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National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: APR 10 1997

In reply refer to: M-97-5 through -11

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Commandant
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Washington, D.C. 20593-001

On June 10, 1995, the Panamanian passenger ship *Royal Majesty* grounded on Rose and Crown Shoal about 10 miles east of Nantucket Island, Massachusetts, and about 17 miles from where the vessel's watch officers thought the vessel was. The vessel, with 1,509 persons on board, was en route from St. George's, Bermuda, to Boston, Massachusetts. There were no deaths or injuries as a result of this accident. Damage to the vessel and lost revenue, however, were estimated at about $7 million.[1]

The National Transportation Safety Board determines that the probable cause of the grounding of the *Royal Majesty* was the watch officers' overreliance on the automated features of the integrated bridge system, Majesty Cruise Line's failure to ensure that its officers were adequately trained in the automated features of the integrated bridge system and in the implications of this automation for bridge resource management, the deficiencies in the design and implementation of the integrated bridge system and in the procedures for its operation, and the second officer's failure to take corrective action after several cues indicated the vessel was off course.

Contributing factors were the inadequacy of international training standards for watchstanders aboard vessels equipped with electronic navigation systems and integrated bridge systems and the inadequacy of international standards for the design, installation, and testing of integrated bridge systems aboard vessels.

About 52 minutes after the *Royal Majesty* left St. George's, the antenna cable connection for the global positioning system (GPS) receiver had separated enough that the GPS switched to the dead-reckoning (DR) mode, and the autopilot, not programmed to detect the mode change and invalid status bits, no longer corrected for the effects of wind, current, or sea. Over time, the effects of the east-northeasterly wind and sea set the *Royal Majesty* in a west-southwesterly

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[1] For more information, read Marine Accident Report—*Grounding of the Panamanian Passenger Ship Royal Majesty on Rose and Crown Shoal near Nantucket, Massachusetts, June 10, 1995* (NTSB/MAR-97/01).

direction and away from its intended track, resulting in the vessel straying more than 17 miles off course.

Although the officers' inadequate monitoring led to the errant track and was a serious deviation from acceptable methods of operating automated equipment, the grounding itself could have been avoided had the chief officer and the second officer followed longstanding good watchkeeping practices when approaching land. During the 1600-to-2000 watch preceding the accident, the chief officer did not visually identify the buoy he saw on the radar about 1900 and apparently assumed that it was the BA buoy, which marked the entrance to the traffic lanes. The target that he probably observed was the AR buoy, which marked a wreck about 17 miles west of the traffic lanes, and it was probably coincidental that he detected it when and where he anticipated seeing the BA buoy. He later explained that he was not concerned about confirming that the target was the BA buoy because the information displayed at the time on the central console indicated to him that confirmation was not necessary.

When the second officer assumed the following watch, he did not see the next buoy in the traffic lanes, the BB buoy, when it was expected. Contrary to standing orders from the master, he failed to report that he had not seen the BB buoy; and when the master called the bridge asking the second officer whether he had observed the buoy, the second officer stated that he had.

The second officer continued to miss opportunities to avoid the grounding when the lookouts reported sighting tower lights (later determined to be on Nantucket Island), sighting a flashing red light on the port bow, and sighting blue and white water ahead of the *Royal Majesty*. He acknowledged these observations, but he failed to take any action.

The second officer's response to these sightings should have been deliberate and straightforward. He should have been concerned as soon as the BB buoy was not sighted and then again when the lookouts sighted red lights. Had he then increased the radar range from 6 miles to 12 miles on the one radar in use or turned on the second radar and set it to the 12-mile range, he would have detected Nantucket Island. He would also have seen that the radar pictures did not conform to the radar maps exhibited on the display of the automatic radar plotting aid (ARPA). In addition, had he checked a chart of the area for the source of the flashing red light, he would have learned that the nearest flashing red light was the Rose and Crown Shoal buoy and, thus, would have been warned that the ship was not in the traffic lanes, as he believed it was. The chart would also have shown him that if the ship was in the inbound traffic lane, as he apparently believed it was, there should have been no shallow water where the lookout sighted blue and white water.

