Intelligent Maritime Navigation with the Automatic Identification System

Abstract

Speaking on the Canadian Intelligent Transportation Systems (ITS) Deployment and Integration Plan, on May 18, 2004, the Federal Transportation Minister Mr. Tony Valeri said, "The Government of Canada is committed to promoting the adoption of new and innovative technologies to make Canada's multimodal transportation system safer, integrated and more sustainable. In fact, in the 2004 federal budget, companies are being encouraged to adopt new technologies which will increase productivity and create more jobs."[1]

ITS plays an important role in the Government of Canada's Innovation Strategy, the goal of which is to nurture innovation every step of the way - from pure research, to applied science, to product development and deployment.

One of the manifestations of Intelligent Transportation Systems in the sphere of maritime transportation is the currently ongoing introduction of the Automatic Identification System (AIS). It is a technology that enables the tracking of vessels by shore-based stations and other vessels. The AIS is expected to have widespread use in the maritime transportation industry due to the approval of the AIS standard and the adoption of carriage requirements by the International Maritime Organization (IMO).

[1] Transport Canada News Release No. H035/04 – May 18, 2004
http://www.tc.gc.ca/mediaroom/releases/nat/2004/04-h035e.htm

Spurred on by the imperative need for a foolproof maritime security environment following the tragic World Trade Centre terrorist attacks of September 11, 2001, in New York City, Canada and the United States have been in the forefront of constructing the infrastructure and implementing the Marine AIS. The St. Lawrence Seaway Management Corporation took a giant leap forward in the enhancement of navigation safety, efficiency and maritime security by implementing the Automatic Identification System and integrating it with the Seaway's Traffic Management System (TMS), at the opening of the 2003 navigation season, on March 31, 2003.

As an Intelligent Navigation Aid, the AIS will have a far-reaching impact on safety and security at sea. It will be required on most ocean-going commercial ships, and will also be integrated into shore based surveillance and vessel traffic control systems.

This paper examines the role of the Automatic Identification System as an Intelligent Marine Navigation Aid of the future and concludes that its use will become indispensable:

a) **As an Intelligent Electronic Navigation Aid**
b) **As an Intelligent Vessel Traffic Monitoring Tool in Ports, for Vessel and Port Safety and Security, and**
c) **As an Intelligent Means of Controlling and Managing Vessel Traffic for Efficient and Cost-Effective Traffic Flow and Commercial Port and Vessel Operations.**

Introduction

The use of Intelligent Transportation Systems in the road, rail and air transportation sectors has been well publicized, both for personal travel and for mass transit. These systems have been gradually developed, tested, introduced and marketed over a period of time, giving the service providers and the travelling public extensive opportunities to adjust to and become familiar with the systems, at their own pace. However, in the marine sector, the use of such systems are less well known, perhaps because historically these

systems have been rapidly introduced (usually adapted from existing technology to suit the desired requirement) often following a significant event or catastrophe, causing a public and media furor and hence necessitating swift action mandated by governments or by international conventions rather than by the proven principles of feasibility, availability and sustainability.

The disastrous events of September 11, 2001, and the impervious security environment evolving as a consequence, spearheaded the rapid introduction of the Automatic Identification System as an Intelligent Navigation Aid in the marine sector worldwide, stimulated by intense political pressure from the United States of America.

The December 2002 International Conference on Maritime Security hosted by the International Maritime Organization (IMO) in London, U. K., adopted a number of revisions to the Safety of Life at Sea (SOLAS) Convention, particularly on the implementation date for Automatic Identification Systems (AIS). The Conference moved the deadline forward for fitting of the AIS on ships engaged in international voyages. All such ships over 300 gross tons had to install an AIS by December 31, 2004. The deadlines for these ships had previously been as late as July 1, 2007. The deadline for ships not engaged in international voyages remained July 1, 2008, but the national authorities in several countries (including Canada) voluntarily moved this date forward for their domestic fleets.

The IMO SOLAS Convention Revision of December 2002 states that an approved shipboard AIS system shall be able to perform the following functions:

- Automatically provide information on the ship's identity, type, position, course, speed, navigation status and other safety-related matters to appropriately equipped shore stations, other ships and aircraft.
- Receive automatically such information from similarly fitted ships.
- Monitor and track ships.

