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Agent-based microsimulations for emergency evacuation in Rocky Mountain National Park

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Abstract

Introduction

National parks provide ample opportunities for outdoor recreation to millions of visitors each year. Before the coronavirus pandemic, the US national parks attracted over 90 million people annually (National Park Service, 2021b). While high visitation may be detrimental to the environment and the visitors` wellbeing, it also increases the risk of physical harm to visitors. During a human-caused or natural disaster, the increased visitor counts may lead to a slower evacuation, putting visitors' health and safety at risk. Moreover, this risk is exacerbated during certain periods of the year as national parks are generally subject to the effects of seasonality. On a typical day in the peak season, visitors often park at overflow spaces near popular destinations, and roads are already congested with vehicles. Therefore, emergency evacuation in national parks during peak seasons is more difficult to implement when the resources remain limited. Furthermore, enlarging these roads or increasing the number of lanes for a faster evacuation is not the optimal solution as it would necessitate converting the public lands of exceptional value to more roads. Coupled with increasing annual visitations, climate change poses another layer of risk, as national parks are anticipated to face natural disasters such as floods, landslides, and wildfires with higher magnitudes and frequencies in the future.

Rocky Mountain National Park (ROMO) set a record in recreation visits with over 4.6 million people prior to the pandemic and ranked the third most visited national park in the United States in 2019 (National Park Service, 2021a). Reaching peak visitation numbers during the summer months, parking lots at Bear Lake and Wild Basin are fully occupied from the very early hours of the day. The two of the most popular attractions at the national park, namely Bear Lake and Wild Basin, are connected to the park entrances through narrow corridors, which has the potential to limit the evacuation speed on these roads. While the long history of fire suppression and the epidemic of pine beetles increased the forest fuel, lightning contributes to the onset of wildfires several times annually (National Park Service, 2019). Having experienced a major wildfire in 2012 in Fern Lake Road due to an illegal campfire that prompted evacuation orders (National Park Service, 2019), it is imperative for the park to prepare for disasters to ensure visitors' health and safety. This study aims to utilize agent-based traffic microsimulations to capture traffic flow in Bear Lake and Wild Basin areas to provide park management with estimated evacuation times under different scenarios.

Methods

Unlike traditional statistical methods, agent-based models (ABM) can model travelers' behavior in a dynamic system where group behavior is determined as an outcome of the interactions between autonomous individuals (Chen, 2008). ABMs were used in outdoor settings for different purposes such as assessing visitor's travel mode choices (Orsi & Geneletti, 2016), impacts of tourism on wildlife (Anwar et al., 2007; Pirotta, et al., 2014), and participatory processes (Edwards & Smith, 2011). Moreover, previous studies have modeled emergency evacuation in the park and public squares (Yang et al., 2019) urban parks (Chen & Zhan, 2014), neighborhoods (Cova & Johnson, 2002), outdoor events (Tan et al., 2015), and concert venues (Wagner & Agrawal, 2014) under different types of disasters such as tsunamis (Lämmel, 2011), fires (Wagner & Agrawal, 2014), or hurricanes (Chen, 2008; Liang et al., 2015). Cole (2005) highlighted the contributions of computer simulations to the planning and management of outdoor recreation settings through 12 case studies. Lawson et al. (2011) utilized microsimulations to model shuttle bus systems to evaluate the transportation system performance patterns in ROMO. This study will add to the literature by utilizing ABM models for emergency evacuation in a national park.

Procedure

Step 1. Secondary data collection

The secondary data used in this are broadly composed of parking lot imagery and capacities, average vehicle speed rates, Digital Elevation Model (DEM), shuttle rider counts, on-trail hiker count, and vehicle counts, which were provided by the Continental Divide Research Learning Center (CDRLC) under National Park Service. To build the initial models, OpenStreetMap (OSM), an open-source geographic database verified by aerial imagery, GPS devices, and low-tech field maps, was used to import the road networks surrounding Bear Lake and Wild Basin areas to the ABMs.

Step 2. Pilot Test

Before the primary data collection, a pilot test was conducted on June 9, 2021 to test the accuracy of three different speed guns used in the field. The measurements gathered by speed guns were compared with the speed rates captured via the Speed Tracker Pro app, and the pilot tests demonstrated high accuracy of the speed measurements.

Step 3. Field data collection

The primary data collection took place between July 16 and July 25, 2021, in ROMO. As part of the collection process, vehicle speed rates at curves and dirt roads were captured using speed guns as visitors are expected to drive slower on these roads compared to the roads where the tube counters were located. Due to lack of secondary data on vehicle counts in the Wild Basin area, hourly vehicle counts were collected at Copeland Lake parking lot and at the intersection between Wild Basin Entrance station and Country Road 84 W. Travel time between designated road segments as well as Bear Lake and Moraine Park shuttle routes were captured by Speed Tracker Pro app to calibrate the vehicle speed rates in the models. The traffic signal cycles, speed limit signs, and traffic signs in the park were collected and built into the models.

Step 4. Base model construction

The ABMs were created in Aimsun Next traffic simulation software. The road networks were derived from OSM data and were imported to the Bear Lake and Wild Basin area models. The road sections that are outside of the study boundaries were removed. The road networks were compared with Google Map imagery prior to field data collection to define or correct the road sections, nodes, number of lanes, lane directions, turns at nodes, turns restrictions (e.g., yield and stops signs), signal groups, and speed limits zones. The traffic demands were reflected through origin-destination (OD) matrices. These OD matrices include centroids that represent traffic demand at trailheads, campgrounds, bus stops, major parking lots, and entrance stations. After field data collection, traffic signal cycles, Bear Lake, and Moraine Park shuttle routes were built into the models. The models were validated through primary data to accurately reflect the traffic patterns at the park. Base models for Bear Lake and Wild Basin areas under free-flow conditions were created. Calibrations to these models were implemented based on the traffic conditions on a typical day at the park at 7 AM.

Step 5. Scenario design

To provide park management with acceptable evacuation times, several scenarios were developed to reflect different conditions. The scenarios were determined considering the potential management strategies that can be implemented at the park. The scenarios included different traffic volumes under different timed-entry reservation systems in 2017, 2020, and 2021, different parking lot occupancies (80%, 100%), staggered vs. non-staggered evacuation, and different control plans at the between Bear Lake Road - Highway 36 junction under which the evacuation times were estimated.

Step 6. Comparisons

Evacuations were determined to take place at 2 PM, the peak hour, to investigate the most extreme condition at the park. The evacuation scenarios were composed of three different travel demands that capture three different stages of evacuation. The pre-evacuation stage represents a typical summer day at 1 PM in ROMO and lasts for an hour. During this stage, the park roads fill with vehicles as they originate from centroids to reach their destinations. During the second stage, evacuation orders are prompted, and vehicles start to exit the parking lots, bus stops, and campgrounds. During the third stage, all vehicles are assumed to have left their origin and are on their way to their respective exit by 2:20 PM. The last car that exits the park determines the evacuation time. Evacuation times were compared to provide effective solutions for managing the traffic capacities.

Initial Results

According to the initial results, agent-based traffic microsimulations are found to be effective in providing alternative evacuation times under different scenarios. Although the simulations require an extensive set of data to be used as input and validations, they provide the evacuation planners and managers with the opportunity to experiment with different management strategies under which evacuations take place. ABMs are also found to be effective in visually representing traffic conditions such as bottlenecks over time and space.

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