Additionally, the second officer should have checked the Loran-C to crosscheck his position, as he knew the Loran-C to be accurate in this area. Had he still been uncertain about the position of the *Royal Majesty* after checking the Loran-C, he should have called the master and the navigator to the bridge for assistance. The Safety Board concludes that the sighting of lights not normally observed in this area and the second officer's inability to confirm the presence of the BB buoy should have taken precedence over the automation display on the central console and compelled the second officer to promptly use all available means to verify his position.

Innovations in technology have led to the increased use of advanced automated systems on modern maritime vessels. However, bridge automation has also changed the role of the watch officer on the ship. The watch officer, who previously was active in obtaining information about the environment and used this information for controlling the ship, is now "out of the control loop." The watch officer is relegated to passively monitoring the status and performance of the automated systems. As a result of passive monitoring, the crewmembers of the *Royal Majesty* missed numerous opportunities to recognize that the GPS was transmitting in the DR mode and that the ship had deviated from its intended course. The Safety Board examined why the watch officers missed the opportunities.

When the GPS unit defaulted to its DR mode, it displayed both *SOL*[2] and *DR*, indicating that the GPS solution was no longer valid and the unit had switched to a DR mode. Although the watch officers testified they used the GPS data for plotting, each officer also testified that he did not see *SOL* displayed on the GPS unit. Ineffective monitoring of sophisticated automated equipment is not new. The problem of poor monitoring of automated systems was also known to STN Atlas, the manufacturer of the navigation and command system (NACOS) 25. In the conclusion of the navigator's operating manual, STN Atlas warns that operators, with little to do, could fail to adequately monitor the automated NACOS 25.

The Board's investigation also found that the watch officers failed to use independent alternative means to verify the *Royal Majesty*'s position. Research on operator monitoring performance suggests that the reliability or trustworthiness of an automated system could have affected the officers' verification of the GPS position data. The complete automated navigation system, including the GPS, on the *Royal Majesty* had proven to be a highly reliable and accurate system, and the watch officers' testimony suggested that they believed the GPS was superior to other onboard position instrumentation. Also, the watchkeeping procedures of the master and the watch officers did not include an effective mechanism for comparing the GPS with other position instrumentation. Although the master required the watch officers to plot fixes manually as an apparent check on the system, this procedure did not provide an independent verification of the GPS information. The Safety Board concludes that the watch officers on the *Royal Majesty* may have believed that because the GPS had demonstrated sufficient reliability, the traditional practice of using at least two independent sources of position information was not necessary.

Despite their failing to recognize the mode change on the GPS system, the *Royal Majesty*'s watch officers had numerous opportunities to detect the course deviation. The failure of the chief officer and the second officer to recognize the *Royal Majesty* was off course may be explained by how convincing the display of position information was. The NACOS 25 presented the watch officers with a detailed map view (on the ARPA display) that indicated the position of the ship. The map display provided a very salient and seemingly accurate picture of the *Royal Majesty*'s course. Research on decisionmaking indicates that cues that are most salient, such as the map display, tend to bias operators when they make diagnostic decisions. Further, research on decisionmaking in the presence of automation has indicated that automation can bias an operator's decisions.

[2] *SOL* is meant to indicate that the GPS satellite position solution is invalid or not available. According to the Raystar 920 operation manual, *SOL* means the unit can not calculate its lat/long position.

Both the chief officer and the second officer exhibited decisionmaking bias toward the automated map display. During the 1600-to-2000 watch preceding the accident, the chief officer did not visually identify the buoy he saw on the radar about 1900 and apparently assumed that it was the BA buoy, which identified the entrance to the Port of Boston Traffic Separation Scheme (Boston traffic lanes). The target that he probably observed was the AR buoy. He felt no need to visually verify his identification of the BA buoy based on information from the map display. The second officer was overly reliant on the map display when he failed to crosscheck the vessel's position despite repeated indications of the *Royal Majesty*'s deviation from its intended course. The Safety Board concludes all the watchstanding officers were overly reliant on the automated position display of the NACOS 25 and were, for all intents and purposes, sailing the map display instead of using navigation aids or lookout information.

