Abstract

Washington State Ferries (WSF) provides a critical state highway across Puget Sound, with 20 terminals in Western Washington utilizing 29 vessels, more than 25 million passengers and 11 million vehicles are carried each year, see Figure 1. It is the largest ferry operator in North America. With several capital replacement projects planned for the near future, WSF decided to reevaluate how it transitioned between fixed structure and floating vessel. This became paramount after an accident in 2001, when, presumably, a cable failed, dropping both the bridge (transfer span) and its operator into the water.
While lift bridges serving auto ferries in Puget Sound have been running successfully since the 1930s and by WSF since the 1950s, and has provided a vital link for the unrestricted movement of vehicular and pedestrian traffic in and around the Puget Sound area; for most of this time, the bridge lift mechanism has been a single winch mounted on the transfer span, operating a cross-reeved cable and featured cable supported counterweights. This design scheme provided many years of reliable and safe service for WSF. Emergent operational problems, however, initiated the search for an alternative lifting mechanism to increase both safety and effectiveness.

**Project Objectives**

Foremost among the project objectives was to increase safety for the span operators and for the public. Early on in the project, it was determined that what was primarily needed was a failsafe design. That is, a design that, in the event of a single component failure, or credible failure cascade, would fail in a safe and predictable manner and must not result in harm to vehicles or persons. The failsafe system would not necessarily result in an operable system after a single failure.

The existing system operates between a fixed horizontal distance of 32 meters (105 feet) of which the main span is 27.4 meters (90 feet) and the apron is 4.6 meters (15 feet), and a variable vertical distance of 6.1 meters (20 feet) depending on tide and vessel. At near extreme tides, trucks with low clearances are restricted from traveling across a transfer span. Occasionally, a truck becomes stuck on the transfer span, most often exiting a vessel after the tide changed while in transit, and has to be towed off the span. This has created hours of delay. To alleviate this problem, a desired capability of the new lift system was identified to be the ability to lift a single truck, should it become stuck on the span.

Many of the existing transfer spans had been retrofitted, as a Y2K operational assurance, with the ability to be operated by vessel backfeed in the event of a power outage. This capability needed to be maintained.

Finally, it was an objective to be able to operate portions of the lift system remotely from the vessel. The transfer spans are generally set during the overnight closure in the up position and, in the event of a low tide in the morning, are high above the vessel at a terminal, which may not be staffed at that time.

The design concept ultimately identified was required to provide WSF with an improved operational and control systems at its vehicle transfer spans.

**Evaluation of the Existing Lift System**

The existing lift system for WSF vehicular transfer spans consists of three elements; a single winch cable hoist system, a cable supported counterweight system, and a live load pin with hanger bar system.
The existing cable-hoist system consists of a winch mounted on the transfer span, reducer, drum, and a series of fixed sheaves and blocks. This system suspends the offshore end of the transfer span from the headframe. The existing counterweight system consists of two weights suspended from sheaves in the headframe by four wire ropes. The existing live-load support system is a slotted bar suspended from each side of the headframe and attached to the transfer span by hydraulically actuated pins.

Search for Alternative Lift Systems

The search for an alternate system was only limited by the distance between the fixed structure at the existing trestle, hinge end, the existing mooring structures, and vessel end. The following systems and alternatives were considered:

- **Operating System**
  - Cable Hoist
  - Hydraulic
  - Electric Screw Jack
  - Rack-Pinion
  - Floating

- **Failsafe System**
  - Brakes
  - Cylinders
  - Redundancy

- **Dead-Load Support System**
  - Wire Rope
  - Floating
  - Linkage
  - Operating System

- **Live-Load Support System**
  - Boat
  - Operating System
  - Friction Clamp Hanger
  - Pin Hanger

Criteria for Safety, Operation, and Design

AASHTO publishes two standards for movable bridges, *AASHTO LRFD Movable Highway Bridge Design Specifications, First Edition, 2000* and the *Standard Specifications for Movable Highway Bridges, 1988*. These standards specifically address bascule, swing and vertical-lift bridge criteria. Vehicle transfer spans, as operated by WSF, are relatively small structures designed to transfer vehicular live loads between a fixed structure and a marine vessel subject to movement induced by...
wind, tide, and wave actions, as well as changing freeboard due to loading and offloading of vehicles. Interestingly, these AASHTO standards were not found to be sufficient to address the safety, design, and operational needs for these structures. Where AASHTO standards were found not to apply, engineering judgment was used for the establishment of design criteria.