● Exchange data with shore-based facilities.[2]

The Automatic Identification System (AIS) is an intelligent shipboard broadcasting transponder system in which ships continually transmit their identity, position, course, speed and other data to all other nearby ships and shore based authorities, on a common Very High Frequency (VHF) radio channel. The concept is derived from the pioneering work of a Swedish inventor named Håkan Lans, who in the mid 1980's, developed an ingenious technique for spontaneous and automatic communication, which permits a large number of transmitters to send data bursts over a single narrowband radio channel by synchronizing their data transmissions to a very precise timing standard.[3]

The AIS is designed to perform the following functions:
● A collision avoidance device for safe navigation
● A means for coastal states to obtain information about a ship and its cargo
● A traffic management tool when integrated with a Vessel Traffic System (VTS)

The end result is a tightly integrated, intelligent navigation and traffic monitoring aid that enhances the safety of ships at sea, especially near heavily congested harbours and inland waters, assists the ship's staff to navigate with a high degree of accuracy and reliability, enables the vessel's movements to be tracked for security purposes and allows the shore based authorities to control and manage the movements of vessels for efficient and cost-effective commercial operations.

[2] IMO (SOLAS Convention) Resolution MSC 74 (69), Annex 3, Chapter 6: AIS Shipboard Equipment
[3] The Complete Guide to Automatic Identification Systems by Leica Geosystems Inc. – Chapter 1: What is AIS?

Description of the Automatic Identification System

Picture an intelligent shipboard radar display, with overlaid electronic chart data, that includes a 'mark' for every significant ship within radio range, each with a velocity vector (indicating speed and heading). Each ship 'mark' reflects the actual size of the ship, with position to Global Positioning System (GPS) or Differential GPS accuracy. By 'clicking' on a ship 'mark', the navigator can learn the other ship's name, call sign, position coordinates, course, speed, classification, registration number, navigation status, and other information transmitted by the AIS of that ship.

Manoeuvering information, Closest Point of Approach (CPA), Time to Closest Point of Approach (TCPA) and other navigation data, more accurate and more timely than information available from an Automatic Radar Plotting Aid (ARPA), are also obtainable. Display information previously accessible only by modern, intelligent Vessel Traffic System (VTS) operation centres is now available to every AIS-equipped ship.[4]

The AIS can operate in three transceiver modes:
1) Autonomous Mode: The autonomously operating AIS transponder determines its own schedule for transmission of its position.
2) Assigned Mode: The AIS transponder operating in the Assigned Mode uses a transmission schedule assigned by a competent authority's base or repeater station, and
3) Polled Mode: The AIS transponder operating in the Polled Mode automatically responds to interrogation messages from a ship or a competent authority. Operation in the Polled Mode does not conflict

[4] The U. S. Coast Guard Navigation Centre Web Site – AIS Overview: What is the Automatic Identification System (AIS)?
http://www.navcen.uscg.gov/enav/ais/default.htm

with operation in the other two modes. The response is transmitted on the channel on which the interrogation message is received.[5]

With this intelligent, autonomous and reliable information, the navigator can call any ship in the vicinity over the VHF radiotelephone by name, rather than by an imprecise identifier (eg. "ship off my port bow"). The navigator can also talk to the vessel directly using the Global Maritime Distress and Safety System (GMDSS) equipment or send and receive short, safety-related e-mailed messages.

The AIS is an intelligent shipboard broadcasting system with a transponder, operating in the VHF maritime band, which is capable of handling about 4,500 data reports per minute and updates as often as every two seconds. It uses Self-Organizing Time Division Multiple Access (SOTDMA) technology to meet this high broadcast rate and to ensure reliable ship-to-ship operation.

The current AIS data transmissions utilize a robust 9.6 kbps FM/GMSK (Frequency Modulated/Gaussian Minimum Shift Keying) modulation technique. The International Telecommunications Union (ITU) has designated two dedicated frequencies for the AIS. They are: 161.975 MHz (marine band channel 87B) and 162.025 MHz (marine band channel 88B). In some parts of the world, such as the United States, where these frequencies may not be available for AIS, other channels are designated.

The ship's AIS station has two independent VHF receivers, which are normally tuned to the two AIS frequencies, as well as one transmitter, which alternates its transmissions between the two receivers. The intelligent shipboard system can also be tuned to other frequencies, for instance when operating under the control of a shore-based VTS.

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[5] EuroCom Industries (ECI) Booklet: The Automatic Identification System (AIS): Technical Background

This can be done either manually or remotely by the AIS shore station.

The AIS data must be updated and retransmitted every few seconds at a minimum, since the usefulness of the data decays rapidly as a function of time. To accommodate this high updating requirement, the AIS utilizes the unique SOTDMA data communications protocol, which uses the precise timing data in the GPS or DGPS signals to synchronize multiple data transmissions from many users on a single narrowband channel.