As the grounding of the *Royal Majesty* shows, shipboard automated systems such as the integrated bridge system and the GPS can have a profound influence on a watchstander's performance. However, the full impact of automated systems on watchstanding performance has yet to be examined in detail. The U.S. Coast Guard has begun this effort by examining how automation affects watch officers' tasks and workloads. The Safety Board believes further research is necessary. Therefore, the Safety Board recommends that the Coast Guard continue its research on shipboard automation, focusing on watch officers' monitoring and decisionmaking aboard ships with automated integrated bridge systems.

The performance of the watch officers during the voyage and the circumstances leading to the grounding were linked to several error inducing deficiencies in the design of the equipment and to an inefficient layout of system displays on the bridge.

Although the *Royal Majesty* was equipped with multiple position receivers, the NACOS 25 autopilot was not configured to compare position data from multiple independent position receivers such as Raytheon's 920 GPS and 780 Loran-C receivers. Given the *Royal Majesty*'s frequent proximity to land and the expected reasonable accuracy of the Loran-C in that area, the NACOS 25 could have recognized the large discrepancy between the GPS and the Loran-C positions as the vessel approached Nantucket Shoals had it been able to compare them. The Safety Board concludes that had the autopilot been configured to compare position data from multiple independent position receivers and had a corresponding alarm been installed that activated when discrepancies were detected, the accident may have been avoided. The safety benefits associated with the redundancy of such critical systems as position receivers would help prevent such single-point catastrophic failures as occurred on the *Royal Majesty*.

The NACOS 25 central console provided efficient access and display of most information needed to conduct a passage when the GPS was fully operational. However, where various sources of position information were possible (i.e., GPS, Loran-C, or DR), as with the NACOS 25 autopilot, it was important to delineate clearly which mode was in use. On the *Royal Majesty*, because the NACOS 25 could not detect the GPS's change to DR mode, the central console display switched from GPS- to DR-derived positions without changing its display in any perceivable way or notifying the crew. The integrated bridge system, as configured, did not indicate to the officers at the central console that the navigation system had defaulted to the DR navigation mode.

The failure of the NACOS 25 autopilot to recognize the GPS data as invalid and to sound an alarm helped cause a single-point, "silent" failure mode on the *Royal Majesty*. Aeronautical and aerospace design safety practices typically require the analysis of potential failure modes via failure modes and effects analyses (FMEAs). FMEAs of the *Royal Majesty*'s integrated bridge system could have highlighted the need for multiple independent comparisons of positioning systems for discrepancies between systems, the need for removal of the DR input to the Raytheon 920 GPS receiver, and the need for interrogation of the National Marine Electronics Association (NMEA) 0183 *valid/invalid* position data bits by the NACOS 25. The Safety Board concludes that FMEAs of the *Royal Majesty*'s integrated bridge system would probably have disclosed the shortcomings of the system's components. Therefore, The Safety Board believes that the Coast Guard should propose to the International Maritime Organization (IMO) that it develop standards for integrated bridge system design that will require

- multiple independent position receiver inputs;
- monitoring position receiver data for failures/invalid data and subsequent positive annunciation to the crew;
- comparing position receiver data for significant discrepancies between position receivers, and subsequent positive annunciation to the crew; and
- FMEAs during the design process and once again when all peripheral devices and equipment details have been "frozen" if the FMEA done during the design process does not account for all peripheral device/equipment variations.

The investigation determined that although the watch officers on the *Royal Majesty* during the grounding were familiar with the basic operation of the automated navigation equipment, no one, with the possible exception of the navigator, appeared to be fully proficient with the system, as evidenced by the lack of knowledge about the GPS receiver's DR mode capability. The crew's automated navigation equipment training consisted primarily of on-the-job training, the type of training on which the marine industry has historically relied. For example, the second officer's preparation to operate the automated navigation system was described as his reading the equipment manuals acquired with the system installation, observing bridge operations by the other officers, and using the equipment under their supervision. Because the second officer's introduction to the system consisted of watching others or operating the system himself during routine conditions, he probably had very little experience in recognizing and coping with system malfunctions.

