CONTRAFLOW FREEWAY OPERATION FOR HURRICANE EVACUATION IN THE UNITED STATES

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Abstract: Over the past 20 years the vulnerability of U.S. coastal populations to hurricanes has increased. As a result, significant numbers of people may be forced to evacuate under the threat of major hurricanes. The impact of this situation was demonstrated during Hurricanes Floyd (1999) and Georges (1998), when virtual gridlock conditions were experienced on critical evacuation routes. One method that has been suggested to meet the need to evacuate large numbers of people in a rapid and efficient manner involves the reversal of inbound freeway lanes to serve outbound travel. While the concept seems simple, implementation can be complex. This paper presents the concept of contraflow evacuation and discusses the capacity benefits; critical planning, design, and operational issues; and current use plans from highway agencies in the U.S.

Key Words: Evacuation, Contraflow, Disaster Planning, Emergency Preparedness

1. INTRODCUTION

Like coastal regions throughout the tropical latitudes of the world, the Atlantic and Gulf Coast areas of the United States, shown in Figure 1, are threatened by tropical storms. In the U.S., the most powerful of these storms are called hurricanes (also knows as typhoons and cyclones in the South Pacific). The U.S. National Weather Service (NWS) rates the strength of hurricanes based on their wind speed, barometric pressure, storm surge height, and damage potential on a scale of 1 to 5. This rating system, known as the Saffir-Simpson Scale is shown in Table 1. Over the past 100 years, hurricanes have made landfall in every coastal state from Maine to Texas. However, the most significant hurricane threat area, particularly for strong storms (Category 3 and above), is the southern Atlantic seaboard from North Carolina to Florida and the Gulf of Mexico coastal zone from Florida to Texas.

Over the past decade, the risk to the U.S. from hurricanes has increased. This comes from the combination of long-term climatological trends that have seen an increase in major hurricane activity and from population growth trends that have seen high rates of growth in the southern U.S. coastal areas (FEMA 1997). Today more than 45 million Americans (approximately 16% of the U.S. population) live in the coastal counties from Maine to Texas (Jarrell et al. 1992). This increased development and urbanization in coastal areas, combined with recent changing climactic trends and rising sea levels, has led to the exposure of an increasing number of people to hurricanes.

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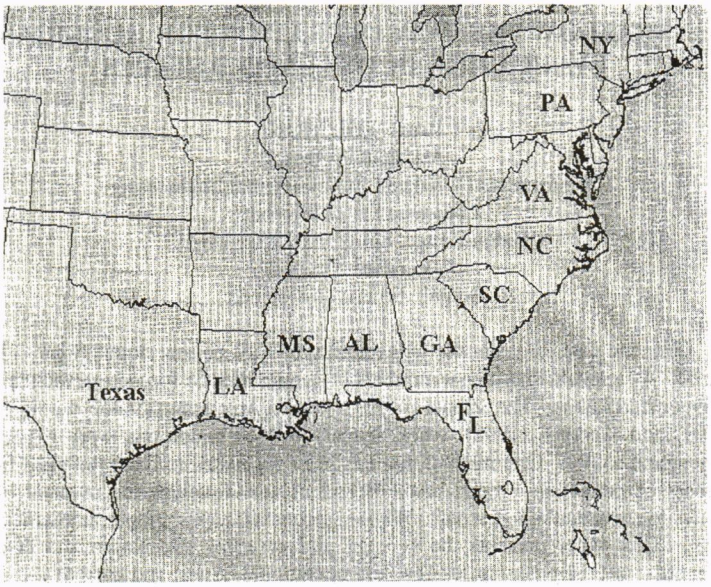

