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Transportation as a protected area management tool: An agent-based model to assess the effect of travel mode choices on hiker movements

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ABSTRACT

There is considerable evidence today that transportation may be used to effectively manage protected areas. The actual possibility to do so, however, depends on managers' ability to understand how a transportation strategy may affect visitor movements prior to its actual implementation. This is inherently difficult in areas served by multiple transport modes because the characteristics and management of such modes as well as the conditions that derive from their use, determining travel mode choices, may impact visitation patterns in unexpected and potentially unintended ways.

This paper presents an agent-based model (ABM) that helps managers capture the overall consequences of a transportation strategy as it merges two key components of protected area visitation, namely the transportation to the area (via different transport modes) and the movement within the area (along hiking trails). Travel mode choice in the ABM is simulated by a discrete choice sub-model that accounts for both management decisions (e.g. road toll) and contingent conditions (e.g. road traffic). Additionally, a method is presented that allows managers to define comprehensively effective strategies by running sequential simulations under different initial conditions and comparing their performances against a series of quality indicators. An application in the Dolomites UNESCO World Heritage Site (Italy) shows the model is capable of providing reliable estimates of a strategy's overall consequences, helping managers use the transportation tool as effectively as possible.

1. Introduction

Transportation is an essential component of nature-based tourism (Manning, Lawson, Newman, Hallo, & Monz, 2014), not just because it enables visitors to travel around protected areas, but also because it can be used as a powerful tool to manage protected areas (Manning, 2007, 2011). In fact, by carefully designing transportation systems, managers can deliver the right number of people to the right places at the right times, therefore preventing issues of overuse and overcrowding (Lawson et al., 2011; Meldrum & DeGroot, 2012; Reigner, Kiser, Lawson, & Manning, 2012). Moreover, by encouraging a shift towards greener transport modes, by favoring specific routes and by controlling the flow of vehicles, managers can keep the negative effects of transportation (e.g. noise, pollution) within limits that are compatible with the preservation of natural resources and the provision of quality recreational experiences (Orsi & Geneletti, 2015a). Finally, by adopting smart transport policies (e.g. road tolls, public transit fares), managers can both control visitor flows and raise financial resources that can be reinvested in the preservation of an area and the maintenance of local infrastructures (Orsi & Geneletti, 2015a).

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Using transportation as a management tool, however, requires the ability to predict the overall effect of a transportation strategy prior to its actual implementation; something that is inherently difficult in natural recreational areas for a couple of reasons. On the one hand, the characteristics (e.g. cost, frequency of service) of the available transport modes (e.g. cars, shuttle buses), having a deep impact on travel mode choice, eventually determine which locations are visited and the rate at which visitors are delivered to those. On the other hand, transportation is often only the first step of protected area visitation, the second one being the outdoor activity (e.g. hiking) that allows visitors to travel from the transportation terminus (e.g. parking lot, bus stop) into nature. Hence, by simply defining a transport-related measure (e.g. introduction of a road toll, modification of the frequency of a bus service), managers can heavily affect visitation patterns across an entire area. Simulation models may be a viable solution to gain knowledge about the functioning of such a complex system.

Starting from the 1970s, the field of protected area management has deeply benefited from computer simulation as a way to assess the effects of different management options (Chang, 1997; Hallo & Manning, 2010; Lawson, 2006; Lawson, Manning, Valliere, & Wang, 2003; Manning & Ciali, 1979; Shechter & Lucas, 1978, 1980; Smith & Krutilla, 1974; Underhill, Busa Xaba, & Borkan, 1986; Wang & Manning, 1999; Zhang, 2005), including transportation-related ones

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(Lawson et al., 2011; Lawson, Newman, Choi, Pettebone, & Meldrum, 2009; Lowry, Laninga, Zimmerman, & Kingsbury, 2011). These latter studies though have generally assumed modal shift to be an input parameter (e.g. 25% of people shift from personal vehicles to shuttle buses) rather than an emerging property (Lawson et al., 2011).

To the best of our knowledge, there are no studies in this field that have considered the case of areas served by multiple transport modes, where modal shift is driven by such modes' attributes (e.g. cost, frequency of service, etc.) and a series of contingent conditions (e.g. traffic on the road, queue at the bus stop). This problem involves an array of complex interactions that need to be modeled, owing to the fact that a visitor's mode choice is dependent on other visitors' choices (e.g. the decision to drive is affected by traffic levels on the road). Among other simulation techniques, agent-based models (ABMs) have been shown to be an effective option to handle such interactions (Bonabeau, 2002; Gimblett, 2002).

ABMs are a class of computational models simulating a system as a collection of autonomous agents that interact with the environment and each other, and make decisions based on a set of rules defined by the user (Bonabeau, 2002). Repetitive interactions between agents, even when driven by very simple rules, may let unexpected and unpredictable phenomena emerge. The ability to capture emerging phenomena comes from the fact that ABMs emulate individuals' behaviors rather than evaluating a set of mathematical equations (Van Dyke Parunak, Savit, & Riolo, 1998). Given their characteristics, ABMs have been applied to a wide array of fields in which observable phenomena are the result of interactions between multiple agents, such as: ecology (DeAngelis & Mooij, 2005; McLane, Semeniuk, McDermid, & Marceau, 2011), economy (Dosi, Fagiolo, Napoletano, & Roventini, 2013; Tesfatsion, 2002), landscape planning (Evans & Kelley, 2004; Ligmann-Zielinska & Jankowski, 2010; Pooyandeh & Marceau, 2013; Valbuena, Verburg, Veldkamp, Bregt, & Ligtenberg, 2010) and sociology (Epstein, 2002; Malleson, Heppenstall, & See, 2010). Many of these applications have taken advantage of the possibility to integrate ABMs and Geographic Information Systems (GIS), therefore enabling practitioners to efficiently simulate real-world environments (Gimblett, 2002).