The watch officers, in particular the second officer and the chief officer, abandoned the good watchstanding practices of properly monitoring and crosschecking the progress of their vessel and instead relied almost solely on the GPS and the display on the ARPA to provide them with information about the vessel's movements. The circumstances of the grounding of the *Royal Majesty* and the discussions at the Safety Board's public forum on the current state of the art in integrated bridge systems suggest that there is a need for the international maritime community to address the issue of improving training for deck officers assigned to vessels equipped with electronic navigation equipment and integrated bridge systems. The Safety Board is concerned that the inadequacy of training given to the crew of the *Royal Majesty* in the use of sophisticated electronic navigation equipment and integrated bridge systems may be typical of the industry. Therefore, the Safety Board believes that the Coast Guard should propose to the IMO that it develop appropriate performance standards for the training of deck officers assigned to vessels equipped with sophisticated electronic navigation equipment and integrated bridge systems and then require this training.

The deficient monitoring of the integrated navigation system by the deck officers and the second officer's failure to recognize the danger to the *Royal Majesty* before the grounding point to the usefulness of training in bridge resource management. As shown by its issuance of Safety Recommendations M-93-18 and -19, the Safety Board has supported such training for deck officers who operate conventional navigation bridges. The grounding of the *Royal Majesty*, however, shows the need to address procedures for, and training in, effective monitoring of automated navigation equipment.

Bridge resource management training adapted for watch officers working with fully automated navigation systems or integrated bridge systems could improve the officers' performance. The training would help them make decisions that are not biased by their use of automated equipment. It would improve their situational awareness,[3] which, research shows,[4] declines when operations are automated.

On June 25, 1993, as a result of its investigation of the grounding of the United Kingdom passenger vessel RMS _Queen Elizabeth 2_ (near Cuttyhunk Island, Vineyard Sound, Massachusetts, on August 7, 1992) the Safety Board issued Safety Recommendations M-93-18 and -19 to the Coast Guard. The Safety Board requested that the Coast Guard:

> Propose to the IMO that standards and curricula be developed for bridge resource management training for the masters, deck officers, and pilots of ocean-going ships. (M-93-18)
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> Propose to the IMO that the masters, deck officers, and pilots of ocean-going ships be required to successfully complete initial and recurrent training in bridge resource management. (M-93-19)

On September 27, 1993, responding to Safety Recommendation M-93-18, the Coast Guard Commandant wrote:

> I partially concur with this recommendation. The U.S. will propose at the 25th Session of the IMO Subcommittee on STW that standards and curricula be developed for bridge resource management training for masters and deck officers

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[3] *Situational awareness* is a concept referring to perception of an operating environment, comprehension of events and circumstances pertaining to that environment, and a projection of their status. Endsley, M., *Situational Awareness*. Presentation to National Transportation Safety Board, June 6, 1996.

[4] Pew, R.W. Situational *Awareness and its Analysis in Accident Situations* Presentation by Bold, Beranek and Newman, Inc. to the National Transportation Safety Board, June 7, 1995. Also, Endsley, M.L. and Kiris, E.O., *The Out-of -the-Loop Performance Problem: Impact of Level of Automation and Situational Awareness.*, *ref.* In Mouloua, M. And Parasuraman, R., Eds., Human Performance in Automated Systems: Current Research and Trends, Hillsdale, NJ, Lawrence Erlbaum, Associates, 1994. Pp. 51, 55.

> of seagoing ships. However, the Coast Guard views pilot qualifications as a matter for port State regulation. I will keep the Board informed of our progress regarding this recommendation.