Figure 1. Eastern Seaboard and Gulf Coast Regions of the United States

Table 1. The Saffir-Simpson Hurricane Intensity Scale

Category	Wind Speed	Barometric Pressure	Storm Surge	Damage Potential
1 (Weak)	75 - 95mph 65 – 82kts	28.94" or more 980.02mb or more	4.0' - 5.0' 1.2m - 1.5m	Minimal damage to vegetation
2 (Moderate)	96 - 110mph 83 – 95kts	28.50" – 28.93" 965.12mb – 979.68mb	6.0' - 8.0' 1.8m - 2.4m	Moderate damage to houses
3 (Strong)	111 - 130mph 96 – 113kts	27.91" – 28.49" 945.14mb – 964.78mb	9.0' - 12.0' 2.7m - 3.7m	Extensive damage to small buildings
4 (Very strong)	131 - 155mph 114 – 135kts	27.17" – 27.90" 920.08mb – 944.80mb	13.0' - 18.0' 3.9m - 5.5m	Extreme structural damage
5 (Devastating)	> 155mph > 135kts	Less than 27.17" Less than 920.08mb	< than 18.0' < than 5.5m	Catastrophic building failures possible

(Source: United States Federal Emergency Management Agency)

This threat has been turned into reality over the past several years as a series of hurricanes have struck the eastern seaboard and gulf coasts of the United States. Two of these storms, Hurricane George in 1998 and Hurricane Floyd in 1999, precipitated the largest evacuations in U.S. history. During these events, tremendous numbers of people took to the highways, resulting in monumental traffic jams on designated evacuation routes. In response to the conditions brought about by Floyd, the South Carolina and Georgia Departments of Transportation closed inbound Interstate Highway routes to the coast and reversed their direction of flow to add two additional outbound travel lanes to accommodate the demand. While these measures did increase the capacity of outbound flow on these roadways, they also resulted in other problems that ranged from the level of inconvenience to potentially life threatening.

In the period since Hurricane Floyd there has been a demand from the public and lawmakers for the widespread use of contraflow operations during hurricane evacuations. Contraflow operation, lane reversals, or "one-way-out" and as it is commonly called, involves the use of one or more lanes of inbound travel for traffic movement in the outbound direction. While contraflow evacuation is viewed as a potential remedy for the colossal traffic jams that were a part of the Floyd and Georges evacuations, they are not without many problems of their own, including issues associated with traffic control, egress, use of roadside facilities, road safety, and cost. This paper summarizes the existing and proposed plans for contraflow evacuation in the United States. It also highlights some of the lessons learned from recent contraflow evacuations, including some of the advantages and disadvantages of its use.

2. WHAT IS CONTRAFLOW FOR EVACUATION AND HOW DOES IT WORK?

Contraflow operation on roadways is not a new concept. Traffic flow reversals are used in many large cities the U.S. to accommodate daily peak period unbalanced flow conditions. Contraflow operation is most common on bridges where one or more outbound lanes are used for inbound commuters during the morning rush hour and one or more inbound lanes are used for outbound traffic during the evening peak period. In Washington D.C., the center two lanes of certain arterial routes into the city are used in contraflow fashion to add capacity during morning and evening peak periods. Contraflow operation is also common in the U.S. to bring traffic into or out of special events, like sporting competitions, where all lanes may be converted to accommodate event traffic.

Contraflow operation for hurricane evacuation has taken several different configurations. In previous storms, highway agencies in the U.S. have varied the number of inbound lanes used for outbound evacuees using one or more of the inbound freeway lanes for outbound flow. In a single lane configuration, the adjacent lane of a 4-lane freeway was maintained in the inbound direction for emergency and service vehicles. Some agencies have also used shoulder lanes for evacuation and service traffic. Figure 2 schematically illustrates several contraflow operation configurations for 4-lane freeway segments. This section discusses the various types of contraflow operation, the capacity benefits they provide, and examples of locations where they are used.