The key to the intelligent SOTDMA protocol is the availability of a highly accurate standard time reference, to which all of the stations can synchronize their timeslot assignments, in order to avoid overlap. This time reference is supplied by the precise timing signal in the GPS satellite transmission. Thus, GPS (or DGPS) plays a critical role in the functioning of the AIS, providing the universal time reference as well as positioning data for each ship.[6]

Each ship broadcasts its AIS data and receives the AIS data from all ships within its VHF radio range. The area in which AIS transmissions can be received is called the ship's 'cell'. Each ship is, in this way, in the centre of its own AIS communications cell. The practical size of the cell can be varied according to the real traffic density on the AIS channel. In situations of high traffic density it becomes necessary to reduce the number of ships in a communications cell. If the number of AIS messages begins to overload the network, the ship's AIS can automatically shrink its cell by ignoring weaker stations further away in favour of those nearby. This enables timeslots used by weak stations far away, to be used also by stations nearby.

The AIS protocol applies very specific rules on how this redistribution of timeslots is carried out in practice. The required ship

[6] The Complete Guide to Automatic Identification Systems by Leica Geosystems Inc. – Chapter 2: AIS Communications Scheme

reporting capacity according to the IMO performance standard amounts to a minimum of 2,000 time slots per minute, though the system provides 4,500 time slots per minute (on two VHF channels). The SOTDMA intelligent broadcasting protocol allows the system to be overloaded by 400% to 500% through sharing of timeslots, and still provide nearly 100% coverage for ships closer than 8 to 10 nautical miles to each other, in a ship-to-ship mode.

In the event of system overload, only targets further away will be subject to drop-out, in order to give preference to nearer targets that are a primary concern to ship operators. In practice, the capacity of the system is nearly unlimited, allowing for a great number of ships to be accommodated at the same time.

Under the SOTDMA protocol, each minute of time is divided into 2,250 timeslots. An AIS data report fits into one or several of these 2,250 timeslots, which are selected automatically, based on data linked traffic and projections of future actions by other stations currently on the network. When a ship first enters the ‘cell’ of another ship, it takes an unoccupied timeslot. Each station determines its own transmission schedule (slot), based upon data linked traffic history and projections of future actions by other stations. AIS stations continuously synchronize themselves to each other, to avoid overlap of slot transmissions. Slot selection by an AIS station is randomized within a defined interval, and tagged with a random timeout of between 0 and 8 frames. When a station changes its slot assignment, it pre-announces both the new location and the timeout for that location. In this way, new stations, including those stations which suddenly come within radio range close to other vessels, will always be received by those vessels. Each station continually updates its internal ‘slot map’ to reflect changes in occupied slots and timeouts. Special provisions are made in the artificial intelligence for automatic conflict resolution in the event two stations end up in the same timeslot, to ensure that stations always choose unoccupied timeslots.

The system coverage range is similar to other VHF applications, essentially depending on the height of the antenna. Its propagation is slightly better than that of the radar, due to the longer wavelength. It is therefore possible to 'see' around bends and behind islands if the land masses are not too high. A typical value to be expected at sea is nominally 20 nautical miles. With the help of repeater stations, the coverage for both ship and VTS stations can be improved considerably.

The AIS is backwards compatible with Digital Selective Calling (DSC) systems, allowing shore-based Global Maritime Distress and Safety Systems (GMDSS) to inexpensively establish AIS operating channels and identify and track AIS equipped vessels. It is intended to fully replace existing DSC based transponder systems.

Additional safety-related data can also be keyed-in for transmission and reception by the AIS at the VTS stations and on board the ships. Thus data such as number of persons on board, Estimated Time of Arrival (ETA), meteorological and hydrographic information and weather forecasts, indication of dangerous cargoes and status of navigation channel congestion can be transmitted and received by the AIS units on board the ships as well as ashore at the VTS centres.

Tests are now being conducted to expand the range capabilities of the AIS beyond the limitations of the VHF coverage area by incorporating it within the compatibility criteria of Satellite Communication (International Maritime Satellite - INMARSAT) and of Medium Frequency/High Frequency Radio. The realization of this goal will dramatically raise the range coverage area afforded by the AIS. In the United States alone the area of benefit is estimated to be over 12,000 miles of coastline and another 25,000 miles of internal waters, without constructing a

VTS. This represents a huge increase from the current 900 miles of surveillance provided by VTS's.[7]

Thus the AIS architecture is intelligent, reliable and accurate with adequate built-in redundancy and features for expansion of data transmission and reception capabilities in the future, due to technological progress, regulatory requirements or upgrading of standards.

