

Message exchange for flow management in maritime traffic management systems.

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Version 0.0
January 14, 2015

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Prepared by the [Danish Maritime Authority](#) as part of the [MONA LISA 2](#) project.



Co-financed by the European Union
Trans-European Transport Network (TEN-T)

v0.0	14 JAN 2015	Thomas Borg Salling < tbsalling@tbsalling.dk >	Work in progress.
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Abstract

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Chapter 1. Introduction

As part of—and as a contribution to—the MONA LISA 2.0 [\[MONALISA2\]](#) project, the Danish Maritime Authority has worked to define message conversation scenarios and detailed message formats for *flow management* in the context of *sea traffic management (STM)* as defined by [\[ARCH\]](#).

The results contain inputs, contributions, and insights from DMA and project partners.

This paper documents the process and the the results, by

1. defining the domain problem,
2. setting the scope of work,
3. establishing design criteria,
4. proposing message conversation scenarios,
5. defining message formats in different formats,
6. validating message formats against design criteria,
7. introducing a reference implementation for AIS using application specific messages, and by
8. supplying test data to validate correctness.

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1.1. Problem definition

1.1.1. Flow management

As defined by [\[ARCH\]](#) flow management is communication which takes place between ships in a peer-to-peer situation, or between ships and a coordinating organisation (e.g. VTS, STCC) in order to:

1. Increase safety and prevent delays through a good flow in narrow channels with high traffic density.

Support vessel in arriving at final destination in due time as efficient as possible.

3. Provide information to interested parties about planned and predicted time of arrival to final destination or other point of interest.

For item 1 the term "good" means that collisions and dangerous situations are avoided and that vessels can safely follow their announced tactical voyageplan through the area.

Flow *management* is based on knowledge of vessels' tactical voyageplans; i.e. announcements from each vessel regarding their intended manouvers in the immediate short-term future. When this knowledge is known either centrally at a coordinating center or distributed between nearby vessels, it is possible for the coordination centre or the nearby vessels to suggest tactical voyageplans to a vessel with the purpose of obtaining a "good" overall flow. This process is called *flow management*.

If flow management takes place in a self-organizaing manner between vessels on a peer-to-peer basis it is called *autonomous flow management*. When a coordinating center is performing it the process is called *controlled flow management*. In a fully managed scenario—whether autonomous or controlled—all vessels can safely and efficiently follow their tactical voyageplans through their entire passage of the area.

Tactical voyageplan

In order to facilitate flow management vessels in the area must broadcast their tactical voyageplan and optionally basic information concerning their manouvering capabilities.

Flow management suggestion

A suggested change to a tactical voyageplan is called a *flow management suggestion*. A flow management suggestion can be transmitted from either a coordination centre or a peer vessel. It can take one of two principal forms:

1. Geometry-based (adding, deleting or changing waypoints)
2. Speed-based (not changing any waypoints)

Changing the geometry of an tactical voyageplan is a relatively complex operation for the vessel's navigator. Among other things the process involves a safety check of the new route and reprogramming of navigational equipment. The cost/workload of this operation reduces the likelihood of a vessel complying with suggested changes.

Changing the vessel's speed (or waypoint ETA's) is a far simpler operation for the navigator. This involves only adjustment of the vessel's speed and recalculation of the wheel-over-point in advance of each waypoint. It is therefore expected, that the likelihood of a of vessel complying with a suggested change of this type is higher than suggested changes to geometry.

1.1.2. Controlled flow management

Controlled flow management always takes place inside a defined geographical area called the *controlled area*. The controlled area is a closed polygon.

Vessels can be located inside the controlled area — or outside the controlled area.

Vessels outside the controlled area can be in state

- *entering* — meaning that the vessel intends to enter the controlled area.

Vessels inside the controlled area can be in states

- *leaving* — meaning that the vessel intends to leave the controlled area.
- *staying* — meaning that the vessel intends to seek berth, drop anchor, or elsehow keep manouvering inside the area.

Some of the vessels are aware of some of the other vessels' tactical voyageplans, and the coordination centre is aware of some of the vessel's tactical voyageplans.

The coordination centre is continuously receiving an AIS data stream, including type 1-3 position messages and type 5 ship and static voyage messages, so that it can maintain an updated real-time picture of the current traffic situation.

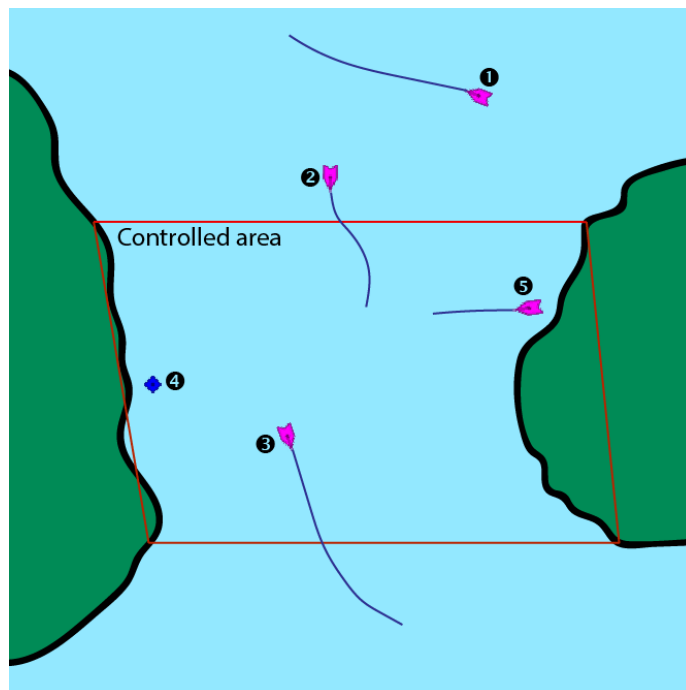


Figure 1. A controlled area and five vessels showing their intended routes. There are vessels outside (1, 2) and vessels inside (3-5) the controlled area. A vessel (2) is entering, a vessel is leaving (3), and two vessels are staying (4, 5).

1.1.3. Autonomous flow management

...

1.2. Scope of work

The scope of the work in this paper is *controlled flow management in a limited area (in order of size as a VTS area) based on flow management suggestions in the speed-based form.*

Chapter 2. Use cases

2.1. Use case: Vessel enters the controlled area

Table 1. Use case.