Since it offers the largest increase in capacity, the most common contraflow strategy is to reverse both inbound lanes of the freeway to the outbound direction, shown in the bottom right inset of Figure 2. Under this type of operation no inbound vehicles are permitted on the freeway and they are prohibited from entering the contraflow lanes by barricades on all ramps. The major advantage to an all-lanes-out operation is the significant increase in outbound capacity. However, the closure of these ramps also eliminates egress from the contraflow lanes and prohibits vehicles in these lanes from using roadside facilities. While this minimizes confusion and keeps traffic moving, it also has inherent problems (discussed later).

The use of shoulders for the movement of outbound traffic can be accomplished in several different ways. In the evacuation for Hurricane Floyd, the shoulder adjacent to one of the outbound lanes was used. This is shown as the bottom left inset of Figure 2. Other agencies have suggested the use of the shoulder adjacent to the median contraflow lane. This configuration will allow the inner inbound lane to remain open for emergency vehicles. Other

suggested configurations have proposed the use of both shoulders in the normal outbound direction (Badget 2000).

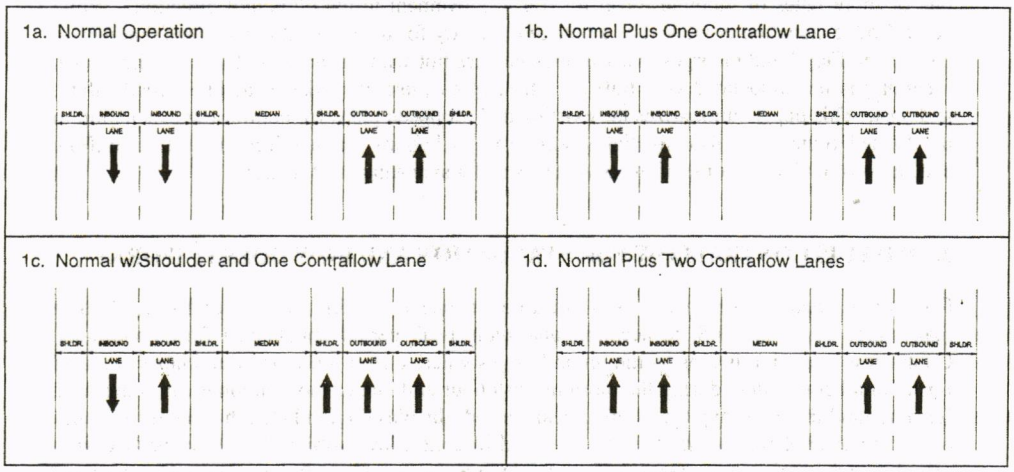

Figure 2. Freeway Contraflow Lane Use Configurations for Evacuations

Although shoulders can increase the capacity of evacuation routes, a high degree of care must be exercised because they are typically more narrow than the travel lanes, constructed with a thinner pavement cross-section, and have a greater cross-slope. They also reduce the area available to accommodate vehicle breakdowns. An additional problem associated with using shoulders is that their widths can vary significantly along interstate segments, particularly on bridges.

During the 1999 Floyd evacuation, the South Carolina Department of Transportation (SCDOT) recorded traffic flow on segments of Interstate 26 under various contraflow configurations (FEMA 2000). The data showed that a single freeway lane operating under evacuation conditions had a flow rate of approximately 1,500 vehicles per hour. This is in contrast to a typical urban freeway lane that would be expected to have a flow rate in excess of 2,000 vehicles per hour during daily commute conditions. The decreased level of flow during evacuation is due a number of different factors, including the high traffic stream densities and the tendency of evacuees to heavily load vehicles and pull trailers with valued personal possessions. In 1999 during Hurricane Floyd, the SCDOT measured flow rates for evacuation traffic under various reversed lane use configurations. These are shown in Table 2.

Table 2. Evacuation Traffic Flow Rates

Use Configuration	Estimated Average Outbound Flow Rate
Normal (two-lanes outbound)	3,000 veh./hr.
Normal plus one contraflow lane	3,900 veh./hr.
Normal & shoulder plus one contraflow lane	4,200 veh./hr.
Normal plus two contraflow lanes	5,000 veh./hr.

