Information Management Infrastructure

for an

Integrated Combat Suite Architecture

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Summary

This paper addresses architecture concepts applicable to the Integrated Combat Suite (ICS) for a Naval Surface Combatant specifically with regard to the provision of an Information Management Infrastructure.

The document commences with an overview of the system-level **allocated requirements**. **Derived requirements** for an Information Management Infrastructure (IMI) are then determined.

A generic **system architecture** is then presented in terms of the allocated and derived requirements. A specific topology, based on anticipated requirements as well as available technology is described. The scalability of the architecture to different platforms, including non-surface platforms, is described.

Some order-of-magnitude system acquisition costs for a range of system complexities and configurations are presented.

Finally some **conclusions** and **recommendations** within the context of the allocated and derived requirements as well as the RSA's politico-economic environment are offered.

Specific detailed results of some preliminary investigations into an ICS LAN are provided in a number of appendices: LAN Technology Comparative Analysis, 1st Order Dataflow Analysis and FDDI Ring Latency Time Analysis.

A report on a mechanism for investigating some of the characteristics of the system, i.e. an Architecture Concept Demonstration Model, is also presented in the form of an appendix.

1. Introduction

While the RSA is not at present involved in the development of a new naval surface combatant, consideration is being given to the technological requirements thereof as well as to the upgrade of present platforms to meet threats possessing ever-increasing technological capability.

From both the threat and ownship capability perspectives, *Information Technology* (IT) is one area which is having a profound effect on warship operation and design.

In the modern combat environment, the force with the best access to **information** is best placed to deal effectively with its adversary, i.e. assuming a reasonable parity in weapon capability. In fact this can be said of almost any organisation operating in a competitive environment.

Three areas of IT, in particular, are influencing the way in which combat systems can function with greater effectiveness; these are **networking**, **graphics** and **image processing**.

2. Architecture Concepts

2.1 Combat System Requirements

Without regarding his intrinsic weapon capability, the user requirement for a highly effective combat system may be summarised as follows :

Fast access to accurate and informative information

to provide the ability to make quick and well-founded strategic and tactical decisions

to defend or attack as his operational requirement may demand.

From this it can be derived that he requires an **integrated**, **available** and **operable** system. Sensors, decision support systems and weapons need to be integrated to provide this capability.

The user also requires the system to be **secure**, **survivable** and **flexible**.

Deriving lower-level requirements from those above means that the system must be **reliable**, **maintainable**, **reconfigurable**, and **electro-magnetically compatible** (EMC) as well as **small in size** and **low in mass**.

Apart from those above, the user organisation has further requirements of any combat system. It must be **user-friendly**, **affordable**, **supportable**, **expandable** and **upgradeable**.

In terms of the functional performance of the combat system, this can be extensively enhanced by the use of **graphics**, **shared databases**, **image processing** and **image databases**. In the medium-term future, **knowledge-based (*expert*) systems** will be required in order to give the user the critical edge over his adversary.

Apart from all the above requirements, the system must operate in a critically **real-time** environment. This demands the capability of handling **high data rates**, **vast data volumes** with **low latency times** in a **deterministic** manner.

The ICS can be described in terms of a Data Flow Model and Functional Flow Block Diagram as depicted in Figures 1 and 2 below.

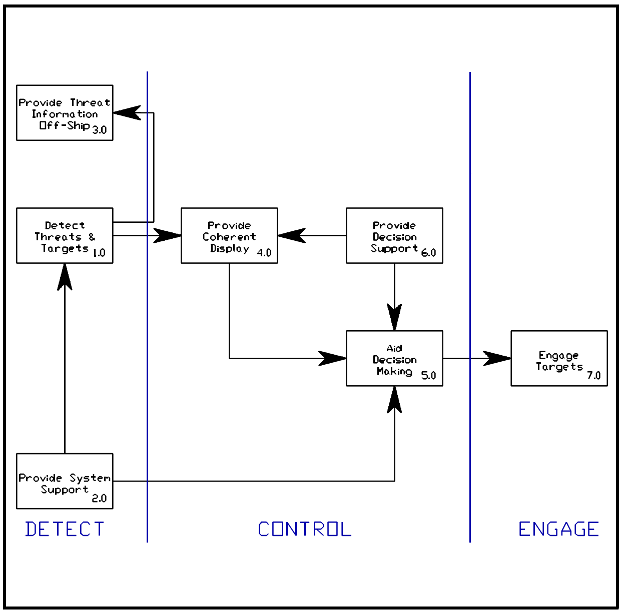

Figure 1 : ICS Data Flow Model

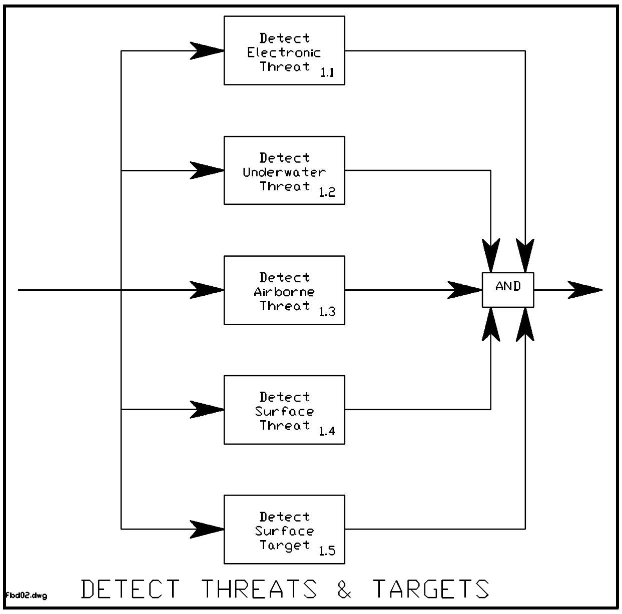

Figure 2 :Functional Flow Block Diagram for Detect Threats and Targets

2.2 Functional Performance Requirements

2.2.1 Real-Time Requirements

a. Critical Characteristics

The three real-time critical functions of the ICS which determine LAN bandwidth requirements are identified as :

i. Tracking of two threat missiles (ASMs) of speed 2,5 Mach (800 ms^{-1}) and engagement of these with own ship's missile (SAM) systems, capable of speed 3,1 Mach (1 000 ms^{-1}). This will require tracking of both the threat and ships's missiles.

ii. Tracking of two threat missiles (ASM) (speed 2,5 Mach) and engagement of these with ship's gun systems.

iii. Tracking of two own missiles (SAMs) (command-to-line-of-sight).

b. Critical Data

The applicable fire-control algorithms involve the transmission of the following time- and mission critical data :

i. Target Track Data (32 bytes) from a Tracker Sub-System (TSS) to a Gun Control Unit (GCU) every 5 ms.

ii. Platform Stabilisation Data (16 bytes) from the Navigation Sub-System (NSS) to the Weapon Control Units (WCUs) every 10 ms.

iii. Target Track Data (32 bytes) from a Tracker Sub-System (TSS) to a Missile Control Unit (MCU) with a maximum latency of 20 ms.

For further detail in respect of dataflow requirements, refer to the appendices addressing 1st Order Dataflow Analysis as well as an FDDI Ring Latency Time Analysis.

2.2.2 Determinism

A major requirement for the transfer of data in a real-time system is that it be deterministic, i.e. transfer of specific data messages occurs within guaranteed time 'windows'. This is so in order that algorithms implemented in real-time by distributed systems do converge. Determinism is also a highly desirable attribute in test, evaluation and qualification.

2.3 Combat System Architecture

This extensive array of requirements focuses the resulting combat system architecture towards one with the following attributes :

Distributed, computer-based system architecture integrated by means of a *system of local area networks* (LANs)

The LAN provides for sub-system interconnectivity, sub-system redundancy as well as supporting the required data throughput. The system of cross-connected LANs supports a high-level of system integration across the major warfare areas. It also facilitates co-ordination and development of a coherent, multi-warfare, tactical picture supporting command team decision making.