No.	Event	Action
1	The coordination centre detects, that a vessel has entered the controlled area.	The control centre transmits an addressed message to the vessel requesting it broadcast tactical voyageplans. [This is done even if the coordination centre already has this information in order to distribute this information to other vessels in the area.]
2	The vessel receives the message.	The vessel responds by broadcasting message, which contains its tactical voyageplans.
3	The broadcast is received by the coordination centre (and likely some of the other vessels in the area).	The control centre recalculates optimal speeds per vessel. [with priority to suggest speed changes for V_0 over other vessels, and fewest possible other vessels, and only for vessels intending to leave A.]
	Exception: The broadcast is never received by the coordination centre.	The coordination centre retransmits its message to the vessel.
4	The coordination centre's recalculation of optimal speeds completes.	The coordination centre transmits an addressed messages with flow management suggestion s to those vessels which (according to the calculation) require changes.
5	A vessel receives its flow management suggestion from the coordination centre.	The navigator is alerted.
	Exception: The flow management suggestion is never received by the vessel.	<i>May lead to special case: Coordination centre discovers new suggestions needed.</i>
6	Navigator of approves flow management suggestion .	The vessel broadcasts a message containing its new tactical voyageplan.

2.2. Use case: Coordination centre determintes new flow management suggestion s needed

Table 2. Use case.

No.	Event	Action
1	The coordination centre detects that the current flow is not optimal ("good")	The control centre recalculates optimal speeds per vessel.
2	The coordination centre's recalculation of optimal speeds completes.	The coordination centre transmits an addressed messages with flow management suggestion s to those vessels which (according to the calculation) require changes.
3	A vessel receives its flow management suggestion from the coordination centre.	The navigator is alerted.
	Exception: The flow management suggestion is never received by the vessel.	<i>May lead to special case: Coordination centre discovers new suggestions needed.</i>
4	Navigator of approves flow management suggestion .	The vessel broadcasts a message containing its new tactical voyageplan.

2.3. Use case: Vessel broadcasts its tactical voyageplan

2.4. Use case: Vessel changes or resends its tactical voyageplan

2.5. Use case: Vessel cancels its tactical voyageplan

2.6. Use case: A tactical voyageplan expires

2.7. Use case: A vessel suggests tactical voyageplan for another vessel

(in a controlled flow management scenario)

2.8. Use case: Receivers of a vessel's tactical voyageplan have different versions

(in case of e.g. transmission ok, reception bad).

Chapter 3. Design criteria

Messaging in the maritime domain has been available many years and communication standards have evolved and been added and augmented several times to accommodate the increasing demand for handling more and more complex scenarios in the maritime domain.

When suggesting message exchange for advanced use cases, such as for flow management, we want to take lessons learned from the past years into account. Literature, such as [\[TOILS\]](#), has therefore been studied to establish a set of design criteria for the messages that are defined for flow management.

In section [Validation against design criteria](#) it will be validated, that the suggested messages layouts and payloads are in compliance with these design criteria.

3.1. General design criteria

3.1.1. Design with the end-user in mind

In accordance with [\[ARCH\]](#), §3, all systems shall be designed with the end user (e.g. mariner, ship owner, operator), in mind.

This shall be achieved, by carefully identifying and defining use cases expressed in user domain terms and approved by user domain experts (such as navigators) before the actual design of message conversations and message layouts takes place. And by validating that the detailed message designs support the defined use cases.

3.1.2. Design for multivendor environment

In accordance with [\[ARCH\]](#), §3 p.6, one of the main goals (here interpreted as *design criteria*) of the MONALISA 2.0 project is to "achieve full and seamless interoperability of systems in Sea Traffic Management (STM) [...] in a multi-vendor environment".

This shall be achieved by ensuring that relevant stakeholders in government and industry can contribute to and review the design of conversations and messages in flow management.

3.1.3. Information transfer involving ships must be bandwidth efficient

In accordance with [\[ARCH\]](#), §7 p.23, information transfer involving ships must be highly bandwidth efficient.

This shall be achieved by designing messages to be as compact as possible, avoiding redundant information in message layouts, and using bit-level compression where applicable and possible.

3.1.4. Ship-shore interactions must be robust

In accordance with [\[ARCH\]](#), §7 p.23, ship-shore interactions must be robust to unstable, changing, high latency links.

This shall be achieved by ???

3.1.5. Ship-shore data IP connections must be initiated from ship

In accordance with [\[ARCH\]](#), §7 p.23, ship-shore data connections must be initiated from ship, to address cyber security.

This shall be achieved by designing the required mechanisms of communication, such that ship-to-shore communication is based on IP-based connection-oriented communication (e.g. TCP/IP), then such a connection can only be initiated from the ship-side.

3.2. AIS-specific design criteria

3.2.1. Consider updated definitions of ASM and related guidance, before developing new ASM;

In accordance with [\[IALA144\]](#), recommendation 4, IALA recommends that members make use of the IALA ASM collection [\[AISASM\]](#) by taking into account other updated definitions of ASM and related guidance, before developing new or implementing the use of existing Regional ASM.

This shall be achieved by consulting the ASM collection [\[AISASM\]](#) to ensure that no other existing ASM already fulfills the requirements of any newly designed message before it is submitted for approval.

3.2.2. Contribute to the IALA AIS ASM collection

In accordance with [\[IALA144\]](#), recommendation 6, members are recommended to contribute to the IALA ASM collection through their National IALA Member.

This shall be achieved by ensuring that the final and agreed ASM messages to support flow management are submitted to the IALA ASM collection by the national IALA member, in this case the Danish Maritime Authority.

3.2.3. Low transmission frequency

In accordance with [\[AISG289\]](#), §3.3, the frequency of message transmission should be limited in order to prevent system overload.

This shall be achieved by careful design of the criteria which trigger a message transmission, in order to minimise the number of transmissions to the lowest possible.

3.2.4. Limit no. of VHF transmission slots

In accordance with [\[AISG289\]](#), §3.4, AIS messages occupying more than three (3) slots should be avoided, unless there is a low load on the VDL or a compelling reason to do so.

This shall be achieved by designing messages to avoid occupying more than 3 slots.

3.2.5. Use 6-bit ASCII

As pointed out by [\[TOILS\]](#) the decision to use 6-bit ASCII encoding in AIS messages is a *blunder*. But as it states: "Some major defects, such as the handling of string data, are too deeply embedded to be removed". Thus in the design of new messages, the 6-bit encoding scheme will be maintained to avoid further complexity to [\[AISPEC5\]](#) and related recommendations and guidelines.

This shall be achieved by designing string fields of new messages to use the 6-bit character encoding scheme defined by [\[AISPEC5\]](#) annex 8.