The use of agent-based modelling for outdoor recreation management in natural settings became fairly common in the years around 2000, when such ABMs as the Grand Canyon River Trip Simulator (GCRTSim) (Gimblett et al., 2002; Roberts, Stallman, & Bieri, 2002), the Recreation Behavior Simulator (RBSim) (Gimblett, Richards, & Itami, 2001) and their updated versions (e.g. RBSim2) (Itami et al., 2003) were developed to assess the overall effects of management decisions on visitor flows across a trail network (see also Itami & Gimblett, 2000; Gimblett, Lynch, Daniel, Ribes, & Oye, 2003). These models combined statistics about visitation patterns (e.g. arrival rates, typical trips) and agents' wayfinding rules (e.g. destination preferences, crowding perception) to simulate the movements of visitors and predict how these could be affected by different management decisions. More recently, ABMs have been used to: understand the effects of transport policies on travel mode choices in protected areas (Takama & Preston, 2008), support participatory management by facilitating appreciation of recreation impacts (Edwards & Smith, 2011) and understand the effects of recreation on wildlife (Anwar, Jeanneret, Parrott, & Marceau, 2007; Pirotta, New, Harwood, & Lusseau, 2014).

This paper presents an agent-based model to estimate how different transportation strategies affect visitor travel mode choices and to simulate the effects of such choices on visitor movements along hiking trails across a protected area. Therefore, the model merges two components - the access to the protected area and the movement within the protected area – in a way that allows the user to understand how intervening on the former affects the latter. Drawing on this model, a method is then proposed that helps managers identify effective strategies based on their ability to preserve the environment and visitors' recreational experiences. The study was conducted in a popular hiking area within the Dolomites UNESCO World Heritage Site (Italian Alps) that is accessible via private vehicles, buses and cableways.

2. Methods

2.1. The model

The model, which was developed using NetLogo (Wilensky, 1999), is described below following a simplified version of the ODD (Overview, Design concepts, Details) protocol (Grimm et al., 2010).

2.1.1. General overview

The purpose of the model is to help managers of a protected area served by multiple transport modes predict the effects of a transport strategy (i.e. set of transport-related management decisions) on visitors' travel mode choices and subsequently visitor flows across the area's trail network. Hence, the model encompasses two main components: visitor access to the area via a series of possible transport modes and visitor movements within the area along hiking trails. These two components result in five main phases that visitors pass through during a simulation run, namely travel mode choice, transportation to the area, hiking itinerary selection, hiking and return. The model is specifically designed to simulate travel mode choice as the effect of the combined influence of both management decisions (e.g. road toll, bus frequency) and the related contingent conditions (e.g. road traffic, queue at the bus stop). Three possible transport modes are considered by the model, namely the private vehicle, buses and cableways (i.e. cable cars, chairlift). Based on the selected transport mode, visitors reach the trailhead served by that mode and start their hike. The hiking component, in terms of both the selection of a destination and the time spent at intermediate locations, is mostly driven by statistics rather than autonomous decisions. This is consistent with what occurs in areas where visitors start their day with a well-defined itinerary in mind and their wayfinding is not particularly influenced by external conditions (e.g. crowding).

The model considers four agent types: visitors, background cars, buses and cable cars. Each visitor agent represents a small group of visitors whose size ranges from one to five members. Buses and cable cars represent two alternative transportation systems which visitors can get on to reach a trailhead. Background cars are the vehicles that move along the road and create the background traffic, which visitors deal with in case they decide to drive a private vehicle. No agents are used to represent cars or chairlift: rather, visitors “act” as cars or chairlift during the transportation phase in case they have chosen these modes. Grid cells with a size of 30 m represent the smallest units of the study area. One time step in the model represents 1 second in the reality and simulations are run for 43,200 steps, equivalent to 12 hours (between 7 am and 7 pm). The use of one-second time steps is consistent with cell size and justified by the need to keep the movements of both vehicles and hikers detectable at all times. Table 1 reports the state variables associated with the four agent types and grid cells.

Table 1
State variables associated with the four agent types considered in the model (i.e. visitors, buses, cable cars, background cars) and grid cells.

Agent type	State variables
Visitors	Size of the group; local origin; visitor segment (i.e. visitor preferring road-accessible trailheads or visitor preferring cableway-accessible trailheads); hiking speed (function of slope); speed factor (i.e. visitor-specific coefficient used to obtain an individual hiking speed); chosen transport mode; mode currently used; chosen hiking itinerary; time at which the visitor was generated; wait time at bus stops/cableway stations; time spent at an intermediate stop during a hike; 20 variables pertaining to the discrete choice model (see Section 2.1.3)
Buses	Occupancy
Cable cars	Occupancy
Background cars	*No variables assigned.*
Grid cells	Slope; aspect; presence/absence of roads or trails; distance to key locations (e.g. huts, trailheads, etc.); number of parked vehicles