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Agent-based analysis and simulation of the consumer airline market share for Frontier Airlines

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ABSTRACT

The complex and interconnected world in which organizations operate presents many challenges to the traditional neo-classical view of research and management and associated research techniques. Fundamental to the operation of financial capital markets, investor confidence relies on accurate investment analyst earnings forecasts. We propose agent-based modeling (ABM) as a viable tool to account for the interaction of local and environmental factors to determine organizational success. In an illustrative case study of Frontier Airlines, we develop and execute an ABM of Frontier's consumer airline market to derive market share for the upcoming year. In the model, Frontier is impacted by internal policies, competitors, and environmental factors of fuel costs, federal regulation, and credit availability. We conclude with a discussion on how ABM can be effectively incorporated into future research activities and decision-making situations.

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1. Introduction

Investor confidence. What is it and what affects it? State Street is one of the world's leading providers of financial services to institutional investors. The company tracks and records the State Street Investor Confidence Index that "provides an objective, quantitative measure of global risk tolerance of the world's sophisticated investors" [30]. Investors rely on investment analyst forecasts as a gauge of performance for individual firms, industries, national economies, and the global financial market as a whole and evidence shows that firms meeting or exceeding analysts' earnings forecasts (i.e. expected revenues) receive an equity price premium (i.e. better stock price return) [25]. Underlying this phenomenon is the belief or confidence in the accuracy of the analyst forecasts [15]. A key component in an analyst's forecast of earnings for a particular firm is that firm's anticipated percentage of sales in the industry or industries in which the firm operates relative to its competitors – commonly referred to as expected or projected market share.

How can a single human being reliably account for all, or even just the most pertinent, factors that may impact the future financial performance of a firm? Research has shown that the human mind struggles to capture and process excessive amounts of information and have difficulty "connecting the dots" of cause and effect relationships when numerous factors come into play in a decision-making scenario [19]. Many simulation approaches such as the Kim et al. [16] reinforcement learning algorithm designed to find the optimal direct marketing strategy focus on static, direct relationships. In an increasingly connected, global business environment, though, more participants and variables than ever exist and they interact and affect each other both directly and indirectly [3]. These indirect effects represent complexity. Social, political, and environmental events on the other side of the world may affect the business success here in the US. For instance, Airlines often engage in 'code-sharing' where the host airline operating the flight will allow key strategic partners to sell seats on the flight. This is particularly common for international travel where one trip from the United States to India may use multiple carriers for different legs of the trip. A pilot strike, change in government regime or travel policies, spike in oil prices, steep discounts offered by a local competitor on a single leg, or a natural event such as the recent eruption of volcanic ash in Iceland may affect the number of flights and routes available between the US and India. These individual events, individually or in combination, directly impact the airlines servicing the various legs as well as all the partners in the trip and, of course, the travelers. Song et al. [28] state traditional capital markets research for the airline industry, particularly when examining international travel, has difficulty controlling and accounting for major external changes in the environment. Computing

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technology through the use of agent-based modeling (ABM) simulation, however, offers a way of modeling the complex, interactive effects of many agents acting and reacting to the actions of each other and the environment thus allowing the modeler to view potential system states given a certain set of parameters [23].

ABM, with direct historical roots in complex adaptive systems (CAS), represents autonomous entities referred to as agents – each with their own dynamic behavior and heterogeneous characteristics – that interact with each other and their environment, resulting in emergent outcomes at the macroscale that can be used to quantitatively analyze complex systems [13]. Intelligent agents and ABM simulation have been used in a wide variety of domains such as planning military operations [14], understanding Web services management [9], monitoring workflow [33], etc. Most of this simulation activity and research focuses on a narrow scope with little to no macro-level environment interaction and offers no guidance on how others can integrate ABM into their own research and/or decision-making toolset. Through an illustrative case study, this paper guides the reader through the development of an ABM designed specifically to account for macro-level factors affecting one specific agent's future business prospects by simulating the market and developing an expected market share for the next year. First, we present background on ABM, in particular emphasizing when ABM is appropriate and the general steps in the ABM creation process. The subsequent section describes the complex business scenario to be modeled followed by a detailed explanation of the modeling process, ABM construction, test design, and simulation results. The final section discusses how ABM can be incorporated into future research activities and complex decisions.