3.2.6. Fixed length messages

By experience and in accordance with [\[TOILS\]](#), "types 1 through 4: Fixed-length felicity", fixed-length messages are simple to parse and can be regarded as one production in the message *grammar*. [\[TOILS\]](#) further states, that "from a reliability-engineering point of view, this [fixed-length messages] is a best case scenario".

This shall be achieved by designing any new messages, so that they have fixed bit-length and fixed field-offsets, unless there are important and documented reasons why this cannot be achieved.

3.2.7. Fixed bit-offset for fields

[TOILS], "Ways forward for AIS", recommends to avoid fields with variable offsets.

This shall be achieved by designing new ASMs to have fixed bit-length for each data field to ensure that each data fields starts at a fixed bit-offset.

3.2.8. Variable fields last

According to [TOILS], "Drawing lessons from the defects", it is a minor defect not to have variable-length fields be the last in the message (such as the variable-length binary payload in message type 26 followed by a radio-status field). Variable-length fieds should first and foremost be avoided. And if, for compelling reasons, they cannot - they should be transmitted last in the message to preserve fixed-offset for as many data fields as possible.

This shall be achieved by designing new ASMs so that any variable-length data fields are at the end of the message.

3.2.9. One dispatch field

[TOILS] states in several places that the no. of protocol extension mechanisms should be minimal and preferably limited to 1. Any *dispatch fields* used to control message variants (such as the message type field), should precede any of the data fields it controls.

This shall be achieved by designing new ASMs so that no new extension mechanisms are introduced, to use a minimal no. of dispatch fields, and take dispatch fields into use in the following order: Message ID, Application Identifier, Message-specific dispatch.

3.2.10. Minimum no. of datatypes

[TOILS] states that good practice is "for there to be just one type per natural kind; e.g. in a geolocation protocol all longitudes should be encoded with the same length, signedness, and special values. Ditto all latitudes, bearings, timestamp fields, etc.". This also holds for the encoding of numeric values [Such as e.g. the "Rate of Turn field in the Common Navigation Block required taking a (sign-preserving) square root and then scaling" - which is different from all other numeric fields.] and the indication of non-existent values in order to avoid complicating exception and variants.

This shall be achieved by designing new ASMs so that they do not introduce any unnecessart new data type or encodings, and so that they (re-)use the most common and widely used type encoding used elsewhere in [AISSPEC5].

3.2.11. Single point of truth

[TOILS] recommends, based on lessons learned from message types 6 and 8, that messages should obey the "single point of truth" principle. This means that there should be no information redundancy inherent in the message, and that one piece of information can only be deduced from a single source in the message.

This shall be achieved by designing new ASMs so that no piece of information is redundant with other information in the same message.

3.2.12. Support stream-based parsers

[TOILS] recommends, based on lessons learned from message type 22, that in order to preserve memory and reduce decoder complexity, stream-based decoders must be supported by the message layouts. I.e. decoders which can decode incoming messages without looking ahead in the bit stream.

This shall be achieved by designing new ASMs so that any dispatch-field, changing the interpretation of the message, is transmitted *before* the data fields whose interpretation it influences.

3.2.13. Don't split data fields across datagrams

As pointed out by [TOILS] some AIS messages, such as type 24, need to be reconstructed from two individually transmitted datagrams. This increases decoder complexity by requiring it to hold state between datagrams - and it adds a new dimension to the set of edge cases and problem scenarios, that must be foreseen. Therefore messages split across multiple datagrams must be avoided and all datagrams must be independent.

This shall be achieved by designing any new ASMs so that their entire state is communicated in a single datagram.

3.2.14. Check design using ASN.1

[TOILS], "Drawing lessons from the implementations", recommends "that application-protocol designers should, as a routine part of their process, render the design as a specification in [ASN.1] or [BDEC]."

This shall be achieved by supplying ASN.1 notation for each new ASM proposed.

3.2.15. Provide a reference implementation

[TOILS], "Drawing lessons from the implementations", recommends to "do a reference implementation before you publish an application protocol as a standard" and "as a best practice, the reference implementation should be open source".

This shall be achieved by developing an open source reference implementation of a decoder for each proposed ASM. This reference implementation must be able to decode all variants of the ASM and should be developed before the protocol is published as a standard.

3.2.16. Provide test data sets for all message variants

[TOILS], "Drawing lessons from the implementations", recommends that "an example binary datagram in each of every possible variation of message shape together with a textual, human-readable decode of that datagram" is supplied to enable test and validation of decoders.

This shall be achieved by supplying example datagrams together with a human-readable decode of that datagram for each message variant.

Chapter 4. Design of flow management message types and conversations

4.1. High-level design

In the high-level design of flow management messages no assumptions are made about the characteristics of the underlying transport layer. Focus here is to identify which pieces of information need to be exchanged, between whom, and when. Following this are detailed specifications mapping this outcome to specific protocols, such as AIS [\[AISSPEC5\]](#).

The messages to support flow management must have following characteristics:

- The message payload should be related to the current tactical execution, the imminent future. I.e. the message should not be designed for planning purposes or announcement of future intentions.
- The message should have carrying capability for as many waypoints as possible.
- The message should optionally support ETA or SOG per waypoint and vessel’s TR.

4.1.1. Message types

Based on the [Use cases](#) it is noted, that the following messages are involved in flow management:

- **tactical voyageplan broadcast.** For a vessel to broadcast its tactical voyageplans.
- **tactical voyageplan inquiry.** An addressed message transmitted by coordination centers and vessels to inquire a vessel about its tactical voyageplan.
- **flow management suggestion.** An addressed message transmitted by coordination centers and vessels to suggest changes to a vessel’s announced tactical voyageplan.

4.1.2. Payloads and transmission triggers

The suggested payloads and transmission triggers of these message types are the following.

Tactical voyageplan broadcast

Table 3. Information payload of message type **tactical voyageplan broadcast**.

Data field	Type	Description
Sender	Required	Sender identification
Activation indicator	Required	Indication of whether the vessel cancels/deactivates its voyageplan or whether it actively follows it.

Data field	Type	Description
Waypoints	Required	Positions of waypoints on the tactical voyageplan.
Active waypoint	Required	Indication of which of the waypoints the vessel is currently navigating towards.
TR	Optional	Ship's turning circle radius in the current area (read more in Definitions).
ETA active waypoint	Required	Estimated time of arrival at active waypoint.
ETA last waypoint	Required	Estimated time of arrival at last waypoint.
ETA other waypoints	Optional	Estimated time of arrival at respective waypoint.

The message must only be transmitted by vessels.