The chief attributes of the LAN are fibre-optics technology and intrinsic redundancy. These attributes provide the capability of high bandwidth, reliability, survivability and electro-magnetic compatibility.

In essence the LAN provides **networking services** by providing interconnectivity, operating system services and shared resources such as input and output devices. Input devices include scanners, video and infra-red cameras and media readers. Output devices include monochrome and colour printers, bulk storage devices such as tape streamers, optical disk drives and magnetic disk drives.

The LAN also provides an infrastructure for **data services**. Data services encompass data access services (database management services), data interchange services (gateways, routers and bridges) and data storage services (mechanisms for interfacing to the bulk storage devices).

Together the networking services and data services provide an *information management infrastructure*.

2.4 Information Management Model

It is clear that a vast amount of data and information is required to be gathered, distributed, processed and presented within the complex combat system. It is also clear that many organisations will be involved in acquiring, defining, designing developing, using and supporting the system.

To simplify these ends, a conceptual Information Management Model is required to be defined and accepted by the parties involved.

It is proposed that the Strategic Information Management (SIM) model is used in the development of the information management infrastructure.

The SIM model addresses the areas of interconnection, distributed services and information presentation and, similarly to the ISO OSI model, utilises a layered approach. The model consists of four layers, namely :

a. User Interface Layer.
b. Application Layer.
c. Data Layer.
d. Processing Layer.

Figure 3 below shows these layers graphically.

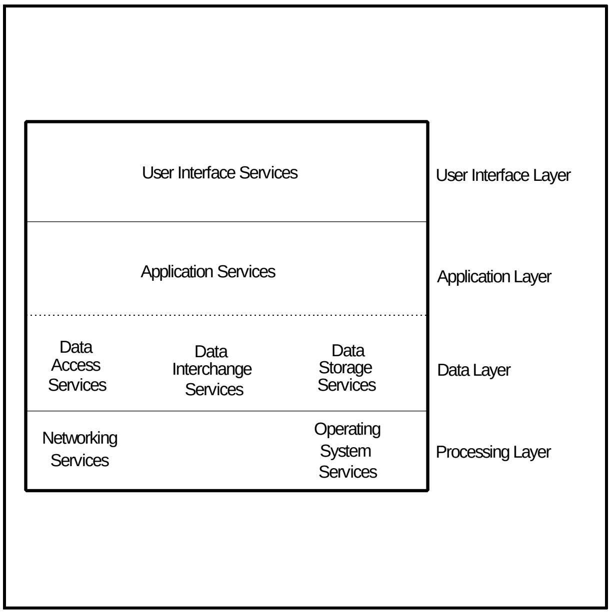

Figure 3 :Strategic Information Management Model

An important objective of the layered approach is to de-couple functionally-different services from each other. This has an advantage in development where different parties can provide functionality within their special areas of capability. The approach also allows for less troublesome functional integration. It has further advantages during product or system upgrade where specific implementations of certain functions can be replaced by more state-of-the-art implementations i.e. effective **management of obsolescence**.

The Information Management Infrastructure consists of all items and services within the Data and Processing Layers. It is proposed that provision of such services should be by a single party because, despite the layered approach, the nature of the services is such that they are *closely-coupled*.

Within the integrated combat system, the Application and User Interface Layers utilise the services of the lower layers. These layers implement the user's higher level of functional requirements.

2.5 Communication Model

As with information management, a communications model is required.

The *Survivable Adaptable Fibre Optic Embedded Network* (SAFENET) model, specifically the SAFENET II model, as defined for the US Navy, is proposed.

Figure 4 overleaf shows the SAFENET profile and its relationship to the ISO OSI 7-layer model. The SAFENET profile is derived from the ISO OSI communications model.

2.6 Real-Time Protocols

In order to support reliable, real-time networks such as those required by an ICS Information Management Infrastructure, there is a requirement for light-weight protocols such as XTP (Express Transfer Protocol) being developed in the USA.

The major attributes of such real-time protocols are error, flow and rate control, optimised inter-network addressing mechanisms and reliable multicast support.

Specific features of XTP are the following :

a. It is a **transfer** (as opposed to transport) protocol and combines the functionality of the network and transport layers of the ISO OSI reference model.

b. XTP is designed for **parallel** operation as opposed to serial operation.

c. XTP is designed for **VLSI** (Very Large Scale Integration) implementation as opposed to soft- or firmware implementation.

2.7 Communication Technology

As is indicated in Figure 4, the ANSI FDDI (Fibre Distributed Data Interface) is prescribed at Layers 1 and 2 for the SAFENET II protocol suite. FDDI is an optical fibre network offering high speed, reliable and fault-tolerant data transfer at 100 $Mbits^{-1}$. FDDI is a commercial networking standard designed to support data-intensive applications such as image processing, image and real-time distributed databases and graphics in LAN (Local Area Network) and MAN (Metropolitan Area Network) topologies.

While FDDI does not strictly support deterministic data transfer (c.f. MIL-STD-1553), its timed-token protocol and synchronous/asynchronous message modes, as well as its throughput, does adequately support reliable networking for an ICS. FDDI also offers the low bit error rate (BER) of $2{,}5 \times 10^{-10}$.

The major features of FDDI as well as an analysis of FDDI Ring Latency Time are detailed in the appendices.

2.8 Topology

The topology of a system will be derived from the system engineering process and will reflect the functionality and complexity of a particular implementation.

The possibilities are extensive, but one approach that is recommended is a topology based on logical system segmentation into principal warfare areas. This approach offers flexibility in terms of reconfiguration and survivability following battle-damage. It also provides for management of bandwidth allocation down to acceptable levels.

One such topology could be a MAN connecting the following FDDI LANs :

a. Weapons LAN.
b. Control LAN.
c. ASW LAN.
d. EW LAN.
e. Ship's Management LAN.
f. Image and Voice LAN.

Interconnectivity between the LANs would be provided by an FDDI router. All critical sub-systems on the LANs would be FDDI Dual-Attachment Stations (DASs). Non-critical sub-systems could be FDDI Single-Attachment Stations (SASs) connected by an FDDI Concentrator. Non-critical, bought-out sub-systems would be connected by gateways. Gateways that would typically be provided are Ethernet, token-ring, MIL-STD-1553B, RS232 and RS422 gateways.

Typical combat scenarios will involve multi-ship co-operation with the sensors of one platform providing targeting data to another's weapons. There are also requirements for concurrent, shared databases amongst a variety of on-board and off-board systems to provide for decision support for the battle group commander and his staff.

Such capabilities will be provided by employing gateways to RF communications systems and would be implemented by radio modems such as Link-16.

Figure 6 represents a topology for a totally integrated combat suite while Figure 7 represents the topology of a single FDDI-based LAN.

