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Modeling decision and game theory based pedestrian velocity vector decisions with interacting individuals

Bryan L. Mesmer [a,*], Christina L. Bloebaum [b]

[a] Technology Hall N135, University of Alabama in Huntsville, Huntsville, AL 35899, USA
[b] 2271 Howe Hall, Iowa State University, Ames, IA 50011, USA

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ABSTRACT

This paper explores the incorporation of decision and game theory in the velocity vector decisions found in human movement. These decisions are made by individuals when maneuvering in an environment occupied by other people or obstacles. The model developed in this paper examines how human movement can be captured as a result of a decision-making process rather than modeling the behavior directly. In this paper, a novel utility function is formed from the biological-based preference of minimizing energy consumption. This energy function is partially fashioned from the energies due to moving, colliding, and waiting. Time and risk preferences are incorporated into the utility function to uniquely capture human desires. Decision and game theories are used to model the decision making process of individuals when alone and when interacting with a range of evacuee types (panicked, distracted and alert). Beliefs are formed and updated concerning both the environment and individuals in the environment, to truly capture the knowledge of individual evacuees. Assumptions that were made during the creation of this novel decision-focused movement model are discussed throughout the paper. This work expands upon previous research performed using the obstacle avoidance technique known as the velocity obstacle method. Common human traits and tendencies are proven to exist in the model through multiple examples. Future modifications of this alternative approach to traditional behavior-focused movement models are discussed.

1. Introduction

In the United States in 2011, deaths from residential and non-residential building fires totaled 2530, injuries totaled 15,000, and the total dollar loss was more than 9 billion dollars (2012). Due to the need to better understand the causes of these large losses, models have been created to predict the evacuation of humans in different types of environments (Santos and Aguirre, 2004). Through this understanding, it is possible for the designers to optimize the environment to maximize occupant safety as it relates to the evacuation process.

The evacuation process of an individual can be broken down into two stages – an exit or goal selection process (Mesmer and Bloebaum, 2014), which was addressed in previous work, and a movement or velocity vector selection process, addressed in this paper. This paper focuses on the determination of which velocity direction and magnitude an evacuee ought to make, and assumes that the goal that the evacuee is trying to reach is predetermined. While closely related, this paper and the past research (Mesmer and Bloebaum, 2014) offer necessary mathematical techniques to simulate two separate decision processes that are inherent to evacuations. It is the culmination of the individual decision making processes that forms the evacuation as a whole, which in turn results in deaths, injuries, and damage. Therefore, by modeling the individual decisions of the evacuees, an evacuation model can be formed that can be used to explore the safety of the environment's design. While the examples of this paper explore a constricted space, the method can be directly related to larger environments, since the same fundamental decision making processes are present (selection of an exit and selection of a velocity vector).

The model used for the movement of individuals is a vital component of an evacuation simulation. Methods to model movement range from modeling the evacuees as particles in a flow problem to cells in a cellular automata problem, as reviewed in (Santos and Aguirre, 2004). Proposed methods have been both nodal based, such as Exodus (Owen et al., 1996) and SIMULEX (Thompson and Marchant, 1995), and non-nodal based such as Vacate (Mesmer

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* Corresponding author.
E-mail addresses: Bryan.Mesmer@uah.edu (B.L. Mesmer), Bloebaum@iastate.edu (C.L. Bloebaum).

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and Bloebaum, 2012; Ries, 2006; Xue, 2009b). One method that has been used to describe motion planning of objects in dynamic environments is the velocity-obstacle (VO) method (Fiorini and Shiller, 1998).

The VO method determines which velocity vectors will result in a collision with obstacles of known velocity. VO and similar approaches have been used in many applications, such as robot motion planning (Fiorini and Shiller, 1993) and missile guidance (Chakravarthy and Ghose, 1998), as well as path finding (Chakravarthy and Ghose, 1998; Fiorini and Shiller, 1993; Kluge and Prassler, 2006). The basis of the VO method, the collision cone, is shown in Fig. 1. In Fig. 1 an agent (individual making a velocity decision), P_i, and an obstacle (other individual that the agent can see), P_j, are depicted. For the agent, any relative velocity that is chosen that falls within the collision cone will result in the agent with radius r_i and the obstacle with radius r_j colliding at some point in time. While non-linear movements can be incorporated into VO (Shiller et al., 2001), for this research combinations of linear movements are assumed. Previous research (Kluge and Prassler, 2006) explains the traditional velocity obstacle method in more detail.