2. Overview of agent-based modeling

ABM is a stochastic simulation modeling approach that provides the unique capability to explore the non-linear, adaptive interactions inherent to CAS [29]. In an ABM, the researcher specifies the rules of behavior at the micro-level for the individual agents and the interactions between agents. Structures may emerge at the macro-level due to the actions of these agents and their interactions with each other and the environment. The consequences at the macro-level that result from ABM are not always obvious or expected. This "discovered" knowledge allows the interested party to identify potential system states that may not have been considered otherwise, thus enhancing decision-making effectiveness. Some unique advantages of ABM include (1) the possibility of modeling fluid or turbulent social conditions when modeled agents and their identities are not fixed or given, but susceptible to changes that may include birth or death of individual agents, as well as adaptation of their behavior; (2) the possibility of modeling boundedly rational agents, making decisions and acting in conditions of incomplete knowledge and information; and (3) the possibility of modeling processes out of equilibrium [6].

Now that we have described what ABM is, when should it be used and how do you create one? North and Macal [23] present an extensive list of points to consider when deciding to use ABM (see Appendix A). Essentially, ABM is appropriate when (1) the problem frame contains agents that interact, adapt, and learn, (2) the past is a poor predictor of the future, and (3) system change is a result of the model, not an input. Starting with problem identification, we present (in Appendix B) a general roadmap of steps to develop ABM based on our own research and experiences.

We now present a case study of an ABM developed to assist in the market share analysis for Frontier Airlines, a low-fare airline. The model includes agents that represent the consumer travelers for the routes Frontier services; an agent each for Frontier and United; a proto-agent for the collective group of other airlines servicing those same routes; and three proto-agents for fuel costs, federal regulation, and availability of credit together represent key environmental factors. The model provides insights into the potential market share for 2007 under various circumstances (i.e. possible system states) to help the investment analyst develop an earnings forecast for the next year, 2007.

3. Illustrative case study

3.1. The complex business scenario

Frontier Airlines operates primarily in a hub and spoke fashion connecting 49 US cities coast to coast, eight cities in Mexico, and two in Canada through their hub at Denver International Airport (DIA). They currently are the second largest jet service carrier behind United Airlines at DIA. During 2007 and 2006 Frontier increased its year-over-year capacity by 14.4% and 8.4%, respectively, and volume of passengers by 14.7% and 12.9%, respectively – outpacing their increase in capacity each year [8]. This is no small feat given the recent turmoil in the airline industry due to rising fuel costs, tightening of access to credit, declining consumer demand, and airline bankruptcies and mergers. The company intends to continue its growth strategy by expanding to new markets and increasing frequency in existing markets. However, due to the company's lack of borrowing capacity under current lines of credit and lack of other borrowing facilities, Frontier must rely on existing cash and operating cash flows for current operations and future growth.

The nature of the airline industry (i.e. customer service orientation, responsibility to society, heavy regulation, and sensitivity to external forces) and Frontier's business situation offer an interesting subject area for complexity-oriented research. The question becomes, which modeling approach is most appropriate. Several modeling techniques exist for complexity-oriented research. Discrete-event simulation offers understanding of the effects of uncertainty in a process. Systems dynamics utilizes a top-down approach to understand system interconnectedness and is extremely useful for identifying important variables and causal linkages in a system. These two modeling techniques were originally developed to address *specific types of problems* while ABM is appropriate for *analyzing systems* that are built from the ground-up [23]. As the focus of this business scenario is to derive an estimated market share for Frontier Airlines, the unit of analysis is the market itself that consists of many consumer agents choosing airlines as travel providers, these airlines responding to aggregate consumer purchasing behavior, the consumers adjusting behavior based on actions taken by the airlines, and the airlines responding to environmental factors. Such agent interaction has been included in other market analyses modeled with ABM: (1) the supermarket/grocery store industry with consumers, retailers, and manufacturers [20]; (2) a wholesale electricity market with sellers of (those with generators) and buyers (electric companies reselling to customers) [22]; (3) artificial stock markets with buyers and sellers [7]; and (4) the fish market in Marseilles with buyers and sellers [17]. The common thread is that agent types interact with each other and act/react to the behaviors of the other agents. For this reason, we pursue the modeling of the Frontier airline market through the design and execution of an ABM. Next, we describe our overall modeling philosophy followed by a description of the agent properties and behaviors.

3.2. General modeling philosophy and approach

A number of pitfalls can occur in designing an ABM. Certain choices need to be made regarding the level of detail to model and types of agents to include and their related behaviors. The

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