<table>
<tr><th></th><th>ISO Layers</th><th colspan="2">ISO Suite (Maximum Interoperability)</th><th colspan="2">Lightweight Suite (Minimum Latency)</th></tr>
<tr><td>9</td><td>Application Process *</td><td colspan="2">Ada Task</td><td colspan="2">Ada Task</td></tr>
<tr><td>8</td><td>Operating System *</td><td colspan="2">POSIX Real-Time Operating System</td><td colspan="2">POSIX Real-Time Operating System</td></tr>
<tr><td>7</td><td>Application</td><td colspan="2">MAP 3.0 File Transfer Private Communications Network Management & Directory Services</td><td colspan="2" rowspan="3">Lightweight Support Services</td></tr>
<tr><td>6</td><td>Presentation</td><td colspan="2">MAP 3.0 Presentation</td></tr>
<tr><td>5</td><td>Session</td><td colspan="2">MAP 3.0 Session</td></tr>
<tr><td>4</td><td>Transport</td><td>ISO Class 4 Transport Protocol</td><td rowspan="2">Global Time Service</td><td rowspan="2">XTP Protocol</td><td rowspan="2">Global Time Service</td></tr>
<tr><td>3</td><td>Network</td><td>ISO Network Protocol</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Data Link</td><td colspan="2">IEEE Logical Link Control Class I Protocol</td><td colspan="2">IEEE Logical Link Control Class I Protocol</td></tr>
<tr><td colspan="2">IEEE 802.5 Token Ring</td><td colspan="2">ANSI FDDI MAC Protocol</td></tr>
<tr><td>1</td><td>Physical</td><td colspan="2">SAFENET Modification (16 MBit/s)</td><td colspan="2">ANSI FDDI Physical Protocol (100 MBit/s)</td></tr>
<tr><td>0</td><td>Cable Plant *</td><td colspan="2">Common Cable Plant</td><td colspan="2">Common Cable Plant</td></tr>
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Note : * denotes outside the scope of the 7-layer model

