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Handbook of System Data Communications

RATIONALE

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FOREWORD

This document has been prepared by the Society of Automotive Engineers (SAE) AS-2A Sub Committee, which is part of the AS-2 Committee of the Avionic Systems Division (ASD). Since this is a "living" document, the officers of the Committee to which correspondence may be addressed are:

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1. SCOPE:

This Aerospace Information Report (AIR) has been prepared by the Systems Applications and Requirements Subcommittee of SAE Committee AS-2. It is intended to provide guidance primarily, but not exclusively, for specifiers and designers of data communication systems for real time military avionics applications within a platform. The subject of high speed data transmission is addressed from two standpoints: (1) the influence of developments in technology on avionics architectures as a whole and (2) the way in which specific problems, such as video, voice, closed loop control, and security may be handled. While the material has been prepared against a background of experience within SAE AS-2 relating to the development of a family of high speed interconnect standards, reference to specific standards and interconnect systems is minimized. It should be noted, however, that many of the concepts described require interconnect systems with advanced operational and performance characteristics, such as those developed by SAE AS-2.

2. INTRODUCTION:

The data communications requirements of future systems, coupled with the capability of emergent data communication technology, have increased significantly the importance of data communications and its influence on overall system performance. This influence extends to the avionics system architecture, where high performance data communication technology offers the opportunity for radical departures from traditional concepts, leading to increased system performance, increased mission effectiveness, and reduced life-cycle cost.

Within the AS-2 Committee of SAE, standards have been developed for high speed data buses and a message orientated backplane. Work continues on a variety of data communications and system related topics. The high speed data bus development is of considerable importance since it is seen as the cornerstone of future avionics systems. Significant effort has been devoted to the real time data transfer requirement in future systems, which is a recurrent theme throughout this document.

Real time data communication systems are characterized by the presence of messages for which there is a requirement to guarantee their delivery within a specific time. Such a requirement arises in one of two ways: (1) either as a consequence of operational requirements, as in the case of control systems, or (2) as a result of the nature of the data itself, as in the case of sources of periodic data. The influence of both of these aspects and the factors that need to be considered for various data sources are included in this document.

3. SYSTEM ISSUES:

A data communication system is a shared communication medium and, as such, it should not be considered a direct substitution for dedicated point-to-point links in a system design. For example, a data communication system utilizing dedicated point-to-point links may be predicated on word-by-word handshakes. Such handshakes would be very difficult, if not impossible, on a shared medium. Analysis of these data communication system designs usually determines that such handshakes are not necessary, but were used to simplify the interface. On a shared medium, handshakes can be provided, but only on a message basis. Therefore, a data communication system utilizing a shared medium should be designed with that shared medium in mind and the system concepts must be changed to accommodate the shared medium.

Developments in data processing technology, allied with the operational requirements of future generations of military aircraft, give rise to the need for high-performance data communication systems. Performance parameters, such as message latency and throughput, are significant factors here, but fault tolerance, flexibility, and logical interfaces to support vendor independence are also required. New approaches are under discussion toward sparing policies and the probable requirement for federated or distributed systems in which process-to-process communication is a key element. Advances in semiconductor technology also have an impact; whereas, in the past, functions have been self-contained, it is likely that more than one function will be contained within a cabinet. As a result, a new approach is required to data communications in the form of:

- Overall architecture
- Low latency, high throughput systems with fault tolerance.

The application of the ISO OSI model is also an issue due to the military's desire for interoperability. However, the OSI model is precisely that - a model. Slavish adherence to the model, rather than using it as a guide, is detrimental in real time systems.

The use of a shared medium also requires the consideration of mixing classified and unclassified (Red and Black) data. It is not desirable to have separate buses for each because of the cost and weight penalties, but such data sharing requires careful consideration in overall system design.

3.1 System Concepts:

In these paragraphs the importance of the data communication system in the total integration of all the subsystems is presented. The need for data communication requirements, such as distributed access control, message priorities, message labels, and data driven operation, are also explained.