A summary of the general design criteria for this project is as follows.

- The failure of any one mechanical or electrical component or system shall not compromise the safety of the structure.
- The mechanical and electrical systems shall be of simple design and substantial construction implementing proven technologies to minimize interruption of service.
- Components requiring replacement, maintenance, and inspection shall be reasonably accessible.
- Operator interaction with the control system shall be minimized.
- Interlocks shall be implemented to prevent span from being damaged or operated in an unsafe manner.
- Use of custom or long-lead item components shall be minimized.
- Construction and maintenance costs shall be optimized, as much as practical, by standardizing components to minimize spare parts inventory.
- Energy requirements shall be optimized as much as practical.
- Electrical service to all equipment that is essential to the loading and unloading of vehicles should be provided with a redundant power source.
- Environmental exposure and associated risks shall be minimized as much as practical.

Lift System Decision Process

Several steps were taken as part of the decision process to select a new vehicle transfer span lift system. The electrical and mechanical systems at each existing transfer span were inspected. Internal wire-rope inspections were also conducted at several terminals. A design report intended to lay the road map for design was drafted. The design report process was conducted under a peer review group made up of WSF engineers and operation personnel, machine designers, consulting mechanical and electrical engineers, and a project manager from another states Department of Transportation (DOT) ferry program.

The means of operating vehicle lift bridges by other ferry systems was investigated. Systems investigated include the following.

- Cable Hoist
  - Cape May, New Jersey
  - The South Ferry, New York, New York
  - Peaks Island Ferry Terminal, Portland, Maine

- Hydraulic
  - Tsawwassen Ferry Terminal, British Columbia, Canada
  - Galveston Terminal, Galveston, Texas
Electric Screw Jack
- PRR Terminal, Greenville, New Jersey

Additionally, electric screw-jack experience at Maine DOT and floating system information from Alaska Marine Highway System along with Maine DOT was gathered.

While hydraulics was considered, events during the course of the lift system selection process convinced WSF decision makers to look for another option. These events, three separate hydraulic fluid incidents, occurred at three different terminals resulting in minor spills into Puget Sound. Additionally, a separate vigilant inspection of the terminals conducted as part of this project identified several areas, which appeared imminently susceptible to causing a spill. These two events coupled together provided little incentive for WSF management to support a hydraulic-system alternative.

Ultimately, a cable-based system was selected that significantly conformed to the following statement made during the peer review.

In machine design, one normally prefers to improve an existing concept instead of adopting a totally new one. The reason is that inherently the designer cannot foresee all the difficulties that will surface in a new concept, and that the new concept will require significant debugging. Consequently, it is generally not wise to replace an existing concept with a new one, unless the old concept has grave faults, or the new concept offers greatly improved qualities. The present overhead support wire rope counterweight and operated systems have shown themselves to be prone to failure and service interruptions under existing maintenance and operator training procedures. However, this committee’s charge relates to design, not to maintenance or operator training procedures. If maintenance and training are taken off the table, then it would appear that the new concepts should be evaluated. Even so, a new concept should not be taken forward unless it shows significant advantages and few disadvantages when compared with the present concept.

The cable-based operating system that was selected, met the safety and operational improvement requirements and the machinery configuration was more similar to AASHTO vertical-lift bridges. Additionally, WSF decided to modify their maintenance and operator training procedures.

**Selected Lift System Description**

The selected lift system consists of two wire-rope drums driven through a common gearbox by electric motors. There is an integral disc brake mounted directly on the main motor and two caliper-type disc brakes mounted on each drum. The machinery is mounted in the headframe above the bridge.

One drum is mounted directly above each bridge girder. The drums are 1.22 meters (48 inches) in diameter and grooved for 25 millimeters (1 inch) wire rope on a single layer. The 25 millimeters (1 inch) wire rope is reeved from each drum to the bridge through quadruple blocks mounted on the headframe and on the bridge girder below. This results in a nine-part line supporting each side of the bridge. Each rope is dead headed on the lower block via a turnbuckle and a tension link. The turnbuckles are used to adjust the wire-rope
lengths. The tension links are used to shut down the system if tension above the high setpoint or below the low setpoint is detected.