The message is only transmitted if vessel is conned along an active voyageplan. In that case, the following transmission triggers apply:

1. Periodically. [Using AIS: Every six minutes (due to what is stated in [AISSPEC5](#)) (§4.2.1) regarding sending interval for voyage related information]
2. On voyage plan activation.
3. On voyage plan change (change to waypoints or ETA at waypoints).
4. On voyage plan deactivation/cancellation.
5. On change of active waypoint.
6. As reply to message "tactical voyageplan inquiry".

Retransmission is not applicable.

Tactical voyageplan inquiry

*Table 4. Information payload of message type **tactical voyageplan broadcast**.*

Data field	Type	Description
Receiver	Required	Receiver identification
Sender	Required	Sender identification
Controlled area	Optional	Indication of controlled area inside which to routinely broadcast tactical voyageplan.

The message can be transmitted by vessels or shore-based coordination centres.

Retransmission is not applicable.

The following transmission triggers apply:

1. On need by control centre to receive tactical voyageplan from a vessel. In case of e.g.:
 - Vessel's arrival to controlled area.
 - Previously announced tactical voyageplan is invalid (e.g. expired, or vessel's manouvers deviate significantly from it).
 - Loss of data in control center.
2. On need by vessel to receive tactical voyageplan from another vessel.
 - The inquired vessel's intentions are unknown to the inquiring vessel; e.g. in case of
 - Tactical voyageplan was never transmitted by inquired vessel.
 - Tactical voyageplan was never received by inquiring vessel.
 - Information about another vessel's tactical voyageplan was lost onboard the inquiring vessel (e.g. due to system restart or improper operation).

Flow management suggestion

Table 5. Information payload of message type **flow management suggestion**.

Data field	Type	Description
Sender	Required	Sender identification
Waypoints	Required	Positions of waypoints on the tactical voyageplan.
Suggested active waypoint	Required	Indication of which of the waypoints the vessel is currently navigating towards.
Suggested ETA of suggested active waypoint	Required	Suggested time of arrival at active waypoint.
Suggested ETA of suggested last waypoint	Required	Suggested time of arrival at last waypoint.
Suggested ETA of other suggested waypoints	Optional	Suggested time of arrival at respective waypoint.

The message must only be transmitted by shore-based coordination centres. It can only be addressed to vessels following an active tactical voyageplan announced via the tactical voyageplan broadcast message.

Retransmission is not applicable.

The following transmission triggers apply:

1. On need to suggest changes to tactical voyageplan to support flow management. E.g. if a coordination center determines, that better overall flow can be achieved by the receiving vessel:

- changing ETA to announced waypoints.

4.2. Detailed message design

4.2.1. ASN.1

TBD

4.2.2. MSDL

TBD

4.2.3. AIS

Existing ASMs

A search in [\[ASMCOLL\]](#) reveals to candidate ASM's worth considering for the "tactical voyageplan" broadcast:

Title	Msg	DAC	FI	SU	Status	Registrant	Spec
Route information	8	1	27	5	in force	IMO Circ. 289	[ASM_001_27]
Intended route	8	219	1	3	initiation	Danish Maritime Authority	[ASM_219_01]

A search in [\[ASMCOLL\]](#) reveals to candidate ASM's worth considering for the "flow management suggestion":

Title	Msg	DAC	FI	SU	Status	Registrant	Spec
Route suggestion	6	219	2	5	initiation	Danish Maritime Authority	[ASM_219_02]

Review of ASM DAC=001; FI=27 - "Route information"

Review of the application specific message DAC=001; FI=27 defined by [\[ASM_001_27\]](#) in the context of flow management yields the following comments:

1. [\[ASM_001_27\]](#) specifies that "13.1 This message ... should only be used in when important route information ... – not already provided by current official nautical charts or publications – needs to be

relayed by authorities or vessels".

It is unclear whether a tactical voyageplan (in MONALISA terms) is "important route information". Certainly tactical voyageplans are not normally on any charts or publications; but are they "important" in the context of this message type?

2. [\[ASM_001_27\]](#) specifies that *"13.4 In order to allow advance notice, this message should be transmitted prior to the start date and time specified for the routing information. It should not be transmitted more than one day in advance"*.

The statement that the message should not "should not be transmitted more than one day in advance" indicates that this message is for planning purposes, and not related to the imminent tactical situation.

3. In the message layout [\[ASM_001_27\]](#) there is a field called "sender classification" which can only take one legal value: "1 = authority". Values 2-7 are reserved for future use. The value 0 is not defined in the specification, but since §13.1 indicates that the message can be used by vessels, perhaps 0 means that the sender is a vessel. But this is unclear.
4. The data field "duration" occupies 18 bits and thus supports a max. value of 262142 minutes (using 262143 to indicate value not available) [\[ASM_001_27\]](#). 262142 minutes equals 4.369 hours or 182 days. This is far beyond the needs for a tactical voyageplan and is therefore not efficient bit-usage for this purpose.
5. In [\[ASM_001_27\]](#) the data field "number of waypoints" is redundant with message length and thus violates the design criteria [Single point of truth](#). Since the specification states that "The number of waypoints is determined by the length of the message." the presence of this field is a mystery. 5 bits could be saved.
6. The message does not support individual ETA or turn radius per waypoint or SOG between waypoints.

In conclusion, DAC=001; FI=27 has an unclear specification, inefficient bit usage, and appears to be intended for planning purposes rather than the imminent tactical situation.

Therefore DAC=001; FI=27 is not suitable or recommended for use in flow management.

Review of ASM DAC=219; FI=01 - "Intended route"

Review of the application specific message DAC=219; FI=01 defined by [\[ASM_219_01\]](#) in the context of flow management yields the following comments:

1. It is well-defined *when* this message must be sent.
2. First waypoint is always active waypoint - thus the message only carries future intentions.
3. The data field "ETA active WP" can be set one year ahead. The good thing about this, is that it complies with the [Minimum no. of datatypes](#) design criteria; but the bad thing is that it wastes bits;

since the lifespan of a tactical voyageplan can probably be expressed in the order of hundreds of minutes corresponding to 10 bits of information.

4. In [\[ASM_219_01\]](#) the data field "number of waypoints" is redundant with message length and thus violates the design criteria [Single point of truth](#). It is unclear whether message length or data field "number of waypoints" determines the no. of waypoint. In either case, the bits used for the data field "number of waypoints" could be saved.
5. The message does not support individual ETA or turn radius per waypoint or SOG between waypoints.

In conclusion, DAC=219; FI=01 has some of the same discrepancies as DAC=001; FI=27, but the events which trigger transmission are more well-defined, it is clear that this message is transmitted by vessels (not shore stations); and it is clear that this message intended for communicating immediate navigation intentions in the same way as required for tactical voyageplans.