On January 7, 1994, the Safety Board responded:

> The Safety Board agrees that, in the end, pilot qualifications are a matter for the port State to enforce. The intent of the recommendation is for the IMO to develop a specified standard that would serve as a model that the port States could adopt. The United States has recently been more receptive to the idea of developing a unilateral standard if it is included in the Standards of Training and Watchkeeping. Consequently, the Board encourages the Coast Guard to pursue this issue at the IMO. Because the Coast Guard states it will propose the recommendation to the IMO, Safety Recommendation M-93-18 has been classified "Open--Acceptable Response," pending implementation by the IMO.

On September 27, 1993, responding to Safety Recommendation M-93-19, the Coast Guard Commandant wrote:

> I partially concur with this recommendation. The United States will propose that IMO agree in principle to requiring masters and deck officers on seagoing ships to complete initial and recurrent training in bridge resource management. However, the Coast Guard views pilot qualifications as a matter for port State regulation. I will keep the Board informed of our progress regarding this recommendation.

On January 7, 1994, the Safety Board responded that for the reasons stated in the discussion of Safety Recommendation M-93-18, the Safety Board encouraged the Coast Guard to actively promote the IMO's acceptance of Safety Recommendation M-93-19. Because the Coast Guard had agreed to "proposing in principle" the recommendation, the Board classified Safety Recommendation M-93-19 "Open--Acceptable Alternate Response," pending the outcome of the Coast Guard's efforts.

Therefore, the Safety Board reiterates Safety Recommendations M-93-18 and -19 and urges the Coast Guard to work closely with the IMO in order to expedite the intended outcome of these recommendations.

The Safety Board also believes that the Coast Guard, as part of the foreign flag passenger ship control verification examination program, should assess the adequacy of installed integrated bridge systems and verify that the ships' officers are properly trained in their operation and possible failure modes. Furthermore, as part of the same program, the Coast Guard should verify that the watchstanding procedures of ships' officers include the use of multiple independent means of position verification.

The lack of human-factors engineering in the design of the integrated bridge system on the *Royal Majesty* concerned the Safety Board in its investigation of the accident. Not only did the GPS receiver on the *Royal Majesty* display the DR coordinates in the same character size and format as the coordinates derived from satellite data, it also switched to the DR mode automatically, without requiring a human to acknowledge that it was acceptable. (However, deficiencies in the alarm, the distance of the receiver from the operator, and the inadequacy of the crew's procedures also contributed to the watchstanders' failure to that the GPS had reverted to the DR mode.)

The size of characters, the viewing distance, and the use of contrasting colors are a few of the factors that should be considered in designing character displays for alerts and warnings. Alert messages and status indicators about critical information, such as the GPS defaulting to the DR mode, should be distinctively displayed. In this case, the *SOL* and *DR* alert messages were much smaller than the normal status information.

The Safety Board concludes that the *Royal Majesty*'s integrated bridge system had several shortcomings with respect to human-factors engineering. First, mode information was not available to the crew at the central console (the normal position). Second, the GPS/DR alarm and status indicators, which could have alerted the crew to the mode change, were either not installed (external alarm) or not salient enough (internal alarm) to attract the watchstanders' attention. Finally, the integrated bridge system as implemented on the *Royal Majesty* failed to adequately define the watch officers' tasks and procedures. If the automation on board the *Royal Majesty* had been appropriately implemented and integrated with the human operator, the vessel probably would not have grounded. Because of the Safety Board's concern that automation on other vessels has not been appropriately implemented and integrated with the human operator, the Board believes that the Coast Guard should propose to the IMO that it apply existing human-factors engineering standards in the design of integrated bridge systems on vessels.

A draft IMO performance standard for integrated bridge systems is currently under review and is expected to be adopted and implemented by 1999. At the Safety Board's public forum on integrated bridge systems, manufacturers of integrated bridge systems pointed out that integrating the various components like ARPAs, autopilots, electronic chart systems (or radar maps), and monitoring systems involve careful matching and FMEAs to eliminate any potential interface problems. The recently developed interface standards from the International Electrotechnical Commission and the NMEA (IEC 1162-2 and NMEA 0183) should facilitate the matching of subsystems manufactured by one manufacturer to an integrated bridge system manufactured by another. These standards and an IMO performance standard should eliminate many of the potential interface problems.

