monitor (Merlin)
	MT-devices:	Beckmann laboratory, Dräger Evita, Cicero B, Ciba Corning 200 laboratory
	World wide: Monitors:	SpaceLabs, Clovers, Minishots
	Respirators:	Dräger, Siemens, Puritan Bennett
	MT devices:	Ohmeda, Nellcor, Bard Urimeter
	Laboratories:	16 different laboratory systems, e.g. Meditech, Burroghs, CHC, Sunquest, Cerner, SM Path Lab, DHCP;
	HCIS/CIS systems:	16 different, e.g. Proprietary systems, Gerber Alley, TDS, DHCP, Meditech, Baxter, SMS

Hewlett Packard CareVue 9000 (Fig. 3)

Network: HP-Network; Ethernat Star LAN; 8 bedside stations. Server: APOLLO 700, PA RISC CPU 66 MHz, 32 MB RAM, 2,4 GB HD. Workstations: APOLLO 700, PA RISC CPU, 50 MHz, 16 MB RAM, diskless. Operating System: HP-UX.

Siemens Emtek System 2000 (Fig. 4)

Network: Ethernet LAN; Ring Topology; 16 bedside stations. Server: SUN SPARCstation 2 Administration server. Workstations: SUN SPARCstation IPC, Operating System: SUN/OS rel. 4.1.2.

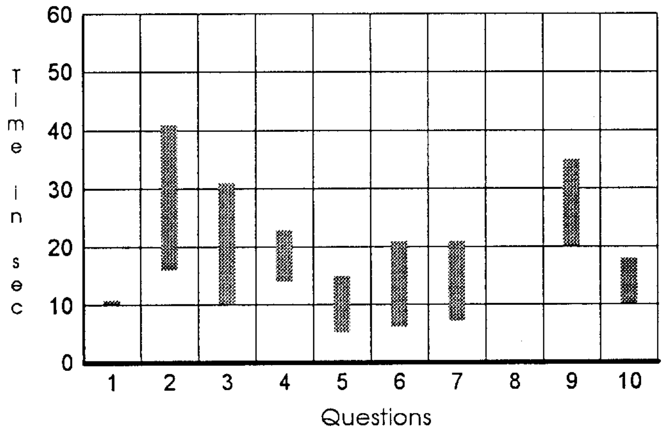

Fig. 3 HEWLETT Packard CareVue 9000, Apollo Series 700

Marquette CliniComp (Fig. 5)

Network: terminals connected via Ethernet, Mainframes: SEQUENT SYMMETRY 2000 with 4×i486 CPUs, 128 MB RAM, Terminals: 52 "Intelligent Display Stations", Operating System: UNIX.

Discussion

The preceeding pages show variations in information delivery, which may be a limiting variable of systems' usefulness as rapid access to patient information may be critical for care [17]. The more time-consuming the work with the PDMS, the less accepted it is by the personnel. The speed of the system and therefore the amount of time needed for data entering and display is an important determinant of the system's acceptance [24]. At our unit there was a reduced information flow after implementation of the PDMS during shifts, which we could explain through a lack of performance and long response times of our own system. Systems acceptance, however is of course influenced by different facts and a result of its overall usefulness, not only of its performance.

Table 8 Technical data: Clinisoft clinical information system

1. Hardware	
1.1. Server	IBM compatible PC-486, 22 MB Ram, 800 MB hard disks, Network adapter, Streamer;
1.2. Workstations	IBM compatible PC-486, 16 MB Ram, 120 MB hard disks, Network adapters, adapter for connection of peripheral devices;
1.3. Displays/Resolution	Any OS/2 compliant graphics adapters; e.g. 1024×768 with XGA-2 or 8514 compatible;
1.4. Network specifications	Any OS/2 compatible LAN;
2. Software	
2.1. Operating system	OS/2 release 1.3; now upgrading to OS/2 V. 2.1;
2.2. Applications environment	CLINISOFT Software, MS SQL Server, MS Excel;
2.3. Database	MS SQL Server;
2.4. Network specifications	OS/2 compatible LAN software, e.g. MS LAN Manager, IBM LAN server;
3. Interfaces	
3.1. Implemented interfaces	HL-7 for connection to laboratory systems;
3.2. Planned interfaces	HL-7 for connection to different CIS;
3.3. Device drivers	Monitoring: Siemens Sirecust, Marquette, HP, SpaceLabs, Kone 565, Datex AS/3 Ventilation: Siemens Servo 900 C/D Infusion pumps: Braun, Ivac Pulsoximeters: Datex Satellite, Oskar Metabolic monitors: Datex Deltatrac