Therefore it is recommended - to use DAC=219; FI=01 as a means for vessels to broadcast their tactical voyageplans flow management. - to suggest one new message, with the same purpose as DAC=219; FI=01, but with the extended capability of expressing individual ETA and turn radius per waypoint.

Review of ASM DAC=219; FI=02 - "Route suggestion"

Review of the application specific message DAC=219; FI=01 defined by [\[ASM_219_01\]](#) in the context of flow management yields the following comments:

1. The purpose of this message is to suggest a new route *geometry*.
2. The message does not support individual ETA or turn radius per waypoint or SOG between waypoints.
3. The data field "ETA active WP" can be set one year ahead. The good thing about this, is that it complies with the [Minimum no. of datatypes](#) design criteria; but the bad thing is that it wastes bits; since the lifespan of a tactical voyageplan can probably be expressed in the order of hundreds of minutes corresponding to 10 bits of information.
4. In [\[ASM_219_01\]](#) the data field "number of waypoints" is redundant with message length and thus violates the design criteria [Single point of truth](#). It is unclear whether message length or data field "number of waypoints" determines the no. of waypoint. In either case, the bits used for the data field "number of waypoints" could be saved.

In conclusion, DAC=219; FI=02 has some of the same discrepancies as DAC=001; FI=27. It is clear that this message intended for communicating suggestions of route geometry - not speed-based flow management.

Therefore DAC=219; FI=02 is not suitable or recommended for use in flow management.

4.2.4. Suggested AIS messages to support flow management

Following the arguments above, the following AIS messages are suggested to be used or defined for use in flow management:

Message purpose	Message type	Defined by
Tactical voyageplan broadcast	ASM DAC=219; FI=01	[ASM_219_01] Appendix: tactical voyageplan broadcast (defined)
Tactical voyageplan broadcast, extended	ASM DAC=219; FI=02	Appendix: Tactical voyageplan broadcast, extended (proposal) .
Tactical voyageplan inquiry	ASM DAC=001; FI=03	Appendix: Tactical voyageplan inquiry (proposal) .
Flow management suggestion	ASM DAC=219; FI=04	Appendix: Flow management suggestion (proposal) .

Chapter 5. Validation against design criteria

5.1. General design criteria

No.	Criteria	Validation
1	Design with the end-user in mind	-
2	Design for multivendor environment	-
3	Information transfer involving ships must be bandwidth efficient	-
4	Ship-shore interactions must be robust	-
5	Ship-shore data IP connections must be initiated from ship	-

5.2. AIS-specific design criteria

No.	Criteria	Validation
1	Consider updated definitions of ASM and related guidance, before developing new ASM	-
2	Contribute to the IALA AIS ASM collection	-
3	Low transmission frequency	-
4	Use 6-bit ASCII	-
5	Fixed length messages	-
6	Fixed bit-offset for fields	-
7	Variable fields last	-
8	One dispatch field	-
9	Minimum no. of datatypes	-
10	Single point of truth	-
11	Support stream-based parsers	-
12	Don't split data fields across datagrams	-
13	Check design using ASN.1	-
14	Provide a reference implementation	-

No.	Criteria	Validation
15	Provide test data sets for all message variants	-

Chapter 6. Test data

The test data pairs listed in this section are calculated (and can be validated) as described in the appendix: [Calculating test data pairs](#).

6.1. Tactical voyageplan broadcast

6.2. Tactical voyageplan broadcast, extended

6.3. Tactical voyageplan, inquiry

This message comes in two variants: With and without geographical boundaries of the controlled area.

6.3.1. Variant 1: Without controlled area

Parameter	Test value
Message ID	6
Repeat Indicator	2
Src ID	219000001
Seq. no.	2
Dest. ID	219019416
Retransmit Flag	0
Spare	0
IAI	DAC = 291
	FI = 5

```
!AIVDM,1,1,0,,63@ndh@l=v9P=dD,2*61
```

6.3.2. Variant 2: With controlled area

Parameter	Test value
Message ID	6
Repeat Indicator	2
Src ID	219000001

Parameter	Test value
Seq. no.	2
Dest. ID	219019416
Retransmit Flag	0
Spare	0
IAI	DAC = 291
	FI = 5
Controlled area	North = 55° 50' 2.7594" = 55.8341
	East = 9° 56' 46.3194" = 9.9462
	South = 55° 48' 39.96" = 55.8111
	West = 9° 59' 35.5194" = 9.9932

!AIVDM,1,1,0,,63@ndh@l=v9P=dD0te;0egdP?us`PFhu`,0*32

6.4. Flow management suggestion

6.5. AIS

Chapter 7. Reference implementation

A reference implementation of encoding and decoding of the flow management related AIS messages programmed in Java is publically available in <https://github.com/tbsalling/AisLib/tree/flow-management>.

7.1. Tactical voyageplan broadcast

7.2. Tactical voyageplan broadcast, extended

7.3. Tactical voyageplan, inquiry

The reference implementation of the *tactical voyageplan, inquiry* message is located in <https://github.com/tbsalling/AisLib/blob/flow-management/ais-lib-messages/src/main/java/dk/dma/ais/message/binary/TacticalVoyagePlanInquiry.java>

with an accompanying unit test class in <https://github.com/tbsalling/AisLib/blob/flow-management/ais-lib-messages/src/test/java/dk/dma/ais/message/binary/TacticalVoyagePlanInquiryTest.java>.

7.4. Flow management suggestion

7.5. AIS

Chapter 8. Recommended further work

- autonomous flow management

Appendix A: AIS message definitions

The following AIS message definitions are proposed for flow management support.

tactical voyageplan broadcast (defined)

Formally proposed specification copied from [\[ASM_219_01\]](#):

This message allows the communication of a vessels intended route to other vessels and shore stations.

The rules for broadcasting this message are the following

- a. Only broadcast when the vessel is following an activated route.
- b. The route must be broadcast every six minutes, due to what is stated in ITU-R M.1371-4 (§4.2.1) regarding sending interval for voyage related information.
- c. On route activation the route must be broadcast.
- d. When active waypoint changes the route must be broadcast.
- e. On route deactivation, or when a route is completed, an empty message with no waypoints must be sent to indicate that the vessel is not following an intended route.

The broadcast waypoints must start with the current active waypoint and include up to the 15 following waypoints, giving a maximum of 16 waypoints.

Broadcasting 16 waypoints will result in a 5-slot message. It is recommended to avoid messages with more than 3 slots, equivalent to no more than 8 waypoints.

See http://enav.frv.dk/ais_route_suggestion.pdf for usage and portrayal details.

