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Evacuation traffic dynamics

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ABSTRACT

Historically, evacuation models have relied on values of road capacity that are estimated based on Highway Capacity Manual methods or those observed during routine non-emergency conditions. The critical assumption in these models is that capacity values and traffic dynamics do not differ between emergency and non-emergency conditions. This study utilized data collected during Hurricanes Ivan (2004), Katrina (2005) and Gustav (2008) to compare traffic characteristics during mass evacuations with those observed during routine non-emergency operations. From these comparisons it was found that there exists a consistent and fundamental difference between traffic dynamics under evacuation conditions and those under routine non-emergency periods. Based on the analysis, two quantities are introduced: "maximum evacuation flow rates" (MEFR) and "maximum sustainable evacuation flow rates" (MSEFR). Based on observation, the flow rates during evacuations were found to reach a maximum value of MEFR followed by a drop in flow rate to a MSEFR that was able to be sustained over several hours, or until demand dropped below that necessary to completely saturate the section. It is suggested that MEFR represents the true measure of the "capacity". These findings are important to a number of key policy-shaping factors that are critical to evacuation planning. Most important among these is the strong suggestion of policy changes that would shift away from the use of traditional capacity estimation techniques and toward values based on direct observation of traffic under evacuation conditions.

1. Introduction

Over the past decade there have been numerous efforts to apply traffic simulation to evaluate evacuation plans and develop efficient strategies to manage evacuation traffic (Theodoulou and Wolshon, 2004; Lim and Wolshon, 2005; Chiu et al., 2005; Edara et al., 2010). Among the critical inputs to these analyses are values of road capacity. These numbers limit outbound flow rates during evacuations and influence traffic operations and congestion formation in static macroscopic and dynamic mesoscopic network models. Sound estimates of capacity are equally important in microscopic simulation models for calibration and validation purposes. Historically, capacity values for evacuation plans have been based on procedures laid out in the Highway Capacity Manual (2010) (HCM) or, in some cases, on empirically observed flow rates during special events or peak periods. Murray-Tuite and Wolshon (2013) in their review of evacuation literature found a glaring gap with regard to understanding traffic flow characteristics and dynamics during evacuation. This paper tries to address this gap.

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In the HCM, capacity is defined as the maximum hourly rate on a uniform roadway section during a given time under prevailing conditions, and assumes "*there is no influence from downstream traffic operation*" (HCM, 2010). As identified by Wu et al. (2010) these capacity values are sufficient for the purpose of transportation planning and design, but are not appropriate for operational level analysis as well as condition during which these capacity values were not measured.

Recently, however, a series of empirically-based observational studies of evacuation traffic flow conditions has suggested that the characteristics of traffic flow during evacuations may actually be fundamentally different from those experienced during routine non-emergency peak periods and special events (Wolshon and McArdle, 2008; Wolshon, 2008). More specifically, despite the enormous and sustained demand generated by a mass evacuation the evacuation flows were found to peak to a maximum value for a brief period and then drop to flow rates that are able to be sustained for several hours as inflow is sufficient to saturate the evacuation route. The same studies also showed that the flows observed during evacuation events are consistently lower than the capacity observed at the same locations during routine non-emergency operations or computed using HCM methods.

Flow rates observed during the evacuations for Hurricane Floyd in Florida and South Carolina (FEMA, 2000), Hurricane Katrina in Louisiana (Wolshon, 2008; Wolshon and McArdle, 2008, 2010) and during Hurricanes Dennis and Ivan in the Florida Keys showed that the one-hour peak flow rate cannot be sustained for periods lasting more than one hour. This concept is illustrated in Fig. 1. This figure shows a pattern typical of most mass evacuations, independent of location. After reaching a peak during the early phases of the evacuation, flows inevitably drop by 10–20% after which they are sustained for periods of six to eight and even up to 12 h. In this paper, the maximum sustainable evacuation flow rate is defined as sustained flows that are observed for greater than or equal to one hour. Similar trends have even been found in simulation studies conducted by the Texas Transportation Institute (Ballard et al., 2008) on I-37, in which maximum sustainable flows of 937 veh/hr/ln were observed, considerably lower than the capacity values computed for routine conditions by the HCM.

Even during normal routine conditions, capacity values have been found to reduce at the onset of congestion and this reduced capacity are often referred to as operational capacity (Wu et al., 2010). It is well known that loss in capacity due to downstream queues (Brilon et al. (2005); Wu et al., 2010) happens when demand exceeds capacity and the densities and flows are in the congested regime. The drop in capacity has been found to be vary across studies with reduction of 3–6% by Banks (1990), Hall and Agyemang-Duah (1991) and; Ponzlet (1996), while, Brilon and Zurlinden (2003) measured an average capacity drop of 24% in Germany and Tu et al. (2010) measured an average capacity drop of 19% in the Netherlands.

The research presented in this paper attempts to systematically study and quantitatively describe this phenomenon that has been consistently observed during evacuations in Louisiana. This study introduces two quantities: "maximum evacuation flow rates" (MEFR) and "maximum sustainable evacuation flow rates" (MSEFR). The MEFR is the maximum evacuation flow rates and are shown as a dashed line in Fig. 1. The MSEFR is the maximum sustained evacuation flow rate that is shown as a solid black line in this same figure.

Possible explanations for these observed differences are both numerous and varied. The difference between MSEFR and MEFR is similar to that between freeway capacity and freeway operational capacity defined in Wu et al. (2010), except that it is during evacuation conditions. Brilon et al. (2005) hypothesized that the causes for capacity drops can be attributed to:

"• *Bottleneck downstream of the study site: The flow at the point under investigation will remain fluent until the section between this point and the bottleneck is filled with congested flow. After this time, the maximum flow will be the bottleneck's capacity.*
• *Different driver behavior: Drivers in fluent traffic accept shorter headways since they expect to be able to pass the vehicles in front. Once they have given up this idea, they switch to a more safety-conscious style of driving and keep longer headways.*"

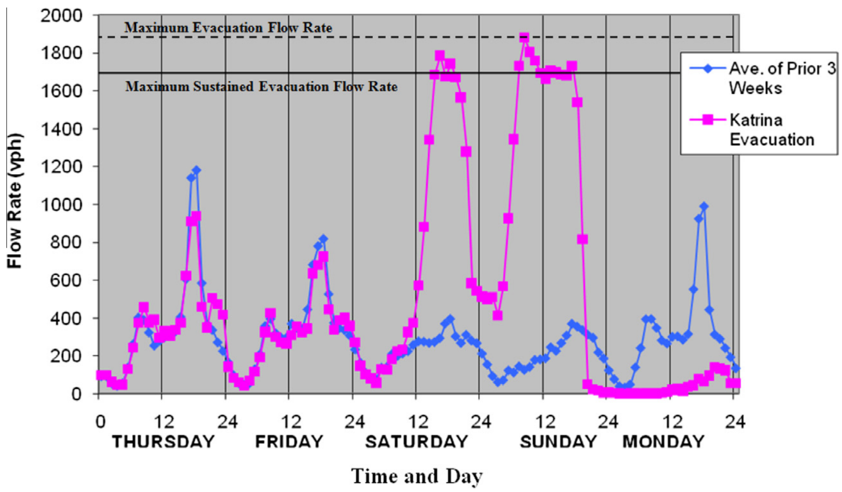

Fig. 1. Hourly Northbound Evacuation Traffic Volume – US-61 LaPlace (2-lane) in Louisiana during Hurricane Katrina. *Data source:* Louisiana Department of Transportation and Development