The traditional VO method assumes the obstacles' characteristics are known by the agent. Previous research on the VO method has modified the method to allow for uncertainty in the obstacle's size and velocity, producing a probability of collision which is a function of an obstacle's characteristics (Kluge and Prassler, 2004). Kluge and Prassler (2004) introduced individual evacuee utilities as a function of the individual's velocity, velocity reachability, and probability of collision. This utility function can be combined with optimization techniques to determine a 'best velocity', however there is not a clear human basis for this type of utility function. This paper forms a biological-based utility function applicable to a non-nodal environment that simulates human traits of discounting and risk preferences.

Interactions between individuals is at the core of movement decisions. Previous research created a methodology of recursive reflection in an effort to capture the interactions between intelligent objects (Kluge and Prassler, 2004) where objects would anticipate other objects' velocity decisions. However, the recursive reflection methodology limits the number of recursions that occur which then limits the ability of the objects. This paper uses the mathematical method of game theory (Von Neumann and Morgenstern, 1944) to develop a novel model for human interactions in movement vector determination incorporated in the VO method and demonstrated through multiple examples.

The incorporation of game theory principles in evacuation simulators has previously been examined for evacuee movement in a limited context. Previous studies (Dogbé, 2010; Hoogendoorn and Bovy, 2003) explored the creation of a utility function and the use of differential games to approximate the flow of crowds. Another study (Tanimoto et al., 2010) has discussed the inherent properties of crowd maneuvering and their relationship to games. The incorporation of game theory principles, with a limited strategy set of three, in a cellular automata model has also been examined (Zheng and Cheng, 2011a). The human behaviors of cooperation and competitiveness in the context of evacuees has been examined using game theory (Zheng and Cheng, 2011b). (Lo et al., 2006) have examined the selection of an optimum exit alternative through a game theory model, where the players are the crowd and a capacity restricting entity.

This paper differentiates itself from previous game theory research by creating a biological-based utility function for velocity determination, formed from a meaningful measure of desire. This paper also uses traditional normative game theory to model the populations' interactions where the players are represented as individuals. Individual preferences and beliefs concerning other individuals are also accounted for in this work. Different types of individuals (such as panicked, distracted, and psychologically alert) are represented and beliefs are formed accordingly. Beliefs are represented through probability distributions, allowing for the use of Bayes theorem to integrate new information correctly. Unlike past research, individuals can have limitless strategy options partially due to the decision-making model being incorporated into a non-nodal based evacuation environment. Hence, the work in this paper is novel because it incorporates a meaningful utility function into the VO method, which captures human interactions through the mathematically rigorous means of utility and game theory, while accounting for individual preferences and beliefs. The utility function and game interactions created in this paper are not perfect representations of human choice modeling and appropriate assumptions are made to simplify the complex problem into a programmable and manageable model (addressed throughout the paper). However, the model developed in this paper offers an initial step based on rigorous mathematics in decision-focused modeling to determine human movements. The decision-focused movement model developed in this paper will serve as a foundation for future work.

The research in this paper is organized in such a way that each section builds upon the last to develop a decision-based movement model. In Section 2 the development of the energy-based value function is discussed. Section 3 describes the use of probability theory to mathematically define and manipulate the beliefs of individuals during a movement decision. Section 4 combines the value function and beliefs to enable the use of the utility theory concept of expected utility in movement decision modeling. Section 5 describes the relationship between the different individuals in the environment. Section 6 discusses the use of the decision theory, employing the knowledge of the previous sections, to determine velocity vectors with non-interacting opponents. Section 7 explores how to model interacting opponents through the use of game theory. Section 8 discusses case studies where the above described approach has been used. Section 9 concludes the paper and discusses future work.

2. Velocity alternative energy consumption

In this section, a meaningful cost is created for each velocity in the velocity space (the two-dimensional space in which the agent is choosing a vector) in order to use the VO method in a real world model of velocity vector decision making. Methods in the VO literature (Chakravarthy and Ghose, 1998; Fiorini and Shiller, 1993; Kluge and Prassler, 2006; Large et al., 2002; Shiller et al., 2001) have rudimentary cost functions consisting of simple constraints on velocities and an objective of getting to the goal as quickly as possible. This formulation typically results in a velocity magnitude at or near the constraint imposed on the magnitude. A more realistic cost would not require constraints on the velocities. Furthermore, some of the past research incorporates a "risk" parameter (a weighting variable on a portion of the function) in order to induce human behavior. This paper takes a more structured examination of risk through the use of utility theory. Each velocity is represented by an energy cost in order to create a useful function. The measurement of energy is used in this paper to represent a more holistic measure of human behavior than that of time, capturing many different physical actions and behaviors. Energy offers a novel approach to capturing movement velocity through a biological-based measurement.

The energy cost of each velocity is multifaceted, consisting of the cost of making a step using the velocity, the cost of reaching the goal after the initial step, the cost of a collision with an obstacle due to the velocity, and the cost of colliding with a wall. The cost of the initial steps and the cost of reaching the goal after the step are