(source: FEMA 2000)

As seen in Table 2 the flow rates in the added lane(s) of outbound travel, whether a shoulder or lane of opposing traffic, are not as high as those measured in a normal outbound lane. The limited increases are due to several factors including driver unfamiliarity or uneasiness in driving on a shoulder or in a contra flow lane. The flow rate for two outbound lanes and a single contraflow lane (with traffic in the adjacent lane continuing to travel inbound) was estimated at 3,900 vehicles per hour. This was an increase of approximately 30% over two normal outbound lanes, or an additional outflow of 900 vehicles per hour. When the shoulder was used, the outflow increased by an additional 300 vehicles per hour or a gain of 8% over single lane contraflow operation. Under full contraflow operation (e.g., one-way-out) the SCDOT recorded average flow rates of 5,000 vehicles per hour. This was a two-thirds gain (67%) over a standard two-lane evacuation, or an additional 2,000 vehicles per hour. These flow rates demonstrate the substantial gains can be made through the use of contraflow operations during evacuations. However, these gains must be contrasted with the substantial cost required to put it into action.

3. STATE PLANS

Although only two states (South Carolina and Georgia) have actually implemented contraflow evacuation on a large scale, nearly every coastal state seriously threatened by the potential of significant hurricane activity now has a contraflow plan. The number, length, and origin-termination location and characteristics of each vary by state.

The need for a contraflow flow section is dictated by the number of people expected to evacuate, the geography of the threat area, and the number of available routes leading away from the coastal area. Most states are currently planning to use a single contraflow route. Florida, considered to be the most vulnerable state to hurricanes because of its location and population, has plans for seven separate contraflow segments. By contrast, the State of Mississippi, with a relatively small coastal population and multiple routes away from the coast has none; although, there are discussions between the States of Louisiana and Mississippi to reverse a segment of Mississippi interstate for the evacuation of New Orleans residents into Mississippi. The length of most of the planned contraflow evacuation segments in the U.S. are also in excess of 100 miles. The lone exception to this is the plan for the City of New Orleans, in which a relatively short (25 mile) segment is planned to move people over the elevated segments of freeway that span the bodies of water that surround the city.

One of the more interesting plans for contraflow evacuation is the "Alligator Alley" segment of Interstate 75 in south Florida. This segment of highway is unique in several respects. Because it traverses a protected section of the Florida Everglades, it has no access/egress points over its 90-mile length. Its direct east-west orientation also makes one of the few routes to carry traffic, uninterrupted, between the Atlantic and Gulf Coasts of the state. Because of these characteristics, it is also the only contraflow segment that is planned for use in both directions. If a hurricane strike is predicted to strike the metropolitan area of Miami, this section of I-75 is planned for use in the westbound direction to evacuate people from this area toward the City of Naples. In the event that a storm in the Gulf of Mexico was moving east toward south Florida, this route would be used in an eastbound direction to serve evacuees moving from the southern Gulf Coast toward Miami.

All of the freeway contraflow routes currently proposed for use in the U.S. are shown in Table 3. This table also includes the length of each as well as the general origin and termination points.

4. CRITICAL CONTRAFLOW EVACUATION ISSUES

The drawbacks of contraflow evacuation operations can at times seem nearly equal to the advantages it affords. From a safety standpoint, contraflow operation of any kind on freeways can be risky. Freeways are designed for travel in one direction. Signs, pavement markings, and safety features will not necessarily be visible to drivers traveling in the opposite direction. Reverse flow can also be confusing for drivers not familiar with this type of operation. Additionally, recent experience has shown that contraflow is inconvenient at best, and typically physically taxing on drivers who are not able to exit the freeway for fuel, food, and use of relief facilities.