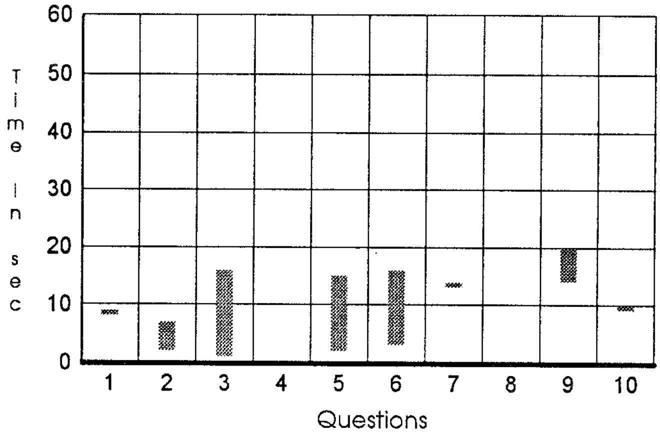

Fig. 4 Siemens Emtek System 2000

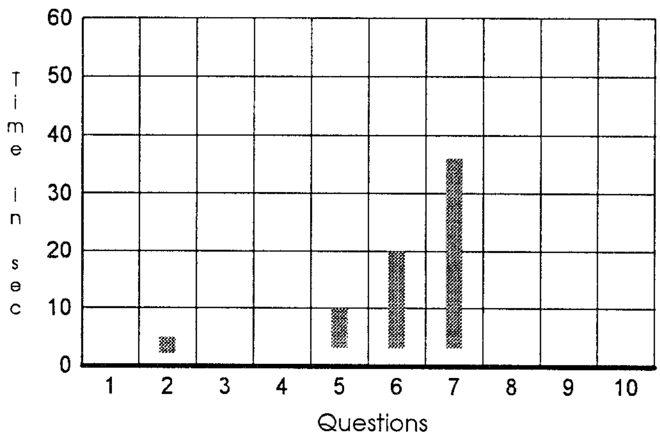

Fig. 5 Marquette CliniComp

Our results show the impact resulting from system design and data arrangement. First, systems with graphical data presentation presented great advantages when answering questions requiring a scroll back in time. This occurs normally with questions which can be represented best through trend graphs, such as changes in renal function or hemodynamic behaviour. A big screen filled with numbers is more an obstacle for easy reviewing than a good alternative for a paper chart, when looking for specific data. The result of being confronted with too many numbers is the loss of information rather than a good overview. Second, the configuration of problem-oriented review screens – consisting of numeric as well as of graphically displayed data – seemed to increase the usefulness of PDMS. The CLINISOFT system is the first one, which uses primarily graphic instead of tabular displays. This provides a different approach to reviewing patient data. Only clinical use in routine work will prove its usability.

Although we didn't have the possibility of designing a "test patient" and entering his data into the different PDMS, one would expect that the different patient data would influence the results of the Information Delivery Tests in a major way. But as we performed our tests with various patients, we realized that this did not affect the outcome to a great extent. Especially in slower systems, most of the time was consumed for switching displays and adjusting the time. This can be explained through the importance of the response time of the database system for data display. The configuration of a "test patient" would have produced more accurate values, but this was not necessary since our aim was only to give some idea of how much the performance of PDM-systems can differ and that this produces an impact on routine work. Therefore, results shown in the figures above should be interpreted carefully in combination with the Table of Functions and System Analyses. They should not be seen as exact statistical comparisons, but as an additional instrument for checking the performance of the PDMS which has to be seen within the appropriate context (such as equipment, number of beds, etc.).