- 3.1.1 Introduction: One of the parameters affecting the choice of data communication system is the type of data that is being passed. Data communication systems are concerned with real time and resource sharing. For real time systems, the transfer of data from one subsystem to another must be carried out within a defined latency, and the latency must be deterministic. For these reasons, the point-to-point link has been used widely in the past for real time systems since the data may be transmitted as soon as it is produced.

3.1.1 (Continued):

In resource sharing systems, the requirement is for many subsystems to access common resources that are to be used. The latency in passing data between the subsystem and the resource is less stringent and data buses provide an excellent way of connecting everything together. The extra cost of the bus interface is offset by the simple interfacing of many types of equipment from different vendors.

Within the military systems arena, there has lately been a move to incorporate the data bus advantages, while still maintaining the attributes of point-to-point links enabling real time systems to be implemented. This move has been spearheaded by the use of the MIL-STD-1553B bus to connect subsystems together. This bus uses a centralized controller to schedule the passing of data between the subsystems allowing the integration of the subsystems into a single system to be carried out more easily.

The trend of the military systems integration is now being carried further to implement a real time system using a high speed data bus that has a distributed access control. To achieve this end, a radical approach to the design of system architecture is indicated.

- 3.1.2 Data Communication Architecture: A typical present-day data communication architecture is shown in Fig. 1. Processing functions are self-contained and are housed in individual cabinets connected via a 1553B bus. This configuration provides adequate redundancy and lends itself to a sparing policy in which each cabinet supports a dedicated function, and functions are completely replicated. It may be the case, however, that the capacity of the 1553B bus is inadequate, particularly where cooperation between functions is required or where rapid recovery from failure is needed; the 1553B bus is unlikely to be adequate for substantial data base transfers. For reasons of space and thermal considerations, and bearing in mind the increasing levels of integration in semiconductor technology, it would seem logical to progress to the configuration shown in Fig. 2, where discrete functions are contained on a card, and functions communicate over a backplane bus (such as a PI bus). This approach would seem to support a dynamic sparing policy in which uncommitted spares are provided in support of a number of functions; but it suffers, however, from two major weaknesses. First, backplane buses are vulnerable to fault propagation; a single fault on a backplane or its interface can lead to failure of the complete cabinet, including the spares which are intended to provide fault tolerance. While the backplane bus can be replicated, this results in a considerable increase in complexity and, due to the active nature of the connections to the bus, is unlikely to provide the level of integrity required. The second major weakness of the message orientated backplane bus is the set-up time for transfers which places severe restrictions on the latency and throughput characteristics. Moreover, the length of backplanes is limited, and communication outside an enclosure would require a store-and-forward gateway for which message latency is considerable. For these reasons it is considered that message orientated backplanes are of little use in future avionic systems except in certain particular circumstances, such as fully federated systems in which a complete set of processes must always be operational to carry out the function of the subsystem.