Another factor to be considered in reverse lane evacuations is access for inbound service vehicles. Before a hurricane, access for public safety personnel must be maintained to protect the health and safety of evacuees and their property. After the event, utility and construction crews need to be able to quickly access affected areas to restore utilities and clear or reconstruct infrastructure systems. Contraflow operation, particularly one-way-out, virtually prohibits inbound access for any vehicles during the reversal. Finally, the cost to plan, design, construct, and operate a contraflow operation is also an important consideration. By no means comprehensive, this list of issues has been identified as some of the most critical by transportation and emergency management officials experienced in contraflow evacuation.

4.1 Safety

The most significant issue of contraflow operation during hurricane evacuations is the potential for traffic accidents, particularly from opposing traffic. Thus, one of the most critical needs is the prevention of inbound vehicles from entering into the contraflow lanes. In most plans this will be accomplished using road closure barricades at all access points to the contraflow lanes. Since it is felt that traffic control devices alone will not eliminate illegal entries, all states have (or plan to) post State Police or National Guard troops at ramp locations. In the NCDOT plan, at least one "Road Closed - Do Not Enter" type III barricade and one police officer with a vehicle will be positioned at each on-ramp into the contraflow lanes (NCDOT 2000).

Table 3. State Contraflow Hurricane Evacuation Routes

State	Evacuation Origin	Route (direction)	Approx. Distance	Contraflow Termination Point
Virginia	Virginia Beach/Norfolk/Newport News	I-64 (west)	100 miles	Richmond
North Carolina	Wilmington	I-40 (west)	90 miles	I-95
South Carolina	Charleston	I-26 (west)*	95 miles	Columbia
Georgia	Savannah	I-16 (west)*	100 miles	Dublin, Georgia
Florida	Miami/Ft. Lauderdale	I-75 (east-west)**	90 miles	Naples
	Tampa/St. Petersburg	I-4 (east)	80 miles	Orlando
	Jacksonville	I-10 (west)	150 miles	Tallahassee
	Pensacola	I-10 (east)	190 miles	Tallahassee
	Fort Myers/Charlotte County	I-75 (north)	110 miles	Tampa/St. Petersburg
	Fort Pierce	"Florida Turnpike" (north)	110 miles	Orlando
	Titusville/Cocoa	SR 528 "Beeline Expressway" (west)	40 miles	Orlando
Alabama	Mobile	I-65 (north)	135 miles	Montgomery, Alabama
Mississippi	----------	----------	----------	-- *See: Louisiana Route* --
Louisiana	New Orleans	I-10 (west)	25 miles	I-55
		I-10/I-59 (east/north)	115 miles	Hattiesburg, Mississippi
Texas	Corpus Christi	I-37 (north)	150 miles	San Antonio, Texas

*Some of all of these routes were used during a recent evacuation.
**Contraflow evacuation on the "Alligator Alley" segment of I-75 is planned for use in both directions.
(These routes are based on information provided by each state and may not include plans currently under study)

Opposing vehicles left over in the contraflow lanes at the start of operations can also be a problem. To address this issue, all states will complete a full visual verification prior to the cross-over to make sure that all vehicles have been cleared. In Florida and Texas the contraflow traffic platoon will be led by state police vehicles directly in front of the evacuees and another driving approximately one half mile ahead (Henk 2000). Some states have also proposed the use of aircraft to verify the clearance of vehicles prior to the start of contraflow operations.

Since freeways have not historically been designed for reversed flow, signs and pavement markings will not be visible to drivers. Safety appurtenances like guardrail transitions, crash attenuators, and post support bases have not been designed to provide the adequate protection at hazardous locations from the opposite direction of travel. To address this issue some states are planning to redesign or retrofit existing systems to provide increased levels of safety protection. The North Carolina Department of Transportation has proposed the reconstruction of guardrails and end treatments along designated reverse flow sections of I-40 to protect vehicles traveling in the opposite direction (NCDOT 2000). Similar protection for blunt objects, such as bridge abutments, using crash impact attenuators was also proposed. Both the North Carolina and South Carolina DOTs have also suggested the construction of permanent overhead dynamic message signs that are readable from both the normal and contraflow directions.