There are many promises waiting to be fulfilled. For example, every vendor of a PDMS promises easy data access for scientific research – but three of the systems only have the ability to produce or export data in the well-known ASCII format (CAREVUE, ATLANTIS, CLINISOFT). Such data has to be reconverted into a database format. Finally the assertion of a vendor to be compatible with almost every database perhaps does not mean much more than providing data in text format. Although all database systems used are SQL compatible, only Siemens Emtek and the Medisoft PICIS (successor of the Hospitronics Atlantis) provide SQL support at the moment; Marquette uses its non-standard, proprietary query language CCIDB. None of these latter research stations was installed in Europe at the time of investigation. PDMS vendors will still have to invest some more work to improve the capability of using acquired patient data for scientific and quality controlling purposes, which will be of increasing importance in coming years.

Since computers are able to manage more data in less time, many more examinations are carried out, which produces more and more data accordingly. The availability of more data only makes sense if it can also be presented in a useful way [3]. Interest is focusing on the possibilities of displaying complex data sets [25, 26]. Graphical instead of numerical display is one of the first possible solutions. Trend graphs are not only a method of showing compressed information, they also present – in contrast to single numbers – a new dimension: the time scale, which gives you an additional aspect of the patient's development. New ways of data presentation need new abilities of abstract thinking, which may on the one hand provide new and interesting aspects of therapy, but may also be an obstacle for spreading these technologies. Different centers are working on that problem [22, 27, 28]; primary results should soon be ready. Wave forms represent another level of data presentation. Since they are a more accurate form of displaying complex information, they produce a lot of data. As today's computer systems are not powerful enough to handle such amounts of data, they are not commonly used in PDMS at present. When data presentation is discussed, one has to think about validity and reliability of those data. Since accurate artefact recognition is still not at an applicable stage, the quality of automated data cannot be guaranteed [29]. Median filtering of such data is an approach to reduce artifacts, which are regulary produced through the applied care activities. Manual versus automatic validation should be an issue for further discussion and standardization.

Discussions today focus on the development of "decision support systems" which are based on making use of patient data. Although we think that support of clinical decision making should be one of the main responsibilities of a PDMS, we could hardly compare systems functionality from this aspect. Decision support systems themselves have seldom been practicable until now and there is no definition as to what decision support may mean for the individual clinician, or what it means in the context of a PDMS. It could just mean delivering important data in the appropriate context, or could even be a sophisticated "artificial intelligent" program which makes decisions based on different strategies [30]. Patient Data Management in Intensive Care requires of course more than simple data display. Providing problem oriented displays are one possibility, providing accessorial information (e.g. drug interactions) may be another.

At least it has to be mentioned that the state of art in PDMS is not satisfying at the moment. A lot of work has still to be done to improve the performance, to correct the defects and to fulfill the promises which were given years ago. Evolution of computer systems caused the development of interfacing programs which allow an easy communication between different systems today. Although data exchange shouldn't cause any difficulties, vendors of medical technical devices still have problems with this issue. As long as there are no PDMS standards defined – or even rejected by the industry – customers have to rely upon the good will of vendors to reduce such deficiencies. This has to be seen from two sides: as long as clinicians cannot exactly define what they want, they will get what the vendors want them to get. The time has come to form a medical establishment powerful enough to set standards and thus communicate with the industrial partners as well as with the hospital management responsible for planning, purchasing and implementing PDMS. A European project is running, which tries to specify standards for PDMS: the EURISIC project (European Users Requirements for an Information System for Intensive Care). Primary results have been presented during the European Congress of Intensive Care Medicine in Innsbruck, Austria, June 1994 and will be officially published by the end of this year [31]. Clinicians as well as medical informatic engineers have worked out detailed specifications, which include process flows as well as data descriptions and are intended to be guidelines for the industry. Additionally, the Dutch and the Austrian project group are working on the definitions for a nationwide Intensive Care database system, which could be the basis for a national quality control and assurance program for Intensive Care, but could also realize national clinical investigations [18].

However, as long as the communication between the different partners is not improved, results will be poor: "For the science of medical informatics to be successful in achieving the primary goal of improving health care, it requires that the combined skills and knowledge of computer scientists, clinicians, nurses, paramedical professionals and researchers be brought together in a harmonious collaborative effort" [29].

Major parts of the results of this study have already been published as proceedings of the "Wiener Intensivmedizinischen Tage 1993" (Vienna Days of Intensive Care) [32].

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