Registrant: Danish Maritime Authority

Message number: 8

DAC: 219

FI: 1

Used by: DMA, EfficienSea

Number of Slots (max): 3

Reporting rate: Every 6 minutes and on active route change

How portrayed: See http://enav.frv.dk/ais_route_suggestion.pdf for usage and portrayal details.

Permitted as from: 11/03/2011

Status: initiation

Technical Point of contact:

Ole Borup

Danish Maritime Authority

obo@frv.dk

Details:

Table 2.1

Intended route (broadcast)

Parameter	No. of bits	Description
Message ID	6	Identifier for Message 8; always 8.
Repeat Indicator	2	Used by the repeater to indicate how many times a message has been repeated. 0 - 3 0 = default 3 = do not repeat anymore
Source ID	30	MMSI number of source station.
Spare	1	Not used. Set to zero.
IAI	16	DAC = 219; FI = 1
ETA active WP		The ETA at the active waypoint (first waypoint). For a cancellation of active route, the default values can be used.
UTC Month	4	1 - 12 0 = not available = default
UTC Day	5	1 - 31 0 = not available = default
UTC Hour	5	0 - 23 0 = not available = default
UTC Minute	6	0 - 59 0 = not available = default
Duration	18	Minutes from ETA at active waypoint to ETA at the last broadcast waypoint. The duration allows for the calculation of an average intended speed on the broadcast route. + 0 = not available = default

Parameter	No. of bits	Description
Number of Waypoints	5	Number of Waypoints + 1 - 16 0 = no active route = cancel route 17 - 31 (not used)
Waypoints	n × 55	Variable number of waypoints 0 – 16 (55 bit each), refer to table 2.2.
Spare		Not used. Set to zero.
Total	99-979	Occupies 2 – 5 slots. 1 - 4 waypoints = 2 slots 5 - 8 waypoints = 3 slots 9 - 12 waypoints = 4 slots 13 – 16 waypoints = 5 slots

Table 2.2
Waypoints

Parameter	No. of bits	Description
WP Longitude	28	Longitude in 1/10,000 min, ±180 degrees as per 2's complement (East = positive, West = negative).
WP Latitude	27	Latitude in 1/10,000 min, ±90 degrees as per 2's complement (North = positive, South = negative).

Tactical voyageplan broadcast, extended (proposal)

Transmitter

Vessels only.

Transmission prerequisites

The message is only transmitted if vessel is conned along an active voyageplan.

Transmission triggering events

The following events must trigger a transmission of this message:

1. Periodically. [Using AIS: Every six minutes (due to what is stated in [\[AISSPEC5\]](#) (§4.2.1) regarding sending interval for voyage related information]
2. On voyage plan activation.
3. On voyage plan change
(change to waypoints or change of ETA to any waypoint of more than 10 minutes).
4. On voyage plan deactivation/cancellation.
5. On change of active waypoint.
6. As reply to message "tactical voyageplan inquiry".

Retransmission

Retransmission is not applicable.

Message format Waypoints are denoted WP_0 , WP_1 , WP_i , ..., WP_n and are navigated in sequence. WP_0 is the *active waypoint* currently steered towards. WP_i , where $i \geq 1$, is called *following waypoints*.

Parameter	No. of bits	Description
Message ID	6	Identifier for Message 8; always 8.
Repeat Indicator	2	Used by the repeater to indicate how many times a message has been repeated. 0 - 3 0 = default 3 = do not repeat anymore
Source ID	30	MMSI number of source station.
Spare	1	Not used. Set to zero.
IAI	16	DAC = 219; FI = 4

Parameter	No. of bits	Description
<i>Message may end here to indicate cancellation of previously announced tactical voyageplan.</i>		
TR	7	Turn circle radius. Type: Integer. Unit: 1/100 of a nautical mile. 0 = no value 1 - 127 = turn circle radius of 0.01 nm - 1.27nm
ETA of WP ₀	5	UTC hour Integer value Values outside the range 0-23 are illegal and must not be used. Values are current or future.
	6	UTC minute Integer value Values outside the range 0-59 are illegal and must not be used.
WP ₀ , longitude	28	Longitude in 1/10,000 min, ±180 degrees as per 2's complement (East = positive, West = negative).
WP ₀ , latitude	27	Latitude in 1/10,000 min, ±90 degrees as per 2's complement (North = positive, South = negative).
Following waypoints with ETA	n × 63	Variable no. of planned waypoints and ETA's. n {0..14} See table 2
Total	55	55 bits for cancellation of tactical voyageplan.
	128	128 bits for WP ₀ , no following WP's.
	191	191 bits for WP ₀ , 1 following WP.

	1010	1010 bits for WP ₀ , 14 following WP.

Table 6. Waypoints with relative ETA's.

Parameter	No. of bits	Description
Longitude of WP_i	28	Longitude in 1/10,000 min, ± 180 degrees as per 2's complement (East = positive, West = negative).
Latitude of WP_i	27	Latitude in 1/10,000 min, ± 90 degrees as per 2's complement (North = positive, South = negative).
Relative ETA at WP_i	8	Relative ETA from previous waypoint; measured in minutes. Integer value; [0-255]. 0 = Not used. Illegal value. 1 - 255 = Relative ETA measured in number of minutes from previous waypoint.
Total	63	

Table 7. No. of transmission slots.

Payload	Bits	Slots
Cancellation	55	1
Active waypoint, no following waypoints	128	1
Active waypoint, 1 following waypoint	191	2
Active waypoint, 2 following waypoints	254	2
Active waypoint, 3 following waypoints	317	2
Active waypoint, 4 following waypoints	380	3
Active waypoint, 5 following waypoints	443	3
Active waypoint, 6 following waypoints	506	3
Active waypoint, 7 following waypoints	569	3
Active waypoint, 8 following waypoints	632	4
Active waypoint, 9 following waypoints	695	4
Active waypoint, 10 following waypoints	758	4
Active waypoint, 11 following waypoints	821	5
Active waypoint, 12 following waypoints	884	5
Active waypoint, 13 following waypoints	947	5
Active waypoint, 14 following waypoints	1010	5

Tactical voyageplan inquiry (proposal)

Transmitter

Vessels and coordination centres.

Transmission triggering events

The following events should trigger transmission:

1. On need by control centre to receive tactical voyageplan from a vessel. In case of e.g.:
 - A vessel's arrival to controlled area.
 - A vessel's previously announced tactical voyageplan is considered invalid by the inquirer, e.g. because
 - the timestamp of the active waypoint is in the past.
 - the vessel's manouvers deviate significantly from its announced tactical voyageplan.
 - Loss of data in control center.
2. On need by vessel to receive tactical voyageplan from another vessel.
 - The inquired vessel's intentions are unknown to the inquiring vessel; e.g. in case of
 - Tactical voyageplan was never transmitted by inquired vessel.
 - Tactical voyageplan was never received by inquiring vessel.
 - Information about another vessel's tactical voyageplan was lost onboard the inquiring vessel (e.g. due to system restart or improper operation).