4.2 Regional and Interstate Traffic

The crossing of political boundaries, both within and between states, is another critical issue that must also be addressed during the contraflow planning process. Until recently, almost no regional hurricane evacuation planning was done. Evacuations have been largely regarded as the responsibility of local emergency management officials. Thus, evacuations are implemented on a local, county-by-county, basis. In the State of Florida, the DOT found that this lack of coordination caused significant congestion as traffic from one county evacuated onto the already-congested roads of a neighboring county. They are now addressing these problems in one of the first statewide hurricane evacuation programs (State of Florida, 2000).

Interstate planning is also important. A major state-to-state overlap of interstate evacuating traffic occurred during Hurricane Floyd in 1999. During the Floyd evacuation, traffic from both Florida and Georgia contributed to the monumental traffic congestion on evacuation routes in South Carolina. Some of these evacuees traveled as far as Tennessee. The South Carolina, Georgia, and Florida DOTs are now working together to correct these deficiencies. Interstate regional plans will now consider interstate contraflow and the use of secondary highways to keep local traffic off of interstate routes whenever possible.

One location where contraflow operation could cross over state lines is the I-59 border crossing between Louisiana and Mississippi. The existing road network and geography will force a significant percentage of New Orleans evacuees to shelter in Mississippi. Because of the number of people that need to evacuate southeast Louisiana (estimated in excess of one million), current Louisiana evacuation proposals seek to contraflow all lanes of I-10 eastbound out of New Orleans (Masteri 2000). From a practical standpoint, the locations of interchanges and orientation of the freeways do not permit a reasonable merge point until well after the Mississippi State Line. Due to safety, personnel, and cost issues, the Mississippi DOT is reluctant to continue the Louisiana contraflow operation into their state. At this time negotiations are underway to resolve this issue.

4.3 Accessibility

Issues of accessibility for both the evacuees and emergency service personnel are critical in the planning of contraflow evacuations. By definition, one-way-out evacuation strategies prohibit the movement of inbound vehicles into threatened areas. However, police, National Guard, DOT and utility service vehicles often need access into the evacuation zone before and after the storm. One way to accomplish this is by keeping a single lane of travel open in the inbound direction on the freeway. However, as shown in Table 1, this can significantly decrease the outflow from the threatened region. To overcome this problem many agencies have proposed the use of parallel U.S. and State Highway secondary routes for service access (FHWA 2000).

Accessibility is also an issue for evacuees. An important consideration is the ability to egress contraflow segments for evacuees requiring vehicle or medical services, food, fuel, and access to restroom facilities. The Georgia experience in Floyd showed that numerous vehicles overheated or ran out of fuel while sitting in traffic gridlock. For this reason the new GDOT plans will now permit exits from all interchanges on its 95-mile contraflow segment out of Savannah (Smith 2000).

4.4 Cost

When compared to the potential for mass loss of life, issues of cost seem insignificant. However, they must still be considered. States have varied in their plans to make significant investments to modify existing or construct new roadway infrastructure to facilitate contraflow evacuation. Most State DOTs, like Florida, feel that contraflow evacuations are relatively rare and exceptional situations and have attempted to limit major investments in highway redesign. Except for the cost of capital infrastructure improvements, the primary source of cost for contraflow evacuation is related to the personnel needs for the implementation and enforcement of the operation.

Labor and personnel cost considerations start with the time for personnel involved in the pre-operational planning and engineering of the contraflow plan. Once the plan is initiated, field operations personnel will be required to set up of all temporary traffic control devices and ramp barricades. Once in effect, state police, National Guard, and other law enforcement personnel will need to be stationed at all inbound entrance ramps to prevent unauthorized access into the contraflow lanes. For the 18 interchanges involved in the NCDOT lane reversal, it is estimated that 30 uniformed officers with cruisers will be needed to prohibit entry into the contraflow lanes. They also estimate the need for 38 DOT field personnel to close the ramps and 4 DOT personnel to assist with motorist information at rest areas on the route (NCDOT 2000). In Louisiana plans call for the use of both National Guard troops and law enforcement agents from all available state agencies.