The gearbox and motors are mounted on a common frame in the center of the headframe. The quadruple reduction gearbox connects with the drums via 173-millimeter-(7-inch) diameter floating shafts that span the 7.3-meter (24 foot) width of the bridge. The gearbox is driven by a 15 HP motor and a 5 HP motor connected to a common shaft. Both motors operate on 460 VAC, 60 HZ, at 900 rpm and are NEMA D rated. Under normal operating conditions and when using vessel backfeed, only the 15 HP motor is running; when lifting live load, the 5 HP auxiliary motor kicks in. The hoist system is constrained to 15 HP by the vessel backfeed system and operation with live load while powered by vessel backfeed is prohibited.

The bridge is counterweighted to be approximately 13.5 tonne (15 tons) nose heavy. The two steel counterweights are located in the towers that support the headframe. Each counterweight is connected to two 44-millimeter (1.75 inch) wire ropes, one going to each side of the bridge. This cross-reeved configuration adds effective torsional stiffness to the bridge.

As the vessel is being loaded and unloaded, the live load is supported by a hydraulic-pin and hanger-bar system. One end of each hanger bar is supported by the headframe and the other is allowed to travel freely through the live-load hanger fabrication while the bridge is being adjusted. When the bridge reaches the desired position, the hydraulic pins are inserted into holes in the hanger bars and the bridge is lowered to rest on the pins.

The largest contributor to the size of the equipment used in the lift-system design is the decision to allow for the lifting of live load. Anecdotally, this has occurred with the existing systems contrary to allowable operation rules. Designing for this ability, however, resulted in winch demands three times higher than a no live-load system. Additionally, the appropriate factor of safety for each component had to be reevaluated.

Design for the lift system was required to meet different demands under normal operation, during a component failure, and during the overnight tie up as follows.

**Normal Operating Conditions**
- Loads from lifting/lowering bridge + operator + snow load + wind load
- Span speed minimum 1.98 meters (6.5 feet)/min
- Live-load pins carry live load during loading/unloading

**Live-Load Operation** – Occurs when truck becomes stuck on bridge.
- Lifting/lowering bridge + operator + HS25 vehicle
- HS25 vehicle is off center
- Reduced span speed is acceptable

**Failure Conditions** – Must not result in harm to persons, vehicles, or structure if the following occur while performing the above operations.
- Loss of any one cable or any one system component
- Loss of one counterweight, two broken counterweight cables, or one jammed counterweight
- Loss of power
  - Requires operation on vessel backfeed, limited to 15 HP.
- Lifting/lowering bridge + operator
- Reduced speed acceptable
- Jammed transfer span
  - Span jammed on one side
  - Connections, rope, machinery, and structure must withstand stall torque of motor.

*Overnight Tie-up Operation*
- Vessel tied up in slip with incoming tide.
- Hoist and live-load systems must allow movement of bridge.
- Slack cable must be prevented.
- Alarm shall signal situation.

Final design criteria determined for the new transfer span lift system is as follows.

<table>
<thead>
<tr>
<th>Critical Mechanical Elements</th>
<th>WSF Final Design Parameters for the Lift System (Allows Live Load)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Factor of safety, hoist wire rope (normal operating load)</td>
<td>21</td>
</tr>
<tr>
<td>2. Factor of safety, hoist wire rope (maximum load condition, jammed span)</td>
<td>4</td>
</tr>
<tr>
<td>3. Factor of safety, counterweight wire rope</td>
<td>9</td>
</tr>
<tr>
<td>4. Minimum number of hoist wire ropes</td>
<td>2</td>
</tr>
<tr>
<td>5. Minimum number of counterweight wire ropes</td>
<td>2</td>
</tr>
<tr>
<td>6. Live load allowed during raising or lowering</td>
<td>Yes (HS-25 Vehicle)</td>
</tr>
<tr>
<td>7. Number of cable wraps left on drum at furthest travel</td>
<td>3</td>
</tr>
<tr>
<td>8. Motor brake required</td>
<td>Yes</td>
</tr>
<tr>
<td>9. Machinery brake required</td>
<td>Yes</td>
</tr>
<tr>
<td>10. Grooved hoist drum required</td>
<td>Yes</td>
</tr>
<tr>
<td>11. Cable allowed to stack in multiple layers on drum</td>
<td>No</td>
</tr>
<tr>
<td>12. Means to prevent slack rope</td>
<td>Yes</td>
</tr>
<tr>
<td>13. Limit switch(es) to shut off hoist and set brake</td>
<td>Yes</td>
</tr>
<tr>
<td>14. CW sheave size</td>
<td>33 times rope diameter</td>
</tr>
<tr>
<td>Hoist sheave size</td>
<td>24 times rope diameter</td>
</tr>
<tr>
<td>Hoist drum size</td>
<td>19 times rope diameter</td>
</tr>
<tr>
<td>15. Counterweight guides</td>
<td>Yes</td>
</tr>
<tr>
<td>17. LLP engagement verification</td>
<td>Yes</td>
</tr>
<tr>
<td>18. Wire-rope type</td>
<td>6x37 class, 6x36 WS construction, IWRC, right regular lay, XIP preformed, cold drawn galvanized</td>
</tr>
<tr>
<td>Counterweight ropes shall have these requirements in addition to those listed above</td>
<td></td>
</tr>
</tbody>
</table>