The AIS: An Intelligent Navigation Aid

The primary operating mode for the AIS is the autonomous ship-to-ship reporting mode. In this mode, each ship transmits its data to all other AIS-equipped ships within VHF range. The unique communications scheme permits the data transmissions to take place independently, without the need for a master control station.

Position and other data are fed automatically from the ship's sensors into the AIS, where the data is formatted and transmitted in a short data burst on a dedicated VHF channel. When received on the other ships, the data is decoded and displayed for the officer of the watch, who can view the AIS reports from all other AIS-equipped ships within VHF range, in graphic and text format. The AIS data may optionally be fed to the ship's integrated navigation systems and radar plotting systems to provide AIS 'tags' for radar targets. The AIS data can also be logged to the ship's Voyage Data Recorder (VDR) for playback and future analysis.

In pilotage waters, a pilot can plug a laptop computer, loaded with the pilot's navigation programme, directly into the ship's AIS system. In this way, the pilot can monitor the position and movement of all other vessels in the area, independent of the ship's installed navigation aids.

[7] "U. S. Coast Guard Plans for Universal AIS" – Presentation by Commander Ken Prime, Chief, VTS Facilities Division

Radio communications and Radio Detecting and Ranging (Radar) have been used on ships for several decades. However, the weak link in this generation of collision-avoidance electronics is the inability to identify any given Radar target when multiple contacts are being tracked, especially at night or in reduced visibility, when it is impossible to verify a ship's identity visually. This inevitably leads to confusion, and has been cited as a contributing factor in many collisions and near-collision incidents at sea.

As an invaluable and modern aid to navigation, vessel safety and vessel control, the AIS provides some unique benefits to the shipping industry.

1) The AIS enhances safety, especially under adverse weather conditions, through real-time ship-to-ship communications of vessel locations, speeds and courses.

2) The AIS reduces transit times (and thus fuel consumption and emissions to the environment) through improved traffic management and enhanced scheduling of transits through locks, waterways, harbours and rivers.

3) The AIS is an asset in fleet management as arrival times can be estimated with a fair degree of accuracy, leading to more efficient scheduling of appointments with pilots, ship inspectors, suppliers, service personnel, terminal operators and others interacting with the ship, and thus minimizing delays and costs.

4) The AIS provides timely and accurate environmental information broadcasted through the AIS channels in certain areas (like the St. Lawrence Seaway System) and thus permits safe navigation and reduction of delays caused by the weather.

As is apparent from the discussion above, the AIS will play a crucial role as an intelligent ship tracking and identification device, by providing current and constantly updated information on other vessels in the vicinity, thus enhancing the safety of navigation using a modern, intelligent navigation aid.

The AIS: An Intelligent Vessel Traffic Monitoring Tool in Ports, for Vessel and Port Safety and Security

In the aftermath of the September 11, 2001 disasters in New York City, there was a genuine fear of ships being used directly by terrorists as Weapons of Mass Destruction (WMD) or ships carrying cargoes or contraband goods that could be used to cause damage and destruction (eg.: in containers).

In coastal waters, the harbour or shore authorities may establish automated AIS stations to monitor the movement of vessels through the area. These intelligent and autonomous stations may simply monitor the AIS transmissions from passing ships, or may actively poll vessels via the AIS channels, requesting data such as identification, destination, Estimated Time of Arrival (ETA), type of cargo and other information. Coast stations can also use the AIS channels for shore-to-ship transmissions, to send information on tides, notices to mariners and local weather forecasts. Multiple AIS coast stations and repeaters may be tied together into Wide Area Networks (WAN) for extended coverage.

Coastal nations may also use the AIS to monitor the movement of hazardous cargoes and to control commercial fishing operations in their territorial waters. The AIS data can be logged automatically for playback in investigating an accident, oil spill or other significant event. The AIS will also be a useful tool in Search And Rescue (SAR) operations, allowing the SAR coordinators to monitor the movements of all surface ships, aircraft and helicopters involved in the rescue effort.

The exchange of AIS data and the ability to poll vessels in advance of their arrival, using the AIS, will indubitably become an imperative means of enhancing the Safety and Security environment of all Coastal Nations.