Figure 4 : SAFENET I and II Standards Suites

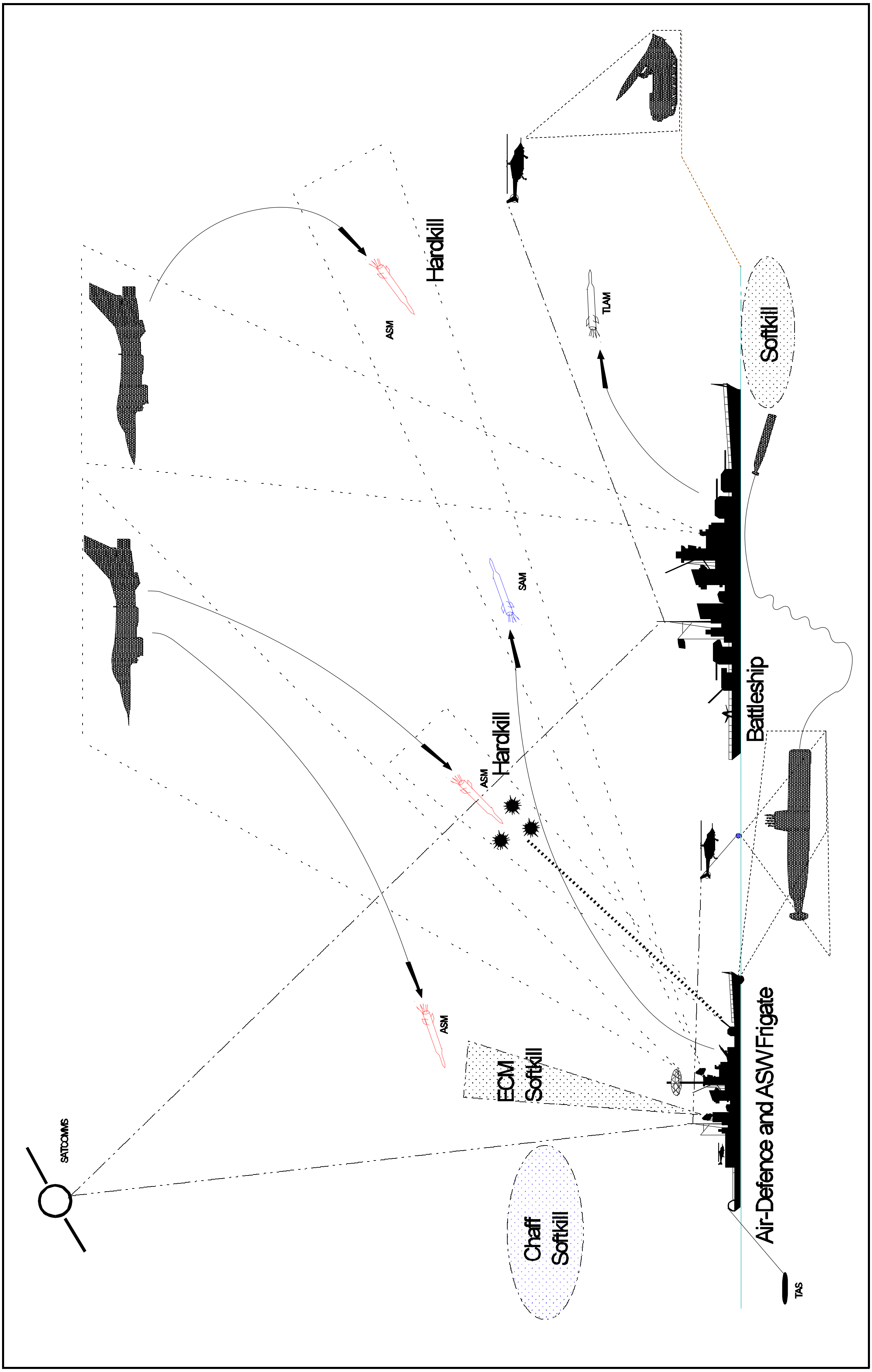


Figure 5 : Typical High Density Threat and Target Environment

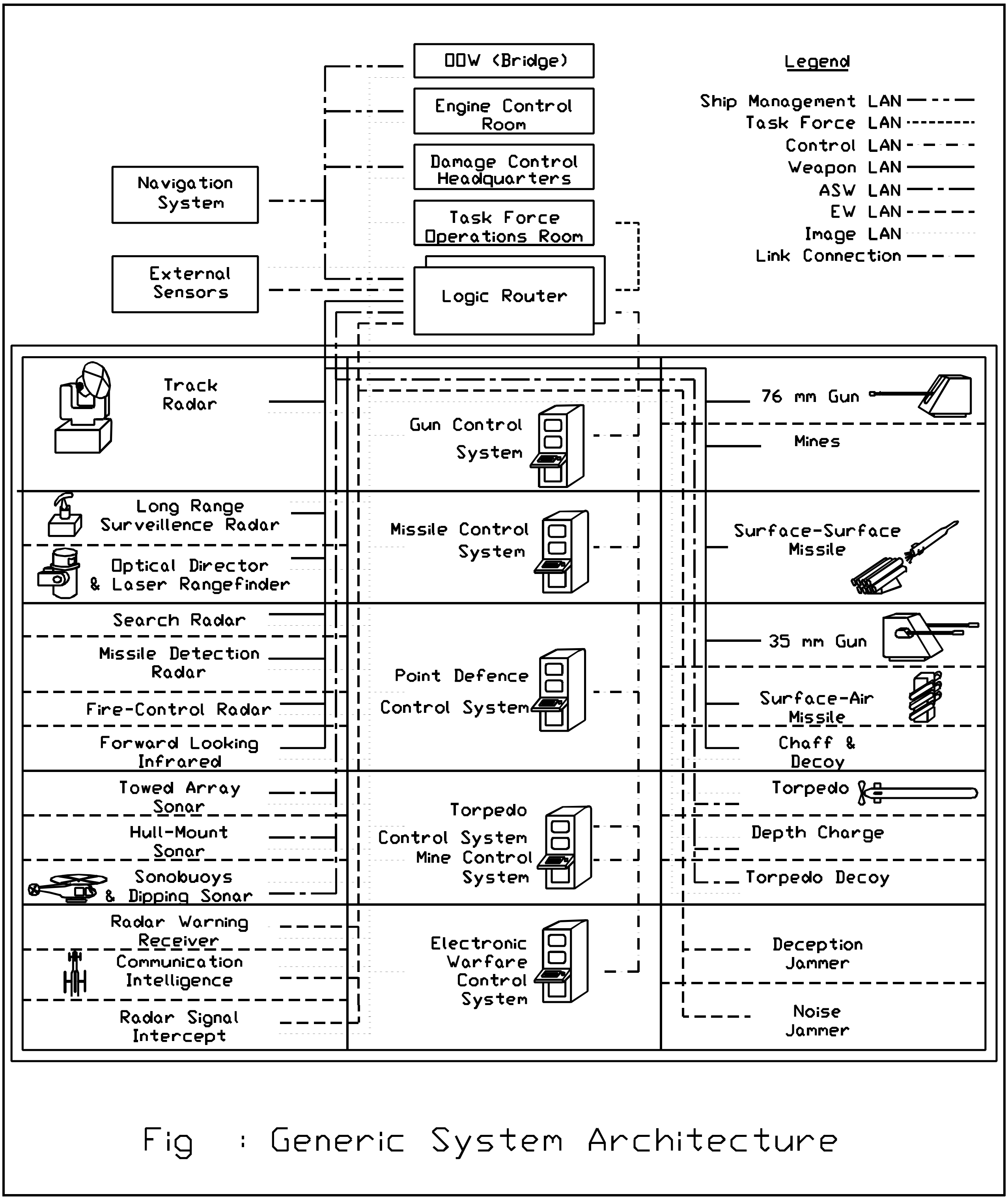


Figure 6 : Generic Fully-Integrated ICS Architecture

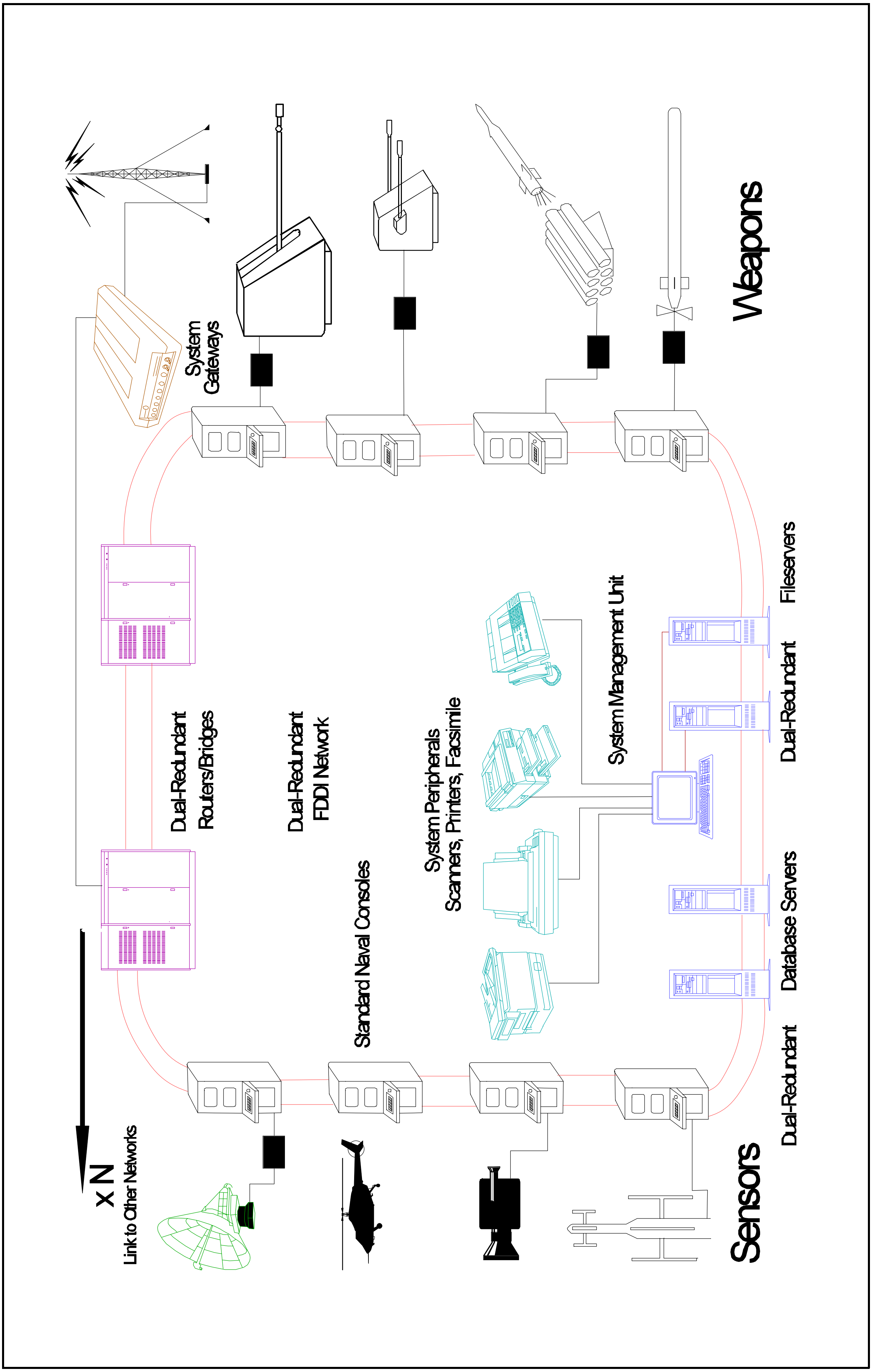


Figure 7 : Topology for a Single FDDI LAN

2.9 Fault Tolerance and Reconfigurability

The requirement for availability of a system is derived from two perspectives; firstly the system must be ***available*** when called into use and secondly the system must be ***fault-tolerant*** whilst in use. The attributes of reliability, redundancy and maintainability contribute to the availability of a system whilst reliability and redundancy contribute to fault-tolerance.

Fault-tolerance can be achieved by the implementation of multiple levels of redundancy; from integrated circuit (IC) level, through card, sub-assembly and assembly level to sub-system level. On-line reconfiguration and **system BIT** (built-in test) are important mechanisms by which fault tolerance can be achieved.

Implementation of such technologies such as **Flash EPROM** offers significant advantages in achieving on-line reconfigurability. Flash EPROM, in particular the capability of In-System Write (ISW), allows for the on-line download of code from a central fileserver while still maintaining code integrity in the case of power failure or LAN failure. This capability also provides for enhanced upgradeability as computer boards do not have to be removed from equipment racks, thus providing for less down- and requalification time as well as increased user confidence following set-to-work.

As increasingly greater levels of system functionality are achieved through software, this is a critical area where products are required to exhibit intrinsic fault tolerance. High-level languages (HLLs) such as Ada and real-time operating systems such as POSIX are examples of products which have been designed specifically for this purpose.

2.10 Database Management

Knowledge is an abstraction derived from the processing of information. Information is similarly an abstraction derived from the processing of data. On a weapons platform, data is gathered from many and varied external sources, including on- and off-board sensors. The repository for this data, assuming an integrated system, is a number of shared databases. These databases are managed by database management systems. These are constructed from computer hardware and software building blocks. The required attributes for these database management systems are real-time and on-line capability.

Many different configurations of databases exist; i.e. distributed, centralised, relational and client-server. Problems arise in the resolution of providing coherency, integrity and security for these databases. Specific configurations are better suited to mission-critical, real-time applications.

For a fully-integrated combat system, three types of databases will exist; these are tactical, decision support and ship support databases. While the latter may only require on-line capabilities, the tactical database will be both real-time and mission-critical.

2.11 Image Processing

Image processing will play an increasing role in providing enhanced war-fighting capability.

Image processing consists of the following processes :

a. Image capture from infra-red, video or low-light cameras as well as radar and other imaging systems.

b. Digitisation of the input analog signals by means of frame grabbers and scan converters.

c. Digitisation of document images by means of digital scanners.

d. Image manipulation including format conversion, image enhancement, image recognition and compression.

e. Image transmission by means of high-bandwidth media.

f. Image transmission multiplexing from various sources to various destinations simultaneously.

g. Image storage in image databases supported by high-capacity storage systems such as optical disk drives.

h. Image rendition by means of high-resolution colour display systems.

Typical image databases may contain perceived threats that may be encountered on a mission and maps of the areas where the mission is carried out. Any other digitised image, e.g. actions captured photographically during a mission, new enemy threats encountered and photographed as well as reconnaissance photographs can also be stored in the image database.