![Image](image.png)
Selected Control Systems

Early controls consisted of push buttons and individual controls with little or no integration of controls. In the late 1980s, WSF began to integrate bridge and hydraulic controls with the use of relays and lighted pushbuttons. In the late 1990s, WSF begins to use Allen Bradley SLC 500 programmable controllers as the center of the electrical control of the lift bridges.

The control system, when connected to the WSF network, provides e-mail messages to WSF maintenance to inform maintenance that the apron hydraulics filters are clogged or hydraulic level is low. In addition, the system generates e-mails whenever the cable-system cable tensions exceed predetermined levels allowing for predictive maintenance schedules for the cable system.
For further safety, the new control system has added an over speed and reverse span operation to prevent the transfer span from becoming overloaded and free falling. This system is required to prevent the bridge from becoming overloaded when lifting the design live-load vehicle.

A display screen is provided to show the condition of the bridge systems in easy-to-understand displays. The display screen also helps the technician to troubleshoot the system without the need to access the PLC. The display screens are layered in three separate levels.

The first layer of the operator display provides information to the operator as to the performance of the lift bridge’s three-main system, live load support, bridge status, hydraulic/apron status, as shown in figure 2.

The second layer provides more detailed information regarding the lift bridges system and is directly accessible from the operators screen by touching any area on the operator’s screen. The second layer, figure 3, is generally intended for use by the technician in evaluating the operation of the lift-bridge systems.

The layer-two screens provide information on the subsystems of the lift bridge. More information is available to the technician regarding the subsystems by depressing any area on the screen. For example, to access information regarding the bridge status the technician depresses the bridge status, area of the screen and acquires a layer-three screen, as shown on figure 4.

The technician may then obtain more information regarding the individual components of the subsystem alarms and shutdowns in this case, the bridge. The display screen may be returned to the operator screen by pressing the return to main screen or automatically if no screen inquiries are made in five minutes. The alarms generated by the PLC, and accessible from the display screen, are also e-mailed to the watch supervisors as well as engineering.

Figure 4: Operator Display Screen, Third Layer
Prototype Construction

The construction of the operating system, complete with new transfer span and towers, will be complete in the fall of 2003. The system is being constructed and tested off site in the fabricator’s yard. This first system will be installed at the Friday Harbor Terminal in the fall of 2004.

Acknowledgements

Design report and inspections were performed by a consultant, Parsons Brinckerhof, under the direction of the BERGER/ABAM project management team of Michael Wray, PE, SE, and Phil Birkland, PE, SE. The design was performed by Naomi Sandberg, PE, WSF; and electrical design was by Ron Reygers, PE, of RL&R and Associates, under the direction of the BERGER/ABAM project management team of Michael Wray, PE, SE and Phil Birkland, PE, SE. Construction was performed by Jesse Engineering under the watchful eye of WSF project engineer, Eddy Chu; WSF marine project engineer, Lisa Parriot; and WSF chief inspector, Mike Morrow.

References

Final Design Report for Vehicle Transfer Spans, Revision 1, July 2002, Parsons Brinkerhof Quade and Douglas


Standard Specifications for Movable Highway Bridges, 1988, by AASHTO