The AIS: An Intelligent Means of Controlling and Managing Vessel Traffic for Efficient and Cost-Effective Traffic Flow and Commercial Port and Vessel Operations

When integrated with shore-based Vessel Traffic Systems (VTS), the AIS provides a powerful tool for monitoring and controlling the movement of vessels through restricted harbours and waterways. The AIS can augment the traditional radar-based VTS installations, providing an AIS 'overlay' on the radar picture, or can provide a cost-effective alternative in areas where it is not feasible to establish radar-based systems. When integrated with radar, the AIS can ensure continuous coverage, even when the radar picture is degraded by heavy precipitation or other interference.

The AIS channels can be used to transmit port data, pilotage information, berth assignments, shipping agency information, tides and currents, notices to mariners and other information from shore to ship, as well as from ship to ship and from ship to shore. It is also possible for the VTS to broadcast the complete harbour picture to all ships in the area, so that the vessel Captains and Pilots share the same 'big picture'.

The VTS centre can assume control over the assignment of timeslots for AIS messages to ensure optimum data exchange within the coverage area. Special dedicated channels may be designated for local-area AIS operations. The shipboard AIS equipment will have the ability to shift to different channels automatically when directed by the shore based VTS controller.

The St. Lawrence Seaway's Traffic Management System (TMS) broadcasts through AIS channels other pertinent data such as local wind speed and direction, water levels and flow, ice conditions, availability for transit of the next Seaway System Lock, and safety related messages as dictated by circumstances.

The St. Lawrence Seaway Management Corporation has reported the following benefits obtained from using the AIS:
1) Accurate and real-time vessel position information
2) Efficient traffic management with continuous monitoring of vessel location and speed, under all weather conditions.
3) Enhanced scheduling of lock transits and vessel tie-ups.
4) Faster response times in the event of an accident or incident, along with more accurate information concerning hazardous cargoes.
5) The ability to monitor all vessel speeds in real-time and to ensure compliance with the speed limits of the St. Lawrence Seaway.
6) Greater coordination in the scheduling of ship inspections.
7) Enhanced monitoring of vessels for safety and security purposes.

As a vessel control and management tool, the AIS thus has tremendous potential in terms of scheduling, warning, guiding and preparedness. It will be a vital aid for intelligent traffic control and monitoring which will improve commercial operating standards with the consequential cost and time benefits going to ports, shippers of goods, vessel operators and indeed the community at large.

The Current Limitations of the AIS

Like all other radio broadcasting devices, the AIS is sensitive to radio frequency interference. It is also subject to the range limitations of VHF propagation. The AIS relies on Global Navigation Satellite Systems (GNSS) data for position and timing inputs, which are central to its functioning, and, as such, it is subject to the vulnerabilities inherent in satellite navigation systems. Furthermore, vessels not fitted with an AIS would be less 'visible' and could therefore be a danger or a threat to navigation, safety, security and commercial operations.

These limitations will however be overcome in course of time as the AIS technology develops to meet the demands of future commercial shipping.

Conclusion

The AIS can be characterized as a gigantic mirror in the sky. If the sky was a mirror, and it was a very clear day, one could look up and see a reflection of one's surroundings. One could see all other vessels as they move in relation to one's own vessel, providing a single macro-situational picture. Also, all the other users of the system (including other vessels and port and harbour authorities and Vessel Traffic Systems) could likewise look up and see the very same macro-situational picture. The AIS is this and much more. The AIS not only provides a display to all the system users of the physical vessel traffic situation, it also provides key navigational and operational information as per the requirements of the users, and not available through other navigational aids such as the radar. In short, the AIS is an intelligent navigation system that provides each user with an accurate and reliable picture of the common navigational information that all other participants are using.[8]

The potential of the AIS:
a) As an Intelligent Navigation Aid
b) As an Intelligent Vessel Traffic Monitoring Tool in Ports, for Vessel and Port Safety and Security, and
c) As an Intelligent Means of Controlling and Managing Vessel Traffic for Efficient and Cost-Effective Traffic Flow and Commercial Port and Vessel Operations,
have been evaluated and it has been unequivocally established that the benefits of the AIS in all these cardinal areas of maritime commerce are awesome, far-reaching and positive.

In the extensive array of Intelligent Transportation System tools, the Automatic Identification System stands out as a unique and stellar device on the limitless avenue of inexorable international maritime progress and development.

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[8] Automatic Identification System (AIS): Presentation by Jeff McCarthy, Deputy Executive Director and AIS Project Manager, California Department of Fish and Game, Office of Spill Prevention and Response