The proposed IMO performance standard for integrated bridge systems includes a requirement that the manufacturers of integrated bridge systems be certified by the International Standards Organization. Thus, it would appear that the safeguards for guaranteeing the quality of software during manufacturing likely will become an IMO requirement. Such a requirement could ensure that the people responsible for developing the software are well qualified and that the manufacturer has procedures for verifying the quality of the software. Developments in electronic equipment, however, are very rapid, and it is sometimes possible for developments to occur more quickly than standards can be produced. Further, the possibility exists that software may be changed, possibly inappropriately, during the life of an integrated bridge system. Therefore, the selection and matching of electronic equipment will still require highly qualified personnel who are familiar with the equipment, the data to be transmitted, the format of the data, and the applicable standards. The Safety Board believes that there is a need for some competent authority to conduct continuing oversight to ensure that future changes in subsystems or software on integrated bridge systems are compatible and that system integrity is maintained. Also, the Safety Board believes that certifying navigation bridges equipped with integrated bridge systems should be done by a qualified independent authority. In summary, the Safety Board believes that the Coast Guard should propose to the IMO that a provision be included in the performance standard for integrated bridge systems that would require that a competent independent authority inspect and certify the navigation bridge of each commercial vessel equipped with an integrated bridge system when the system is installed and periodically throughout its life.

Therefore, the National Transportation Safety Board reiterates Safety Recommendations M-93-18 and -19 and recommends that the U.S. Coast Guard:

> Propose to the International Maritime Organization that it develop appropriate performance standards for the training of watch officers assigned to vessels equipped with integrated bridge systems and require this training. (M-97-5)
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> Propose to the International Maritime Organization that it develop standards for integrated bridge system design that will require
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> - multiple independent position receiver inputs;
> - monitoring position receiver data for failures/invalid data and subsequent positive annunciation to the crew;
> - comparing position receiver data for significant discrepancies between position receivers, and subsequent positive annunciation to the crew; and
> - failure modes via failure modes and effects analyses (FMEAs) during the design process and once again when all peripheral devices and equipment details have been "frozen" if the FMEA during the design process does not account for all peripheral device/equipment variations. (M-97-6)
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> Propose to the International Maritime Organization that it apply existing human-factors engineering standards in the design of integrated bridge systems on vessels. (M-97-7)
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> Propose to the International Maritime Organization that a provision be included in the performance standard for integrated bridge systems that would require that a competent independent authority inspect and certify the navigation bridge of each commercial vessel equipped with an integrated bridge system when the system is installed and throughout its life. (M-97-8)
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> Continue its research on shipboard automation, focusing on watch officers' monitoring and decisionmaking aboard ships with automated integrated bridge systems. (M-97-9)

As part of the foreign flag passenger ship control verification examination program, assess the adequacy of installed integrated bridge systems and verify that the ships' officers are properly trained in their operation and possible failure modes. (M-97-10)

As part of the foreign flag passenger ship control verification examination program, verify that the watchstanding procedures of ships' officers include the use of multiple independent means of position verification. (M-97-11)

The Safety Board also issued Safety Recommendations M-97-1 through -4 to Majesty Cruise Line; M-97-12 and -13 to STN Atlas Electronik GmbH; M-97-14 and -15 to Raytheon Marine; M-97-16 through -18 to the National Marine Electronics Association; M-97-19 and -20 to the International Electrotechnical Commission; M-97-21 through -26 to the International Council of Cruise Lines; and M-97-27 and -28 to the International Chamber of Shipping and to the International Association of Independent Tanker Owners.

The Safety Board is interested in any action taken as a result of its safety recommendations. Therefore, it would appreciate a response from you regarding action taken or contemplated with respect to the recommendations in this letter. Please refer to Safety Recommendations M-97-5 through -11. If you need additional information, you may call (202) 314-6450.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman