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A STUDY TO DETERMINE THE FEASIBILITY OF USING REMOTE SENSING TECHNIQUES TO PREVENT SHIP COLLISIONS WITH SELECTED DRAW/LIFT BRIDGES
Contract Research

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Final Report

A STUDY TO DETERMINE THE FEASIBILITY
OF USING REMOTE SENSING TECHNIQUES
TO PREVENT SHIP COLLISIONS WITH
SELECTED DRAW/LIFT BRIDGES IN GEORGIA

by

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Contract with

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State of Georgia

April, 1974

"The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Department of Transportation, State of Georgia. This report does not constitute a standard, specification, or regulation."
ABSTRACT

The collision of an ocean going freighter with the Sidney Lanier Bridge in 1972, and subsequent collisions between ships and bridges spanning the State's navigable waterways led the Georgia Department of Transportation to fund this study to determine if an electronic sensor can be developed to warn of an impending collision between a ship and a bridge before impact. It was concluded that a radar warning system could be designed and built that would diminish the possibility of future collisions with the Sidney Lanier Bridge, Brunswick, Georgia.

A radar sensor, computerized signal processor, ship's pilot display and bridgetender's display system for the purpose of collision avoidance is detailed in this report. This system would monitor the ship's progress during its approach to the bridge. The system displays location and speed information to the pilot. Should the ship leave a safe passage channel, the pilot would receive a warning, as would the bridgetender. Should the ship remain outside the safety channel for a given speed, distance, and time, a warning of impending collision would be issued by the system. The general design of the system would be applicable to most bridges in the United States.

Key words: Bridge-ship collision radar warning system
Bridge-ship collision detector
Radar collision detector
Computerized collision avoidance
Bridgetender's display
Pilot display system
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FOREWORD

This research program designated as Georgia Tech Project A-1586, entitled, "A Study to Determine the Feasibility of Using Remote Sensing Techniques to Prevent Ship Collisions with Selected Drawbridges in Georgia," was carried out by personnel of the Radar Division, Engineering Experiment Station, Georgia Institute of Technology, Atlanta, Georgia. The research was conducted under the general supervision of Dr. H. A. Ecker, Chief, Radar Division and Mr. J. L. Eaves, Manager, Radar Technical Area. Mr. E. F. Greneker served as Project Director. The program was supported by the Department of Transportation, State of Georgia, under GDOT Contract 6-73.

The authors express gratitude to Mr. A. C. Burnham, Director of the Traffic and Safety Department, for his help and advice. In addition, the authors acknowledge the assistance rendered by Mr. R. A. Graves, Project Monitor, and Mr. A. Z. Farkas and Mr. H. L. Tyner, of the Research and Development Bureau, GDOT.

During the data gathering phase of this program interviews were conducted with numerous persons associated with maritime operations in Savannah and Brunswick, Georgia. The authors express appreciation to those individuals for their assistance in providing information used in this program.
SECTION I
INTRODUCTION

Ten persons were killed when the Sidney Lanier Bridge, near Brunswick, Georgia, was rammed by the African Neptune, an 11,000-ton freighter, on November 7, 1972. The bridge was closed to vehicle traffic for seven months while repairs were being made to the damaged parts of the span. The SCL railroad bridge in Savannah has been struck by passing ships on two occasions; as a result, the railroad totally abandoned use of the bridge and subsequently, the U.S. Coast Guard condemned the bridge as a hazard to ship navigation. The Eugene Talmadge Bridge was struck and damaged this year by a passing barge loaded with concrete. The Sidney Lanier Bridge was damaged in another collision when a stolen shrimp boat struck the bridge fender system during 1973. This record of accidents verifies that bridges spanning the navigable waterways of Georgia are vulnerable to damage by passing ship/barge traffic, and that they are struck with some regularity. More importantly, a potential exists for additional loss of human life and damage to state property. This potential danger is particularly acute for the case of the Sidney Lanier Bridge.

This report presents the results of a study that was undertaken to determine if it is feasible to employ an electronic sensor for ship/bridge collision warning and avoidance, and for sounding an alarm to those on a bridge when conditions indicate that a collision may occur. In addition, the study has considered the possibility of employing a display system to alert the pilot aboard ship as to ship location with respect to the centerline of the river channel. The electronic sensor system also could
determine ship speed, and that information could be made available to the pilot. Thus, the probability of ship/bridge collisions would be diminished if real-time location and speed data were supplied to the pilot so that he could perceive existing conditions sooner than is now possible.

There are a number of sensor concepts that could be used to detect the location of a ship on a waterway, and there are various degrees of sophistication that could be employed in a given collision warning system. A simple system might be designed to sound an alarm when a ship crosses a defined channel/course boundary. A more sophisticated system might not only sound an alarm when a ship crosses a channel/course boundary, but also might automatically adjust the boundary to reflect the effect of existing conditions, such as tide levels, water currents, wind speed, and wind direction. A sophisticated system of this nature would require precise measurements of a ship's heading, speed, and position within the channel/course boundary, and real-time display of that information to the pilot such that collision avoidance/warning action may be taken when necessary. In the event of an accident or near accident, a sophisticated system could provide a record of the ship's course in the form of a punched paper tape or recorded magnetic tape.

The final design of a sensor system for ship/bridge collision avoidance/warning is influenced by numerous parameters, and as a consequence, this study has not only addressed the configuration of the sensor proper, but also has considered the effects of harbor and channel geometry, winds and tides, human factors, and the configuration of individual bridges.

The discussions presented in the following sections deal with numerous considerations associated with designing a bridge collision sensor
system. In addition, several possible design approaches with accompanying analyses are presented. However, before final design of a given system can be determined, a specific bridge must be selected and then the system design must be tailored for that particular bridge and its environment.
SECTION II
SELECTION OF BRIDGES TO BE STUDIED

A. Moveable Span Bridges in Georgia

The name and location of the 15 candidate bridges considered in the study are given in Table I. Additional information on the bridges is included in Appendix I of this report. Six of the 14 moveable span bridges have been eliminated as candidates, based on the results of preliminary analysis. For example, three of the bridges were eliminated because their moveable spans are inoperative, and this fact implies that only small craft pass under those bridges. A fourth bridge was eliminated because the moveable span is operated only under special Georgia Department of Transportation (GDOT) supervision. Two other moveable span bridges listed in Table I were eliminated because they are operated jointly by Georgia and neighboring states.

B. Consideration of Non-Moveable Spans

The Eugene Talmadge Memorial Bridge in Savannah is a non-moveable bridge that spans the Savannah River at a location where large maritime vessels pass with regularity. That non-moveable bridge was included in this study because of the potential collision hazard posed by large ocean-going vessels. Thus, a total of nine bridges (eight moveable span and one non-moveable span) in Georgia were considered as potential candidates for an electronic collision warning and avoidance system.

C. On-Site Inspection of Bridges

During December 1973, on-site inspection was made of each of the nine bridges located on the map given in Figure 1. In each case, various
<table>
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<td>Bascule Type High use</td>
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<td>11</td>
<td>Torras Causeway Toll, Back River, Glynn</td>
<td>Lift Span Daily use</td>
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<td>12</td>
<td>Savannah River, 5th St., Old SR 10, Richmond</td>
<td>Swing Style Inoperative</td>
</tr>
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<td>13</td>
<td>Savannah River, US 301, SR 73, Screven</td>
<td>Swing Style One-way bridge South Carolina operated</td>
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<td>14</td>
<td>Skidaway Island, Causeway</td>
<td>Bascule Type Frequent use</td>
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<td>15</td>
<td>Eugene Talmadge Memorial Bridge, US 17A Savannah Harbor, Savannah, Georgia</td>
<td>Non-moveable span</td>
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Figure 1. Map showing the location of the nine bridges considered for installation of an electronic ship collision warning system.
factors were noted relating to the bridge itself and its operating environment. In addition, interviews were conducted with the following persons to determine their opinions concerning cause, effect, and prevention of ship/bridge collisions.

**Savannah**

1. Capt. M. Hanna, Captain of "New York Maru"
2. Capt. W. T. Brown, Master Pilot, Savannah Pilot Association
3. Commander R. F. Bennett, USCG, Commander of the Port
4. Selected members of the tugboat "Savannah"
5. Sanford Ulmer, Savannah Port Authority

**Brunswick**

1. John N. Stubbs, Director, Brunswick Port Authority
2. Capt. Edwin Fendig, Chief Pilot, Brunswick
3. Fritz H. Torkeldsen, Jr., Bridge Supt., Moveable Span, Brunswick

The results of the field investigations indicate that an electronic sensor system for collision avoidance/warning would be extremely valuable for application to selected bridges in Georgia. The field investigation also identified problems in bridge safety that are unrelated to the electronic design study, and those unrelated problems are discussed in Section VII, entitled "Supplementary Findings."

**D. Final Selection of Bridge to Be Studied**

Based on the field inspections and subsequent analysis of all available information, the Sidney Lanier Lift Bridge, Brunswick, Georgia, was selected as the bridge requiring priority attention regarding ship collision avoidance. The Eugene Talmadge Bridge, Savannah, was ranked second in order of priority for the installation of a collision avoidance/warning
The primary reason that these two bridges are given high priority is the fact that both are exposed to the danger of collision with large ocean-going vessels to a much greater extent than are the other bridges considered in the study.

Economic considerations also were important factors in the bridge selection. The GDOT estimates the replacement cost for the Sidney Lanier Bridge to be $17,000,000. The additional loss of tourist dollars to the Brunswick economy through the loss of any part of this bridge was also considered. The GDOT estimates replacement cost for the Eugene Talmadge Bridge to be $20,000,000. The loss of this bridge would eliminate one of Savannah's main links with South Carolina. Debris from a collision and subsequent collapse of the bridge could conceivably block the river channel and bring all commercial traffic into the Savannah harbor to a halt.

Thus, potential damage that could be inflicted by large maritime vessels to either the Sidney Lanier or Talmadge Bridge, coupled with the economic loss to the respective communities led to selection of the two bridges as priority candidates for a collision avoidance/warning system. The other bridges are ranked with lower priority for such a system.

E. The Remaining Moveable Span Bridges

Although the other seven bridges are not subjected to the danger of collision with large ocean-going vessels, a fully loaded barge or dredge could inflict damage and endanger human life. An April 1973 GDOT study entitled, Report on Moveable Span Bridges, outlines a number of measures to minimize the dangers to motorists on or near a bridge, should the bridge be struck during passage of a watercraft. Those findings are presented in Appendix I. The primary safety recommendations in that report concern procedures for getting automobiles off the section of the bridge that
spans the waterway. The GDOT report suggests that vehicle traffic gates be located near the ends of the bridge. Thus, if no automobile traffic is allowed on the bridge, the only danger in a bridge/watercraft collision would be to the boat crew and bridge tender. While this procedure is not optimum for bridge protection, it does appear to be the most cost-effective approach to protecting human life when larger ocean-going vessels are not involved. Any electronic sensor design to be used with the Sidney Lanier Bridge also will be basically compatible for operation with the Talmadge Bridge and the six smaller bridges.

F. Elimination of Talmadge Bridge for First System Installation

The primary threat to the Talmadge Bridge is from large ships and barges. The support columns of the bridge are in shallow water, and they are vulnerable to certain river traffic. The Savannah Harbor pilots contend that a loaded ship, traveling at 5 to 10 knots, could penetrate the mud at the edge of the deep water channel and strike a support column. Although possible, this is considered an unlikely event. The overall height of the Talmadge span decreases the possibility that any point other than the columns will be struck by maritime traffic (although some of the larger container ships clear the bridge by only 5 to 10 feet on high tide). Thus, it is recommended that the bridge support fender system, scheduled for installation by GDOT, be considered as the first line of defense against ship collision with the Talmadge Bridge.

It is recommended that an electronic sensor for collision avoidance/warning be applied to the Talmadge Bridge only after the concept has been demonstrated with the Sidney Lanier Bridge. It is reasoned that the Sidney Lanier Bridge, with its unusual channel geometry, would serve as the best
test installation of a sensor/warning system. Thus, once a system is
developed for the Sidney Lanier Bridge, it should be applicable to the
other spans in Georgia.
SECTION III

SIDNEY LANIER BRIDGE

The Sidney Lanier Bridge is a four lane 4,471-foot span that connects Brunswick with US 17 and the Jekyll Island Causeway. It is located approximately 1,500 yards southeast from the mouth of the Brunswick dock area. The average daily traffic flow over this bridge is 14,000 vehicles. The lift span is operated approximately 4,000 times each year for watercraft ranging in size from large ocean-going vessels to shrimp boats. The moveable span is 295 feet long and it operates in lift fashion.

A. Brunswick Harbor Operations

The Brunswick Harbor, shown in map form as Figure 2, is a naturally protected harbor. The dock facility handles approximately 1.2 million tons of waterborne commerce each year. The depth of the Brunswick Harbor is a maintained 32 feet.

The average size of the large ocean-going vessels using the harbor is approximately 500 feet in length, with a beam of from 50 to 70 feet. The longest ship that used the harbor in 1972 was 630 feet in length. Its width was 90 feet. The weights of vessels using the harbor range up to 28,000 deadweight tons.

In 1972, 133 large ocean-going vessels required the services of the local harbor pilot. In addition, 419 large barges used the Brunswick River facility during 1972. Thus, accounting for both in-bound and out-bound traffic, a total of 266 passages under the Sidney Lanier Bridge were made by large ships and 838 passages were made by barges. These figures are typical of those experienced on a per-year basis during the last several years.
Figure 2. Brunswick Harbor, showing dock area in relation to the Sidney Lanier Bridge.
B. Channel Considerations

The waterways of St. Simons Sound, Brunswick River, Turtle River, Academy Creek, Terry Creek, and East River comprise Brunswick Harbor. The present improved channel is 32 feet deep and 500 feet wide at the sandbar at the mouth of the dock area. The channel narrows to 400 feet across and 30 feet deep from this point through St. Simons Sound.

The deep water channel in the Brunswick River extends from a point 2200 yards south of the US 17 bridge to the sea buoy, off the Brunswick coast. Only 3 nmi of this channel are of interest for the purpose of this study. The three-mile area of interest extends from a point in center channel, just south of Andrews Island, to a point in the center of the channel, south of Brunswick Point. Also considered is the channel area leading to and including the Brunswick Harbor area. The area described lies within the marked channel 1 nmi each side of the Sidney Lanier Bridge.

Ships approaching in the Turtle (Brunswick) River from the southeast make a straight approach to the bridge for a distance of approximately 1.8 nmi. As a consequence, very little maneuvering is done by ships approaching the bridge from this direction, and the maneuvering done is usually confined to minor course corrections. The critical part of navigating the channel occurs between the Sidney Lanier Bridge and the Brunswick Port Authority docks. Approximately 500 yards north-northwest of the bridge, the channel forms a "Y" intersection. The right fork goes to the dock area, while the left fork continues up-river. The angle formed by the intersection of the river and dock area channels is about 50 degrees. Thus, all large vessels entering or leaving the Brunswick dock area must
negotiate a 50-degree turn over a distance of less than approximately 4 ship lengths. It is during the performance of this maneuver by outbound ships that almost all problems occur that lead to potential collisions with the bridge.

The left fork of the intersection, just south of the dock area, extends northwest up-river well past Andrews Island. A point due south of Andrews Island is used as a turning basin for ships sailing out of the port on an ebb tide. (The reasons for this maneuver are explained in Subsection 2.) A sandbar extends well into the river just south of Brady Point. This sandbar also plays a part in river channel navigation problems for ships leaving the port.

C. Ship Docking Procedures

When a large vessel arrives at a point approximately ten miles southeast of the Brunswick Light, the harbor pilot boat meets the ship. The local harbor pilot boards at this point and proceeds to act as navigation consultant to the visiting captain. When the ship reaches a point approximately 1.5 nmi southeast of the Sidney Lanier Bridge, two 450 horsepower harbor tugs come alongside. The speed of the ship and tugs approaching the bridge will average 4 to 8 knots. Before the bridge is reached, lines for docking purposes are made fast to the two tugs. According to Chief Pilot Edwin Fendig, the tugs play no active part in control of the ship until the mouth of the Brunswick Port Authority dock area is reached. While it may seem advisable for the tugs to guide vessels through the bridge, they do not because they would have little or no control over the vessel, due to their limited size and 450 horsepower ratings. Thus, because of their size, the tugs would not attempt to control the ship
during passage through the bridge, and the only reason that they meet the ship south-southeast of the bridge is to make fast their docking lines before the ship reaches the dock area. After negotiating the 50° right turn into the harbor channel, the vessel sails under its own power to the harbor turning basin just northeast of Brady Point and west of the Brunswick dock area. The tugboats then rotate the ship around the center channel point. When the ship has been turned 180° and is headed back out toward the deep water channel and parallel to the dock, the tugs push the ship to the Brunswick dock area where the vessel is secured.

D. Sailing from Brunswick Harbor

The most serious threat to bridge safety occurs when a ship leaves the Brunswick dock area, headed to sea. This situation arises from the fact that the ship must make a 50° turn within a distance of less than one mile between the mouth of the Brunswick Harbor and the Sidney Lanier Bridge. A photograph of the harbor and bridge area is shown in Figure 3.

A ship leaving the harbor will use the services of the local harbor pilot and one or two 450 horsepower tugboats. The local pilot serves as a navigation consultant to the visiting captain. The pilot will issue all maneuvering orders to the crew from the time the ship leaves the mouth of the harbor until it reaches a point off the coast approximately 10 nmi southeast of the St. Simons Lighthouse. The tugs will be used in several ways, depending on tidal conditions.

1. Flood Tide Sailing

If the departure time coincides with the period of "flood tide,*" the ship will be moved from the dock to mid-channel by the attending tugboat(s) and the vessel will make a normal departure. From center channel,

*During the "flood tide" condition, the ocean tides are coming into the river. Thus, the incoming water serves to moderate the normal river currents.
Figure 3. Channel configuration between the Brunswick dock area and the bridge.
the vessel proceeds toward the bridge under its own power in a radial turn at a speed between 4 to 8 knots. The tugs do not follow the ship beyond the mouth of the harbor.

The lift span on the bridge is 295 feet wide, and is located approximately 500 yards from the intersection of the river and harbor channels. Thus, the ship must negotiate the $50^\circ$ turn, line up with the center of the lift span, and make all final steering corrections within a maximum of four ship lengths.

If excessive left rudder is applied during the turn, the ship could overshoot the bridge opening and strike the bridge north of the lift span. If too little left rudder is applied or if steering commands are misunderstood and right rudder is used, as in the case of the "African Neptune," the ship will strike the bridge south of the draw span. From the time that the ship leaves the Brunswick dock/harbor area until it passes through the lift span, numerous course corrections must be made in order to properly execute the $50^\circ$ turn. If any of these corrections are missed or executed improperly, the pilot must make an immediate compensating correction to bring the ship back into a narrowly defined trajectory. Thus, the sooner the pilot observes the effect of a course correction, the sooner a change can be made if a problem develops. It is not always easy for the pilot to determine that the ship is not at a proper point in the channel for a given point in time. Depending on location, his point of reference may be a structure or range light a mile away. His indication of the effect that the rudder is having may be the displacement angle of the bow referenced to his landmark. Thus, when the pilot makes the $50^\circ$ outgoing turn in the Brunswick River, he must "feel" his way up to and through the bridge.
If a developmental electronic system is designed to inform the pilot of the immediate effect of his course change, then the probability of collision with the bridge is lowered. Thus, any system designed as a result of this study should display to the pilot the ship's position with respect to center channel, and the vessel's speed. A system operating on this principle would serve to prevent collisions by furnishing the pilot with updated information of his course corrections and also feedback when his corrections are ineffective while making the departing 50° turn. Also, such a system could warn a bridge attendant and motorist if a collision appeared probable.

2. Ebb Tide Sailing

When a vessel sails on the ebb tide,* the departure techniques may differ from those used during flood tide. A large vessel sailing on the ebb tide, in most instances, will not be taken to sea directly through the bridge. Instead, the ship with accompanying tug(s) will emerge into the river from the harbor channel. The pilot will then turn the ship into the main river channel and proceed up-river to a point south of Andrews Island. The ship is turned 180° in the channel with the help of the tugboats. Once turned, the ship is headed down-river. The bow is lined up with the center of the channel and the center of the bridge lift span. After being turned, the ship proceeds through the bridge. It is generally true that only small course corrections are necessary to keep the vessel on the centerline of the main channel when this technique is used.

*When the tide is going out, during the ebb-tide phase, the river is rapidly being drained of the water that flowed upstream during the flood and high tide cycle. Thus, the river outflow currents are at their maximum velocity during the ebb-tide condition.
Not all ships sailing on the ebb tide are turned in this manner. The determining factor as to which departure method will be used is based on ship size. Deep draft vessels present an almost broadside profile to the river when they emerge from the dock area. The force of the river current on the ships during ebb tide could sweep the larger vessels down river at a faster rate than the vessel could negotiate the 50° turn. Under this condition, the ship would probably impact the bridge in a broadside position. Thus, all larger ships are turned in the river. A smaller ship, with a tighter turning radius and less hull surface area may be able to sail on the ebb tide from the Brunswick dock without utilizing the river turnaround, but the final decision as to departure procedure rests with the local river pilot.

It would be preferred to turn all ships up-river for bridge safety. However, this maneuver requires from 45 to 60 minutes to complete, and the portion of the river where the turn is executed has no maintained turning basin. Thus, visiting captains are reluctant to allow the pilot to perform this procedure except in the case of ebb tide sailings, and then, only if the vessel is one of the larger ships using the Brunswick Port.

E. Steering and Control of Large Ships

Large ships, by virtue of their size, are not highly maneuverable. Each ship has a design turning radius that cannot be reduced at will. The turning performance is further degraded when the current vectors of the surrounding water are aligned with the thrust vectors of the ship. The rudder size on the larger vessels requires that hydraulic systems be used to relay steering commands from the wheel to the rudder actuator. There are no direct mechanical linkages between the wheel and the rudder.
Thus, the wheel can be positioned to show a given degree of rudder before the rudder actually reaches the specified offset. In the case of large course corrections, the wheel may reach an indicated offset in the order of five to six seconds before the rudder. Thus, the ship's rudder may not fully move to the desired position until some time after the wheel is thrown.

Rudder effectiveness is determined, in part, by the degree of offset and the speed of the vessel. In short, the greater the water pressure against the surface of the rudder, the faster the ship can be made to respond to the steering command. Stated in terms of speed, the faster the ship moves, the more effect the rudder has for any given degree of offset.

In the open channel, speed is desirable to give the ship optimum handling characteristics. However, the faster the ship travels, the longer it will take to stop in the case of human or system steering failure. Thus, when a ship sails from the Brunswick Harbor and makes the 50° turning approach to the bridge, a paradoxical situation occurs. The ship must maintain a degree of speed for maximum rudder effectiveness while making the turn, yet the speed cannot be greater than the velocity that would allow the ship to stop should proper alignment with the bridge opening fail to occur. There is a very narrow range of speeds that should be maintained to ensure the proper balance between maneuverability and safety. Thus, any system designed to aid the pilot in avoiding a collision with the Sidney Lanier Bridge should have the capability of displaying the ship's true speed to the pilot.
It should be recognized that there is a "point of no return" reached by every ship passing through the Sidney Lanier lift span. Once this point is reached, the vessel is committed and the ship's anchors and reversed engines cannot stop the ship in the distance remaining to the bridge.

No electronic system can take the place of the pilot's judgement in determining where the ship should be in the channel or at what speed the vessel should travel for any given point in time. However, additional information supplied to the pilot as to his speed and his location with respect to the channel centerline will aid in making quicker decisions. An electronic system that gives the pilot real-time location and speed information also gives the pilot an earlier indication that the ship has not responded to a course correction. The sooner it is recognized that a ship has left the proper position in the channel for a safe passage, the sooner corrective action can be taken. Thus, any electronic system that gives the pilot real-time feedback on the effects of his course changes could qualify as an electronic bridge collision/warning system. Any system with these capabilities could also warn motorists, the bridge tender, and others that a collision was imminent if corrective measures were not taken by the pilot. A system of this nature would also have the capability of recording each ship's river track for the purpose of documenting the ship's entire water track, should a maritime disaster occur.

There are certain primary capabilities that all electronic bridge collision/warning systems should have, and there are other capabilities that must be added to any sensor used on the Sidney Lanier Bridge, due to the unique 50° turn required to navigate the bridge from the Brunswick
Harbor mouth. The desired capabilities that should be considered when designing a bridge collision avoidance and warning system are discussed in the following section.
SECTION IV
DESIGN CRITERIA

The electronic design of a collision/warning system should meet certain basic criteria regardless of where it will be installed in the state. Once a good basic design is developed the system can be modified to suit the non-standard requirements of the individual bridges.

A. Basic Capability

A system designed for the purpose of supplying bridge collision/warning information must have the ability to locate the approaching vessel's position in the waterway. Once located electronically, the speed of the vessel can be computed by determining the time taken to travel to another location over a known distance. With position, speed, and heading determined accurately, a prediction of the ship's position at a future time can be made. (Any prediction of this nature automatically assumes that the ship will maintain the heading and speed registered during the sample interval.) If a memory element is added to the system, the ship's location in relation to a "safe passage corridor" can be determined.

Thus, if a system has the ability to compute a ship's location, speed, heading and relationship to a "safe passage corridor," it also can warn of an impending collision with a known fixed object. All of these features should be the design goal for any system installed on the state's waterways.

B. Display System

It is desirable that location, speed and trajectory data on each passing ship be presented to the human users in a meaningful form. The
display device should be as simple as possible and yet possess the capability of displaying all of the information available. It is possible that the sensor system could employ two types of displays, one for the pilots use and the other for the bridge tender.

It is desirable that the bridge tender have a display to warn him when an approaching ship leaves the channel boundary. The primary purpose of the bridge tender's system would be to warn him and others on or near the bridge that a collision may occur. Also it is desirable that a second display system be used to provide information to the pilot about his location in relation to center channel and his closing speed with the bridge. Both display systems would receive data from the main sensor unit.

1. Bridge Tender's Display

The data processed for the benefit of the bridge tender would be for warning purposes. The first level of warning might call the bridge tender's attention to the fact that the ship had momentarily moved past some predetermined channel boundary. The second warning might indicate that proper corrective measures had not been taken and should the vessel continue its course, collision is imminent. The third level of warning would require that the bridge tender and all motorists evacuate the bridge area.

Such a system would be useful in various situations. For example, should a ship carrying explosive cargo strike the bridge, there may be no danger to motorists from the initial impact, particularly on bridges.
where motorists are kept off the active spans during bridge operations. If however, the cargo were to explode after initial impact, any early warning given that the ship was going to hit the bridge could serve to save lives.

2. Pilot's Display System

The purpose of the pilot's display system would be to aid him in safely navigating the channel, thus decreasing the chances of his ship colliding with the bridge. The pilot's display system would alert him to the changes of the ship's position in relation to the channel centerline. The ship's closing speed with the bridge could also be displayed to the pilot.

The designer of the pilot's display should keep several facts in mind: (1) the pilot cannot always be expected to take time to rig special equipment each time that he goes aboard a visiting ship, and (2) the use of the display should not require the pilot to change his field of view greater than \( \pm 20 \) degrees from the center of the bow. It is important that the pilot not lose his visual reference point of the bow and the horizon due to a requirement that he continually look away from the forward direction to consult his display. Thus, the display must be located within the normal field of view of the pilot.

When the approach to the bridge is straight and the draw can be seen from the channel, the display can be located on the bridge. If the channel is not straight and there is a turn near the bridge, two separate display systems may be necessary; one mounted on the bridge and another displaying identical information located across from the last bend in the river.
SECTION V
CANDIDATE SENSOR SYSTEMS

Four types of sensor systems were chosen as candidates to meet the
criteria outlined in Chapter IV. In addition, two types of display
systems were considered for use with the candidate sensor. The sensor
systems considered are (1) a time of arrival radio location system,
(2) a television sensor, (3) a high resolution sector scan radar sensor,
and (4) a LASER rangefinder system. The candidate display systems chosen
were a "billboard" display and a "heads up" video projection system.
The principle of operation of each of these systems is discussed in the
following paragraphs.

A. Time of Arrival Radio Location System

A system that utilizes time of arrival measurements of a transmitted
signal for deriving distance and location requires at least three receivers
and one transmitter. If the transmitter location is unknown, it is possi-
bile to use time of arrival of the transmitted signal at the receivers to
calculate a location for the transmitter. A diagram showing how such a
system would be installed on the Sidney Lanier Bridge is shown in Figure
4.

Receivers A, B, and C would be located along a common baseline, in
this case, the bridge. Receivers A and C would be located equidistant
from Receiver B. If the transmitter is located at some point along line
D, it can be seen that the pulse from the transmitter will be received at
the same time by receivers A and C. Thus, by measuring the time of
Figure 4. Hypothesized deployment of time of arrival location system on Sidney Lanier Bridge.
arrival of the transmitted pulse at receivers A and C and determining that the arrival times were equal, one could conclude that the transmitter was located somewhere along line D. However, without information from receiver B it would be impossible to determine where the transmitter is located on line D.

Since receiver B lies midway between receivers A and C, the time of signal arrival at receivers A and C can be compared to the time of arrival at receiver B, and as a result, the location of the transmitter in relation to the bridge can be computed.

In a three-receiver time of arrival system, the location of a transmitter can be determined automatically. However, it must be known in which 180° segment of coverage the transmitter is located. In short, one must know from which side of the bridge a given ship is approaching. The use of additional receivers could eliminate this problem, but since the bridge tender knows the side of the bridge that a given ship will approach, this information can be given to the system manually.

In a typical operating sequence, the pilot would carry a small radio transmitter on board ship. He would place the unit in a clear area on or near the bridge of the ship. The highway bridge tender would specify the direction of approach to the system. Location would be carried out automatically from that point in time.

B. Television Location System

A television location system would locate a vessel based on the ability of an electronic processor to determine the ship's location in the viewed scene. The camera used would be mounted near the top of one of the
support towers on the bridge. The camera would be mounted in this position to allow broad coverage of the area and also to form an angle unique to a specific location in range to any point in the waterway.

A standard television camera scans 525 lines every full frame. The scan goes from left to right across the scene starting at the top of the picture and moving down one line at a time. The scan always moves from left to right starting again at the left side of the scene after dropping to the next line. The human eye does not perceive this scan pattern on a TV picture because the complete 525 line pictures are painted at a rate of 30 per second.

An electronic processor can determine the location of a target of interest at any time by determining the X and Y coordinates of objects to be located in the scene. If there are no objects except the specific target in the scene, the task of recognizing the desired target is a simple matter of determining the X and Y location of the target within the 525 lines scanned. However, in the case of locating a ship on the waterway approaching the Sidney Lanier Bridge, the problem is complicated by the fact that the background details of the river may stand out to the processor greater than the ship itself. Thus, some form of enhancement must be added to the desired target to make it stand out over all other targets.

The recognition problem could be solved by requiring that the pilot carry on board a small high intensity strobe, very similar to a photographic unit. The strobe would be placed in any visually unobstructed area on or near the bridge of the ship. The flash duration of the strobe must be at
least 1/30th of a second to ensure that it would be visible during any one scan of an entire frame. Thus, synchronization between the strobe firing and the scan period is not necessary. The repetition frequency of the strobe on board ship would be totally dependent on the rate at which location information would be updated for display and warning purposes.

C. Instrumental Shore-Based Radar

Radar is an acronym for Radio Detection And Ranging. Thus, by name alone it is implied that radar has the ability to determine the location of objects at unknown ranges. Location of an object at an unknown range and azimuth is accomplished by a radar set in the following manner. The transmitter generates a pulse of radio frequency energy, and this energy is propagated from an antenna with a very narrow beam. When the pulse or energy packet strikes the object a small portion is reflected back to the radar. The antenna captures the small amount of returned energy and feeds it to the receiver. The receiver amplifies the pulse to a level that can be displayed on an indicator or used to drive processing circuits.

The distance between the radar and the objects of interest is determined by measuring the time taken for the radar pulse to travel from the transmitter to the object and back to the radar receiver. For all practical purposes, the radar wave propagates at the speed of light, which is approximately 186,000 statute miles per second. At this speed, the radar signal will travel one mile each 5.38 millionths of a second. Since the radar signal must make a trip to the object and return the period is doubled. Thus, if a delay of 10.76 millionths of a second occurs between the time that the radar pulse was transmitted and the echo is received, the range of the target is one statute mile.
The target's position in azimuth is determined by knowing where the radar antenna is pointing when the echo is received. The antenna beam at radar frequencies can be directed much like a searchlight. The narrow searchlight beam illuminates the object with radio frequency energy only while the antenna is pointed in the direction of the object. Thus, if range and azimuth angle are known, then by definition, the location of the object is known as well.

The ability of a radar to locate an object in range and azimuth makes it worthwhile to consider this type device as a primary sensor system for use with the bridge collision/warning system.

In an application such as tracking ships through the Sidney Lanier Bridge, the radar would probably not be located on the bridge itself. Instead it might be located at Point A in Figure 5. From this vantage point, the radar would have a clear view of the entire river channel from the mouth of the Brunswick dock area to the bridge. If it were located above existing terrain there would be little chance of blockage by cars, trucks, or man-made objects in the vicinity of the tower. In order to cover the area of channel between the dock area and the bridge, the antenna would be required to operate in the sector scan mode and cover an angular sector of approximately 90 degrees.

In actual operation, it is envisioned that the radar would be placed in operation only at times when larger ships are passing through the bridge. The radar would track the ship as it left the Brunswick dock area until it reached the bridge. The radar would supply information concerning the
Figure 5. Proposed location site of high resolution tracking radar system.
location of the bow and the stern of the ship. This information would be
fed to a radar signal processor. The output of the processor would in
turn supply data to the display system as to the ship's speed and location
with respect to the center of the channel, and sound an alarm if the ship
posed a danger to the bridge.

D. LASER Range Finding System (LIDAR)

A LASER rangefinding system would operate in much the same way as the
radar system. The major difference being that the laser transmits pulses
of light energy, whereas the radar transmits pulses of radio frequency
energy. The pulse of light travels to the target, strikes the target and
a small portion is scattered back in the direction of a photo detector
located near the LASER. The arriving pulse or packet of photons strikes
the sensitive area of the photo detector and causes electrons to be
"shaken loose" in the photo detector tube. The electrons are attracted
to the cathode of the photo detector causing a small current to flow.
This current is amplified and the output is applied to an indicator or
processor.

Just as in the case of radar, the range to the target is determined
by the time taken for the LASER pulse to travel to the target and back.
Since radio waves and light propagate at the same speed, it requires
10.76 millionths of a second for the pulse to make a round trip of one
statute mile.

Azimuth bearings can be determined much more accurately with a ruby
LASER ranging system than with a radar system. The coherent LASER pulse
does not spread the same diameter as a radar beam for a given distance in
range. Thus, depending on the radar antenna size, the beam may spread
100 feet.
The importance of azimuth resolution is realized when the problem of bow and stern location is considered. An important parameter of the system is its ability to determine where the bow of a ship begins and where the stern ends. If the radar azimuth cell (beam diameter) is 100 feet across, then the starting point of the bow can be determined within approximately 100 feet. The LASER, with a 10-foot beam width would allow the determination of where the bow begins with an accuracy of approximately 10 feet. Unfortunately, extreme resolution has its disadvantages in this type application. If the angular cell is only 10 feet in diameter (horizontal and vertical) at one mile the slightest misalignment could cause the beam to miss the ship entirely. There are ways to overcome this and other problems that are inherent to LASER range finding techniques, at the expense of increased complexity and associated cost.

E. Signal Processing Systems

In order for the information received from the sensor to be useful, it must be processed in an appropriate manner. The signal processor takes range and angle data supplied by the sensor, and applies this information to a number of logical tests. First, the processor compares the location of the ship to a predetermined set of channel boundaries. The channel boundary data previously stored may take the form of a numerical value that represents the number the sensor would generate if the ship were in the center of the channel. Thus, the first test an incoming set of data may undergo is a comparison between the known center channel value and the value generated by the sensor detecting the ship's location. If
the numbers were equal, then the display would show that the ship was in
the center of the channel. When the number is higher than the number in
memory it could be an indication that the ship is to the right of center,
while a low indication may show the ship to left of center.

The distance the ship moves from center channel can also be determined.
Such information would be the basis of the data displayed. The processor
could determine the ship's closing speed with the bridge by storing the
position of the ship at point \( X_1 \) in time in a memory element. After a
measured amount of time the new location of the ship \( X_2 \) could be compared
with the old value. Because the time and distance traveled would be known,
speed in nautical miles per hour or knots could be determined. Thus, the
processor has the ability to take the output from any of the four sensors
discussed above and convert their numerical outputs into meaningful data
for use by humans in the form of a display.

**F. Display Systems**

An illustration of the type display system which might be used with
the sensor is shown in Figure 6. The yellow light in the center of the
array would represent the center of the channel while a set of blue lights
on each side would represent an increment of finite distance from the
channel centerline. As the ship proceeds toward the bridge, the pilot
would see all lights lit on the display. Assuming the ship were 50 feet
left of center channel, the pilot would see the second light left of
center blinking. If course corrections are made and the ship goes cross
channel to the right, the blinking light would step across the continuously
lit panel, thus signifying the ship is within 12.5 feet of the increment
Figure 6. Proposed pilot display system.
designated by the blinking light. Discussion of two possible forms for the panel display follow.

(1) "Heads up" display

The heads up display is a projection system developed for use in aircraft instrument systems during critical maneuvers when the pilot must be looking straight forward. During such times the aircraft pilot cannot look down into the cockpit to consult indicators monitoring critical aircraft parameters. Instead the "heads up" display system projects the data onto an area of canopy that has a special partially reflective coating. The area of coating is generally just below the pilot's field of view when he is looking straight ahead. Thus, by looking slightly down from center canopy, the pilot can ready his "heads up" display without losing the general location of his point of reference ahead of the aircraft. If necessary, such a system could be used to display speed and channel location to the ship's pilot.

A shore based telemetry transmitter would send the output of the signal processor to a belt clip receiver worn by the pilot. Upon his arrival on the bridge of the ship the pilot would stick a partially reflective piece of plastic on the ship's bridge window at the location where he will stand. The small projection unit could be worn on his head in much the same manner as a miner's lamp. Thus, both hands would be free and by glancing slightly up the pilot could see the channel location and speed display reflected on the window. Such a system would not require the pilot to lose his visual reference point ahead of the bow.

(2) Billboard Display System

The alternative to the "heads up" system would be the use of high intensity lights in a full-size display system. The center channel
location system would consist of a row of lights mounted horizontally across the support. The speed readout could be a single, 7-segment display device capable of displaying any number of 0 thru 9, and could be calibrated in miles per hour or knots. The display size should be large enough to permit recognition from distances of one mile. If the billboard display system were used, two units would be required, as shown in Figure 7. One unit would be mounted on the lift portion of the bridge. The yellow center channel marker could be located at the center channel point. However, care should be taken not to mount the array behind the standard navigation range lights on the bridge. The speed readout could be mounted above the channel marker.

The second display would be located to the west of the south end of the bridge. The necessity of a second display results from the fact that when the ship leaves the dock area, the center of the bridge is 50° to the left of the pilot's field of forward vision. It is important that he look down the center of the bow during the turning maneuver. Thus, the need for two displays is likely.

The pilot would use the display west of the south end of the bridge, while emerging from the dock area until reaching a point halfway through the 50 degree mid-river turn. Halfway through the mid-river 50° turn, the pilot's field of view would shift to a point near the center of the bridge. At this point, he would use the channel display mounted in the center of the bridge itself.

G. Bridge Tender's Display

The display system used by the bridge tender would be a miniature version of the pilot's system mounted on a panel in the control room on
Figure 7. Proposed location of entire system in relation to bridge.
the bridge. The ship's closing speed would be displayed on a 7-segment display and a channel display would be mounted in a panel in some convenient location. Thus, the bridge tender would have access to the same information as the pilot. An additional feature would be available to the bridge tender. The signal processor would sound an alarm when the ship poses a danger to the bridge. A second alarm would be sounded if the ship reached a point that collision was imminent. A plan of action could be developed by GDOT to warn motorists based on the two levels of warning available to the bridge tender.

H. Fail Safe Warning

It is important that all users have confidence in the system. Therefore, the system must have a built-in failure detection mode to shut the system off if failures occur. It is important that the system be off entirely rather than possibly providing incorrect information if failures occur.

Test targets would be placed at known locations on the nearby shore area. The signal processor would continuously check the known location of these targets against the location information provided by the sensor. If any of the known targets were found to be yielding erroneous data the system would automatically shut down. The bridge tender would be signaled that such an action had occurred and that repair was necessary.

I. Liability for System

There is a question of who will be responsible if the system is installed and a collision occurs because of a malfunction. The unofficial
opinion of Commander R. F. Bennett, Commander of the Coast Guard District for both Brunswick and Savannah, is that if the pilots were not required by legislation to use the system then there would be no liability to the state of Georgia. If the system were operated as a private aid to navigation, then the pilots could choose to use the system only if they wished to do so. Commander Bennett's opinion is unofficial and before proceeding to display the pilot's information the liability involved should be determined by the State Attorney General's Office.

The liability aspect does not extend to a warning system for the bridge tender. Thus, the entire system minus the pilot's display, can be built, installed, and tested without any liability considerations. If during the period it should be determined that the state must share liability if information were displayed to the pilot, this phase of the project could be abandoned. The bridge tender would still have a warning system for impending collisions with the bridge, which would be most beneficial in itself.

J. Final System Selection

Although four sensors and two types of displays have been presented as possible candidate systems, one system must be selected for final application. The television and time of arrival sensor systems require that the pilot carry an emitter on board. Thus, these systems are eliminated as final candidates because the ideal system should require no interaction on the pilot's part. For the same reasons, the "heads up" display system is rejected for this application. It should be pointed out that while not applicable to the immediate problem, all systems
mentioned may have a place in similar applications at other bridges over Georgia and other U. S. waterways.

The LASER can give excellent azimuthal information, but because of critical alignment requirements there may be times when it could not properly locate the ship. More importantly, however, the LASER is an optical device. Fog, and even salt deposits on the optical window of the LASER sensor housing can degrade its operation. Designing a LASER system to overcome these problems is possible, but since radar is a proven system for use in this application with superior all-weather capabilities, it is suggested that radar be used as the primary sensor in this program.

Thus, the system suggested to be used in a trial application with the Sidney Lanier Bridge would consist of (1) a land based sector scan radar system (2) a radar signal processor (3) a bridge tender's display and warning unit and (4) a paper tape punch unit to record permanently the channel track of each large ship approaching the bridge from the harbor and (5) two billboard display units (if decision of liability is favorable). The proposed system is discussed in the following section.
SECTION VI

DESIGN FOR A BRIDGE APPROACH
AND GUIDANCE RADAR FOR SHIPS

The detailed design approach of a radar system for assisting in guidance of ships in narrow waterways and bridge approaches will be discussed. The radar system consists of the radar sensor, the radar signal processor, and display system.

A critical consideration in the design of the radar sensor is the location of the sensor. It is desirable to locate the sensor such that it looks across the shipping channel rather than along the channel. Such a location exploits the higher range resolution capability compared to angle resolution capability of conventional radars. Figure 8 shows the shipping channel in the vicinity of the Sidney Lanier Bridge and Brunswick Harbor, and a desirable location for the radar sensor. It might be desirable to locate the antenna for the radar 30-50 feet above ground to maintain line-of-sight conditions at all times to ships to be tracked.

The radar sensor must be designed to acquire the range and angle information of ship locations at frequent intervals in time. The requirement on accuracy of ship's speed determination is an important consideration in the sampling rate of the radar sensor. The antenna must be designed to provide suitable angle resolution to identify the bow and stern of the smallest ships of interest. The pulsewidth of the radar transmitter and the bandwidth of the receiver must be selected to provide suitable range resolution of the smallest ships of interest, and location of the ship relative to the proper shipping channel.
Figure 8. Location of the radar sensor and scan area for tracking ships.
The radar signal processor must convert the radar signal information into a form useful to drive a display for a bridge attendant and ship's pilot. The radar with proper coding yields only data of location and speed of objects, and it remains for a processor to apply rules and logic to determine the qualities of the information, such as safety or danger, which are needed for the displays. Depending on the complexity of the rules and logic in determining safety or danger, the processor may be simple or complex. It appears desirable to consider a small mini-computer in the case of the Brunswick Harbor, due to the number of variables which may require analysis. There is a possibility that variables such as wind speed direction and river current direction will require monitoring. This situation would mean sensors, in addition to the radar, would provide inputs to the processor.

Many additional considerations can complicate the design of the signal processor, but it is the goal of any design to provide only the needed capability so that the solution is cost-effective. A detailed tradeoff analysis is important to achieving this goal.

The display system has been previously discussed. The flashing lights and seven-segment numeral display will be considered as the destination for information processed by and transmitted by wire from the signal processor.

A. Radar Sensor Design

The radar sensor consists of a scanning antenna, a pulse transmitter, and a superheterodyne wideband receiver. Video signals from the receiver will be supplied to the signal processor discussed in the next section.
As shown in Figure 8, the indicated desirable location for the sensor would permit ships of interest to be viewed by radar at ranges no more than about 3,000 feet. This maximum range would represent the worst case conditions for both radar detectability and angle resolution.

Under the assumption of the smallest ship of interest being 50 feet in beam by 300 feet in length, the angle and range resolution requirements are defined. As seen in Figure 8, the ship is almost always broadside to the radar, which means the resolution along the length of the ship will depend on the antenna beamwidth, while the resolution in width of the ship will depend on range resolution (pulsewidth). An antenna beamwidth of 2° results in a resolution cell size at 3,000 feet of 105 feet, thus resolving a 300-foot long ship into three cells. A transmitter pulsewidth of .05 microseconds (μsec.) results in a range resolution cell size of 25 feet, thus resolving a 50-foot wide ship into two cells. Therefore, the smallest ship of interest 300 feet by 50 feet would result in 3 by 2 cells of radar information, which should be sufficient for the signal processor.

Before final parameter selection, a more detailed analysis must be performed to determine the data requirements of the signal processor. If more resolution is indicated, then a smaller beamwidth and/or smaller pulsewidth will be selected.

In the interest of satisfying the system requirements without involving high risk technology, the initial selection of frequency of operation is 16 GHz. To operate at a higher frequency poses some problems in obtaining suitable hardware for the transmitter and receiver at a reasonable cost and with high reliability. To operate lower in frequency sacrifices the advantages of short wavelength, 0.738 inches, which eases construction
requirements on the antenna size. Over a half-mile range, 16 GHz should yield very good all-weather operation (no severe rain attenuation).

The operating frequency of about 16 GHz (exact frequency must be determined before final commitment to the system in negotiations with the Federal Communications Commission) leads to an antenna diameter of 27 inches. This value is based on good antenna sidelobe design.

The receiver signal bandwidth is determined by the transmitted pulsewidth; in this case, .05 µsec. The bandwidth for good sensitivity and range resolution should equal the reciprocal of the pulsewidth; thus, the bandwidth should be about 20 MHz. This bandwidth will permit 25-foot range resolution with minimum noise degradation. The present state-of-the-art in receiver technology should permit the selection of a microwave receiver with a 15-dB noise figure at 16 GHz.

The reflectivity or radar cross section of a small freighter has been determined to be about 140 square meters in previous research studies. The resolution being considered in this design would divide the freighter into six adjacent cells. If the reflectivity were uniformly distributed among the six cells, the radar cross section of each cell would be about 23 square meters. For satisfactory detection, each of the cells or separate targets in the radar sense, should be detected with at least a 10-dB signal-to-noise ratio.*

All of the factors which influence the detection capability of a radar have now been identified, and parameter values have been selected, except for the requirement of radar transmitter power output. Now, from

*That is, the return signal from the ship should be a factor of 10, i.e., 10 dB, greater than the receiver noise.
the standard radar range equation, the transmitter output power can be determined. The form of the range equation used is given below, and the parameters which help define the transmitter power are listed.

\[ P = \frac{\text{SNR} R^4 B F K}{G^2 \lambda^2 \sigma} \]

SNR: signal-to-noise ratio = 10
R: radar range = 0.5 nmi or 914.41 meters
B: receiver bandwidth = 20 MHz
F: receiver noise figure = 32 (15 dB)
G: antenna gain = 7500 (27 inch diameter)
\( \lambda \): radar operating wavelength = 1.87 centimeters (16 GHz)
\( \sigma \): radar cross section = 23 square meters
K: scale factor = 0.935

Substitution of these parameter values into the equation results in a power requirement, \( P \), of 0.083 watts. The use of a one-watt transmitter would yield a safety factor of 10, and it would be possible to satisfy the one-watt power requirement at 16 GHz with a high reliability transmitter.

From Figure 7, it can be seen that about a 90° sector must be searched by the radar to follow ships from the vicinity of the dock to the bridge. It has previously been stated that the ships travel between 4 and 8 knots approaching the bridge. It is desirable to scan the antenna past the ship being tracked at least each time the ship moves to a new angular resolution cell. For the ship located at the maximum range of 3,000 feet, it will move the 105 feet (one angle cell at 3000 feet) in 7.9 seconds. Thus, the antenna must rotate at 7.6 revolutions per minute (RPM) to scan
past the ship every 7.9 seconds. A value of 8 RPM is a realistic value for a scanning antenna only 27 inches in diameter.

Clockwise rotation of the antenna would result in detection and tracking of the ship nearest the bridge first, in cases of more than one ship. If it were necessary to track more than one ship at a time, the ship nearest the bridge is most important probably, and clockwise scanning would ease the signal processor requirements of identifying the ships.

B. Signal Processor Design

The signal processor will obtain its inputs from the radar sensor and convert data to a format suitable for transmission by wire to the displays located on the bridge. The input data will be video signals which are normally routed to a cathode ray tube display. In the case of an unattended automatic detection radar system, the signal processor must make the decisions that a radar operator would normally make.

In the system under consideration, the processor must determine within the resolution limits of the radar sensor (25 feet in range and 105 feet in angle at 3000 feet), the position of the ship being tracked and decide if the position is (1) safe, (2) potentially dangerous if not corrected, or (3) dangerous - alarm to evacuate the bridge. Naturally, more levels of danger could be used if needed, but the logic requirements can be defined with the three categories mentioned. This information is most important, but it may also be advantageous to give an indication of position information in terms of the safe channel to the pilot aboard the ship. This information, if supplied in a useful way, should assist the pilot in approaching and making the 50° turn prior to approaching the bridge. It is likely that this information would help prevent dangerous conditions developing near the bridge.
The volume of data from the radar sensor that must be processed can be seen by scaling the 90° sector of interest into a rectangular range-angle diagram, as shown in Figure 9. The range information inside a range of 2000 feet is not shown because it is not needed in the system, and would be gated out to simplify the processor. The same argument holds for range information beyond 3500 feet. In fact, the only range information needed by the system is within the navigable waterway, and is shown by the lines bordering the shaded area. The dashed line through the shaded area represents the center of the main channel and the desired track of ships. Slightly above the dashed line near the center are six resolution cells, more darkly shaded, which indicate the shape of a ship if this were a conventional radar display.

It is necessary to determine the decisions which a human radar operator would make, and develop a sequence of steps to follow to arrive at a decision of safe or dangerous to measure forward speed, and to measure distance between the ship and the center of the channel. All of this information might be derived by position information only. However, if additional information is needed such as wind speed/direction and river current speed/direction, this information would be included in the decision process for simulating a radar operator.

The total number of radar resolution cells in the lightly shaded area is about 1000. This value represents an array of data that must be processed; therefore, a small mini-computer for the processor is a possibility. The advantages of a mini-computer over a specially designed processor are that development of the computer program offers greater flexibility in design and development time would be less. The design (computer program)
Figure 9. The 90-degree sector of interest scaled into a rectangular range-angle diagram.
could be developed on another mini-computer and debugged, then the program could be transferred to the processor computer. The design could be developed with the best available information, and later, after the system has been in use for a time, improvements in the design could easily be made. Also, current relatively low costs of mini-computers make them attractive from an economy viewpoint.

Initially, the design should be based on a system that will track a single ship at a time. The data from the radar sensor would be simple signals to turn on lights and indicate conditions of safety and distance between the ship and channel centerline. The processor would be located in a small building on the ground below the radar sensor, which would be located on a 30-50 foot tower. The output from the processor would be transmitted by wire to control the lights making up the display for the bridge attendant as well as the display for the ship's pilot.
SECTION VII
SUPPLEMENTARY FINDINGS

During the on-site inspection and the interview phase of the project, other aspects of bridge safety were brought to the attention of the authors. No effort was made to confirm the degree of validity of the problems, nor has there been any attempt to assess the impact the suggested solutions would have on the problems. However, because bridge safety could be affected by some aspects of these findings, these reported problems are presented in this section for evaluation by the Georgia Department of Transportation.

A. Unrelated Findings Concerning the Talmadge Bridge, Savannah, Georgia

1. The members of the Savannah Pilots Association are concerned with the fact that the support columns of the bridge are exposed to river shipping. The north support was struck earlier this year by a concrete barge with minor damage occurring. The pilots contend that a large ship with an exaggerated bow flare and some speed could strike the supports, even though they are not in the deep water channel. They theorize that a fully loaded ship traveling at 5-8 knots would penetrate the mud walls of the river channel. The extended distance of the bow overhang, added to the channel penetration distance, would place the bow in contact with the bridge, inflicting damage to the structure. Thus, it was their request that a fender system be placed around the two support columns closest to the river channel.
2. The Savannah pilots are concerned about the possibility of explosion when tankers pass under the bridge. They cite instances of persons throwing fireworks off the bridge during their passage. The fireworks are purchased at "Looney Luke's Fireworks Stand," approximately one mile north of the bridge at the South Carolina State Line. In addition, motorists dropping cigarettes from their automobiles are a threat to the tankers passing under the bridge. The center span of the bridge is constructed of steel mesh. Thus, all cigarettes and other small objects dropped out of automobiles over the channel fall into the river below the bridge.

3. Although the Talmadge Bridge is not a draw span, the Savannah pilots propose that gates be installed behind the span on both sides of the bridge. During periods when tankers were passing under the bridge, the gates would close, thus keeping traffic off the bridge. It is the pilots' contention that gates could serve other safety functions, other than times when tankers are passing the bridge.

Should the superstructure of a ship sever the main span over the river, there is no manned point of traffic control on the South Carolina side of the bridge. Thus, it may be reasonable to assume the motorists might drive through the broken span until Georgia or South Carolina authorities could reach the other side to block traffic. During periods of icing in the winter months, the gates could be used to close the bridge to traffic. The activation of the gates could be controlled
from the toll booth until its scheduled close in the near future. After the closing of the toll house, another system for gate activation would be required.

B. Unrelated Findings Concerning the Sidney Lanier Bridge, Brunswick, Georgia

1. Captain Edwin Fendig, Chief Pilot Brunswick, suggests that several construction projects be undertaken by the U.S. Corps of Engineers to improve bridge safety. The primary danger of a ship colliding with the Sidney Lanier Bridge occurs from the time that the ship emerges from the Brunswick dock area until it makes the 50° turn and clears the bridge. As explained in the study, the longer the period of time the ship has to line up with the bridge, the better the chance of safe passage through the bridge. The basic recommendations to the Corps of Engineers are the following: (1) widen the up-river portion of the channel leading from the dock area by removing the tip of Andrews Island and extending the channel boundary to mid-river from that point, and (2) dredge a maintained turning basin near the intersection of the river and dock area channels. Such a facility would allow ships to be turned much quicker during ebb tide conditions, and other times when bridge safety would be endangered by large ships attempting the turning departure maneuver.

2. The two Brunswick Harbor tugboats used to maneuver ships are each 450 horsepower vessels. It is Captain Fendig's contention that in order to be adequate for handling all classes of ships under all situations, the harbor tugs should have at least
2,500 to 3,000 horsepower. Presumably, if larger tugs were used, they would be adequate to control ships while passing through the bridge area. There is little likelihood that the local Brunswick tug company will get vessels of this size in the near future. The closest 3,000 horsepower tugs are located in Savannah, and it would require a day's travel time for those tugs to reach Brunswick. Thus, the inadequate tugboat situation is not likely to change in the near future.
A. Conclusions

The Sidney Lanier Bridge was chosen as a prime candidate for system installation because of the importance and cost of the bridge, and because of the complexities of the steering problem to navigate the channel. Also, it is probable that a system developed for use with the Sidney Lanier Bridge could be used with any other of the remaining eight spans in Georgia. Thus, by developing one trial system for use on the Sidney Lanier Bridge, a new concept in bridge safety can be evaluated for possible use on the other bridges in Georgia, and the remainder of the nation as well.

The Sidney Lanier Bridge is an ideal candidate for an experimental electronic warning system. The 50° turn that ships must make when leaving the Brunswick dock area is a dangerous maneuver under the best of conditions. The addition of an experimental electronic sensor system could serve two purposes in the improvement of bridge safety.

1. A display operated by the system could indicate to the pilot his ship's position in relation to the channel centerline, and also give his ship's closing speed with respect to the bridge. This information would give the pilot advance notice when a steering command is missed, or when course corrections were not sufficient for the intended maneuver,

2. A bridge tender warning system operated by the sensor system would give those on the bridge a warning when a ship assumes a collision course, with respect to the bridge.
B. Recommendations

It is recommended that a trial electronic system be designed, installed, and tested on the Sidney Lanier Bridge as soon as possible. This task should be carried out in the following six basic phases. This work could be carried out by the Radar Division, Engineering Experiment Station, Georgia Tech, commencing immediately.

Phase I - The radar system would be designed and the exact radar site would be chosen.

Phase II - The radar would be built and the tower and other facilities would be constructed at the Brunswick site.

Phase III - The radar would be mounted on the supporting structure and tested against actual targets. Radar measurement data would be taken during this period on ships passing the bridge area. Range, speed, azimuth angle, and other associated variables would be recorded. The resulting data would be the basis for the design of the processing unit that would drive the pilot's display and the bridge tender's warning system.

Phase IV - Based on the data obtained in Phase III, the processing unit would be designed and constructed.

Phase V - Based on the processor and radar designs, a display design would be generated to permit GDOT to construct and install the required displays.

Phase VI - The prototype sensor system would be installed and tested during this phase. The signal processor would be taken to Brunswick and installed with the radar. After testing and final alignment, the system would be coupled to the display units.

The work period required for the complete six phase program should not exceed one year.
It is recommended that the Engineering Experiment Station at Georgia Tech be retained during the year of operational testing to monitor the system's operation, and to make adjustments if required. At the end of the first full year of operation, the Georgia Department of Transportation (GDOT) should require an evaluation report. On the basis of the results reported, GDOT could then decide if other bridges in the state should be equipped with a similar sensor system.
APPENDIX I

REPORT ON MOVEABLE SPAN BRIDGES
The following is a report on the movable span bridges in Georgia for which positive recommendations are established to improve traffic control. These recommendations are based upon current requirements as set forth in the Georgia Manual on Uniform Traffic Control Devices, FHWA PPM21-15 and information received by this office as a result of an inquiry to the Bridge Maintenance Section of the Department of Transportation, the U.S. Coast Guard, and the field district traffic engineers in those districts in which these bridges are located. The reason for this study can be related directly to the study and findings on the Sidney Lanier Bridge disaster of November 7, 1972. As a result of these evaluations and from information now in hand, it can be concluded that there presently does exist insufficient and non-uniform measures to protect the motoring public utilizing these bridges. The non-conformity in bridge traffic control devices now in use on the state system in Georgia can be improved, as established in the recommendations of this report.

In Georgia, there are 13 movable span bridges. See findings and recommendations for a complete listing. Of these 13, two are maintained on a cost share basis by the state of Georgia with the states of Alabama and South Carolina and one additional is maintained by the state of Florida and is inoperative. There are three other Georgia bridges considered inoperative. The seven remaining bridges are found to be in operating condition used daily and located on the coastline in and around the cities of Brunswick and Savannah, with one location on the Savannah River midway between Augusta and Savannah.

A review of the information furnished this office by the Department of Transportation Bridge Maintenance Section inspection teams, the field district traffic engineers, and the U.S. Coast Guard in Miami, has revealed that the marine traffic currently operating in those waterways
on which the movable span bridges are located is currently a threat to traffic safety. These marine vehicles are of sufficient size and length to inflict possible major damage to the bridges. Thus, there does exist an atmosphere for possible loss of life or severe damage to highway traffic utilizing these bridges.

As was indicated in a letter from Mr. C. G. Blitch, Jr., Bridge Administrator for the U.S. Coast Guard in Miami, Florida, a large volume of marine traffic, both commercial fishing, and towing presently operate in addition to the large volumes of pleasure craft on the rivers and waterways along the coastline. Additionally, it was indicated that regular traffic of barge and tug towing type currently is underway on the Savannah River between the cities of Savannah and Augusta. The tug towing traffic utilizing the waterways are generally 142 feet in length with a width of 40 feet usually requiring a draft of approximately 7 1/2 feet. It should be pointed out that in addition to the normal marine traffic, large dredges will occasion these waterways in performing dredging operations which could also cause possible major damage. There has been at least one example where damage to the bridge functions of a movable span was sustained as a result of dredging operations.

Indications from our field district traffic engineers, in their review of each bridge location within their district, have pointed out another problem that presently exists. Many motorists fail to stop when bridge gates are lowered for the purpose of restricting travel on bridges during operations. This, in part, was noted as a result of the non-uniformity in the location, height, and size of gates, barriers, and existing signals, both audible and visible, presently in place. These have for the most part been varied as they were replaced after a hit of some type.

CONCLUSIONS

From the information obtained by this office, we have concluded that nine (9) of the thirteen (13) bridges are recommended for improvements. The bridges requiring change and/or update are located along the coastline of Georgia and on the Savannah River. Because of the type of marine traffic utilizing these bridges, and the possibility of major damage inflicted by these crafts, there is a definite need to provide a greater margin of safety to the motoring public in Georgia through positive corrective measures. These will include actions such as providing appropriate gate locations and a uniform application of bridge traffic control devices.
RECOMMENDATIONS

It is recommended that improvements be made on nine (9) movable span bridges found to be in need of a more positive application of traffic control devices. A plan has been developed to upgrade or replace existing traffic control devices on these bridges to meet the current requirements as outlined herein. This updating will consist of the replacement and double-indication of existing signs and signals as well as the relocation and/or replacement of existing gates and barriers to a new position on the bridge in the prescribed manner. It is also recommended that the office of Traffic Engineering and Safety conduct an annual review of each location to ensure continuous updating that may be required because of possible changes in marine traffic utilizing the bridges. Additionally, consideration should be given for periodic investigation by the Department of Transportation Bridge Maintenance Section in conjunction with the U.S. Coast Guard for the purpose of determining the need for updating the present navigational aids as exist at the aforementioned bridge locations.

SPECIFIC FINDINGS AND RECOMMENDATIONS

The following is a listing of the 13 movable span bridges investigated, with our findings and proposed recommendations:

See Summary Listing - Chart I
(Next Page)

After the Sidney Lanier Bridge disaster of November 7, 1972, it was determined that a comprehensive evaluation of all Georgia draw bridge locations was warranted. The following findings and recommendations support this contention by enumeration of several appropriate actions. The following is a capitulation of findings and recommendations at each bridge site. The factors outlined therein are those recognized as desirable practice under standards promulgated by the Georgia Manual on Uniform Traffic Control Devices, PPM21-15 "Safety Devices for Movable Bridges", and sound engineering judgement resulting from a personal inspection at each bridge location. It is the intention of this office to recommend implementation of the recommendations contained herein to the appropriate parties in responsible charge.
<table>
<thead>
<tr>
<th>No.</th>
<th>Location</th>
<th>Type &amp; Use</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>St. Mary's River, US 17, SR 25, Camden</td>
<td>Swing Style, Inoperative</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>Savannah River, US 17, SR 25, Chatham</td>
<td>Swing Style, Frequent use</td>
<td>Upgrade traffic control devices; advance warnings; relocate signal and outer gates, one end</td>
</tr>
<tr>
<td>3</td>
<td>Wilmington River, US 80, SR 26, Chatham</td>
<td>Bascule Type, High use</td>
<td>Upgrade traffic control devices; relocate gates</td>
</tr>
<tr>
<td>4</td>
<td>Wilmington River Toll, US 80, SR 26, Chatham</td>
<td>Bascule Type, High use</td>
<td>Upgrade traffic control devices; relocate gates</td>
</tr>
<tr>
<td>5</td>
<td>Ocmulgee River, US 441, SR 31, Coffee</td>
<td>Swing Style, Seldom used</td>
<td>None</td>
</tr>
<tr>
<td>6</td>
<td>Flint River, US 27, SR 1, Decatur</td>
<td>Bascule Type, Inoperative</td>
<td>Bridge to be replaced</td>
</tr>
<tr>
<td>7</td>
<td>Chattahoochee River, US 84, SR 38, Early</td>
<td>Swing Style, Alabama operated</td>
<td>To be replaced by Alabama, fiscal 74</td>
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<tr>
<td>8</td>
<td>Jekyll Island, SR 50, Glynn</td>
<td>Lift Span, Frequent use</td>
<td>Upgrade traffic control devices; relocate signals, one end, and gate both ends</td>
</tr>
<tr>
<td>9</td>
<td>Sidney Lanier Bridge, US 17, SR 25</td>
<td>Lift Span, Frequent use</td>
<td>Redeveloped traffic control concept</td>
</tr>
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<td>10</td>
<td>Torras Causeway Toll, Fredrica River, Glynn</td>
<td>Lift Span, Daily use</td>
<td>Upgrade traffic control devices; relocate outer gate and signal, one end; replace inner gates with resistance type gate</td>
</tr>
<tr>
<td>11</td>
<td>Torras Causeway Toll, Back River, Glynn</td>
<td>Lift Span, Daily use</td>
<td>Upgrade traffic control devices; relocate outer gate and signal, one end; replace inner gates with resistance type gate</td>
</tr>
<tr>
<td>12</td>
<td>Savannah River, 5th St, Old SR 10, Richmond</td>
<td>Swing Style, Inoperative</td>
<td>None</td>
</tr>
<tr>
<td>13</td>
<td>Savannah River, US 301, SR 73, Screven</td>
<td>Swing Style, One-way bridge South Carolina operated</td>
<td>Upgrade traffic control devices on Georgia end</td>
</tr>
</tbody>
</table>
FINDINGS

1. St. Marys River Bridge, U.S. 17, S.R. 25, Camden County - This is a narrow, two-lane bridge with a turret, swing style movable span located on the St. Marys River. This bridge, maintained by the state of Florida, connects Georgia with Florida and carries approximately 9,500 vehicles daily. The bridge has been inoperative since 1930 and has no existing traffic control devices, except that on the Georgia side, signs and markings for narrow bridge are in place. There are no proposed improvements to this bridge by either Georgia or Florida in the near future.

2. Savannah River Bridge, U.S. 17, S.R. 25, Chatham County - This bridge is located in the city of Savannah. It is a two-lane bridge, 1,446 feet long, with a turret, swing style movable span of 240 feet. The average daily traffic on this bridge is 4,789 vehicles. The movable span was operated approximately 457 times in 1972, with marine traffic consisting primarily of tugs and barges along with some pleasure craft. Existing traffic control devices for this bridge consist of one set of gates and barriers, audible and visual traffic signals, and warning signs on approaches to the bridge.

3. Wilmington River Bridge, U.S. 80, S.R. 26, Chatham County - This bridge is also located in the city of Savannah. It is a two-lane bridge, 1,293 feet in length, with a bascule type, clam shell movable span of 150 feet. The average daily traffic on this bridge is 11,635 vehicles. The movable span was operated 5,654 times in 1972, with marine traffic consisting primarily of commercial fishing boats, tugs, and barges, and some pleasure craft. The existing traffic control devices for this bridge consist of one set of traffic gates, audible and visual signals, and warning signs on approaches to the bridge.

4. Wilmington River Toll Bridge, U.S. 80, S.R. 26, Chatham County - This is a third bridge located in the city of Savannah. It is a two-lane bridge, 748 feet in length, with a bascule type, clam shell movable span of 150 feet. The average daily traffic on this bridge is 4,920 vehicles. The movable span was operated approximately 5,400 times in 1972, with marine traffic consisting primarily of commercial fishing boats, tugs and barges, and some pleasure craft. Most frequent times of operation are in the fall and spring of year. Existing traffic control devices consist of one set of traffic gates and audible and visual signals.

5. Ocmulgee River Bridge, U.S. 441, S.R. 31, Coffee County - This is a two-lane bridge with a turret, swing style movable span. The average daily traffic on this bridge is 1,725 vehicles. This bridge is considered inoperative and is only opened under the supervision of the DOT.
Maintenance forces of Georgia. This bridge is seldom opened because the type marine traffic required to open the bridge cannot navigate the Ocmulgee River at this point. When an opening of the bridge is required, advance notice must be made to State Maintenance forces in that district and during operations, traffic is kept off the bridge by means of flagmen.

6. Flint River Bridge, U.S. 27, S.R. 1, Decatur County - This bridge is located in the city of Bainbridge. It is a two-lane bridge with a bascule type, clam shell movable span. The average daily traffic on this bridge is 7,825 vehicles. This bridge is considered inoperative and was last opened in 1929. The normal mechanism for the operation of this structure is considered nonfunctional and special equipment would be required in order that the span be raised. One attempt to open the span was made in 1971 at a cost of $8,000. Only one leaf could be raised and the other was considered impossible. It has been recommended that the bridge not be opened again. The type of marine craft which is normally found on the Flint River at this location is considered to be of insufficient size to seriously damage the structure or warrant the raising of this bridge. This structure is programmed for relocation and replacement in the first quarter of fiscal year 74.

7. Chattahoochee River Bridge, U.S. 84, S.R. 38, Early County - This is a two-lane bridge with a turret, swing style movable span, located at the Georgia-Alabama state line on the Chattahoochee River. The bridge is operated and maintained by the Alabama Highway Department and carries 3,171 vehicles daily. The bridge is reportedly opened several times weekly, and when movable span operations for this bridge are underway, traffic is controlled by means of flagmen. These flagmen do not allow traffic on the bridge during operations. There exist on either side of the bridge traffic control devices consisting of gates and flashing lights, although these are considered to be substandard as outlined in the Georgia Manual on Uniform Traffic Control Devices. The Department of Transportation of Georgia has received both verbal and written notice from the Alabama Highway Department that this bridge is to be relocated and replaced with an up-to-date structure in 1974, and that the project has been let.

8. Jekyll Island Bridge, S.R. 50, Glynn County - This is a two lane, lift span bridge, connecting Jekyll Island with the city of Brunswick. The bridge is 1,357 feet in length, with a lift span of 117 feet. The average daily traffic on this bridge is 3,956 vehicles. The movable span was operated approximately 8,375 times in 1972, with marine traffic consisting primarily of commercial fishing boats, tugs and barges,
and some pleasure craft. The peak periods of operation during the year are in the fall and spring months. Existing traffic control devices consist of two sets of gates, audible and visual signals, and warning signs on the approaches to the bridge. The gates consist of outer detention traffic gates, along with barrier gates at the movable span.

9. Sidney Lanier Bridge, U.S. 17, S.R. 25, Glynn County - This bridge is located in the city of Brunswick. It is a four-lane bridge, 4,471 feet in length, with a lift span of 295 feet. The average daily traffic on this bridge is 14,000 vehicles. The lift span was operated approximately 4,000 times in 1972 with the marine traffic consisting primarily of large freighters, tugs and barges, and commercial fishing boats. This bridge was struck on November 7, 1972, by an ocean going freighter and sustained considerable damage. This bridge is presently closed and under repair.

10. Torras Causeway Toll Bridge on the Fredrica River in Glynn County - This bridge is also located in the city of Brunswick. It is a two-lane bridge 1,287 feet in length with a vertical lift span of 117 feet. The average daily traffic on this bridge is approximately 12,500 vehicles. The movable span was in operation approximately 6000 times in 1972 with marine traffic consisting primarily of commercial fishing boats, tugs and barges, and some pleasure craft. Peak periods of operation for this span are during the fall and spring months. Existing traffic control devices for this bridge consist of two sets of traffic gates, and both audible and visual signals. No warning signs exist on the approaches to the bridge.

11. Torras Causeway Toll Bridge on the Back River in Glynn County - This is a third bridge located in the city of Brunswick. It is a two-lane, lift span bridge, 853 feet in length with a lift span of 117 feet. The average daily traffic on this bridge is 12,500 vehicles. The movable span was in operation approximately 6000 times in 1972 with marine traffic consisting primarily of tugs, commercial fishing boats, and some pleasure craft. Peak periods of operation are during the fall and spring months. Existing traffic control devices consist of two sets of traffic gates and both audible and visual signals. No warning signs exist on approaches to the bridge.

12. Savannah River Bridge, 5th Street, Old S.R. 10, Richmond County - This bridge is located in the city of Augusta. This is a two-lane bridge 1,202 feet in length with a turret, swing style movable span of 186 feet. The bridge is considered inoperative as far as movable span operations. After being rebuilt in 1931, attempts were made to operate the movable span and at that time excessive vibrations and difficulties encountered...
made it inadvisable to continue the operation. The bridge operation has since been tried and again found unsuccessful. Operation of the movable span bridge is to be considered inadvisable at this time. Presently, there exist no traffic control devices on this bridge.

13. Savannah River Bridge, U.S. 301, S. R. 73, Screven County - This is a one-way bridge 2,870 feet in length with a turret, swing style movable span of approximately 240 feet. This bridge is located on the Savannah River and connects Georgia with South Carolina. It is maintained and operated by the Highway Department of South Carolina on a cost share basis with Georgia. The average daily traffic on this bridge is 5,671 vehicles. The bridge is opened infrequently (approximately once a month) with marine traffic consisting primarily of tugs and barges with some pleasure craft noted. Existing traffic control devices consist of two sets of traffic gates with flashing lights and audible signals for warning. These devices are located on both sides of the bridge. However, it should be noted that the gates, signals, and flashing lights on the South Carolina side are inoperative. This is due to past dredging operations which severed the electrical cable that operates these gates and bells.

**RECOMMENDATIONS**

The following are the proposed recommendations for those bridges in this study:

1. **St. Marys River Bridge, U.S. 17, S. R. 25, Florida-Georgia State Line** - There are no recommendations for this location since this bridge swing span is inoperative.

2. **Savannah River Bridge, U.S. 17, S. R. 25, city of Savannah** - It is recommended that the following actions be taken:

   a. Upgrade traffic signals by providing double-indication with red-amber-green displays.

   b. Relocate and position placement of signal displays to provide adequate response area (one side only).

   c. Relocate (one side only) and upgrade outer traffic gates to extend across both lanes.

   d. Adjust to a minimum height of 4 feet, all traffic control gates.
e. Install on both approaches to the bridge, "Draw Bridge Ahead" signs with alternate flashing, wig-wag hazard beacons to operate prior to and during all openings.

3. Wilmington River Bridge, U.S. 80, S.R. 26, city of Savannah - It is recommended that the following actions be taken:

a. Upgrade, relocate, and double-indicate traffic signals with red-amber-green displays.

b. Relocate (one side only) and adjust to a minimum height 4 feet existing traffic gates.

c. Attach alternate flashing, wig-wag hazard beacons to existing "Draw Bridge Ahead" signs located on the approaches to the bridge and operate prior to and during all bridge openings.

4. Wilmington River Toll Bridge, U.S. 80, S.R. 26, city of Savannah - It is recommended that the following actions be taken:

a. Upgrade traffic signals by double-indication with red-amber-green displays.

b. Refurbish existing traffic gates and adjust to a minimum height of 4 feet.

c. Erect on both approaches to the bridge, "Draw Bridge Ahead" signs with alternate flashing, wig-wag hazard beacons to operate prior to and during each bridge opening.

5. Ocmulgee River Bridge, U.S. 441, S.R. 31, Coffee County - It is recommended that this location continue operations as in the past; utilizing maintenance personnel to operate this bridge, to open the bridge only on occasion, and to control traffic during said openings by means of flagmen.

6. Flint River Bridge, U.S. 27, S.R. 1, Decatur County, city of Bainbridge - No recommendations since the bridge is inoperative and will soon be replaced.

7. Chattahoochee River Bridge, U.S. 84, S.R. 38, Early County - This bridge is operated and maintained by the Alabama Highway Department. There are no recommendations for improvements to
this bridge as existing policies maintained by Alabama are considered adequate until such near future time when the bridge will be replaced.

8. Jekyll Island Bridge, S.R. 50, Glynn County - It is recommended that the following actions be taken:

   a. Upgrade and relocate existing traffic control signals to provide double-indication of red-amber-green displays.

   b. Relocate and adjust to a minimum height of 4 feet, existing outer traffic gates.

   c. Replace existing yellow stop bars at traffic signals with white, 18" markings extended from centerline to curb as presently required by Georgia Manual on Uniform Traffic Control Devices.

9. Sidney Lanier Bridge, U.S. 17, S.R. 25, city of Brunswick - No recommendations other than complete implementation of previous report for traffic control at this bridge location.

10. Torras Causeway Toll Bridge, Frederica River, city of Brunswick - It is recommended that the following actions be taken:

   a. Relocate and upgrade existing traffic signals to provide double-indication of red-amber-green displays.

   b. Relocate and upgrade existing outer traffic gates and adjust to a minimum height of 4 feet.

   c. Replace inner traffic gate with high impact, resistant type gates.

   d. On both approaches, install in advance of bridge, "Draw Bridge Ahead" signs with alternate flashing, wig-wag hazard beacons to operate prior to and during each opening of the bridge.

11. Torras Causeway Toll Bridge on the Back River, city of Brunswick - It is recommended that the following actions be taken:

   a. Relocate and upgrade traffic signals by providing double-indication of red-amber-green displays.

   b. Adjust to a minimum height of 4 feet and refurbish the existing outer traffic gates.
c. Upgrade the inner gates to high impact resistant type gates at the lift span.

d. Install at both approaches to the bridge, "Draw Bridge Ahead" signs with alternate flashing, wig-wag hazard beacons to operate prior to and during each bridge opening.

12. Savannah River Bridge, 5th Street, Old S. R. 10, city of Augusta - No recommendations since this bridge is inoperative and will not be opened.

13. Savannah River Bridge, U.S. 301, S. R. 73, Screven County - It is recommended that the following actions be taken:

   a. Existing traffic control devices be upgraded and relocated on the south end so as to comply with the current Georgia Manual on Uniform Traffic Control Devices.

   b. Recommend that South Carolina be invited to participate in the cost of activating the now inoperative gates, bells, and flashing lights, and other traffic control devices on the South Carolina side for elimination of the sometimes wrong-way movements that have been noted in the past.

   c. Recommend that flagmen be utilized to supplement existing control when bridge is opened on infrequent schedules.

The recommendations contained herein are considered neither elaborate nor expensive but are essential to the display of appropriate information to the motoring public to insure proper response and cooperation. After approval of the report, separate recommendations shall be forwarded to the appropriate parties involved. We appreciate your interest in this matter involving highway safety and trust you will call on us if additional information is desired.

Yours very truly,

Archie C. Burnham, Jr., P.E.
State Highway Traffic and Safety Engineer

ACB:bw