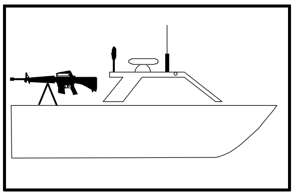
A digital scanner would provide the ability to scan threats, maps as well as any illustration or document. A colour printer would be provided to print maps or images from the image database. These can be used for mission planning, debriefing procedures, intelligence gathering and operational records.

3. Costs

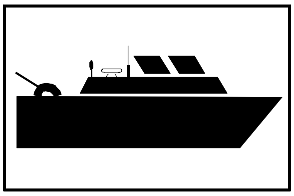
The following are typical **order-of-magnitude** costs for various implementations. The medium, high and very high complexity implementations assume some measure of value-added engineering as well as amortisation of development costs over at least four platforms.

The costs indicated are applicable to both new constructions as well as refit to existing vessels, but would be marginally higher in the latter case.

Configuration	Cost
Low Complexity	
5 x PC Workstations Fileserver FDDI LAN C Software Laser Printer Video Camera Facsimile Tactical Data Link Meterological Station GPS (Commercial) Navigation Radar (Commercial) Echo Sounder (Commercial) Laser Range Finder Low-light CCD Camera System Engineering Installation Integration Qualification	$200 000



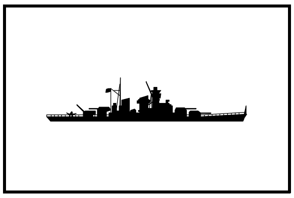
EEZ Protection Vessel



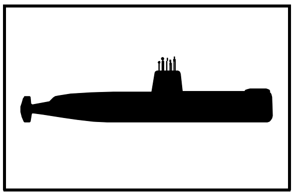
Armed Merchantman

Note : The cost **does** include the price of the Standard Naval Consoles

Configuration	Cost
Medium Complexity	
5 x Workstations Fileserver On-line Database Server FDDI LAN C Software Laser Printer A4 Colour Printer A4 Colour Scanner Video Cameras Frame Grabbers System Engineering Installation Integration Documentation Qualification	$1 000 000



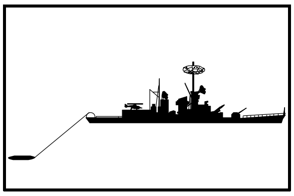
Strike Craft



Coastal Submarine

Note : The cost does **not** include the price of the workstations

Configuration	Cost
High Complexity	
20 x Standard Naval Consoles Mirrored Fileservers Network Management Unit SAFENET II Real-Time Database Server Logic Router Gateway Ada Software Laser Printer A3 Colour Printer A4 Colour Scanner Video Cameras Frame Grabbers System Engineering Navalised Hardware Installation Integration Documentation Qualification	$2 000 000

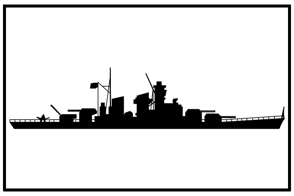


ASW Frigate

Note : The cost does **not** include the price of the Standard Naval Consoles

Very High Complexity

40 x Standard Naval Consoles $5 000 000
Mirrored Fileservers
Network Management Unit
SAFENET II
Image LAN
Real-Time Database Servers
Logic Routers
Gateways
Ada Software
Laser Printer
A3 Colour Printer
A4 Colour Scanner
Video Cameras
Frame Grabbers
Scan Converters
Image Processing
System Engineering
Military Hardware
Installation
Integration
Documentation
Qualification
Full Integrated Logistic Support


Destroyer/
Battleship

Note : The cost does **not** include the price of the Standard Naval Consoles

4. Conclusions

4.1 War-fighting Capability

Applying Information Technology to warship combat systems greatly enhances their war-fighting capabilities. Information Technology will play an increasingly important role in providing the *critical edge* in the combat environment.

In the medium term, i.e. 5 to 15 years, a surface combatant without such capabilities could, in fact, be effectively defenceless even in a typical third-world threat environment.

4.2 Architecture Concepts

It is concluded that the proposed architecture concepts offer considerable advantages over centralised, star-wired systems. The attributes of fault-tolerance, survivability, flexibility, expandability and upgradeability are well supported by a LAN-based distributed architecture.

The FDDI LAN standard offers intrinsic redundancy, determinism, low error rates and electro-magnetic compatibility while supporting high data throughput at affordable cost.

4.3 Scalability

The architecture, technologies and topologies that have been proposed are scalable to provide value-added, cost-effective solutions to **any** class of vessel, from a multi-purpose destroyer, to an ASW frigate, a submarine, a coastguard vessel or even an EEZ protection vessel.

In the case of the latter two classes of vessel, a modest investment in an **integrated system** will provide a **force multiplication** which is affordable to even organisations of limited means.

The proposed systems are applicable to both new constructions as well as refit to existing vessels.

4.4 The Paperless Operating Environment

A paperless operating environment contributes significantly to a more effective war-fighting capability. It will also contribute to lower crew-levels and enhance supportability.

The Paperless **Operations Room** is achievable within context. Some paper will always be required, however.

4.5 User Commitment

The implementation of an Information Management Infrastructure is not inexpensive and requires full commitment from the user organisation in terms of planning, construction, implementation, operation and support.

4.6 Rapid Prototyping and Risk Reduction

Effective application of rapid prototyping reduces implementation timescales as well as technical risks.

Rapid prototyping also provides for performance benchmarking which is critical in the environment of off-the-shelf building blocks. Specific areas where this is critical are timing, synchronisation, throughput and interfacing.

4.7 Standard Commercial Building Blocks

There are many hardware and software products available supporting specific areas of an information management infrastructure solution.

There are many companies offering partial, product-based solutions. When these products become obsolete, so will their systems.

Non-standard solutions have limited life-cycles.

4.8 Image Processing

Real-time image processing requires computer resources far in excess to that that can be provided by software hosted by general purpose computers. To achieve acceptable performance requires purpose-built, image processing hardware usually utilising RISC and digital signal processing techniques.

4.9 System-Engineered Solution

A system-engineering solution is required to properly determine the requirements and solution.

4.10 Local Capability

Few organisations in the RSA have all the capabilities in-house to provide the total solution.

It is concluded however, that using foreign-procured building blocks and consultation, capabilities do exist within the RSA to provide systems that will meet the foreseen level of requirements. In fact, this would be the only way to achieve an optimum solution in terms of performance, timescales and cost.

5. Recommendations

5.1 System Engineering

A system engineering effort should be applied to provide a total solution to the implementation of a combat platform's information management infrastructure. This effort should be tailored strictly according to the extent of the requirements.

The solution should be tailored strictly according to the user's needs and means.

The provision of the Information Management Infrastructure should be co-ordinated by a single party because, despite the layered approach, the nature of the services is such that they are *closely-coupled*.

Individual capabilities, mainly in the Application and User Interface Layers, should be provided by specialists in their particular fields.

5.2 Rapid Prototyping

Rapid prototyping should be employed to aid the system engineering efforts, especially so as to involve the user's operational staff as early as possible during development.

5.3 Standards

The solution should be strictly standards-based.

The system should be constructed from available, off-the-shelf building blocks.

5.4 Open-Systems Architecture

The solution should be based on an open-systems architecture providing for product obsolescence management, flexibility, upgradeability and life-cycle support.

5.5 FDDI and Protocols

While SAFENET II is considered the ultimate technological objective in terms of LAN implementation, this should be achieved by a *stepping-stone* approach; i.e. by migration through FDDI and protocols such as TCP/IP and/or ISO OSI.

5.6 Operating Systems

The POSIX operating system should be used as a real-time, deterministic, multiprocessing, Ada-compatible, networkable operating system.

6. Acknowledgements

The author firstly wishes to acknowledge the support of Messrs Anton Jordaan and Brian Blackbeard whose confidence and enthusiasm were instrumental in both the sponsorship of the work underlying this paper, as well as its presentation at **RINA NAVTEC '91.**

He secondly wishes to acknowledge and thank Gerhard Krüger for his participation in the requirements analysis and concept design, especially the Dataflow Analysis.

The views expressed in this paper are those of the author and do not necessarily represent those of the South African Navy or South African Government.

7. Reference Documents

7.1 Standards

a. MIL-STD-1553B - Digital Time Division Command/Response Multiplex Data Bus (Notice II).

b. DOD-STD-2167A - Defense System Software Development.

c. MIL-STD-1815A- Ada Language Reference Manual.

d. STANAG 3910 - High Speed Data Transmission under STANAG 3838 or Fibre Optic Equivalent Control

e. SAFENET I - Survivable Adaptable Fiber Embedded Network (MIL-Hndbk-MCCR-0034).

f. SAFENET II - Survivable Adaptable Fiber Embedded Network (MIL-Hndbk-MCCR-0035).

7.2 Other Documents

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8. Appendices

8.1 Appendix 1

Comparative LAN Analysis

A summary of characteristics of LAN standards is presented below.

Military Standards

MIL-STD-1553B

Sponsor	Society of Automotive Engineers (SAE), USA, on behalf of US DOD
Developer	Many
Status	Established and widely used
Medium	Twisted-Wire Pair
Bandwidth	1 $Mbits^{-1}$
Length	100 m
Terminals	31
Topology	Linear Bus
Protocol	Command/Response

DOD-STD-1773

Sponsor	US DOD
Status	Established, but not widely used
Medium	Fibre-Optic
Bandwidth	1 $Mbits^{-1}$
Length	100 m
Terminals	31
Topology	Linear Bus
Protocol	Command/Response

STANAG 3910

Sponsor	NATO
Developer	Various European Companies
Status	Full-Scale Development
Medium	Fibre-Optic High-Speed Channel Twisted-Wire Pair Low-Speed Channel
Bandwidth	20 $Mbits^{-1}$ Data Bus 1 $Mbits^{-1}$ Control Bus
Length	100 m
Terminals	31
Topology	High-Speed Bus - Ring Low -Speed Bus - MIL-STD-1553B
Protocol	Command/Response

EFABus

Sponsor	European Fighter Aircraft (EFA) Consortium
Developer	Various European Companies
Status	Full-Scale Development
Character-ristics	Derivative of STANAG 3910

Commercial Standards

Ethernet (IEEE 802.3)

Status	Mature Product
Developer	Xerox Corporation
Medium	Co-axial Cable
Bandwidth	10 Mbits^{-1}
Length	300 m (without Repeaters)
Terminals	. 250
Topology	Tree Network
Protocol	Carrier-sense, Multiple Access with Collision Detect (CSMA/CD)

IBM Token Ring (IEEE 802.5)

Status	Maturing Product
Developer	IBM
Medium	Co-axial Cable
Bandwidth	4 or 16 Mbits^{-1}
Length	Unknown
Terminals	. 250
Topology	Ring Network
Protocol	Token Passing

FDDI

FDDI Fibre Distributed Data Interface

Sponsor	ANSI
Developer	Many Commercial Companies
Status	Approaching Standardization
Medium	Fibre-Optic
Bandwidth	100 Mbits^{-1}
Length	100 km
Terminals	1 000
Topology	Dual-Redundant Counter-Rotating Ring
Protocol	Timed Token

8.2 Appendix 2

FDDI Ring Latency Time

The latency of an FDDI ring is dependent on two factors, *medium propagation delay* and *PHY latency*.

8.2.1 Medium Propagation Delay

Medium Propagation Delay (MPD) is a function of the path length i.e. FDDI ring diameter (RD) :

MPD	5,1 µs/km	(FDDI standard)
ICS	RD . 1 km	(assumed)
Worst Case	RD = 200 km	(FDDI standard)

8.2.2 PHY Latency

PHY Latency (PL) is a function of the sum of the physical interface (PHY) latencies (PL). For a dual-attachment station (DAS), each DAS has two active PHYs; this case is applicable when one station has failed and the ring is in the ***wrapped*** configuration.

PL	0,6 µs per PHY	(FDDI standard)
ICS	No. of DASs (D) . 30	(assumed)
Worst Case	No. of DASs (D) = 500	(FDDI standard)

8.2.3 FDDI Ring Latency Time

Thru' Ring Configuration

RLT = MPD.RD + PL.D

RLT_{ICS} = 5,1 x 1 + 0,6 x 30

= <u>23,1 µs</u>

RLT_{WC} = 5,1 x 200 + 0,6 x 500

= <u>1 320 µs</u>

= <u>1,320 ms</u>

Wrapped Ring Configuration

RLT = MPD.RD + 2PL.D

RLT_{ICS} = 5,1 x 1 + 2 x 0,6 x 30

= <u>41,1 µs</u>

RLT_{WC} = 5,1 x 200 + 2 x 0,6 x 500

= <u>1 620 µs</u>

= <u>1,620 ms</u>

8.2.4 ICS Cycle Times

Cycle times for the ICS are derived from the mission- and time-critical dataflows. The FDDI protocol employs a *timed-token protocol*. The **Target Token Rotation Time** (TTRT) is a fundamental characteristic of a specific FDDI implementation and efforts are required to determine a suitable value for the ICS in respect of the system-level performance characteristics.

The **Token Rotation Time** (TRT) of an FDDI ring defines the time taken for the timed-token to circumnavigate the ring and thus defines the time taken for a station to gain access to the LAN's message transfer services.

In can be proven mathematically that the timed-token protocol of FDDI has two important properties :

$$TRT_{average} \ \# \ TTRT$$

$$TRT_{maximum} \ \# \ 2 \times TTRT$$

The proof of these properties is somewhat complex and reference should be made to an article *Cycle Time Properties of the FDDI Token Ring Protocol* by K.E. Sevcik and M.J. Johnson.

8.2.5 TTRT for the ICS

The choice of TTRT for a system is not only dependent on the *ring latency time*, but also on the relative bandwidth allocation to synchronous and asynchronous traffic. Sevcik and Johnson provide two formulae to determine *Minimum TTRTs to Permit Various Fractions of Total Capacity to be Allocated to Synchronous Traffic*.

$$TTRT \ \$ \ \frac{N \times Z + P}{1 - S} \qquad \text{(Formula 1)}$$

$$N \times Z + P \ . \ 0{,}005 \times (RD + N) \qquad \text{(Formula 2)}$$

where N Number of PHYs
S Proportion of Synchronous Traffic

If allocation of between 50% and 70% of the bandwidth to synchronous traffic is made, it can be determined from Formulae 1 and 2 that the possible choice of minimum TTRT lies in the range 0,61 ms to 1,02 ms.

In order to effect accurate synchronization via the FDDI ring, the TTRT should be minimised, however this may have implications on sub-system interrupt processing overhead.

It is recommended that should a synchronization accuracy of better than 2 ms be required, a TTRT of 1 ms be adopted; if a synchronization accuracy of better than 10 ms is sufficient, a TTRT of 5 ms should be adopted.

8.3 Appendix 3

1st Order Dataflow Analysis

This appendix presents a dataflow analysis for a specific configuration of an Integrated Combat System. An attempt has been made to derive the dataflow requirements from the concept descriptions of each of the systems identified and by consultation with the various parties involved with these systems. Where no information was available due to the very early stage of the design, assumptions have been made using generic requirements.

The analysis was performed only on critical and major information flow between the sub-systems.

Data throughput is a major requirement in applications such as distributed databases where large volumes of data need to be transferred in short times.

No level of sub-system redundancy has been considered.

Whatever the reliability attributes of a system, maintenance will be required. Differentiation between on- and off-board maintainability requirements is essential as this affects the design of the system and sub-system as well as the total logistic support policy for the equipment. This was seen as a minor requirement.

With a high degree of redundancy and reconfigurability the requirement for on-board maintenance will be significantly reduced. This will lead to other system requirements such as on-line system monitoring and tracking of configuration state and Line Replaceable Unit (LRU) status. This was seen as a minor requirement.

The use of reconfigurable Standard Console Assemblies (SCAs) provides significant advantages in terms of mission mode optimisation, system availability and damage control.

In order to effect system data coherency, there is a requirement to maintain a central shared database. Working images of segments of the database may be downloaded to remote workstations on a read-only basis. The database is updated from these same workstations, as well as other sources, but not via the remote database segments.

Logic Routers are provided for the interconnection of all the different LANs on the vessel. These routers do not require a Man-Machine Interface (MMI). The router delays were assumed to be minimal.

The maintenance station / Station Management Unit (SMU) is housed in a Standard Console Assembly (SCA) with a standard Man-Machine Interface (MMI) providing the following functions :

a. Status of any sub-system connected to any of the system LANs.
b. Any of these sub-systems may be tested from this station.
c. Indication of sub-systems at any moment utilising the LAN.
d. LAN performance measurements.
e. Connecting or removing any sub-system from a LAN.
f. Graphical overview of the total system configuration.

8.3.1 Databases

Two types of databases are provided :

8.3.2 Tactical Database

This database stores the tactical information, battle actions, ship's manoeuvres, etc. This database is a real-time database guaranteeing access times of < 20 ms. All the Target Track Data is also stored in the Tactical Database for the tactical picture compilation by the Tactical Editor Console.

8.3.3 Online Support Database

This database provides online operator and maintainer manuals, a stores management database (for managing the munitions, fuel, spares, food, electricity and water consumption, etc.) and an image database (providing storage for threats, maps and other graphical files).

Optical drives are fitted to the servers (fileservers and database servers) for the storage of application software, databases and back-ups.

8.4 Appendix 4

ICS Concept Demonstration Model

The scope of the project addressed the development of a LAN-based, distributed processing, Naval Integrated Surface Combat System (ISCS) Architecture Concept Demonstration Model (ACDM) in terms of the following **Description of Work**.

a. Acquisition and integration of commercially-available, industry-standard, hardware and software building blocks into a skeletal system representing the ICS's LAN-based, distributed processing architecture.

b. Value-added software development to support architecture concepts.

c. Characterisation of the following requirements :

   i. System timing and synchronisation.

   ii. Critical resource redundancy.

   iii. Global data distribution i.e. broadcast of common data (Calendar Time and NAV Data).

   iv. Image transfer (i.e. digital video).

   v. Reconfigurability and station management.

   vi. Multi-protocol data transfer i.e. gateways.

   vii. Data transfer determinism.

   viii. Resource sharing.

   ix. Preliminary data transfer protocol.

   x. System security.

d. The following outputs were to be generated :

   i. A demonstration of the integrated system.

   ii. A report on the system and the characteristics addressed above.

   iii. *Preliminary Protocol Description*.

8.4.1 Work Completed

Work, as detailed in the contract Work Breakdown Structure (WBS), was completed as described below. Refer to Figure A1 *ICS ACDM Topology* for a diagrammatic representation of the system topology and applicable technologies.

8.4.1.1 Network

A fileserver hosting Novell NetWare V3.11, supporting NetWare Streams and TCP/IP, was set up. The fileserver supports disk mirroring as disk storage is a critical network resource.

The fileserver and the network workstations (386 and 486 PCs) host dual-attached FDDI communications controllers.

The network also supports an Ethernet bridge to the external company wide-area network (WAN).

8.4.1.2 1553 Gateway

One FDDI network PC acts as a MIL-STD-1553B gateway to two 286 PCs on a MIL-STD-1553B bus.

One 1553 PC simulates a Navigation Sub-System ('NSS') which broadcasts simulated NAV Data to the whole network. The 'NSS' receives Calendar Time information from the Global Positioning System (GPS) host via the FDDI/1553 gateway.

8.4.1.3 Image Transfer Infrastructure

This has been implemented by using a commercial Super VHS video camera mounted on a remotely-controllable pan and tilt system. The analogue video signal is digitised by a PC-compatible frame grabber card.

The digitised images are transferred by FDDI and TCP/IP from the Frame Grabber Unit (FGU) to an Image Monitor Unit (IMU) where they are displayed immediately. They can also be converted to high-resolution VGA for display, storage and retrieval.

Images acquired from the video camera or image database can also be printed on an A4 Tektronix Phaser II thermal wax colour printer.

A high-resolution, A4, flatbed, colour scanner is used to capture digital images, including maps, threat images and documents.

8.4.1.4 GPS

A PC-compatible GPS system is hosted within a network workstation. The GPS provides Calendar Time and Position which is broadcast to all network workstations as well as stored in an on-line database.

The GPS Calender Time provides real-time synchronisation, by means of the broadcast capability, to the system via the network.

8.4.1.5 Meterological Station

An externally-mounted Meterological (Met) Station consists of wind-speed, wind-direction, relative humidity (RH), air temperature and barometric pressure sensors as well as an RS-232 communications interface. The Met Station provides these parameters to a network workstation which in turn broadcasts them to all other network workstations as well as stores them in an on-line database.

8.4.1.6 Database Management System

A client-server architecture SQL database SQLBase provides database management facilities to the system. A database server provides for data storage and manipulation facilities while a database client provides database access.

8.4.1.7 Software Development

A extensive amount of software, supporting FDDI protocol, network operation and synchronisation, image processing, printing, database management, GPS, 1553 gateway, Met Station and MMI functions has been developed and can be demonstrated.

8.4.1.8 Communication Protocols

The FDDI/NetWare interface has been implemented by means of the TCP/IP and SPX/IPX protocols, supported by commercial PC FDDI Boards. The two protocols have been proved to co-exist peacefully together.

8.4.2 Problems

8.4.2.1 Real-Time Image Transfer

The requirement for animation-quality (real-time) image transfer is some 25 frames per second. This translates to some 25 $Mbits^{-1}$, which is well within the specified 100 $Mbits^{-1}$ of FDDI as well as the quoted 30-40 $Mbits^{-1}$ of the PC FDDI boards.

Extensive effort has been expended in attempting to achieve transfer rates of 20 to 25 frames per second. Thus far, 5 frames per second has been achieved successfully. Rates in the order of 10 frames per second have been achieved, however integrity of the image is not maintained at this rate.

It has been determined that the solution to the problem lies in the resolution of processing and transfer bottlenecks. The processing bottlenecks are due to the fairly low sophistication of the PC frame grabber card as well as the limited throughput of PC ISA backplane bus. The transfer bottlenecks lie in the area of non-optimised protocols i.e. TCP/IP.

It is concluded that a Multibus II processing platform, including frame grabber and FDDI Communications Controller, will support real-time image transfer. Protocols such as XTP will further enhance real-time data communications.

Despite this, real-time image transfer was not a project objective in itself. It was mainly a mechanism of stressing the throughput capability of the FDDI LAN. Progress is nevertheless still being made in this area and in consultation with the PC FDDI Board supplier, as well as further software effort, there is confidence that a significant improvement in frame rate will be achieved before the end of the year.

8.4.2.2 Real-Time Database Management

While SQL database management systems such as SQLBase do provide adequate **on-line** capability, these cannot provide **real-time** performance. One reason for this is that the databases are stored in serial-access, magnetic or optical storage systems. A real-time database will have to exist in random-access memory, preferably non-volatile.

8.4.2.3 Fileserver Mirroring

As a fileserver is a critical item within the LAN system, this should be mirrored to provide redundancy. At present NetWare does not support fileserver mirroring, but does support disk mirroring and duplexing, the latter having been implemented. It has been determined that such operation is not totally reliable and requires further investigation into causes and solutions. Further releases of NetWare, i.e. Version 3.2 in early 1992, should offer better reliability and functionality in this area. Full server mirroring is also expected shortly.

8.4.3 Conclusions

FDDI is reliable, affordable and effective.

FDDI is sufficiency deterministic to support real-time synchronisation, i.e. within 200 µs (where LANs are geographically small to medium in size i.e. less than 2 km in diameter).

Unicast, multicast and broadcast of messages can be achieved.

Gateways to support a variety of data communication standards are easily implemented.

Integrated data and image is possible.

Real-time digital video, i.e. image, with FDDI is possible although not optimum in the case of geographically extensive LANs (i.e. in excess of 10 km in diameter).

Real-time image multiplexing with compression hardware is possible.

The FDDI II LAN protocol will provide for real-time voice and video.

Multiprotocol operation is possible. Protocols (NetWare V3.11 SPX/IPX and TCP/IP) do co-exist peacefully.

There is a requirement for high-performance protocols e.g. XTP (Xpress Transfer Protocol).

There is a requirement for a real-time operating system e.g. POSIX.

There is a requirement for a real-time database management system.

8.4.4 Recommendations

Future combat systems should be constructed from building blocks based on commercial technology, including the following standards :

Standard	Function
FDDI	Dual-Redundant Fibre-Optic LAN
SAFENET II	*Survivable Adaptable Fibre Embedded Network* Profile
Futurebus+	Parallel Backplane Bus
POSIX	Real-Time Operating System
Ada	High-Level Language
TBD	Real-Time Database Management
TBD	Presentation Layer Interface

8.4.5 Abbreviations and Acronyms

ASM	Anti-Ship Missile
ACDM	Architecture Concept Demonstration Model
AMDR	Automatic Missile Detection Radar
BER	Bit Error Rate
CCD	Charge-Coupled Device
CCS	Command and Control System
CIWS	Close-in Weapon System
CPU	Central Processing Unit
DJ	Deception Jammer
DOD	Department of Defense
EEZ	Exclusive Economic Zone
EMC	Electro-Magnetic Compatibility
EW	Electronic Warfare
EWSS	Electronic Warfare Sub-System
FGC	Frame Grabber Card
FGU	Frame Grabber Unit
GCU	Gun Control Unit
GPS	Global Positioning System
GPU	Graphics Processing Unit
FCR	Fire Control Radar
FDDI	Fibre Distributed Data Interface
FLIR	Forward Looking Infrared
HMS	Hull Mount Sonar
HSS	Helicopter Sub-System
ICS	Integrated Combat Suite

IMI	Information Management Infrastructure
IMU	Image Monitor Unit
IP	Internet Protocol
ISO	International Standards Organisation
ISW	In-System Write
LAN	Local Area Network
LSS	Lightweight Support Services
MAN	Metropolitan Area Network
MAC	Media Access Control
MCU	Missile Control Unit
MIPS	Mega-Instruction Per Second
NATO	North Atlantic Treaty Organisation
NDI	Non-Developmental Item
NJ	Noise Jammer
NPU	Numeric Processing Unit
NRSS	Navigation Radar Sub-System
NSS	Navigation Sub-System`
OBP	Onboard Programming
OFCC	Optical Fibre Cable Components
ORT	Optical Radar Tracker
OS	Operating System
OSI	Open Systems Interconnect
PFM	Platform
PHY	Physical Layer Protocol
PMD	Physical Medium Dependent
PC	Personal Computer
RAM	Random-Access Memory
RISC	Reduced Instruction Set Computer
RTU	Remote Terminal Unit
R-T	Real-Time
SAE	Society of Automotive Engineers
SAFE-NET	Survivable Adaptable Fibre-Embedded Network
SAM	Surface-to-Air Missile
SCA	Standard Console Assembly
SCS	Standard Computing Segment
SMU	Station Management Unit
SRS	Surveillance Radar System
SSM	Surface-to-Surface Missile
TAS	Towed Array Sonar
TBD	To Be Determined
TCP	Transmission Control Protocol
TDS	Torpedo Decoy System
TFCS	Torpedo Fire Control System
TLAM	Tactical Land Attack Missile
TSS	Tracker Sub-System
USN	United States Navy
WBS	Work Breakdown Structure
WCU	Weapon Control Unit
WER	Word Error Rate

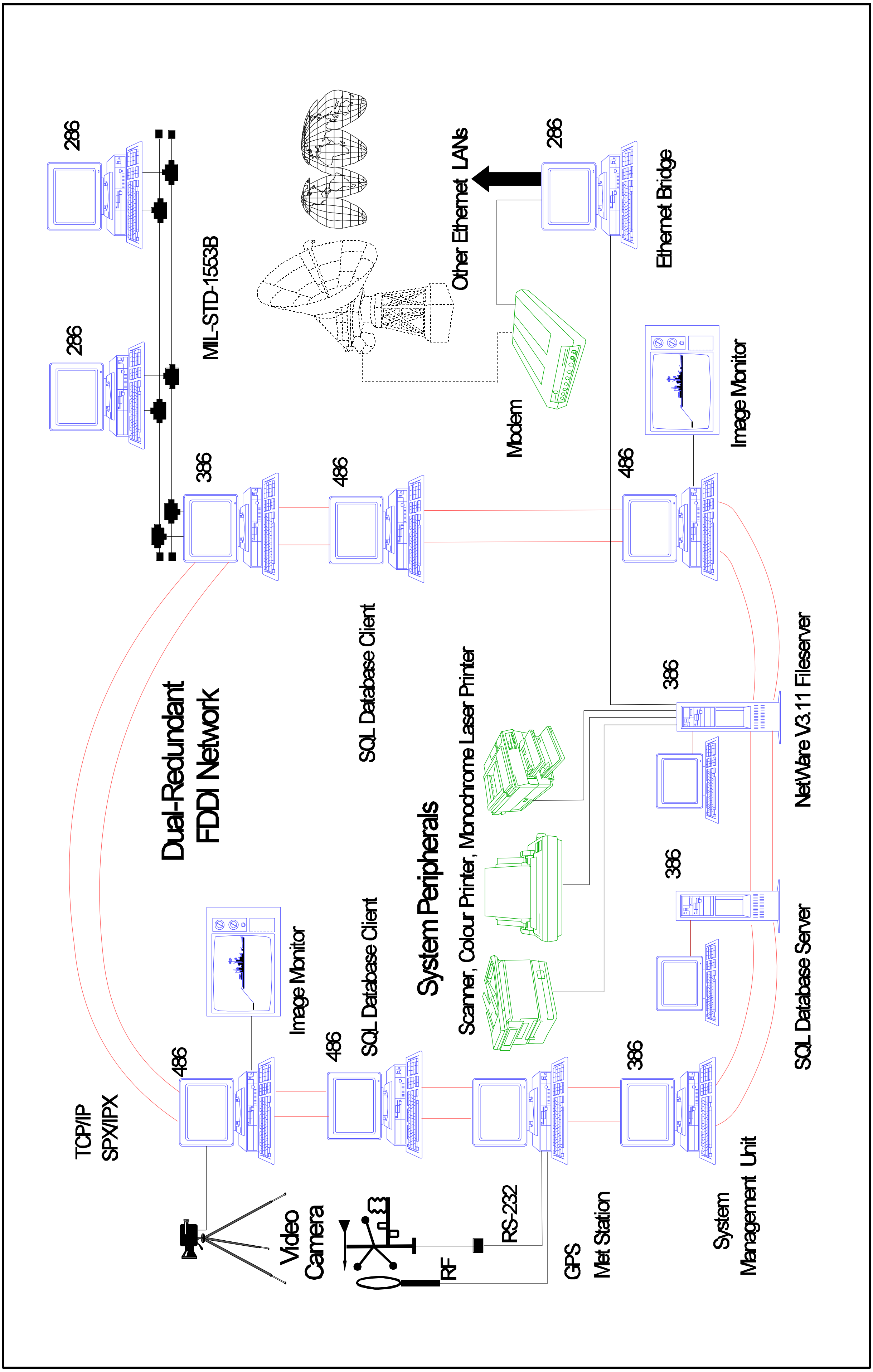

Figure A1 : ICS ACDM Topology