Most states are reluctant to use personnel other than DOT or traffic enforcement police. This reluctance is based on the lack of traffic direction expertise in other personnel. The Florida DOT plans to use only police and has estimated the need for more than 300 law enforcement personnel to implement their contraflow operation (FHWA 2000). Managerial DOT and police staff will also be required to monitor the flow conditions and manage the operation on a strategic level.

In states where infrastructure improvements were required to facilitate contraflow evacuation the upgrades typically involved only minimal capital investments. The only significant infrastructure enhancements required for contraflow in the Carolinas and Louisiana were the

construction of permanent paved cross-over lanes between the outbound to inbound lanes. The NCDOT estimated the total cost of construction items for the reversal of I-40 at $275,000 (NCDOT 2000). This amount included all paving, and the enhancement of safety and traffic control devices in the contraflow lanes. The purchase of the traffic control devices including barricades, variable messages signs, and highway advisory radio transmitters have additional benefits since they can be used for routine incident management functions.

5. CONCLUSIONS

Census figures show that the population of the coastal areas of the southeastern and gulf coast states of the U.S. continues to grow rapidly. As shown during Hurricane Floyd in 1999 and during Hurricane Georges in 1998, many of these areas may not be suitably prepared to deal with need for mass evacuations under threat of hurricanes. To meet the need for faster and more efficient evacuations, disaster planning agencies are presently seeking to move actively involve transportation professionals in the evacuation planning and preparedness process to develop strategies to effectively use and manage the transportation infrastructure when the need arises. However, the general level of involvement and awareness in the transportation community remains limited with regard to these issues. Despite the fact that evacuations are rare events, transportation officials in threatened states need to consider them in the planning of future highways, control plans, and ITS systems. Efforts must also continue to research better ways to address issues of safety, efficiency, information exchange, and post-storm re-entry during evacuations.

Contraflow freeway evacuation has been shown to be a successful method to rapidly and efficiently move large numbers of people during major hurricanes. Under contraflow operation, one or more of the inbound lanes are used for outbound evacuation. Recent studies of contraflow operation have shown that it can increase the flow rates of evacuating traffic by nearly 70%.

However, reverse flow scenarios are not without significant problems. There are the inherent safety risks associated with reverse flow on interstate freeways. Traffic control devices and safety appurtenances have not been designed to accommodate reverse flow. The costs to plan, design, implement, enforce, and terminate the lane reversals can also be significant, as are the costs for specialized equipment and construction required to operate it. Some contraflow operations eliminate the ability of service vehicles to enter into the evacuated area during the evacuation. They may also limit the ability of evacuees from exiting the contraflow lanes to service their vehicles and accommodate personal needs.

Traffic and transportation engineers are typically concerned with traffic safety and capacity under routine conditions. As such, rules and practices have been developed to safely and efficiently move traffic under routine conditions. No life and death consequences are attached to travel time and delay. In contrast, during hurricane evacuations, time is of the essence, and delays can mean catastrophic loss of life. The point is to get as many people out of a threatened area as quickly as possible. While great attention is paid to traffic safety during evacuations, it is not necessarily the primary consideration. Because of this, the traffic professionals must be willing to take actions that may be outside of standards of accepted practice and think in new and innovative ways. Contraflow operations are one valuable tool to help move the maximum number of people from high-risk coastal areas

Unfortunately, contraflow is not a cure to all evacuation needs. Emergency managers and highway engineers look upon contraflow as an extreme response to an extreme threat. However, the point is that these agencies have few other capacity increasing options. Hurricane evacuations, unlike almost any other function of traffic and transportation engineering, can have an immediate and direct impact on tens of thousands of lives.

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