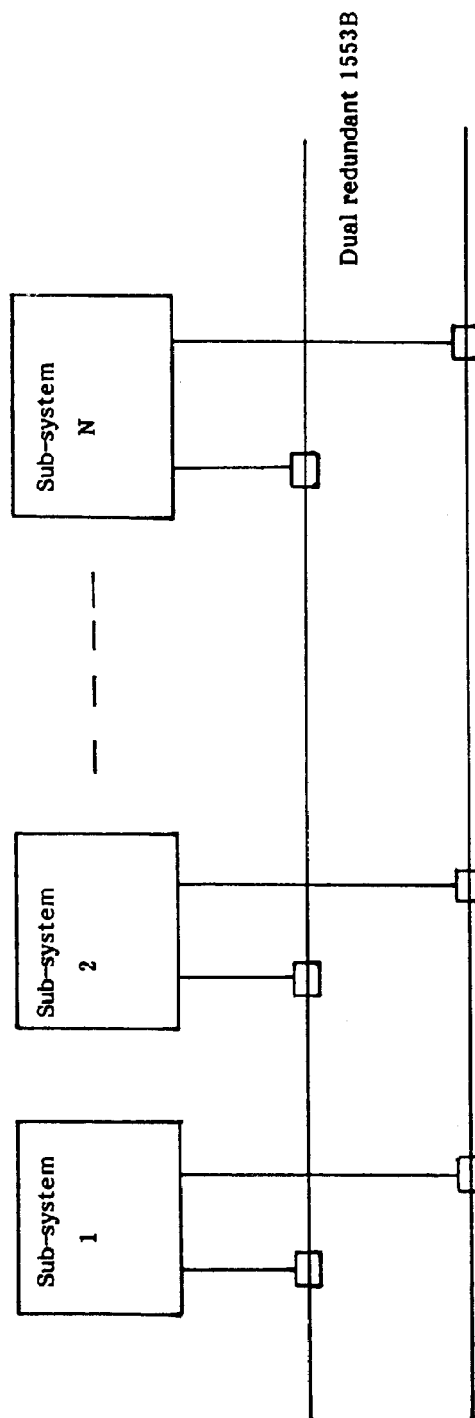


FIGURE 1 - Typical Present-Day Configuration

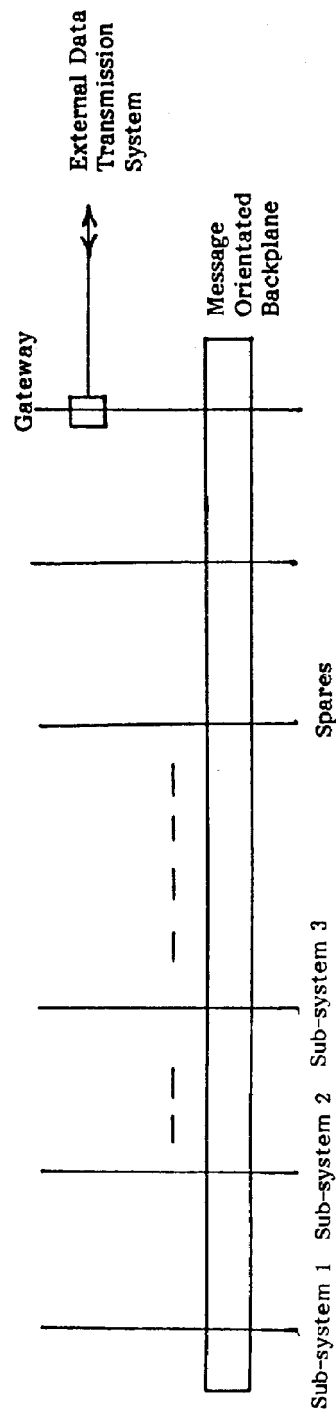


FIGURE 2 - Use of Message Orientated Backplane

3.1.2 (Continued):

Requirements are anticipated in which sensor data will be processed in two stages. In the first stage, data from each sensor would be processed separately, and in the second stage, processed data from a number of sensors would be combined for further processing. In such a configuration it is necessary that data be available at the first stage, both for operational reasons and for reconfiguration in the event of second stage processor failure. Two examples of the need for second stage processing, but not at the expense of reduced availability of the prime processing functions, are multispectral signal analysis and the use of AI processing; while it is important that messages between the two stages of processing should not be subject to significant delay, it is also important they not be directly in-line.

An approach in which process-to-process communication can be carried out both internally and externally to a cabinet, is shown in Fig. 3. Here, a high speed data communication system is used throughout, avoiding gateways, or bridges in any interface for which low message latency is required. In this case, the probability of fault propagation can be minimized, fault tolerance can be provided and a serial data communication system can be used to minimize complexity, size, weight, and power consumption. In this configuration, a function sparing policy or an uncommitted-sparing policy can be implemented, with spares either inside or outside the cabinet containing the primary function. It should be noted that the data communication system is integrated into the system architecture at a higher level than has been the case hitherto.

The approach shown in Fig. 3 is seen as part of an overall data flow architecture, Fig. 4 allows committed processor, uncommitted processors, and spares to be connected via a high speed bus both for normal interprocess communications and for reconfiguration. Data sources are connected to processors via a signal processing data communication system.

3.1.3 The High Speed Data Communications System: The key element in the architecture shown in Fig. 3 is the high speed data communication system, the requirements for which include:

- Deterministic protocols
- Low message latency
- High data throughput
- Fault tolerant and reconfiguration properties
- Low probability of fault propagation
- Ability to operate over long or short distances

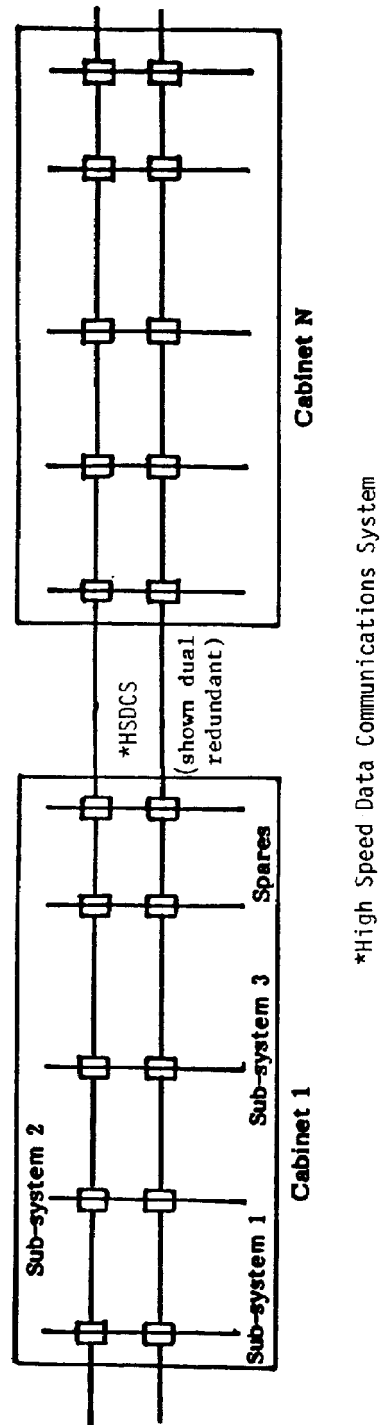


FIGURE 3 - Homogeneous Approach to Data Transmission

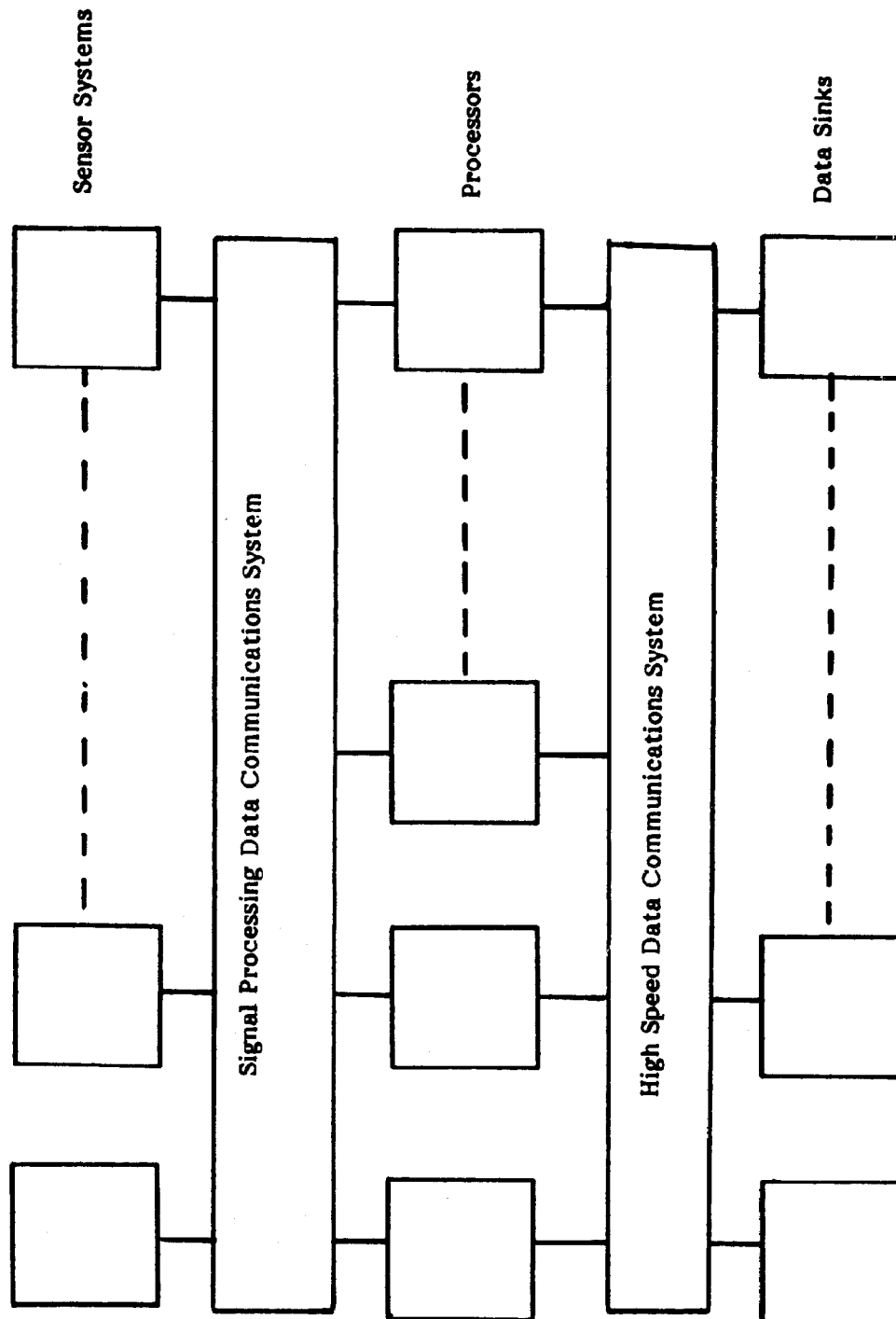


FIGURE 4 - Data Flow Architecture

3.1.3 (Continued):

The high speed data bus (HSDB), a high speed data communication system, will support a data driven system to connect processes. In general, data will be transmitted onto the bus when it is produced and will be received by those subsystems requiring the data. The transmission will not depend on the subsystem requiring the data commanding the relevant subsystem to transmit the data (as is done in MIL-STD-1553B). In real time systems, this will create synchronization problems not readily solved unless the HSDB has been designed and is used properly. To enable the HSDB to be operated in this manner it is required to have the following capabilities:

- Distributed access control
- Message priority
- Message labels

In a military environment, the use of a central element to allow access to the bus is undesirable in terms of integrity since it leaves a single point failure, even though this element might be duplicated. The use of central elements to control bus access also leads to protocols that are significantly less efficient than those using a distributed access control.

The use of distributed access control can lead to lower latency for the data transfer since the data is transmitted at the first opportunity after it has been produced. Using centralized access control, the data will be transferred either at the time prescribed in the central controller's routine, which may bear no resemblance to a processor computing cycle, or the heavy overhead of polling must be carried out by the central controller to extract the data as quickly as possible after production. However, it is more important that the access latency is deterministic than that it is as small as possible. On lightly loaded contention buses, the access latency is as low as a point-to-point link (immediate). As the bus loading increases though, the access latency increases in an undeterministic manner due to the contention of the bus, thus making contention buses unsuitable. With the use of a data driven communications system with a distributed access control, care must be taken that the bus is not swamped by data of low importance to the exclusion of higher importance data. For this reason, a portion of the distributed access control will be concerned with enabling higher priority data to be transferred across the bus before that of lower priority.

An important aspect of the priority scheme is that it is deterministic. This allows the system designer to specify the maximum latency for a particular priority level determined from the operation of the priority scheme, the number and length of messages at higher and the same priority level and the maximum delay before the priority scheme may operate (e.g., maximum length message). Data transfers can then be categorized by the required latency to the relevant priority level. With a deterministic priority and access scheme, the real time system can be integrated using a multiplexed data bus.

The normal way to transfer data in a resource sharing network is for the transmitting station to address the data to the intended receiver station. The receiver station recognizes its unique address and copies the data. For a data driven system the data is broadcast to all the stations with a label (or logical address) indicating the data contained in the message. Each station checks the message label against the list of required message labels and copies the data, if required. The copying of data related to a message label may be carried out by one, many or all stations.

3.1.3 (Continued):

One of the advantages of message labels is that the reconfiguration process only effects those portions of the data communication system that are reconfigured. A station that has not taken part in the reconfiguration will still transmit the data using the same label, unaware that the data is now going to a different station. When a station host undertakes a new function, the station is informed of the new set of message labels from which it is to copy data.

The use of unique station addresses (called the station physical address) is still required for the management of the data communication system. The physical address is often used to indicate from where the message came.

Standards for data communication systems to meet these requirements have been developed by the AS-2 committee of SAE.

3.2 System Design:

When designing an integrated data communication system, it is important to reflect the use of the multiplex medium rather than constraining it with concepts from the use of point-to-point links which the multiplex medium replaces. The following information is intended as a checklist of topics to be considered during the data communication system design and an explanation of the subjects and the environment in which the SAE HSDB standards evolved.

3.2.1 Media Sharing: The shared medium, or HSDB, reduces the cabling required and presents a single interface to the subsystem to communicate to all the other subsystems. This requires a more complex interface to allow the subsystems to share the medium and results in a required data rate that is the sum of all the data rates required by the point-to-point links and the overhead in sharing the bus (protocol, bus quiet, etc.). The shared medium also allows data to be sent to all or some of the subsystems at the same time (broadcast or multicast) rather than requiring it to be sent to each subsystem individually. With all the data being presented on the same media, monitoring of data being passed between subsystems is easier.

3.2.1.1 Transfer Type: Within a system, it may be necessary to send periodic and aperiodic messages. The periodic messages will, in general, impose requirements on the message delay (how long it takes the message to travel from sender to receiver) and on message jitter (how far in time from the ideal reception point can a message move, both before and after the ideal reception point, due to different messages experiencing varying amounts of delay). The aperiodic type of message will impose requirements on the maximum amount of delay that can be experienced by that message. In exceptional circumstances, an aperiodic message may also impose requirements on the minimum amount of delay that can be experienced by the message.

The requirements for both types of message must be carefully calculated and, in a data communication system with both types of transfer, the most stringent requirements reflected in the system design. Having used the requirements imposed by both possible types to calculate the required system performance, the existence of the different types of message is then transparent to the communication system.

- 3.2.1.2 Message Latency: The latency experienced by a message is governed almost entirely by the queuing that it has to experience on its way from sender to receiver (the message will experience a certain amount of simple transfer delay but this is likely to be small compared to the queuing time).

The queuing to be considered can be encountered in a wide number of areas. The HSDB itself, due to its multiplexed nature, will create queues of messages awaiting service. The communication software servicing the HSDB will probably be a multiplexed resource again creating queues. Higher layers of software within the communication path will also create queues. In most systems, some, if not all, of the communications software will reside on the same processor as the application software. This will mean that the communication software itself will be required to queue before it can even be run.

Due to the fact that the above queues are unlikely to be matched, buffers will have to be provided between the queues. The implementation of these buffers could also cause an additional delay to the transit time experienced by the messages. Should any of the buffers become full, further queuing will be caused due to waiting for available buffer space.

All of these above factors will have to be taken into account during the calculation of the latency that will be experienced by any particular message.

- 3.2.1.3 Jitter: Consideration of the discussion in 3.2.1.2 will reveal that the delay experienced by any particular message can be quite different from that experienced by a similar message occurring at a different time.

As pointed out in 3.2.1.1, in the case of periodic messages there will be requirements on the maximum amount of acceptable jitter. For instance, for a (regular) track update, if the jitter experienced is kept to acceptable limits, it should be possible to simply send the updates (for instance, to a smoothing filter). If the amount of jitter is not controlled, it may be necessary to "time-tag" each update to prevent the filter from decoupling. Whereas the use of time-tagging may occasionally be necessary, careful control of allowable jitter may remove the need for such an action in many cases.

- 3.2.1.4 Priorities: The use of a priority scheme, both on the HSDB itself and within the communication software, can help considerably to ease both the message latency and the jitter problem. Without some sort of priority scheme all queued messages, whether queuing for the HSDB or queuing for service from the communication software, will inevitably be treated as equals. However, within the system different messages will require different maximum values of message latency and will have different requirements with regard to jitter. The use of priorities allows messages that are required to experience smaller latency to be provided with a better service by virtue of being able to precede other messages that do not require the same level of service. In the same way, the use of priorities can be used to minimize the amount of jitter experienced by some messages.

- 3.2.1.5 **Determinism:** The higher the level of determinism in the system, the easier it is to provide the level of service (message latency and low jitter) to those messages that require it.

If the system is highly deterministic, the calculation of a parameter, such as the maximum delay to be experienced by a message, is possible. If the system is not deterministic, the calculation will depend on the use of statistics and probabilities. Many of the requirements in a real time system are not of a statistical or probabilistic nature. Many of the requirements are of a fixed and absolute nature. For example, a missile defense system does not want to stop incoming missiles (by, for instance, firing chaff in time) most of the time, but all of the time.

In a nondeterministic system, the requirements on individual elements of the system are likely to be much more stringent than they would have been in a deterministic system, simply in order to ensure that the probability of an event happening or not happening is kept within reasonable limits.

- 3.2.1.6 **Message Length:** On many HSDBs, and in a great deal of communication software, longer message lengths are more efficient. This is, obviously, because the amount of overhead involved with handling a message is somewhat constant, therefore the overhead per word is less for longer messages.

Longer message lengths affect the latency (and jitter) experienced by other messages. In general, if a high priority message must wait for the processing of a previous message in transit, then it will have to wait longer if the message in transit is longer. Careful attention therefore, must be paid to the maximum allowable length of messages in any particular system with a careful trade being made between efficiency and allowable message delay.

- 3.2.2 **Message Labels:** The use of message labels is under consideration by a task group of the AS-2A subcommittee.

- 3.2.3 **Communications Management:** Communications management provides a mechanism to maintain the performance, configuration, and fault tolerance of the HSDB. Management is necessary to meet the high availability demands imposed by tactical platforms. The management functionality, similar to the communications functionality, is distributed throughout the data communications system. This compels each station to cooperate in order to ensure integrity.

The management entities interact with the communications protocol entities to monitor and control the network. Most management operations are initiated by the management entities and directed toward the protocol entities. There are two distinct types of management support: station management and network management.

Station management provides those functions required to maintain the operation of individual network stations. These functions are limited to a single station in the network. Network management functions extend beyond a single station, and involve the operation of the entire network. Network management entities interact with station management entities to perform various management operations.