Retransmission

Except in the sense of missing protocol acknowledgement as per [\[AISSPEC5\]](#), Annex 8 §3.5 — retransmission is not applicable.

Message format

Parameter	No. of bits	Description
Message ID	6	Identifier for Message 6; always 6. [Message type 25 could also be considered. But this message type is very rare and not known to be used in any other applications.]

Parameter	No. of bits	Description
Repeat Indicator	2	Used by the repeater to indicate how many times a message has been repeated. 0 - 3 0 = default 3 = do not repeat anymore
Source ID	30	MMSI number of source station.
Sequence number	2	0-3; refer to [AISSPEC5] §5.3.1, Annex 2
Destination ID	30	MMSI number of destination station.
Retransmit Flag	1	Retransmit Flag should be set upon retransmission: 0 = no retransmission = default 1 = retransmitted.
Spare	1	Not used. Set to zero.
IAI	16	DAC = 219; FI = 5
<i>Message may end here - remaining fields are optional (all or none)</i>		
Flow managed area	28	Northern limit, longitude Longitude in 1/10,000 min, ±90 degrees as per 2's complement (North = positive, South = negative).
	27	Eastern limit, latitude Latitude in 1/10,000 min, ±180 degrees as per 2's complement (East = positive, West = negative).
	28	Southern limit, longitude Longitude in 1/10,000 min, ±90 degrees as per 2's complement (North = positive, South = negative).
	27	Western limit, latitude Latitude in 1/10,000 min, ±180 degrees as per 2's complement (East = positive, West = negative).
Total	88-198	

If the *flow managed* area is included in the transmission, it is to be interpreted by the addressed

vessel as a request for it to broadcast message "Tactical voyageplan broadcast, extended" as per its transmission trigger criteria, whilst the vessel is inside the designated area.

Table 8. No. of transmission slots.

Payload	Bits	Slots
Inquiry without area	88	1
Inquiry with area	198	2

Flow management suggestion (proposal)

Transmitter

Coordination centers (for controlled flow management).

Transmission prerequisites

The message is only transmitted if the receiving vessel has previously broadcast a tactical voyage plan which is still considered valid by the control center (e.g. ETA of active waypoint is in the future).

This message can only be sent in response to a "Tactical voyageplan broadcast" or a "Tactical voyageplan broadcast, extended".

The latitude and longitude of suggested active and planned waypoints must match exactly those received in the latest "Tactical voyageplan broadcast" or a "Tactical voyageplan broadcast, extended". If this is not the case, the vessel, to which the flow management suggestion is addressed, must disregard it, and broadcast a new tactical voyageplan message.

If the flow management suggestion is sent in response to a "Tactical voyageplan broadcast" containing 15 or 16 waypoints, only the first 14 need to be included.

Transmission triggering events

The following events must trigger a transmission of this message:

1. On coordination center determining that speed-based changes to tactical voyageplan of vessel will lead to a better overall flow.

Retransmission

Retransmission is not applicable.

Message format Waypoints are denoted WP_0 , WP_1 , $WP_i...$, WP_n and are navigated in sequence. WP_0 is the *suggested active waypoint* currently to be steered towards. WP_i , where $i \geq 1$, is called the *following suggested waypoints*.

Parameter	No. of bits	Description
Message ID	6	Identifier for Message 8; always 8.
Repeat Indicator	2	Used by the repeater to indicate how many times a message has been repeated. 0 - 3 0 = default 3 = do not repeat anymore
Source ID	30	MMSI number of source station.

Parameter	No. of bits	Description
Spare	1	Not used. Set to zero.
IAI	16	DAC = 219; FI = 6
Suggested ETA of WP ₀	5	UTC hour Integer value Values outside the range 0-23 are illegal and must not be used. Values are current or future.
	6	UTC minute Integer value Values outside the range 0-59 are illegal and must not be used.
WP ₀ , longitude	28	Longitude in 1/10,000 min, ±180 degrees as per 2's complement (East = positive, West = negative).
WP ₀ , latitude	27	Latitude in 1/10,000 min, ±90 degrees as per 2's complement (North = positive, South = negative).
Following suggested waypoints with suggested ETA	n × 63 n {0..14}	Variable no. of suggested waypoints and ETA's. See table 2
Total	121-1003	

Table 9. Waypoints with relative ETA's.

Parameter	No. of bits	Description
Longitude of WP _i	28	Longitude in 1/10,000 min, ±180 degrees as per 2's complement (East = positive, West = negative).
Latitude of WP _i	27	Latitude in 1/10,000 min, ±90 degrees as per 2's complement (North = positive, South = negative).
Relative ETA at WP _i	8	Relative ETA from previous waypoint; measured in minutes. Integer value; [0-255]. 0 = Not used. Illegal value. 1 - 255 = Relative ETA measured in number of minutes from previous waypoint.

Parameter	No. of bits	Description
Total	63	

Table 10. No. of transmission slots.

Payload	Bits	Slots
Suggested active waypoint, no following suggested waypoints	121	1
Suggested active waypoint, 1 following suggested waypoint	184	2
Suggested active waypoint, 2 following suggested waypoints	247	2
Suggested active waypoint, 3 following suggested waypoints	310	2
Suggested active waypoint, 4 following suggested waypoints	373	3
Suggested active waypoint, 5 following suggested waypoints	436	3
Suggested active waypoint, 6 following suggested waypoints	499	3
Suggested active waypoint, 7 following suggested waypoints	562	3
<i>Suggested active waypoint, 8 following suggested waypoints</i>	625	4
<i>Suggested active waypoint, 9 following suggested waypoints</i>	688	4
<i>Suggested active waypoint, 10 following suggested waypoints</i>	751	4
<i>Suggested active waypoint, 11 following suggested waypoints</i>	814	5
<i>Suggested active waypoint, 12 following suggested waypoints</i>	877	5
<i>Suggested active waypoint, 13 following suggested waypoints</i>	940	5
<i>Suggested active waypoint, 14 following suggested waypoints</i>	1003	5

Appendix B: Calculating test data pairs

A test data pair can be computed like this: First, a message variant is chosen - and test data values are chosen for each data field. This is an example for the *tactical voyageplan, inquiry* message in its simplest variant:

Parameter	Bits	Test value (decimal)	Test value (binary)
Message ID	6	6	000110
Repeat Indicator	2	0	00
Src ID	30	219000001	001101000011011010110011000001
Seq. no.	2	0	00
Dest. ID	30	219019416	001101000011011111100010011000
Retransmit Flag	1	0	0
Spare	1	0	0
IAI	10	DAC=291	0011011011
	6	FI=5	000101
Total		88	

Then, concatenating all the binary values and grouping them into 6-bit nibbles yields:

```
000110 000011 010000 110110 101100 110000
010000 110100 001101 111110 001001 100000
001101 101100 0101
```

Since the last nibble contains only four bits, it must be zero-padded to fill up an entire nibble, like this:

```
000110 000011 010000 110110 101100 110000
010000 110100 001101 111110 001001 100000
001101 101100 010100
```

Using table 2 in the "AIVDM/AIVDO Payload Armoring"-section of [\[RAYMOND\]](#), these 15 6-bit nibbles can be converted into ASCII like this:

```
000110 -> "6"  
000011 -> "3"  
010000 -> "@"  
110110 -> "n"  
101100 -> "d"  
110000 -> "h"  
010000 -> "@"  
110100 -> "l"  
001101 -> "="  
111110 -> "v"  
001001 -> "9"  
100000 -> "P"  
001101 -> "="  
101100 -> "d"  
010100 -> "D"
```

In conclusion the ASCII-armoured representation of this message is: **63@ndh@l=v9P=dD**.

In communication with a base station or a transponder, this ASCII-armoured value needs to be in the payload of an NMEA0183 message like VDM or VDO, like this:

!AIVDM,1,1,0,,63@ndh@l=v9P=dD,2*61

A good explanation of NMEA encapsulation of AIS data is found in the "AIVDM/AIVDO Sentence Layer" section of [\[RAYMOND\]](#).

The *-separated suffix ("*61") is the NMEA 0183 data-integrity CRC32 checksum for the sentence, preceded by "*". It is computed on the entire sentence including the AIVDM tag but excluding the leading "!" and the trailing "*". The checksum is computed as the last two digits of the XOR of all of the bytes in the sentence in hexadecimal notation. As explained by [\[WIKINMEA\]](#) the C implementation can look like this:

```

#include <stdio.h>
#include <string.h>

int checksum(char *s) {
    int c = 0;

    while(*s)
        c ^= *s++;

    return c;
}

int main()
{
    char mystring[] = "AIVDM,1,1,0,,63@ndh@l=v9P=dD,2";
    printf("Checksum: 0x%02X\n", checksum(mystring));
    return 0;
}

```

Running the algorithm as a C program yields:

```

$ gcc checksum.c
$ ./a.out
Checksum: 0x61

```

Thus — this particular case — the checksum is 0x61 and thus the complete NMEA amou containing our AIS data is:

```
!AIVDM,1,1,0,,63@ndh@l=v9P=dD,2*61
```

Glossary

Definitions

Term	Definition
Strategic voyageplan	MONALISA 2 term for long term planning that consists of a route with a voyage number (and other Route information), a list of waypoints (geometry), a schedule, charter parties, legal conditions, and more. When a Strategic voyage plan is given to the ship as a voyage order it changes to <i>dynamic voyageplan</i> .
Dynamic voyageplan	MONALISA 2 term for an optimised version of the <i>strategic voyageplan</i>
Tactical voyageplan	MONALISA 3 term for a dynamic voyageplan in conning mode; i.e. under tactical execution. Whole or parts of the tactical voyage plan can be transmitted to increase situational awareness and support flow management.
Turn circle radius	Merchant ships usually turn in a circle having a radius of about 6–8 times the length between perpendiculars. Turn radius varies little with speed, but can vary significantly between manouvers in deep and shallow waters. The radius depends on the size and geometry of a vessel, the size of its rudder, and the no. and characteristics of propellers. Cf. [SBTCD] for more.

Abbreviations

Abbreviation	Expansion	Description
MSDL	Maritime Service Definition Language	A computer language used to defined services in a maritime
AIS	Automatic Identification System	A tracking system used on ships and by vessel traffic services for identifying and locating vessels by electronically exchanging data with other nearby ships, base stations, and satellites.
ASM	Application Specific Message	Used only in the context of the automatic identification system, as a method of allowing "competent authorities" to define additional AIS message subtypes, based on message types 6, 8, 25, and 26 which support a custom payload.

Abbreviation	Expansion	Description
CC	Coordination Center	A term specific to this document invented to cover all types of VTS, STCC, and other centres with responsibility for traffic management and coordination.
STM	Sea Traffic Management	The aggregation of the seaborne and shore-based functions (sea traffic services, maritime space management and sea traffic flow management) required to ensure the safe and efficient manouvering of vessels during all phases of operation.
STCC	Sea Traffic Coordination Center	A central, shore-based, hub maintaining record of all vessels at sea using AIS and/or radar to enable managed distribution of vessel routes between ship-to-ship and ship-to-shore.
VTS	Vessel traffic service	A vessel traffic service is a marine traffic monitoring system established by public or port authorities, somewhat similar to air traffic control for aircraft.
IALA	International Association of Lighthouse Authorities	The International Association of Marine Aids to Navigation and Lighthouse Authorities is a non-profit organization founded collect and provide nautical expertise and advice.
ITU	International Telecommunication Union	The International Telecommunication Unio is an agency of the United Nations that is responsible for issues that concern information and communication technologies, such as coordinating the shared global use of the radio spectrum, promoting international cooperation in assigning satellite orbits, assisting in the development of worldwide technical standards.
ASCII	American Standard Code for Interformation Interchange	A character encoding scheme used in computers, communications equipment, and other devices that use text, to represent text with numbers.
ETA	Estimated time of arrival	-

Abbreviation	Expansion	Description
SOG	Speed over ground	Speed made good (often measured in knots).
TR	Turning circle radius	Turning circle radius (often measured in nautical miles).

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[ASM_001_27] "Specification of Route information - (broadcast)". Specification of the AIS application specific message for route information broadcast. <http://www.e-navigation.nl/content/route-information>.

[ASM_219_01] "Specification of intended route - (broadcast)". Specification of the AIS application specific message for intended route broadcast. <http://www.e-navigation.nl/content/intended-route>.

[ASM_219_02] "Specification of route suggestion". Specification of the AIS application specific message for intended route broadcast. <http://www.e-navigation.nl/content/route-suggestion>.

[SBTCD] Blog entry on "Turning Circle Diameter for a Container Ship". <http://shipsbusiness.com/turning-circle.html>.